The Economics of Soil Conservation in Developing Countries:

The Case of Crop Residue Mulching

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ISSN 1383-6803
ISBN 90-5808-089-7

Distribution:
Backhuys Publishers
P.O. Box 321
2300 AH Leiden
The Netherlands

Printed in the Netherlands

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Abstract

The study contributes to the search for a methodology to assess soil conservation, particularly in developing countries. The study first assesses the economics of soil conservation in general - with special emphasis on the relationships between technology, economic analysis and policy implications. The quantification and valuation of soil erosion and soil conservation are highly controversial and present considerable analytical challenges that have been tackled in varying ways. By implication, government intervention is controversial too - and has typically been unsuccessful. This has direct implications for both the development of conservation technology and the implementation of conservation interventions.

The study subsequently assesses the economics of one particular technological conservation option: crop residue mulching (also known as conservation tillage). An analytical framework is developed to assess the socio-economics of the technology in developing countries. The technology assessment framework follows a stepwise expanding analysis along a three-tier hierarchy: crop production, the farm household and the institutional setting. This results in a private and a social assessment of the technology, and the formulation of corresponding policy implications. The framework is applied in *ex ante*, *ex post* and partial analyses of crop residue mulching in different settings in Mexico and Central America. Conclusions are drawn regarding the technology assessment framework and crop residue mulching.

Preface and acknowledgements

"If we do not change the direction we are going, we will end up where we are headed" (Chinese proverb cited in WRI, UNEP and UNDP, 1992). This proverb can be variously interpreted, but is particularly apt here. It applies to the development of this study. It also applies to its subject matter, which has progressed painfully slowly and once was paraphrased as a merry-go-round (El-Swaify, 1981). Indeed, a most disturbing finding upon reviewing the literature is the lack of progress. With this study I hope to contribute to the body of literature that tries to move away from traditional soil conservation research and implementation towards a more integrated approach. Such an approach is more likely to be efficient and effective, both for farmers and society at large.

The present study is published by the Wageningen University, both as a thesis and in the Mansholt Studies. However, it is based on research that I originally carried out while working for CIMMYT's Economics Program and the Natural Resources Group in Mexico. Most of the presented case studies are derived from collaborative work between CIMMYT and other institutions, particularly INIFAP, PSSM AC, FIRA, and CIRAD. I am grateful to CIMMYT and the collaborating institutions for being able to draw on the results from these collaborative studies. The Ford Foundation and the French government funded most of the collaborative field work, whereas the Dutch government funded my position in Mexico and the study leave thereafter.

The present study has sole authorship. However, many people contributed time, efforts and ideas. During my stay with CIMMYT in Mexico I benefited from the help of, and interaction with, numerous colleagues. Martien van Nieuwkoop, Rob Tripp and Derek Byerlee were helpful in getting me up and running in Mexico. Larry Harrington, Daniel Buckles, Melinda Smale, Paul Heisey and Tony Fischer provided useful feedback on my research proposal and the research project thereafter. I would also like to acknowledge Hector Barreto, Mauricio Bellon, Jorge Bolaños, Jerome Fournier, Dewi Hartkamp, Damien Jourdain, Michael Morris, Prabhu Pingali, Ellie Rice, Gustavo Sain, Ken Sayre, Eric Scopel and Jeff White for their input at various stages. In addition, Betty Rojon, Alejandra Arias, Maria Luisa Rodriguez, Angelica de la Vega, Sylvia, Pedro Aquino and Victor Hernandez always provided friendly support. Kelly Cassaday, Alma McNab, Mike Listman, Adriana Maldonado, Concepcion Castro, Tim McBride and Miguel Mellado's design and production team were helpful in getting the research project's publications out.

I also would like to acknowledge the various collaborators in the case studies. The Jalisco case study benefited from the assistance of Eric Scopel, Martin Areola, Johan Glo, Naima Martin, Alfredo Gonzalez Avila and Enrique Chavez Guerra. The Veracruz case study benefited from the assistance of Daniel Buckles, Ellie Rice, Lourdes Godinez and other PSSM staff. The Chiapas Highlands case study benefited greatly from the original endeavours of Pedro Cadena Iñiguez. The Central Chiapas case study benefited from the assistance of Martien van Nieuwkoop, Pedro Cadena Iñiguez, Ruben de la Piedra, Aurelio Lopez, Dagoberto Flores and Carlos Alberto Ruiz. The Guanajuato case study benefited from the assistance of Juan Ignacio Valiente and other FIRA staff, particularly from the Villadiego centre.

The development and write-up of this study benefited greatly from the constructive criticisms from my supervisors Arie Kuyvenhoven, Henk Moll and Leo Stroosnijder. I also appreciate the opportunity they gave for distance-write-up and the time freed for interaction - despite busy agendas and short notices. I also would like to acknowledge the support from all the other staff members from the development economics group at Wageningen University. Helpful comments were received from Rudy Rabbinge, David Lee and two anonymous reviewers for the Mansholt studies. The study also benefited from insight gained during a complementary World Bank study (Erenstein, forthcoming) and the corresponding collaboration with Christian Pieri, Derek Byerlee and others.

I thank friends and relatives for putting up with me while "working on it". And finally, Anne Bouma for giving me the time and support. In the end our dual delivery did not coincide - but at least we beat the turn of the century.

Accra, August 1999

CHAPTER 1

SETTING THE STAGE

1.1 Degradation and conservation of natural resources

Concern for the global environment has increased in recent years (*e.g.* WCED, 1987; UNCED, 1992; World Bank, 1992). The resource degradation associated with agriculture in particular has been identified as a most serious worldwide problem (Napier *et al.*, 1994b). With limited potential to develop new land, increases in agricultural production must come largely through better use of the land already in production (Shaxson *et al.*, 1989). Yet resource degradation has usurped the productive capacity out of some environments, and is undermining the productive advances in others. Degradation thus puts further strains on the prospects of feeding the world - although for now, technological development kept Malthus' (1798) prophecy at bay. Nonetheless, population growth continues, and the world remains finite - inducing a quest for sustainable resource use.

Sustainable development is 'development that secures increases in the welfare of the current generation provided that welfare in the future does not decrease' (Pearce and Warford, 1993: 49). This definition - and its frequently cited Brundtland-commission precursor[1] - might seem straightforward to some, yet others object. For one, that development is a subjective term, a value word implying change that is desirable and as such no consensus is bound to exist (Pearce *et al.,* 1990). In addition (though related), the interpretation is in terms of human welfare only, and implicitly welcomes economic growth (Perman *et al.,* 1996:52). Notwithstanding these objections, this definition - and its precursor - conceivably appeals to many (van Pelt, 1993) and has filtered through into various other definitions.

While few would argue against sustainability, it is a wide, many faceted concept meaning different things to different people. Indeed, the definitions of sustainability are extremely varied, leading some to fear there might be as many interpretations as there are practitioners.[2] Part of the confusion relates to semantics, as ambiguous or subjective terms litter the debate around sustainability and its components (Pearce *et al.,* 1990; Lele, 1991). Another major contributor to the confusion is the perspective of the practitioner. One can distinguish ethical, ecological and economic arguments for sustainability - each with their corresponding set of definitions (Harrington, 1995; Perman *et al.,* 1996). Sustainability thus

[1] *I.e.* 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987:43).

[2] For instance, Frye and Blevins, 1989; Conway and Barbier, 1990; Gajewski *et al.,* 1992b; Lovejoy and Sanders, 1994; Perman *et al.*, 1996. One interpretation of sustainability is maintaining a consumption or production stream indefinitely without degrading the (natural) capital stocks (Lingard, 1994). Other interpretations, applied to agriculture, include Crosson's (in Harrington, 1995): an agricultural system that can indefinitely meet demands for food and fibre at socially acceptable economic and environmental costs. Or in the case of Lal (1990): profitable farming on a continuous basis while preserving the natural resource base.

touches upon varied interests and proves to be yet another battlefield where the different stances are pitted against each other.

The present study does not present another essay on sustainability.[3] Yet, there is a need to realise the ambiguities that exist in the debate around sustainability and its components. As highlighted by Bie (1990), the lack of standard definitions is an obvious pitfall in the current discussion, especially in view of the diverse backgrounds and interests of the actors involved. Without adequate tools of communication and with the great amount of disagreement on the essential terms, the discussion becomes exceedingly confusing to all. Further, with reports using varying criteria, any comparison or considered opinion becomes difficult as it becomes almost impossible to ensure that views and facts presented by the different authors do in fact refer to the same basic phenomena (*ibid.*).

Despite definitional issues, the challenge remains of how to develop and intensify agricultural production without degrading the resource base upon which it all depends (Shaxson, 1993). This study focuses on technological considerations within the broader sustainable development debate. Notably, it aims to assess promising agricultural production technologies that may contribute to the conservation of natural resources.

1.2 Focus of the study

Land degradation reduces the capability of land to satisfy a particular use (Blaikie and Brookfield, 1987:6). It encompasses any process that lowers land productivity, assuming other factors such as technology, management and weather remain constant (Bojö, 1996). Soil degradation is one specific subset of land degradation[4] that is of particular relevance for agricultural production. It is 'a process that describes human-induced phenomena which lower the current and/or future capacity of the soil to support human life' (Oldeman *et al.* in WRI *et al.*, 1992). Such degradation occurs when the soil resource is not used according to its capability/suitability. It generally is a complex and long-term process, a form of stress[5] that undermines soil productivity. In this regard, Brown (1981 in Blaikie and Brookfield, 1987) has described soil degradation as the 'quiet crisis' which nevertheless erodes the basis of civilisation. The problem is pervasive, often insidious but crucial to the future of humankind (Blaikie and Brookfield, 1987).

One problem with soil degradation is just to identify what it is, since there are so many types (Biot *et al.*, 1995 in Sanders *et al.*, 1995). It is a broader umbrella term for a decline in soil quality encompassing the deterioration in physical, chemical and biological attributes (Eaton, 1996) - and includes soil erosion, soil fertility depletion, soil compaction, and soil pollution. Several classifications of degradation processes exist in the literature (*e.g.* FAO-UNEP, 1983; Oldeman *et al.*, 1990). The multitude of classifications can be partly

[3] For instance, see Goodland, 1989; Pezzey, 1989; Conway and Barbier, 1990; Pearce *et al.*, 1990; Lele, 1991; Gajewski *et al.*, 1992b; Chapter 2 of Pearce and Warford, 1993; Turner, 1993; van Pelt, 1993; Harrington, 1995; Chapter 3 of Perman *et al.*, 1996.

[4] The concept of 'land' is wider than that of 'soil', and includes natural flora and fauna, water and microclimate next to the soil proper.

[5] Stress is a frequent, sometimes continuous, relatively small, predictable force with cumulative effect (Conway and Barbier, 1990).

explained by the fact that soil degradation is generally a combination of processes. Another problem is the generally incomplete distinction between the causes and (biophysical) effects of degradation.

Lal *et al.* (1989:53) make a particularly useful distinction between (i) processes and (ii) factors of soil degradation. *Soil degradation processes* include chemical, physical and biological actions and interactions that negatively alter the soil resource. *Factors of soil degradation* are natural and human-induced agents and catalysts that set in motion these processes. In other words, the factors are largely the *cause* and the processes the (biophysical) *effect* of soil degradation.

Soil erosion takes an intermediate role in the cause-effect chain of soil degradation. Factors of soil degradation can accelerate soil erosion, which in turn leads to physical, chemical and biological degradation processes. This intermediate role is a potentially confounding factor upon assessing soil erosion. First, soil erosion is only one amongst several linkages between cause and effect. For instance, soil erosion contributes to the chemical degradation of the soil resource. However, the existence of chemical degradation (or soil degradation for that matter) does not imply the existence of soil erosion - as it may be induced by other degradation factors (*e.g.* soil fertility depletion through 'soil mining'). Second, soil erosion itself has manifold consequences. Soil erosion is most easily associated with physical soil loss but this singles out only one of its consequences.

Soil erosion is generally defined as the wearing away of soil by water, wind or ice. This occurs naturally in the physical environment, but human interference can significantly accelerate this natural process (Blaikie and Brookfield, 1987; Napier *et al.,* 1991:368; Camboni and Napier, 1994). This adds another confounding factor to the assessment: Where runs the line between natural and accelerated? The fact that restorative processes exist - both natural and human - further confounds the problem. Actual soil erosion thus is the net result of various forces, both human and natural, both degrading and restorative.[6] Generally, concern is about accelerated - and thus positive - soil erosion: *i.e.* when the detrimental human interference far outweighs the other processes. For practical purposes, some - including this study - therefore interpret soil erosion as synonymous with human-induced or accelerated soil erosion (Bork, 1987 in Grohs, 1994).

Soil erosion is widely considered to be the most serious form of soil degradation - and environmental hazard for that matter (Southgate *et al.,* 1984; El-Swaify, 1994; Lal, 1994). It undermines the long-term viability of agriculture in many parts of the world and vast areas of land now being cultivated may be rendered (economically) unproductive if erosion continues unabated (Lal, 1994; Eaton, 1996). Soil erosion is also the best known of all forms of soil degradation, amongst others due to its (relative)[7] visibility, measurability and impact, and being dramatically increased by human action (van Kooten, 1993; Pagiola, 1994a; Eaton, 1996).

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[6] Therefore, various outcomes are conceivable, including 'negative' net soil erosion (*i.e.* soil formation) when the beneficial forces outweigh the detrimental. This is widespread in areas of soil deposition and most obvious in river deltas and other alluvial plains.

[7] Relative to other degradation processes. As will be illustrated in Chapter 2, the visibility and measurability of soil erosion itself is not as straightforward as may be implied.

Soil conservation and rehabilitation

As with most problems, one can envisage three possible scenarios when dealing with soil degradation: it can be (i) ignored, (ii) prevented or (iii) cured. Upon ignoring soil degradation, the effects (and costs, if any) accumulate over time. The two other venues of action try to mitigate the effects of soil degradation - respectively through conservation and rehabilitation (also see Annex A).

Soil conservation is a preventive intervention to limit the extent of soil degradation actually taking place. It can be defined as prolonging the useful life of soil resources. It revolves around satisfying current human needs from soil resources without harming or destroying their capacity to do so in the future (Shaxson *et al.*, 1989). Soil conservation may be defined technically as any set of measures intended to control or prevent soil degradation (Stocking *et al.*, 1989 in de Graaff, 1993). Others simply see soil conservation as the wise use and management of soil resources (Shaxson, 1988; Swader, 1994).

Soil rehabilitation (or reclamation) is a curative intervention to compensate for previous soil degradation. It can be defined as restoring the useful capabilities of soil resources. It is only feasible when the degradation is reversible.

The economically optimal course of action largely depends on the magnitude, nature and timing of the costs and benefits associated with each scenario.[8] The *neglect scenario* poses cumulative degradation-induced costs upon society, typically in terms of future on-site productivity losses and eventual off-site damages. The *conservation scenario* typically offsets these degradation-induced costs (partially or fully) but implies investment costs. The *rehabilitation scenario* still incurs the degradation-induced costs (partially or fully) but also postpones the mitigation costs.

Severely degraded soils generally offer a spectacular and dramatic desolate view, making a visual case for rehabilitation. However, economically speaking, the prospects of the rehabilitation scenario are relatively poor: such rehabilitation implies drastic costly action and is a long-term healing process with no immediate benefit (Frye *et al.*, 1985; Shaxson *et al.*, 1989; Stocking, 1993; El-Swaify, 1994). Shaxson *et al.* (1989) claim that much of the past rehabilitation was wasted money on two accounts. First, the degraded soil generally had little remaining productive potential to be reclaimed. Second, it was ineffective as long as it did not address the true cause of soil degradation. Degradation prevention is generally far more effective and efficient than its cure (Frye *et al.*, 1985; Shaxson, 1988; El-Swaify, 1994; Bojö and Cassells, 1995).

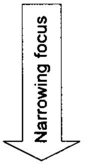
Semantics once more complicate the discussion. First, the distinction between conservation and rehabilitation is rather crucial both technically and economically. Yet, many fail to make this distinction (Shaxson, 1988). Second, soil conservation and rehabilitation can both be interpreted in a narrow and a wide sense. In the narrow sense, focus is only upon mitigating soil erosion. In the wide sense, it would mitigate any soil degradation process (including soil erosion; see Table 1.1).

This study focuses on: (i) the soil erosion subset of soil degradation (more specifically, accelerated soil erosion by water); and (ii) the narrow soil conservation subset of mitigating

[8] However, whether this is actually the *preferred*, let alone the *implemented* scenario, depends on numerous other factors.

soil erosion. Specifically the study focuses on the socio-economic[9] implications of soil conservation.

Table 1.1 Terminology issues



Problem	Preventive action	Curative action
Land degradation	Land conservation	Land rehabilitation
Soil degradation	Soil conservation (wide sense)	Soil rehabilitation (wide sense)
Soil erosion	Soil conservation (narrow sense)	Soil rehabilitation (narrow sense)

Societal and technological considerations

The socio-economic implications of soil conservation vary over societies. First, the costs imposed by soil erosion varies in terms of its extent and consequences. Second, there are marked differences in resource endowments, technology, preferences and institutions and these directly affect the costs of implementing soil conservation.

In this regard, soil conservation appears to be particularly critical in developing countries. First, the potential of soil erosion appears to be higher in most developing country environments (soils more vulnerable, climate more damaging - Shaxson *et al.*, 1989). Second, the impact of soil erosion tends to be more severe as developing economies are relatively more dependent upon soil resources for their development. Third, these societies tend to be more resource constrained - and hence the opportunity costs of soil conservation are likely to be higher. Fourth, the prevalent underdevelopment typically implies a marked preference for current consumption - which further penalises conservation. Fifth, the institutional set-up is typically less supportive for conservation - *e.g.* in terms of missing, incomplete and imperfect markets.

Consequently, although conservation may be most needed in such settings, it is unlikely to be given high priority.[10] Aggravating the situation, underdevelopment and soil erosion can be mutually reinforcing. Resource degradation undermines and frustrates economic development, while low levels of economic development can have a strong causal impact on the incidence of resource degradation (Blaikie and Brookfield, 1987).[11] Further,

[9] Socio-economics denotes a methodological middle road between holistic institutional economics and individualistic neoclassical economics (Luzar, 1994).

[10] The same economic constraints affecting soil conservation are also likely to make rehabilitation prohibitively costly. Indeed, only a few spontaneous rehabilitation exercises have been documented in developing countries. In one such instance, Reij (1994) describes the rehabilitation of degraded land in Burkina Faso (by contour stone bunding and planting pits). This was facilitated by a marked increase in population pressure on limited agricultural land.

[11] However, although several elements contribute to this vicious circle, it is by no means universal (*e.g.* see Reardon and Vosti, 1995).

governmental intervention in soil conservation has been typically unsuccessful because of institutional weaknesses.

One conceivable way to break the soil conservation deadlock is to make soil conservation more compatible with the farm households' objectives. Traditionally, soil conservation has emphasised physical conservation measures, which implied substantial investments with distant and relatively low returns. Therefore, notwithstanding the potential costs of soil erosion, the farm households' typically limited resources and accompanying preferences tend to ensure the disutility of such conservation efforts. The challenge is to enhance the utility of conservation. One option is to develop productive technologies that embody soil conservation. Such technologies would ostensibly provide an immediate payback as well as resource conservation over the longer term. Research has identified various types of crop management practices (or land husbandry) as promising conservation alternatives. These measures conceivably provide an effective means to reduce soil erosion and recover the conservation costs through simultaneous factor productivity increases.

Crop residue mulching - also known as conservation tillage - is one such promising conservation technology. It proposes to leave crop residues as protective cover over the soil surface. Such a protective cover (or mulch) greatly reduces the incidence of soil erosion by reducing both the detachment and transportation of soil particles. To maintain the protective mulch, various crop management changes are needed - for instance, a reduction in soil tillage. These changes *may* imply cost savings in terms of labour and capital input in crop production. In addition, the technology *may* increase crop yields through the simultaneous conservation of water and fertility.

Crop residue mulching has already proven itself extensively in the developed nations - in a number of instances providing an economic conservation alternative with substantial adoption levels. In turn, the success of the technology in the developed nations has led to its promotion in developing ones. However, it is still largely unclear how this technology would perform - or has performed - in the farmers' field in developing nations.[12] This study hypothesises that a direct transfer of conservation technology without adaptive research is inappropriate. More specifically, it hypothesises that farm households in developing nations face more and tighter constraints, and consequently different and higher trade-offs in adopting such conservation technology.

In sum, the study focuses on the socio-economic assessment of soil conservation - particularly for farm households in developing nations. Within this context, it addresses the economic and policy implications of soil conservation technology in general, and crop residue mulching in particular.

[12] Farmers is used in a generic sense to represent those individuals - male or female - who manage land - owned, rented or otherwise - to produce agricultural products (crops and/or livestock). Farmers in developing countries typically are member of and/or head a farm household with limited resources for income generation.

1.3 Objectives

The present study contributes to the search for a methodology to assess soil conservation. It provides an analytical framework to assess the socio-economic implications of soil conservation - focusing specifically on crop residue mulching as a promising technology. The objectives of this research are three-fold:

- to assess the economics of soil conservation in developing nations - with special emphasis on economic analysis and policy implications;
- to develop an analytical framework to assess the socio-economics of the crop residue mulching technology in developing nations;
- to assess the proposed technology assessment framework in the *ex ante*, the *ex post* and the partial analysis of crop residue mulching in Mexico and Central America.

The study expects to contribute to existing literature in several ways. First, by clarifying the soil conservation dilemma and its implications for economic analysis. Advances in soil conservation research have been compared to a merry-go-round (El-Swaify, 1981) and reinventing the wheel is not uncommon. To a large part this can be attributed to the complexity of the issue. Other factors include the limited institutional memory and the numerous terminology and data issues. Different studies tend to address different aspects of the relationships, but the debate is sometimes too general, resulting in seemingly conflicting evidence (Reardon and Vosti, 1995; Enters, 1998). The present study hopes to provide a guide through the myriad of details. In doing so, it will help establish that there are implicit and misleading assumptions in many standard economic models of soil conservation. It will also highlight the fuzzy nature of the problem, particularly in developing nations: there simply are no neat solutions, whereas obtaining reliable data presents formidable problems (Pearce *et al.*, 1990:x).

Second, the study provides a contribution to the adoption literature. This contribution specifically addresses a relatively neglected field in the literature: the assessment of soil conservation investments within the context of the farm household and its institutional setting (Reardon and Vosti, 1997). The proposed analytical framework revolves around the private viewpoint - a perspective that is particularly useful in identifying adoption barriers and the corresponding policy implications. The analytical framework is subsequently applied to different settings. A major problem in the adoption literature is the difficulty of comparing and interpreting results over studies (SRAPTF, 1993). The cases analysed in the present study tend to supplement each other. This facilitates putting the results into context and allows for comparison over space and time (*e.g. ex ante versus ex post*).

Third, the study contributes to the policy discussion on soil conservation. Past public intervention in soil conservation has not been very successful. By clarifying the complexity of the underlying problem, the study highlights more promising approaches to intervention. It is therefore expected to have a wider relevance for the efficiency and effectiveness of soil conservation measures in particular, and sustainable development in general.

1.4 Outline

The study consists of two parts. The first part assesses soil erosion and conservation, specifically the implications for economic analysis and policy. This part comprises three chapters. Chapter 2 discusses the evidence and analysis of soil erosion. It assesses how the various facets of soil erosion - space, time and location (*i.e.* state of nature) - determine on-site and off-site effects and give rise to scale issues. It also addresses some of the controversial issues such as substitutability of the soil resource and (ir)reversibility of soil erosion.

Chapter 3 addresses the economic analysis of soil conservation. It first introduces some definitional and analytical issues. It subsequently addresses the analytical approaches applied to soil conservation - broadly categorised as the evaluation and adoption schools. The evaluation school tries to quantify the economic impact of different soil conservation scenarios. The discussion focuses on the analytical implications of costing erosion and the mode of analysis. The adoption school tries to explain and predict the divergences in soil conservation behaviour between economic agents, and specifically discusses the roles of technology, household resources and preferences, and institutions.

Chapter 4 addresses the policy implications for intervening in soil conservation. It briefly discusses the controversy about whether intervention is warranted, given the current understanding of the problem. It then derives lessons from past soil conservation interventions - particularly in terms of the mode of intervention and conservation technology used. It subsequently delineates new directions to make conservation intervention more effective and efficient, thereby focusing on conservation technology development. Finally, it introduces some promising technological options, specifically crop residue and cover crop mulching.

The second part of the study assesses one of the promising technological options: *crop residue mulching* (CRM). It comprises five chapters. Chapter 5 provides an overview of the CRM technology. It discusses definitional issues, technological characteristics and implications for productivity and conservation. It also highlights some of the complications specific to the technology - in particular its inherent complexity, externalities and imperfect information.

Chapter 6 develops a conceptual framework to assess the CRM technology. Following a stepwise expanding analysis, the technology assessment (TA) framework delineates the implications of the CRM technology for crop production, the farm household and the institutional setting. This subsequently allows for a private and a social assessment of the technology, and to derive the corresponding policy implications. The chapter also discusses a number of methodological considerations for the application and validation of the TA framework. The subsequent chapters apply the TA framework in different case study settings.

Chapter 7 applies the TA framework in an *ex ante* analysis of CRM. It assesses how the CRM technology would potentially fit in the farming systems of two distinct sites in Mexico. The first (*ex ante*) case is a mechanised, market oriented production system; the second case a marginal, home consumption oriented system. The prospective application of the TA framework provides insight in both the technology and the applicability of the framework.

Chapter 8 applies the TA framework in an *ex post* analysis of CRM. It assesses how the technology actually fitted in the farming systems of two other case study sites in Mexico. The first (*ex post*) case is a marginal, semi-market oriented production system; whereas the second case encompasses a mixture of arable and non-arable market-oriented systems. The retrospective application of the TA framework provides further insight in both the technology and the applicability of the framework.

Chapter 9 addresses the partial application of the TA framework. It does so for two further distinct sites in Meso America.[13] The first (partial) case is an irrigated, mechanised, market oriented production system in Central Mexico; the second case a more marginal, semi-market oriented production system in El Salvador. The partial application of the TA framework provides a rapid, superficial assessment of the technology at limited cost.

The study concludes with Chapter 10. It presents and discusses the main conclusions from the whole study in terms of methodology, technology and policy.

The study outline implies an increasingly narrow focus. The first part is concerned with both the social and private viewpoint, whereas the second part - particularly the TA framework and case studies - emphasise the private viewpoint. The narrowing focus also applies to the spatial, temporal and technological dimensions of the problem. This 'zooming-in' is a direct consequence of the underlying soil conservation problem. To enhance the prospects of adoption, conservation technology needs to be in line with farm households' objectives. This implies a need to emphasise the on-site and immediate dimensions of the problem. In addition, the underlying problem is complex and in this regard, case studies look promising.[14]

The four main case studies specifically focus on crop residue mulching in maize-based farming systems in Mexico - thus facilitating comparisons over sites. Yet, this narrow focus on a single measure, crop and country also has its drawbacks, as effectiveness and efficiency of a specific measure is bound to differ over space and time. Nonetheless, the complexity of farming systems is such, that the focus is on only one (albeit complicated) technological option with cases from only one (albeit large, diverse and erosion-prone[15]) country. The focus on maize (*Zea mays*) links back to the prevalence of this crop in Mexico - and Meso America for that matter (ASERCA, 1994; CIMMYT, 1994).[16] Furthermore, maize enhances soil erodibility, as this row crop tends to provide poor ground cover - especially in the early growing season when rainfall erosivity tends to be highest. Notwithstanding the narrow focus of the case studies, the developed TA framework is expected to have wider relevance. Conceivably it could easily be adapted to accommodate other conservation options, and applied to other crops or in other geographic settings.

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[13] Meso America denominates the region encompassing Mexico and Central America.

[14] Case studies imply 'an enquiry in which a small number of study units are investigated in great detail' (Poate and Daplyn, 1993:363).

[15] See Posner, 1982; Maass and Garcia-Oliva, 1990; McIntire, 1994.

[16] Maize area encompasses an estimated 70% of total cereal area in both Mexico as the larger Meso American region (CIMMYT, 1994).

PART I:

Soil Erosion and Conservation:

Economic Analysis and Policy Implications

CHAPTER 2

SOIL EROSION: EVIDENCE AND ANALYSIS

Opinions vary substantially on the dimensions and consequences of soil erosion. Some of the presented evidence is certainly worrying, yet at the same time business goes on as usual. The current chapter assesses some of the specific features of soil erosion that explain some of the controversies and the challenges it poses for an objective analysis. The first section provides a brief overview of the main physical and economic issues. The subsequent five sections provide a detailed account of the main analytical issues of soil erosion. Sections two to four assess the on-site effects of erosion in terms of physical soil loss, biological productivity loss and its socio-economic valuation. The fifth section assesses the off-site effects and the sixth some of the scale implications. The seventh section discusses some of the resulting controversies. The last section provides a concluding summary.

2.1 The global picture

'That accelerated soil erosion is a serious global problem is widely recognised. What is difficult to assess reliably and precisely, however, are the dimensions - the extent, magnitude, and rate - of soil erosion and its economic and environmental consequences' (Lal, 1994:1). The present section will briefly assess some of the physical and economic aspects of the problem.

Physical aspects

Much of the debate about soil erosion - and environmental degradation for that matter - is beset by uncertainty. On the one hand, there seems to be a pressing problem that urgently needs scientific data in order to kindle a response; on the other hand, there are only confusing and ambiguous snippets of evidence (Stocking, 1987:62). Indeed, 'before the early 1990s no reliable estimates of the amount of soil erosion around the world were available, let alone estimates of productivity consequences' (Crosson, 1997:6).

In one attempt to deal with this issue, the Global Assessment of Soil Degradation (GLASOD) implemented a first baseline study using a consistent methodology to estimate global soil degradation. This study estimates that during the 45 years up to 1990, 17% of the earth's vegetated surface - nearly 2 billion ha - suffered light to extreme soil degradation because of human intervention (Oldeman *et al.*, 1990 in WRI *et al.*, 1992). Most of this acreage suffered light or moderate degradation, implying that productivity was adversely affected (Table 2.1). However, almost 3% of the vegetated surface is estimated to have suffered severe or extreme degradation, implying the productive capacity was largely lost.

The GLASOD study assumes 83% of the vegetated surface not to have been degraded by human intervention during the considered time-span. Notwithstanding, half this 'non-degraded' area is still subject to a high degradation hazard, and only about a third is considered 'stable' land (in de Graaff, 1996:19). The study estimates that overgrazing, deforestation and crop production activities have contributed about equally as causes of land degradation at the global level (in WRI *et al.*, 1992). The same study identifies soil erosion by water as the most widespread type of degradation (having affected 56% of the degraded surface, with soil erosion by wind accounting for an additional 28%, *ibid.*).

Table 2.1 Estimated world-wide human-induced soil degradation, 1945-90

Type of soil degradation	Degraded area		Implication
	Million ha	% of vegetated land	
Extreme	9	0.1	Unreclaimable and beyond restoration, biotic functions fully destroyed
Severe	296	2.6	Reclaimable only with major assistance, biotic functions largely destroyed
Moderate	910	7.8	Agricultural productivity greatly reduced, but can still be used for agriculture
Light	749	6.5	Lost some productivity, but this can be restored through farm conservation practices
Total	1,964	17.0	

Source: Oldeman *et al.*, 1990 in WRI *et al.*, 1992

Numerous other facts and figures can be quoted. A FAO study dating back to 1980 (in Sanders, 1988) estimated that 5-7 million ha were lost annually to degradation, which compares reasonably with the combined 'severe and extreme' estimate of the GLASOD study. However, others diverge substantially from the above estimates. Speth (1994 in Pimentel *et al.*, 1995) estimates 80% of the world's agricultural land to suffer from moderate to severe erosion. Barrow (1991 in *ibid.*) estimates *average* soil erosion rates as high as 30-40 Mg ha^{-1} yr^{-1} in Asia, Africa and South America. The USA and Europe averaged 17 Mg ha^{-1} yr^{-1} (*ibid.*), still greatly exceeding the average rate of soil formation of 1 Mg ha^{-1} yr^{-1} (Troeh and Thompson, 1993 in *ibid.*).

Several interrelated factors explain the prevailing uncertainty around the physical dimensions of soil erosion. A first issue is *measurability*: soil erosion poses a severe challenge to contemporary scientific methods (Anderson and Thampapillai, 1990). Even the above mentioned and frequently cited GLASOD study is based on expert estimates of the degree, type and causes of the human-induced soil degradation that has occurred post W.W.II (WRI *et al.*, 1992:112). Indeed, quantitative objectively measured data on the dimensions of soil erosion are still typically lacking in many regions of the world.

A second issue is *data reliability*. Quantitative information is not only typically lacking, it may also be unreliable (Southgate and Macke, 1989). This is a serious problem in soil erosion research: the quality of available data is extremely uneven and the literature is polluted with unreliable data (Lal *et al.*, 1989; Lal, 1994).[1] Many studies do not rely on

[1] One notorious example (Lal, 1987a; Stocking, 1987) compares maps from different sources depicting erosion rates on the basis of global denudation rates (based on annual sediment discharges

data in a strict sense but use arbitrary and questionable guesstimates and excessive extrapolation (Scoones *et al.*, 1996; Enters, 1998). Yet wrong data are worse than no data, giving a spurious impression of accuracy and possibly leading to wrong decisions (Gill, 1993).[2]

A last (and related) issue is the *complexity* of soil erosion. Soil erosion may be a visible symptom, but the problem is often much more elaborate than it appears at first glance (Fones-Sundell, 1992). Indeed, *human-induced* soil erosion is of particular concern, yet it is often difficult to single out the effect of humans (Blaikie, 1985), let alone proof the causal relationships (Stocking, 1988). There simply is no straightforward cause-effect relationship.

The complexity is reflected through the various dimensions of soil erosion: (i) time, (ii) space and (iii) location (*i.e.* state of nature). Soil erosion affects the subsequent productivity of the *in situ* soil resource - *i.e.* the *temporal* aspect. The first law of thermodynamics implies that the eroded material must appear elsewhere - *i.e.* the *spatial* aspect. Both the temporal and spatial dimensions vary over geographic location and are extremely site-specific - *i.e.* the *locational* aspect. It is especially this site-specificity that confounds the debate and makes generalisations dangerous (Greenland *et al.*, 1994; Enters, 1998). Indeed, 'variability in climate, soils, and topography make universal truths extremely difficult to discover, and specific truths are extremely costly.' (Jolly *et al.*, 1985:477).

Soil erosion is not a new problem and has been pervasive since the beginning of agriculture (Blaikie, 1985; Sanders, 1990). Others have therefore sought historical evidence, and numerous examples have surfaced of previous civilisations where excessive soil erosion/degradation has contributed to, if not caused, their downfall.[3] However, the retrospective view frequently makes it no easier to disentangle soil erosion from the other confounding factors (Wittfogel, 1957 and Adams, 1965 in Wolman, 1985).

The global soil erosion problem is therefore likely to be either exaggerated or neglected because of the paucity of solid data (Lal, 1987a). Indeed, with a wide range of patchy data it is easy to choose and quote those figures that suit the purposes best (Chambers, 1997:40).[4]

Economic aspects

Existence of (human-induced) soil erosion is not necessarily evidence of an economic problem (Blyth and McCallum, 1987). There would be an economic problem when the costs of soil erosion outweigh the benefits of the underlying degrading process. Yet this assessment is less straightforward than it may seem. Most accelerated soil erosion is an unintended side effect of other productive activities - be it forestry, livestock production,

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into the ocean). The maps differ by several orders of magnitude, highlighting that such estimates are often unreliable, futile and confusing. Even more localised estimates of erosion rates for the same region occasionally vary by several orders of magnitude, including some that are unbelievably high (see Seckler, 1987:86).

[2] How can a policy maker differentiate between solid and 'guesstimated' data? (Lal, 1987a).

[3] Lowdermilk, 1942 in Sanders, 1990; Hymans, 1952 in Wolman, 1985; Hudson, 1971 and Lal, 1990 in Eaton, 1996; Clark II, 1987.

[4] In fact, various stakeholders have an active interest in ensuring that land degradation is perceived as a serious threat (Leach and Mearns, 1996).

crop production or otherwise. Farmers do not deliberately set out to erode their soil resources, but often are obliged to pursue land use practices irrespective of the soil erosion implications.

Soil erosion is also likely to be an economic problem when private and social interests do not coincide. This seems highly probable in view of its temporal and spatial dimensions. The temporal aspect is reflected in the main on-site effect of soil erosion: the generally adverse effect on future *in situ* productivity, thereby generating an inter-temporal externality.[5] The spatial aspect implies the existence of off-site effects which influence the resource base *ex situ*, generating a spatial externality.

While most experts agree that soil erosion incurs costs, the magnitude of those costs is widely debated. One particular controversy revolves around the relative importance of the on-site and off-site costs (Wiggins, 1981; Magrath and Arens, 1989; Pimentel *et al.*, 1995; de Graaff, 1996). Whatever the exact magnitude of off-site costs, some are of the opinion these are significantly larger than the on-site effects in the developed nations (McConnell, 1983; Phipps, 1987; Colacicco *et al.*, 1989; van Kooten, 1993:235). This leads Buttel and Swanson (1986) to consider erosion primarily as a (spatial) externality problem, with added on-site effects. Pimentel *et al.* (1995:1120) disagree, estimating that on-site costs make up over 60% of their US$ 44 billion yr^{-1} cost estimate for soil erosion in the USA.

In developing countries too, opinion is divided, though on-site costs seem to be relatively more important (Wiggins, 1981; Pagiola, 1994a). The frequently cited study of erosion costs in Java by Magrath and Allen (1989) clearly stresses on-site costs (US$ 315 million on-site and US$ 26-91 off-site). On the other hand, Sfeir-Younis (1985 in de Graaff, 1993) concludes that whatever on-site productivity losses, downstream effects are large.

The economic impact of global soil erosion is therefore uncertain. Part of the controversy directly reflects the uncertainties surrounding the actual extent and impact of soil erosion in physical terms. The valuation is further compounded by socio-economic differences over space and time and methodological issues. The subsequent sections look into the main analytical issues of soil erosion, starting with the physical on-site effects.

2.2 On-site effects: (Physical) Soil loss

Soil erosion is basically a process of detachment of soil particles and their subsequent transport (Laflen and Onstad, 1994). Therefore, it is most directly associated with the physical soil loss, *i.e.* the amount of soil actually lost per unit area. However, one of the problems of soil erosion - and of most soil degradation processes for that matter - is the invisibility of the problem itself (Chisholm, 1987a; Camboni and Napier, 1994; de Graaff, 1996).

Most forms of soil erosion are a subtle, rather than an easily detected soil condition (Rickson *et al.*, 1993). The process is slow and unobtrusive at first (Biot and Xi, 1993), yet the effects accumulate over time (Anderson and Thampapillai, 1990). Not surprisingly,

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[5] A (potential) externality 'exists when the implications from a decision carry beyond the boundary of the unit responsible for making a particular decision.' (Bromley, 1982a:219).

farmers consistently underestimate the extent of erosion in the early stages, and misperceptions are common (Rickson *et al.*, 1993). For instance, it is the relatively imperceptible sheet erosion that is extremely serious and conducive to the more visible forms of erosion. Yet it is the visible gullies - symptoms of longstanding degradation - that dominate the observers' and politicians' perception of the problem (Stocking, 1987). The erosion process is especially inconspicuous on relatively flat cropland (Biot and Xi, 1993) and in annual crops, as rills are frequently removed by cultivation (whereas they do eventually expose perennial roots - Thomas, 1988).

Actual soil loss levels are determined by a number of inherently site-specific aspects, such as climate, soil, topography and management.[6] The effect of each individual aspect can generally be predicted. For example, a given land use will produce greater soil losses on land with steeper slopes, *ceteris paribus*. Yet the interaction between the terms, and the sheer multitude of factors, make a prediction of the combined outcome uncertain.[7] Considerable effort has been put in quantifying – with various degrees of success – this physical quantity.

One of the most widely used erosion prediction models is the *Universal Soil Loss Equation (USLE)*. It is a simple multiplicative model, though USLE is somewhat of a misnomer. First, its 'universality' is limited as the model was calibrated on empirical data (2,300 plot years) from the mid-west USA. It has only been verified in temperate climates and cropping systems, medium textured soils and slope gradients of 3-18% (Wischmeier, 1976; Blyth and McCallum, 1987; Seckler, 1987; Stocking, 1987). Second, 'loss' does not refer to the field or catchment sediment yield; *i.e.* the soil that actually leaves the field. Instead, it refers to soil movement off a particular slope segment and does not include deposition (Wischmeier, 1976; Sanders *et al.*, 1995). The literal interpretation of USLE estimates will therefore systematically overestimate actual soil loss, a problem that is compounded when these estimates from a small field plot are extrapolated to larger geographic scales (Stocking, 1987; Bishop and Allen, 1989). In addition, it should be acknowledged that it estimates long-term average gross soil movement (based on a normal 20-22 year rainfall cycle), using time to cancel out the short-term oscillations (Wischmeier, 1976; Sanders *et al.*, 1995).

USLE's simplicity has often led to misuse, most commonly by applying the equation to situations for which its factor values cannot be determined from existing data with acceptable accuracy (Wischmeier, 1976). Indeed the lack of valid site-specific data often leads to excessive extrapolations (El-Swaify, 1994). The use of USLE outside the USA may therefore not be cost effective given the information costs (Chisholm, 1987a).

Despite serious reservations about its reliability, almost all estimates of soil erosion by water are made with USLE (Crosson, 1997:5). Indeed several economic models rely on

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[6] A common distinction is between *erosivity* (*i.e.* intensity of erosive forces) and *erodibility* (*i.e.* physical susceptibility of the soil to erosion).

[7] For instance, estimating soil erodibility on basis of empirical equations developed elsewhere may differ from measured values by a factor of 2-5. Likewise for erosivity (Lal, 1987a:305).

USLE for their erosion estimates in developing countries.[8] Bishop and Allen (1989) see USLE as a compromise solution as the data requirements of more sophisticated models cannot be met. Veloz *et al.* (1985) are of the opinion one can use USLE as long as the shortcomings are acknowledged. Others 'adapted' USLE to local needs, whatever that may imply. Nonetheless, the illusion of precision remains, especially for those lacking the background knowledge to fully acknowledge the limitations.

USLE is a relatively old model and newer models have been developed since then, including the revised USLE (RUSLE - Renard *et al.*, 1994) which retains the one-equation format. SLEMSA (Soil Loss Estimator for Southern Africa) suffers from some of the inadequacies of USLE, but is claimed to be less data demanding using 'rational' parameters (Stocking, 1987:60). WEPP (Water Erosion Prediction Project) provides a more sophisticated, process-based model (Laflen *et al.* 1997). Whatever the model, its use should be subject to prior validation (Enters 1998) - which is typically compounded by the lack of data.

Notwithstanding difficulties in estimating physical soil erosion, it is clear that the problem is unevenly distributed across space and time (Buttel and Swanson, 1986). The highest levels of erosion tend to be concentrated on a fraction of the land; whereas the severest erosion occurs during the occasional extreme event (Blaikie and Brookfield, 1987).

Last, but not least, the physical soil loss itself still says little about the economic costs of soil erosion - either on-site or off-site. As elaborated in the next section, soil loss is a poor indicator of the erosion-induced productivity loss on-site. Further, although soil loss does reflect the potential sediment load, it also says little about the off-site effects: not all eroded soil contributes to sediment related off-site effects due to deposition, whereas sediment is only one of the contributors.

2.3 On-site effects: (Biological) Productivity loss

Soil has value to farmers primarily, if not solely, because of its role in crop production. Soil erosion alters the inherent physical and chemical properties of soils, and thereby soil productivity. For farmers this potential erosion-induced productivity loss is far more important than the amount of soil actually lost (Shaxson et al., 1989:23; Douglas, 1993; Pagiola, 1994b). Productivity loss indeed is the central on-site cost of soil erosion. However, whereas soil erosion itself is inconspicuous, its productive damage is generally even more imperceptible. Based on the temporal dimension of the erosion-induced productivity loss, a distinction can be made between (i) cumulative and (ii) ephemeral effects.

The productive capacity is literally eroded by the *cumulative* degradation of the soil resource, resulting in foregone future productivity.[9] This mainly relates to the loss of

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[8] For instance Veloz *et al.*, 1985; Bishop and Allen, 1989; Carcamo *et al.*, 1994; Pagiola, 1994b; de Janvry *et al.*, 1995; Ramirez and Martinez, 1995.

[9] This is the *user-cost* of soil erosion: the loss of future soil productivity through current resource use (Anderson and Thampapillai, 1990; Conway and Barbier, 1990).

rooting depth, soil fertility, organic matter, and plant available water reserves and the degradation of soil structure (Nowak *et al.*, 1985; Lal, 1987a; de Graaff, 1993). It is these soil related aspects that adversely affect crop productivity in the long run, not soil loss *per se*. Though the effects in one year may be insignificant they become important as they accumulate over time (Lal, 1987a). There can also be critical thresholds. Indeed, it may take some time before the cumulative productivity losses will reach a point where farmers will experience a measurable loss in revenues (Biot and Xi, 1993). In the end, the ability to grow crops (technically and/or economically) might be lost (Pagiola, 1994a).

In contrast, the *ephemeral* damages (Crosson, 1985) bite immediately but are short-lived, generally only affecting the respective season. Soil erosion by water is not just the loss of soil, but also implies runoff of water and washing away of inputs. Water losses as runoff can have an immediate effect on crop productivity - notably when water is the crop production limiting factor. The amount of fertiliser lost through soil erosion may even exceed that absorbed by plants (Lal, 1987a). In addition, soil erosion may result in the loss of crop stand by crop burial, waterlogging or washing away of seeds/plants (*ibid.*).[10]

From soil loss to productivity loss

It is a tricky step to move from soil loss to productivity loss (Bishop and Allen, 1989; Sanders *et al.*, 1995). Much more is known about the erosion process itself than of the consequences of erosion, notwithstanding the considerable resources that have been directed to understanding these relationships (Anderson and Thampapillai, 1990). Indeed, in spite of the billions of dollars invested in soil erosion research, 'we cannot say for sure what effect the loss of a unit of soil depth has on crop yield' (Lal, 1987a:362). The large-scale effects of erosion on the productivity of soils are not well known (Pierce, 1991) and there is a serious paucity of quantitative data (Pierce and Lal, 1994).

This is partly explained by the fact that there is no clear-cut relation between soil and productivity loss. First, physical soil loss singles out only one aspect of soil erosion. But soil erosion is not only the loss of soil; it also implies other ephemeral and cumulative costs. Physical soil loss is thus only a rough proxy for the degradation caused by soil erosion.

Second, soil itself is only one of the factors affecting crop productivity. Crop yields are a function of many variables, including biophysical conditions, crop management and the crop itself (Lal, 1987a; Bishop and Allen, 1989; Rabbinge and van Ittersum, 1994). The effect of soil erosion is thus easily masked by other factors. In fact, the erosion-induced productivity loss in any given year tends to be small relative to annual variations in weather (Pierce, 1991; Shaffer *et al.*, 1994). The various variables also interact, further confounding the assessment of erosion-induced productivity loss (Frye, 1987; Stocking, 1988; Pimentel *et al.*, 1995).

Therefore, the explanatory power of the erosion-productivity relationship is generally limited - *i.e.* soil erosion rates by themselves are poor indicators of the loss in productivity

[10] The line between on-site and off-site effect is somewhat blurred here, literally depending on the boundaries of the farmer's field. In this regard one could distinguish different spatial scales such as intra-field; intra-farm; inter-farm; and further downstream (de Graaff, 1996:117). The scale-issue is elaborated in Section 2.6.

(Larson *et al.*, 1983). In other words, the very measure for soil erosion thus is poorly representative for its main on-site economic cost (Stocking, 1987:62).

Site-specificity

Site-specificity further compounds the assessment of the erosion-induced productivity loss. Soil erosion affects the productivity of certain soils more than others (Frye, 1987; de Graaff, 1993). The effect of slight erosion on a shallow soil may be severe, whereas the effect of severe erosion on a deep fertile soil may only be slight (Lal, 1987a). In the first case crop yields may be affected within a short period of 2-5 years, whereas in the latter no effect may be perceived over 10-20 years (*ibid.*). Similarly, Biot and Xi (1993) suggest that an erosion level of 50 Mg ha^{-1} yr^{-1} on a deep alluvial soil may have little impact on production, while 5 Mg ha^{-1} yr^{-1} may cause substantial losses on an Oxisol. Exceptionally, erosion-induced changes can even lead to *improved* productivity in certain depositional soils by the exposure of more favourable subsoils (Lal, 1987a; Pierce, 1991).

The effect of erosion on crop productivity is determined by a number of soil specific characteristics, including rooting depth, distribution of plant nutrients in the profile, plant available water reserves and qualitative differences between topsoil and subsoil (Frye, 1987; Lal, 1987a:310). In addition to being soil specific, the impact also depends on the magnitude of the production itself which varies among crops, climates and management levels (Lal, 1987a).

The literature suggests some major differences between the temperate and tropical environments. In temperate regions the impact of erosion on productivity is long term and relatively small (Fletcher and Seitz, 1986; El-Swaify, 1994). For example, Crosson *et al.* (1985) report studies that estimate the erosion-induced productivity loss to be in the order of 5-10% for maize over 100 years in the USA. In contrast, the limited available data suggest a more severe impact on highly weathered tropical soils.[11] For example, Biot and Xi (1993) estimate that a maize-cowpea intercropping system in Sierra Leone could lose up to 25% of its average annual production over 100 years. Dregne (in Pimentel *et al.*, 1995) reports an erosion-induced productivity loss for maize of 80% over 15 years in the Philippines. The severity of the yield decline is compounded by the generally lower initial yield levels in tropical areas (Stocking, 1984 in Eaton, 1996).

Several factors contribute to making the productivity impact in the tropics more severe (El-Swaify, 1994). First, tropical regions generally experience higher erosion rates - due to both higher erosivity and erodibility (Lal, 1984). Second, soil erosion causes more severe quality changes in tropical soils[12] (Lal *et al.*, 1990). These soils are generally more fragile than the robust well-buffered temperate soils (Anderson and Thampapillai, 1990). Third, erosion effects are less modified due to lower external input use in the tropics. The more severe productivity impact in the tropics implies that the considerable soil erosion research

[11] Southgate *et al.*, 1984; Lal, 1987a; Pierce and Lal, 1994; Barbier and Bishop, 1995; Sanders *et al.*, 1995.

[12] Tropical soils typically have low inherent fertility, concentration of plant available nutrients and organic matter in topsoil and edaphologically unfavourable and root restrictive subsoils (Lal, 1987a).

base developed in the USA is unlikely to be directly transferable to fill the numerous knowledge gaps in developing countries.

The numerous site-specific factors at play also give rise to a number of controversies. For instance the fertiliser-erosion paradox: whether soil erosion increases or decreases the marginal effect of fertiliser (Figure 2.1).[13] On the one hand, soil erosion implies the loss of fertility. This would conceivably increase the marginal effect of fertiliser on eroded soils, *ceteris paribus* (soil B in Figure 2.1; line of argument of van Vuuren and Fox, 1989: 550-51). On the other hand, soil erosion implies an overall more degraded soil resource. This would conceivably decrease the marginal effect of fertiliser on eroded soils, *ceteris paribus* (soil A in Figure 2.1; line of argument of van Kooten *et al.*, 1989b: 556). Both situations can prevail depending on the erosion-induced loss and the actually limiting factors (*e.g.* see Larson *et al.*, 1985b: 262-3; Lal, 1987a:312).[14]

Soil erosion and its productivity impact are thus highly variable from place to place, making generalisations both problematic and controversial. Site-specificity is indeed one of the recurring findings with respect to erosion-induced productivity loss: potentially devastating in some areas of the world, and amenable to control in others (Wolman, 1985; Lal, 1987a).

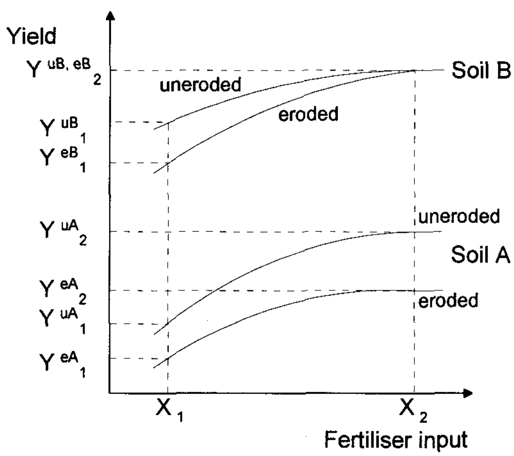

Figure 2.1 Fertiliser-erosion paradox (adapted from Lal, 1987a)

Conceptualising the erosion-productivity relationship

Assessments of the erosion-productivity relationship are easily confounded by the various factors at play. Common sense suggests that production must be lower when the soil

[13] This was one of the controversies surrounding van Kooten *et al.* (1989a). See van Vuuren and Fox, 1989; van Kooten *et al.*, 1989b.

[14] Figure 2.1 also highlights the discussion whether erosion-induced damage is 'permanent' or 'repairable'. For the hypothetical soil B, the erosion-induced damage is repairable by increasing fertiliser input from X_1 to X_2, for hypothetical soil A this is not the case. The permanent *versus* repairable damage discussion is pursued in Section 2.7.

resource is degraded, even if there is a lack of scientific data substantiating the relationship quantitatively (Fones-Sundell, 1992).[15] Indeed, one would expect soil erosion to have a generally negative effect on productivity (Frye, 1987; Bishop and Allen, 1989; Eaton, 1996). Many expect the relationship to be cumulative non-linear,[16] although it is less clear whether it would be convex or concave to the origin (Sanders *et al.*, 1995) - see Figure 2.2.

Empirical data suggest both cases could be present (Biot and Xi, 1993). In some cases, the soil's productive potential drops rapidly and then slows down (hypothetical soil A in Figure 2.2). Soil erosion preferentially erodes the most valuable soil components first, such as the nutrient rich humus layer and finer soil particles. *Ceteris paribus*, such preferential depletion suggests yield loss as depicted for soil A. In other cases, decline is slow at first, but subsequently accelerates (soil B in Figure 2.2). *Ceteris paribus*, the loss of topsoil depth suggests yield loss as depicted for soil B.[17] The figure also highlights that the marginal productivity loss varies - both over soils and time.

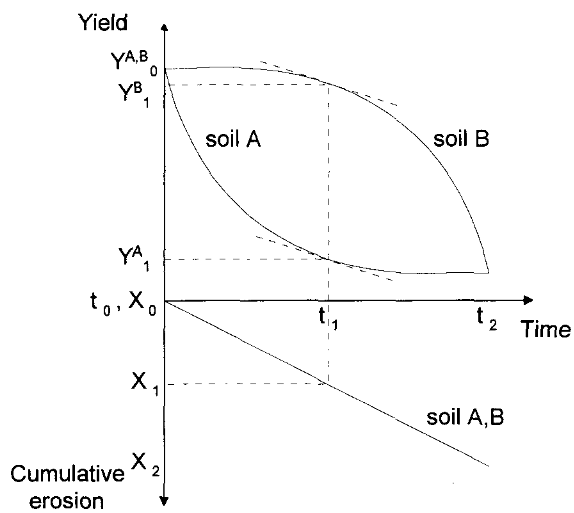

Figure 2.2 Hypothetical relationships between cumulative soil erosion and yield for two soil types (A and B - adapted from Sanders *et al.*, 1995)

A complicating factor for empirical assessment is the time profile of erosion, as most of the current agricultural land has already been subject to past erosion. Cumulative soil loss of X_1 in Figure 2.2 highlights this issue. For both situations the rate of productivity loss at X_1 is similar, but the implications differ substantially. In soil A most of the productive damage

[15] However, this common sense quickly leads to soil conservation fundamentalism.

[16] Crosson, 1985; Nowak *et al.*, 1985; Blaikie and Brookfield, 1987:17; Phipps, 1987; Stocking, 1988; Biot and Xi, 1993.

[17] For empirically based variations of A-type soils see Lal (1987a:334). For variations of B-type soils see Larson *et al.* (1985a:243).

has already been done. Any slowing down of further soil erosion has relatively little productive effect. In contrast, slowing down soil erosion in soil B can substantially reduce future productive losses. Yet in this case no - if little - damage has been perceived yet, making farmers wary of the need for intervention. In either case (soil A or B), the non-linear relationship makes farmers' experience a poor guide to assess future erosion-induced productivity effects (Crosson, 1985:264).

Erosion-induced productivity loss is highly probable in most soils - though the extent and severity are unknown, thereby severely complicating the economic analysis of soil erosion. Further, soil erosion is generally expected to result in a negative trend for productivity, *ceteris paribus*. The problem is other things are never equal, especially over time.

Technical change

Technical change is a major source of 'noise' that confounds the already weak productivity signal over time. Whereas weather generates oscillations around the trend, technical change results in a positive trend for yields, *ceteris paribus*. Indeed, despite massive soil erosion/degradation, global trends in mean crop yields have generally been upwards during the second half of the 20th century (WRI *et al.*, 1992; Crosson, 1997). Grain and other yields generally doubled or tripled since 1950 in the North (Blaikie and Brookfield, 1987). This is commonly attributed to the increased use of inputs (germplasm, agro-chemicals, and knowledge) that successfully masked the adverse effects of soil loss on productivity (Napier *et al.*, 1991; Camboni and Napier, 1994).[18] This has two major consequences for soil erosion. First, technical change masks the real cost of soil erosion (Stocking, 1987). Second, this has created a false sense of security and complacency (Blaikie and Brookfield, 1987), thus forfeiting the need for countervailing action.

The achieved past increases in yields in spite of erosion through general yield-enhancing technical progress indeed leads to a belief that erosion damage is insignificant (Taylor and Young, 1985; Walker and Young, 1986). Or at least, that erosion is not perceived as a major problem (Crosson *et al.*, 1985). This is simplistic as it is based on a simple chronological before-after comparison, whereas the technical change was largely exogenous (independent from erosion). Figure 2.3 illustrates the problem where technology A depicts the original and technology B the new production function after exogenous technical progress. Assuming the reference topsoil depth to be X_1 and the actual depth X_2, the before-after comparison suggests yields increased over time from Y^A_1 to Y^B_2 despite topsoil loss. A

[18] For instance, Crosson *et al.* (1985) estimate that the combined productivity of all resources used in agriculture in the USA has increased by 58% from 1950 to 1979, mainly through technological and management advances, input substitution and economies of scale. These factors thus more than offset the decline in land quality, and highlight the possibility of factor substitution. The authors also expect the effect of erosion on production costs to be small relative to the effects of demand growth, input prices and technology. What's more, the 'cost reducing thrust of technology and managerial improvements' ... 'were more than sufficient to offset the combined cost increasing effects of rising demand, higher input prices and erosion damages to the soil' (Crosson, 1985:259).

correct with-without comparison would assess the damage along the new yield response curve, and highlight a substantial yield loss (difference Y^B_1 and Y^B_2).[19]

If soil erosion imposes real but concealed economic losses, it clearly affects the long-term productivity and efficiency of farming (Barbier and Bishop, 1995). Further, it is likely that there is a positive interaction between technology and soil quality - being complementary inputs (Walker and Young, 1986). The resultant multiplicative technical progress does not mitigate the effect of soil erosion but actually exacerbates the yield damage in terms of foregone potential yields. General yield-enhancing technical progress can therefore not be viewed as a simple substitute for soil conservation (*ibid.*).

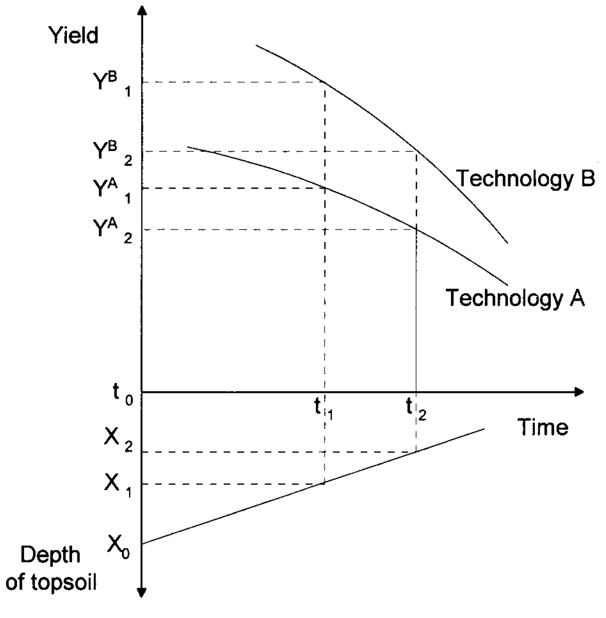

Figure 2.3 Interaction between technical progress and topsoil yield response (adapted from Walker and Young, 1986)

Methodological approaches

Several approaches exist to clarify the erosion-productivity relationship, each with its inherent strengths, weaknesses and biases.[20] There is an increasing emphasis on modelling approaches. Pierce and Lal (1994) categorise these as: (i) statistical and (ii) (physically-based) simulation models. The *statistical models* include regression models, multivariate and factor analyses and geostatistical models (Cassel and Fryrear, 1990 in Pierce and Lal,

[19] *E.g.* for the erosion prone Palouse region in the USA , Jennings *et al.* (1990 in WRI *et al.*, 1992) estimate that the potential foregone due to soil erosion amounts to 670 kg winter wheat ha^{-1}.

[20] For overviews see Lal, 1987a; Biot and Xi, 1993; Olson *et al.*, 1994; Pierce and Lal, 1994:240.

1994). The productivity index model (Larson *et al.*, 1983; Pierce *et al.*, 1984) is an example of a regression-type parametric model. The *simulation models* simulate the underlying biophysical relationships over time, for different crops and management practices - the most renowned being EPIC (Erosion Productivity Impact Calculator - see Williams and Renard, 1985).

The simulation models, being more sophisticated, are also more data demanding. Yet the site-specific data needed to actually calibrate and evaluate model performance may well be limited (Lal, 1988; Sanders *et al.*, 1995). What's more, without an experimental base for validation, the value of models is limited and may be dangerously misleading (Greenland *et al.*, 1994). The more comprehensive methods are probably far too information intensive to be practical in developing countries (Anderson and Thampapillai, 1990).

Data limitations are indeed a frequent stumbling block for quantifying the impact of erosion.[21] It has also favoured the use of simple two-equation models (Blyth and McCallum, 1987; Sanders *et al.*, 1995). In these, the first equation estimates physical soil erosion as function of physical determinants. The second equation relates soil erosion and yields - the dose-response function. However, the same data limitations have favoured the use of empirical equations developed elsewhere, frequently ignoring the underlying complexities and site-specificity.

2.4 On-site effects: Socio-economic valuation

Productivity loss is the main on-site cost of soil erosion. This cost is mainly imposed in three interrelated ways (Crosson, 1985): (i) actual productivity loss, (ii) compensation costs, and (iii) prevention costs. The *loss in productivity* is a direct result of the resource degradation, with lower yields per unit area and lower input use efficiency, *ceteris paribus*. The costs of *compensation* relates to the use of more land-substituting inputs to offset some or all productivity loss. The costs of *prevention* relates to the investment in soil conservation to avoid rather than compensate productivity loss. In case of prevention, on-site costs increase because of potential rather than actual erosion. Whereas actual productivity loss results in lower yields for a given input, the latter two result in higher costs to maintain a given yield. Each entity thereby lowers the returns to agricultural land use. The interdependence between the three entities implies they should be considered jointly.[22]

Whereas the biophysical environment determines the magnitude of soil erosion and its productive on-site effect, the socio-economic environment determines its *value* and thus its seriousness in monetary terms. However, when it comes to the socio-economic valuation, uncertainty is even more rampant and frustrating (Anderson and Thampapillai, 1990). Indeed, the biophysical variability is compounded by socio-economic differences (Stocking, 1993). For instance, the value of a 10% erosion-induced yield decrease is not the same for

[21] In their review, Blyth and McCallum (1987:89) indeed conclude that it is of little meaning to place values on all the measured soil losses in view of the sheer variability among the estimates of both soil and productivity losses.

[22] The methodological approaches to quantify these entities are discussed in Section 3.2.

all locations, as the value of agricultural production is influenced by such factors as (i) accessibility (*e.g.* a peri-urban *versus* a remote plot), (ii) resource quality (*e.g.* favourable *versus* marginal land) and (iii) land use (*e.g.* high value *versus* low value crops). Resource endowments, technology, preferences and institutions vary over space and time and thereby make the valuation of the on-site cost of soil erosion highly site and time-specific.[23] Such considerations typically vary between individual economic agents, between agents and society, and between societies. This obviously complicates the assessment of the economic damage of soil erosion.

Market prices may or may not reflect the opportunity costs and these influence - albeit to different degrees - farmer behaviour. One particular price response that has received some attention in the literature[24] is whether higher output prices would increase or decrease soil erosion/degradation. Though disputed, the two main arguments revolve around the farmers' choice of land extensification or intensification. A farmer may respond to higher output prices by *extensification*, *i.e.* bringing more land in production by expanding his activities onto marginal lands. This seems to have been the case in the USA (so-called 'sod busting'). In developing countries this may involve the cultivation of steep land or clearing of forest and savannah. A farmer may also respond to higher output prices by *intensification* on his existing farmland. Higher output prices make the erosion-induced productivity loss more costly. Especially if the farmer perceives the price rise as permanent, he may be more inclined to conserve his resource base (Repetto, 1987 in Barrett, 1991).[25]

Changes in relative output prices can also influence soil erosion via induced changes in land use patterns (and the corresponding erodibility). However, most farm households in developing countries are only partially integrated in markets and particularly the production of staple food crops is relatively inelastic (Lutz 1992 in Heerink *et al.*, 1996). This inelastic response is sometimes ignored in economic modelling. For instance, Coxhead and Jayasuriya (1995) conclude that reduced trade distortions in developing countries can reduce upland degradation based on the induced shift from erosive annual food crops to less-erosive perennial cash crops. Similarly, Carcamo *et al.* (1994) ignore the fact that subsistence crops (maize and beans) in reality occupy 82% of the agricultural area of their Honduran watershed. The base case for their linear programming model entirely displaces food crops with more lucrative cash crops. Even when they introduce 'risk preference' they ignore any link with farmers conceivably preferring to grow their own food - the prevalent practice in the region.

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[23] In this regard, Seckler (1987:84-85) presents the diamonds and water paradox, highlighting the logical fallacy that confuses the total value of something with its marginal value. While soil (and water) are indeed vital to all life, the value of soil depends on the supply and demand for a little more or less soil in specific locations at specific times.

[24] Amongst others Miranowski, 1984; Edwards, 1987; Barrett, 1991; LaFrance, 1992; Orazem and Miranowski, 1994; Coxhead and Jayasuriya, 1995; Eaton, 1996; Bulte and van Soest, 1997.

[25] This also reflects a major problem with price support in developed countries (Phipps, 1987). If farmers expect these supports will be reduced in the future, they will be less inclined to invest in soil conservation now. At the same time the high current prices encourage them to cultivate fragile lands.

Market integration also helps to mask the effect of soil erosion. First, market integration is closely linked with external input use - and their use frequently masks the productive effects of erosion. Second, market fluctuations easily hide trends. Changing relative prices may induce changes in input use and/or cropping patterns. Such adaptations make it particularly difficult to keep track of productivity trends on a particular piece of land. Input prices may also influence soil erosion directly. For instance, high fertiliser subsidies provide a disincentive to face the real economic cost of soil erosion.[26]

Markets and prices are not the only factors shaping the socio-economic site-specificity. Other institutions such as property rights and tenancy arrangements also play a role. A short-term tenant will most probably place less value on long-term erosion-induced damage than his land-owning neighbour. Similarly, resource endowments, technology and preferences are influential (see 3.3).

A last complicating factor is that farm management decisions regarding the total production cycle and soil erosion are not independent. Management decisions can either exacerbate or mitigate soil loss rates (Lee and Stewart, 1983). Alternatively, farmers adapt their management to the degradation they perceive. Adaptation may thereby postpone any eventual shutdown point when production would become economically unviable (Pagiola, 1994a; Eaton, 1996). This very dependence obviously is the rationale of soil conservation.

2.5 Off-site effects

Soil erosion by water basically is a redistribution of soil: it implies the removal from soil from the upstream source, and the reappearance of the eroded soil further downstream (in a temporary or more permanent sink). The reappearance elsewhere generally has adverse effects. Clark II (1987) divides these into (i) in-stream (in a waterway) and (ii) off-stream (before entering or after leaving the waterway). In-stream impacts include adverse effects on navigation, water storage, water conveyance, recreation and water ecology. Off-stream impacts include flood damages (including road maintenance and undermining of structures) and adverse effects on water use for human consumption, industry and agriculture (in terms of water quality loss and/or water treatment costs).[27]

The off-site effects of soil erosion, however, comprise more than just the reappearance of sediment proper. Specifically, one can distinguish between (i) conventional pollutants (sediment, biochemical oxygen demand, dissolved solids) and (ii) chemical pollutants (fertiliser and pesticides - *ibid.*). Excess sediment was long considered the major form of human-caused water pollution in the world and still exerts a heavy cost (Eckholm, 1976 in Sanders *et al.*, 1995). For instance, sediment adversely affects the potential to develop water resources in developing countries (*e.g.* for irrigation or hydroelectric energy - Southgate and Macke, 1989). The adverse effect of the other pollutants is increasingly

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[26] Whereas at the same time it encourages excessive and inefficient use - increasing fertiliser run-off and environmental pollution (Barbier, 1990; Barbier and Bishop, 1995).

[27] Clark II, 1987; Upstill and Yapp, 1987; Holmes, 1988; de Graaff, 1993; Camboni and Napier, 1994; El-Swaify, 1994; Pimentel *et al.*, 1995; Sanders *et al.*, 1995; Alfsen *et al.*, 1996.

recognised - although occasionally still perceived as a luxury problem in developing countries (Lovejoy and Sanders, 1994).

The reappearance elsewhere may also have positive effects. Some of the prime agricultural land in the rich alluvial plains and deltas were created by (geological) erosion. Whereas Herodutus called the fertile silt deposited by seasonal floods in the Nile delta a 'gift from the gods', a more recent view is that it was a gift from Ethiopia (El-Swaify *et al.*, 1982 in Sanders *et al.*, 1995). Others go even further: Seckler (1987) merely views soil erosion as the removal of soil and water from areas of low valued use (upland) to high valued use (lowland) where both can be utilised more efficiently. Sediment can also be an important source of construction material - *e.g.* in Asia (Enters, 1998). The positive spatial externalities are a frequently neglected factor, partially because they are difficult to measure, but possibly also because of the ethical questions and cross-border conflicts involved.

Most authors agree that soil erosion can have important off-site costs. Anecdotal evidence suggests that these costs are growing (Southgate *et al.*, 1984) - *e.g.* due to land use changes and economic development in flood prone areas (Enters, 1998); or the loss of sites for alternative reservoirs. However, there is no consensus in relation to the magnitude of off-site costs (Cook, 1988; Camboni and Napier, 1994). Off-site costs vary in measurability and relevance (Upstill and Yapp, 1987). Some are a direct financial burden, whereas others are less tangible and do not lend themselves to quantification in monetary terms (Camboni and Napier, 1994). For example, the frequently cited estimate of US$ 6.1 billion annually for off-site costs in the USA by Clark II *et al.* (1985), excludes the 'biological impact' because of the difficulty to assign an economic value (Clark II, 1987:77).

The assessment of off-site costs is further compounded by the fuzziness of the cause-effect relationships. The sequential and multiple purpose use of water implies a complex effect chain. Perhaps even more problematic is tracing the true cause: soil erosion being a typical example of non-point source pollution, where non-point refers to its diffuse nature (Batie, 1986). In fact, the agricultural contribution to downstream problems may often be overstated because of neglect of natural processes and non-agricultural activities (*e.g.* road building, mining, construction - Sanders *et al.*, 1995:28).

Site-specificity once more is a confounding factor. Off-site costs of soil erosion by water are profoundly location-specific as they directly depend on downstream uses (Meyer, 1988:66). Most of the downstream uses will relate to economic activity and population density, but not necessarily so. Damage to the Cahuita coral reef off the Caribbean coast in Costa Rica is a case in point. The area, officially protected as a National Park, has been adversely affected by the effluent of nearby rivers carrying sediment and chemical pollutants from the inland banana growing areas. This also reiterates the tangibility problem of off-site costs. Indeed, costs imposed on downstream economic activity may well be more tangible than damages imposed on non-economic uses, such as wildlife preservation. The latter derives non-use value based upon bequest and/or existence values. In turn, the damage to a coral reef may be valued substantially higher than damages to less conspicuous wildlife. Yet a correct assessment of off-site costs needs to aggregate all these costs.

Even the more tangible costs present their own measurability problems (Stocking, 1988). The cost of soil erosion to hydroelectric reservoirs revolves around (i) the worth of the marginal output foregone (electricity, irrigation, etc.) and (ii) the cost of remediation (dredging; flushing; repairing damaged machinery - *e.g.* see Veloz *et al.*, 1985; Southgate and Macke, 1989; Sanders *et al.*, 1995). However, conceptually sound estimation of downstream impact is often pre-empted because of data limitations (Sanders *et al.*, 1995). For instance, there is a persistent tendency to underestimate reservoir sedimentation rates *ex ante*, most likely due to the use of unreliable/faulty prediction techniques (Enters, 1998).

The combined effect of site-specificity and estimation methods, ensures a wide range of off-site costs estimates (*e.g.* see Sanders *et al.*, 1995:19-28). What is clear though, is that high off-site costs do not necessarily coincide with high soil erosion rates (Ribaudo *et al.*, 1989 in Sanders *et al.*, 1995). Similarly, high off-site costs do not necessarily coincide with high on-site costs (Holmes, 1988).

2.6 Scale issues

The existence of off-site effects makes any assessment of soil erosion scale-dependent, thereby further compounding the analysis. Three scale issues merit highlighting: (i) the soil erosion process, (ii) the accounting boundaries and (iii) the wider picture.

The (physical) *soil erosion process* itself is scale dependent (Lal, 1994). Soil particles are detached and deposited, and sediment delivery ratios[28] vary with scale. Rates of erosion measured at the field scale will, when extended to the watershed scale, grossly overestimate the total amount of sediment leaving the watershed (Stocking, 1987).[29] Various sediment traps assure that not all eroded soil is lost to future agricultural production, and only a small fraction of the eroded sediment actually leaves the immediate area (Crosson, 1997). As much as 90-95% of it may be redeposited somewhere down-slope, along the watershed before reaching a major river (Bishop and Allen, 1989). However, despite the deposition in temporary sinks, off-site damage may already have been inflicted. Temporary sinks typically ensure a long-term supply of sediment even if zero-erosion was subsequently ensured within the watershed (see Enters, 1998 for various references). A case in point is the Mangla reservoir in Pakistan, where sedimentation continues to be an issue despite half a century of watershed management activities (*ibid.*). Notwithstanding, deposition still has a mitigating effect (both on-site and off-site), and utmost care is therefore needed in extrapolating soil erosion rates.

The scale issue also addresses the boundary problem of decision-making and of allocating costs and benefits (Blaikie and Brookfield, 1987). The spatial scale thus determines the *accounting boundaries*. In fact, were it not for the boundaries, there would not be spatial externalities. On a micro scale, farmers are generally only directly affected by the on-site effects of erosion. In most cases they can safely ignore the off-site effects once the eroded

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[28] Delivery ratio is the percentage of eroded material that is delivered from the source to a downstream location (Lal, 1987a:304).

[29] A watershed is a topographically delineated area, drained by a stream system, *i.e.* the total land area that drains to some point on a stream river (de Graaff, 1996).

soil leaves their farm. On a macro scale, however, both the on-site and off-site effects need to be considered and erosion may thus prove to be much more costly.[30]

Productivity loss in one place may be (partially) offset by an increase elsewhere - for instance, when the soil is deposited on agricultural land. Depending on the boundaries though, such gains may remain external to the decision-making framework of the farmer actually suffering the erosion losses (Blyth and McCallum, 1987; Eaton, 1996). Runoff water with suspended sediment recognises no boundaries and erosion is always a watershed-based problem (El-Swaify, 1994). As a result many favour a watershed-based approach to the erosion problem (de Graaff, 1996; 1999), where accounting and problem boundaries would more aptly coincide. Yet watersheds come in different shapes and sizes. In this regard de Graaff (1996:117) distinguishes between watersheds and river basins, the assessment being compounded for the latter when these include vast areas and different nations.

Last but not least, scale determines both the *wider picture* and its resolution (*i.e.* the amount of detail that can be handled). As aptly paraphrased by Harrington *et al.* (1995:25) amongst others: overemphasising micro issues while ignoring the broader trends can be compared to rearranging deck chairs on the Titanic. Yet in the analysis of soil erosion 'everything is related to everything ... This overstates the complexity, but often not by much' (Updegraff, 1994). The scale of analysis therefore presents a significant dilemma. Indeed, scale tends to affect the type of explanation (Blaikie and Brookfield, 1987).

One major issue is the fallacy of scale. Elements that are inherently unsustainable at one level of analysis may be a strong element in favour of sustainability at a higher level (Harrington, 1996). The reverse is also true. Advocates of low external input agriculture may overemphasise micro-level sustainability. Yet such technology is inherently land-using and *ceteris paribus,* implies a further extension of agriculture into intrinsically marginal areas over time. Similarly, an often under-recognised benefit of high external input agriculture is its land-saving potential. Increasing production in favourable areas implies that fragile marginal land can be taken out of production. Scale issues obviously complicate any assessment as one needs sufficient detail and yet place it in the right context.

The Oaxacan Mixteca in southern Mexico aptly highlights some of the scale issues. The region presents some of the most spectacularly eroded landscapes in Mexico - and in the world for that matter (*e.g.* Blacker 1994 in Pretty and Shah, 1997). Denuded and scorched red hillsides proof a sorry sight, with meter deep gullies everywhere. One would tend to focus on the eroded hillsides for an answer, but the usual culprits deforestation, overgrazing and the cultivation of fragile lands are not really the cause. This is one of the few documented cases where humans have purposively eroded sensitive and unresilient uplands to feed their valley fields (Spores, 1969). Over 1,000 years the main valley floors widened from about 1.5 km to 3 km (Kirkby, 1972 and Whyte, 1977 in Blaikie and Brookfield, 1987). In this case, productive loss on marginal land has clearly had a beneficial productive effect on more favourable land.

[30] Similarly, the temporal scale has a profound influence - *e.g.* see discussion of renewability and reversibility issues in Section 2.7.

The Oaxacan Mixteca is not unique in this respect. In central Mexico farmers also have reportedly stimulated erosion up slope (Bocco, 1991:348). In other instances, farmers may not purposively have stimulated erosion, but still capture sediment and run-off behind silt traps to create fertile deposition fields (Wilken, 1987 in Pretty and Shah, 1997). Clearly, any economic assessment of soil erosion hinges on the scale of analysis.

2.7 Reassessing on-site effects: from calamity to complacency

The various facets - time, space and location - of soil erosion go a long way in explaining the prevailing uncertainty. However, it is the interpretation of the underlying soil degradation that is probably the most controversial. Wolman (1985:18) indeed characterised his review of the on-site effects of soil erosion as 'between calamity and complacency'. He found the evidence for cornucopia as impressive as the evidence for calamity.[31]

The discrepancy in views reflects a number of controversial issues. The perceived resource substitution possibilities ('substitutability') is one such field of controversy. Similarly, so is the nature of both the soil resource ('renewability') and its potential degradation ('reversibility'). It is essential to realise how these perceptions both determine and confound the debate.

Resource substitutability

Resource substitution possibilities typically polarise the debate into 'pessimists' and 'optimists' (Taylor and Young, 1985; Perman *et al.*, 1996; Tietenberg, 1996). *Pessimists* generally view all natural resources as ultimately finite, as is the residual carrying capacity of the environment. The mere finiteness of the resources and carrying capacity poses severe limits to economic growth, as was suggested by the Club of Rome (Meadows *et al.*, 1972).[32] Applied to the soil resource, this rapidly leads to soil conservation fundamentalism: since all life depends on soil, conserving soil is considered worth whatever it costs (Seckler, 1987).

Optimists generally prefer to stress the substitutability of resources, especially human-made for natural. For one, resource scarcity will favour a price-induced substitution in production and consumption (Perman *et al.*, 1996). In addition, necessity can be considered the mother of invention, so that technology will eventually solve resource scarcity problems (Barlowe, 1974). Applied to the soil resource, the technological optimists see the possibility of substitution for degraded soil, either through new production methods or alternative land use (Sanders *et al.*, 1995). A frequently cited example in this matter is the advance of cheap chemical fertiliser. Technical advance thus partially substituted an exhaustible stock resource (natural stocks of nutrients in the topsoil) with a renewable flow resource (Barlowe, 1974; Burt, 1981; Chisholm, 1987b).

[31] Despite the fact that the on-site effects have received the bulk of scientific attention (Crosson, 1997; Enters, 1998).

[32] Previous hints to limits to growth had been expressed by Malthus in 1798 (absolute limit); Ricardo in 1817 (relative limits) and Marx in 1867 (social and political unrest) (Turner *et al.*, 1993).

Pessimists and optimists are obviously extremes.[33] To believe in the notion that appropriate technological advances will *always* occur is being unduly optimistic, but the notion that *no* new technology will ever turn up is equally unrealistic (Chisholm, 1987b). Yet differences in conclusions between writers can often be attributed to differences in the assessment of substitution possibilities (Perman *et al.*, 1996). Furthermore, the dichotomy overlaps with disciplinary biases. There is a tendency for economists to see evidence for reasonably high substitution possibilities (although there is by no means a consensus on this), whereas environmental scientists stress limited substitution possibilities (*ibid.*). There certainly are some limits, both in the absolute possibilities of substitution (Crosson *et al.*, 1985) and the dependence on price mechanism to generate correct signals (Perman *et al.*, 1996). For instance, numerous cases of market failure exist in relation to the absence of property rights, 'missing' future markets and imperfect information.

Directly linked to the diverging views about the degree of substitutability between human-made and natural capital is the distinction between 'weak' and 'strong' sustainability (Turner *et al.*, 1993; Perman *et al.*, 1996). *Weak sustainability* requires the maintenance of an aggregate composite capital stock[34] and assumes a good degree of substitutability - notably physical capital and knowledge substituting for exhaustible natural sources. However, if natural capital were essential for production (*i.e.* a complement to human-made capital) and not substitutable (*i.e.* absolutely scarce) one would require more stringent constraints. *Strong sustainability* therefore requires the maintenance of the critical natural capital stock that is not easily substitutable.[35]

Renewability of the soil resource

It is conventional (if somewhat simplistic) to classify resources in terms of whether they are renewable or not (Perman *et al.*, 1996). Theoretically though, all natural resources are renewable, and the 'renewability' thus depends on the time scale considered (Anderson and Thampapillai, 1990). Renewability generally refers to whether the resource is reproducible; *i.e.* exhibits economically significant rates of regeneration (Perman *et al.*, 1996). Notwithstanding, most renewable resources may still be *potentially* exhaustible - and thus become non-renewable - when thresholds for regeneration are surpassed (*e.g.* through overexploitation; Bulte, 1997).

The renewability of some natural resources is relatively straightforward (*e.g.* an oil field *versus* a shoal of fish). For other resources, the distinction is more muddled, with a mixture

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[33] Turner *et al.* (1993:34) make a similar distinction between technocentrism and ecocentrism. They further subdivide these into: 1. Cornucopian: anti-green economy, complete substitution possible; 2. Accommodating: green economy, infinite substitution impossible, constant capital rule; 3. Communalist: deep-green economy, zero economic and population growth to reach steady-state economy; 4. Deep ecology: very-deep-green economy, scale reduction, radical ethical/moral principles (bioethics).

[34] Comprising natural and human-made (physical, human and intellectual) capital (Perman *et al.*, 1996:59).

[35] However, this not the only interpretation of strong and weak sustainability. For example, Pearce *et al.* (1990) equate strong sustainability to a positive change for their vector of desirable objectives for each and every time period; whereas for weak sustainability only the trend is positive.

of both renewable and non-renewable characteristics, and soil may be the typical example (Turner *et al.*, 1993). As a result some consider soil to be non-renewable over the human time scale (Lal *et al.*, 1989:51). Others emphasise the natural soil formation rate (proponents of the T-value, see Chapter 3 - Box 3.1). And yet others, indeed consider soil as a mixed resource (de Graaff, 1993; Grohs, 1994). Von Ciriacy-Wantrup (1968) defined topsoil as a renewable resource with a threshold level below which it becomes non-renewable.

The renewability issue may seem academic, but the nature of the resource influences the management required. For a non-renewable resource management questions relate to the optimal timing of resource use. For a renewable resource the questions revolve around maintaining the regenerative capacity (Turner *et al.*, 1993).

Reversibility of soil erosion

In addition to the renewability question, there is the reversibility issue - *i.e.* the possibility to restore a resource to its original state. The two are obviously related, and many associate reversibility with renewability; but they are also different. A renewable resource may indeed autonomously offset some of the experienced degradation through its natural regeneration - *e.g.* soil formation and erosion. But some forms of resource damage are not offset by natural regeneration. In other instances, resource degradation may potentially be reversed by non-natural (aided) regeneration. As a result, a resource can suffer both reversible and irreversible degradation, irrespective of its renewability. In this regard, Lal (1988:50) - who considers soil to be a finite, non-renewable resource - sees no choice but to restore the productivity of degraded land.

There is a need to qualify irreversibility in technical and economic terms. A specific form of environmental degradation may well be technically reversible, but the cost of doing so may be prohibitive, making it irreversible in practice.[36] Notwithstanding, the possibility of reversal exists in case a certain economic threshold is exceeded (Goodland, 1989).[37] In this regard, Seckler (1987) challenges conventional views by stating that soil can be both recovered and produced if one is willing to pay the cost of doing so. Likewise, Bie (1990) states that no land can be permanently degraded: given enough economic and technological input all land can be restored. Yet he goes on to note that if the costs exceed the benefits of - or the capital available for - restoration, the degradation is at least temporarily 'permanent' until economic factors change. Further confounding the discussion is that irreversibility is dependent on available technology. In this regard Malin (in Wolman, 1985) mentions that much of the land designated 'irreparable' in the USA in the 1930s has not proven to be so. Likewise, Lal (1987a:308) posits that most of the 20 million ha doomed 'essentially ruined' by Bennet in the mid-1930s are now producing economic returns.

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[36] Some therefore interpret irreversibility only in economic terms, considering the damage irreversible if the original state of a resource can only be achieved at infinitely high or prohibitive costs (Chisholm, 1987b; Arrow and Fischer, 1975 in Grohs, 1994).

[37] Compare this economic irreversibility with the technological irreversibility of species extinction.

With the actual degree of reversibility being a function of technology and resources available (Wolman, 1985; Chisholm, 1987b), when does soil erosion become irreversible? Not surprisingly, the field is again divided. Some consider soil erosion to be completely irreversible, as it is not possible to adequately reproduce the soil resource in its original form at least in any time frame relevant to humans (van Kooten, 1993; Sanders *et al.*, 1995 referring to the topsoil school; Perman *et al.*, 1996). Others are of the opinion that the potential losses of productivity can be reduced or reversed - though this may be very expensive (Frye *et al.*, 1985; Wolman, 1985). Others highlight the mixed nature of soils.

Part of the controversy directly relates to the uniqueness of the land resource among production factors. Land is a composite of salient factors that influence crop production rather than a single definable entity (Clark and Furtan, 1983). Gaffney (1965 in *ibid.* and van Kooten and Furtan, 1987) views land as having (i) a Ricardian and (ii) a capital component. The Ricardian component is the enduring matrix that is not conservable or depletable (including factors as location, climate, macro-relief and inexhaustible supplies). The capital component is depletable and has both stock and flow characteristics[38]. It is interpretation of this latter capital component that potentially generates most confusion, depending on which of the two characteristics the emphasis is placed.

Typifying the flow characteristic is the revolving fund of nutrients. Only the flow of nutrients is generally available to crops, consisting of mineralisation and fertilisation. Most nutrients lost through soil erosion represent only a *temporary*, repairable cost component as these can be replaced by fertilisation (Colacicco *et al.*, 1989; de Graaff, 1993; van Kooten, 1993). Fertility loss is thus relatively easy to substitute (Sanders *et al.*, 1995). Some of the physical attributes of the rooting zone highlight the stock characteristics of the resource. Loss of rooting depth and water-holding capacity represent a more *permanent*, residual cost component (Colacicco *et al.*, 1989; van Kooten, 1993). Structure and topsoil may only be recoverable up to a certain point, after which irreversible damage occurs (Sanders *et al.*, 1995).

Irreversible damages imply that the cost of soil erosion is higher than the estimated erosion-induced productivity loss (*ibid.*). In this regard there is the *option value*: the willingness to pay for the option of future use by refraining from an irreversible action that otherwise looks profitable. In a sense an option value can be viewed as an insurance premium to retain the option of being able to use non-degraded land in the future (Chisholm, 1987b). Mention can also be made of the *safe minimum standard* approach, stressing the need to avoid irreversible environmental damages unless the social cost of doing so is unacceptably large (von Ciriacy-Wantrup, 1968). In the face of uncertainty and irreversibility one should minimise the maximum losses (mini-max). Irreversibility thus generally has a larger user-cost and leads to stronger preference for non-use (Perman *et al.*, 1996).

Empirical evidence is scanty on when and whether soil erosion is irreversible (Sanders *et al.*, 1995), compounded by the existence of thresholds and non-linearity's in responses. Variations over locations (*e.g.* soils; climate) and time (*e.g.* technical change; resource

[38] Stock (or fund) resources are relatively fixed and non-renewable. Flow resources are renewable and generally must be used as they become available (Barlowe, 1974).

availability) complicate matters further. Nevertheless, the possibility of irreversibility has profound implications for soil management, the costing of soil erosion and the urgency of intervention.

2.8 In conclusion

The present chapter assessed the analysis of soil erosion. Although most experts agree that (accelerated) soil erosion is a problem, its economic impact is highly controversial. A number of specific features of soil erosion explain some of the controversies and the challenges it poses for an impartial analysis. There is no straightforward cause-effect relationship for soil erosion. The problem is complex, having both biophysical and socio-economic aspects; both only partly understood and hardly measurable.

Soil erosion has various facets - time, space and location (*i.e.* state of nature). The temporal and spatial dimensions of soil erosion imply the existence of externalities. They also make the assessment scale dependent and give rise to often arbitrary decisions regarding (temporal and spatial) boundaries and valuation. Soil erosion is confounded by the locational aspect - the extreme site-specificity of its dimensions and valuation. The assessment of soil erosion thereby inherently depends on the time and place of analysis.

Soil erosion is most directly associated with physical soil loss, a subtle and difficult to estimate entity. However, soil loss itself still says little about the economic costs of soil erosion - either on-site or off-site. The main on-site cost is the erosion-induced productivity loss - irrespective whether this loss is realised, offset or prevented. However, this entity is even more imperceptible than soil loss. There is no clear-cut relationship between soil loss and productivity loss, whereas productivity is influenced by numerous factors. The productivity loss has both ephemeral and cumulative elements and is highly site-specific. Technical change further masks the costs of the erosion-induced productivity loss - leading to a false sense of complacency. In sum, soil erosion provides a weak signal in a very noisy environment.

Erosion-induced productivity loss is highly probable in most soils - though the extent and severity are unknown. Yet, it is the latter indicators of magnitude that are of interest from an economic point of view. The difficulty of establishing the physical relationships in combination with data limitations have favoured the use of uniform empirical equations, frequently ignoring the underlying complexities and site-specificity. Excessive extrapolations over time and space ensure that the reliability of available data is highly uneven.

The biophysical variability is compounded by socio-economic differences. Valuation of on-site effects is highly site-specific indeed, being dependent on local preferences, resource endowments, technology and institutions. Socio-economic variables - like input and output prices - can also influence soil erosion rates directly by inducing land management adaptations (*e.g.* in terms of intensification; extensification; or change in land use). Alternatively, soil erosion itself can induce land management changes. Indeed, farm management decisions and soil erosion are not independent.

The off-site costs of soil erosion revolve around the generally adverse effects imposed by the reappearance elsewhere of the eroded sediment and chemical pollutants. These costs can be important, but present various measurability problems and again tend to be highly site-specific. High off-site costs do not necessarily coincide with either high soil erosion rates or high on-site costs.

A major controversy revolves around when and whether the erosion-induced damage is irreversible. The soil resource presents a mixture of both renewable and non-renewable characteristics. In addition, opinions vary on the possibilities to substitute for the eroded soil resource. Some of the erosion-inflicted damage is only temporary and can easily be substituted. Other damages are more permanent. A confounding factor is that the line between the temporary and the permanent damage is dependent on the time-scale considered, available technology and available resources. The issue is compounded by the existence of thresholds and non-linearity's in responses. Irreversible damages increase the cost of soil erosion and thereby has profound implications for soil management and the urgency of intervention.

CHAPTER 3

SOIL CONSERVATION: ECONOMIC ANALYSIS

Soil erosion is a serious problem in a number of localities. But is counter-action in the form of soil conservation warranted?[1] Some groups argue in favour of soil conservation without questioning its cost effectiveness. Others assert that if soil conservation was economically attractive, farmers would take care of it themselves (Kerr and Sanghi, 1993; van Kooten, 1993:235). However, to adequately answer this question there is a need to assess the economic implications of conservation and acknowledge the private and social dimensions.

The present chapter addresses the economic analysis of soil conservation. The first section introduces some definitional and analytical issues. The subsequent two sections deal with the main schools of economic analysis. The second section presents the *evaluation school*, which basically tries to quantify the economic impact of different soil conservation scenarios. The third section discusses the *adoption school*, which tries to explain and predict the divergences in soil conservation behaviour between economic agents. The last section provides a concluding summary.

3.1 Definitional and analytical issues

The main aim of soil conservation (in the narrow sense) is to reduce the rate of soil erosion. Yet a first hurdle is the exact meaning of 'conservation'. The term has different connotations, directly affecting the amount of reduction implied.

A first interpretation revolves around *absolute* conservation; *i.e.* assure the soil resource does not erode at all. This view can also be labelled as soil conservation fundamentalism (Seckler, 1987) or Buncian conservation (after Bunce - van Kooten, 1993). Such views revolve around stewardship[2] and the strict precautionary principle, a rather pessimistic stance in relation to substitution possibilities and trade-offs (Turner *et al.*, 1993).

A second interpretation revolves around *standards-based* conservation. Standards could reflect the on-site and/or off-site effects of soil erosion. For instance, on-site standards could take into account the soil formation rate (*e.g.* T-value, see Box 3.1) or irreversibility thresholds (*e.g.* safe minimum standard). Off-site standards could reflect the critical load, in terms of the off-site costs or assimilative capacity of the receiving environment (Turner *et al.*, 1993). Standards could also be technology based - *e.g.* the 'best available control

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[1] In the introduction three modes of action were identified: non-action (ignore); soil conservation (prevent) and soil rehabilitation (cure). The focus of this study is on the first two venues. Soil rehabilitation is generally considered to be substantially more expensive than conservation and therefore less attractive.

[2] Views one entity as care-taker of natural resources for another entity. Applied here in an inter-temporal setting, *i.e.* the current generation with respect to future generations. Can also be applied in an intra-temporal setting, *i.e.* land users with respect to the rest of society.

technology' (*ibid.*).[3] Whatever the form of the standard, it takes precedence over directly economic considerations.

A third interpretation could be labelled *efficient* conservation. The basic premise is that it is not worth preventing soil erosion unless the benefits gained are larger than the costs incurred.[4] Indeed, conservation is not economically efficient under all conditions (Pagiola, 1994b). A narrower interpretation could be labelled *optimal* conservation, where the marginal benefits of avoided erosion losses are just balanced by the additional conservation effort.

The underlying interpretation of conservation can explain some of the controversies in soil conservation research. The absolute conservation approach implies that there is *no* (accelerated) soil erosion, whereas the others imply that the soil erodes at a slower (or equal) rate than in the without conservation case. The chances that absolute conservation is economically efficient are quite slim, as the marginal costs of reducing erosion are likely to rise exponentially as the amount of erosion approaches zero (Blyth and McCallum, 1987; Crosson, 1997). In fact, a zero-erosion scenario is likely to be hypothetical and unattainable while maintaining agricultural land use (Enters, 1998). Standards-based conservation will generally also be inefficient, whereas it provides no dynamic incentive for innovation or improvement beyond targets set. Still, it may be the best approach in view of the prevailing uncertainty (Turner *et al.*, 1993).

Although there is much to say for optimal conservation, there are serious methodological difficulties (Stocking, 1987; Upstill and Yapp, 1987). The optimal level of soil conservation will depend on the shape of the cost curves for soil erosion and conservation (Carlson and Zilberman, 1993). In practice most of the required data are rarely available. As a result, most empirical economic assessments of soil conservation have focussed on aggregate, rather than marginal, figures (Blyth and McCallum, 1987). Indeed, economically efficient conservation is often all that can be practically aimed for.

Box 3.1 Soil loss tolerance (T-value)

Soil loss tolerance - the so-called T-value - is one particular standards-based conservation strategy that has received widespread attention. The T-value is defined as the maximum rate of soil erosion consistent with economic production into the indefinite future (Crosson, 1985). The soil is thus considered as a renewable resource, where the T-value can be interpreted as the sustainable off-take; *i.e.* that would maintain the stock intact (Turner *et al.*, 1993). In practice, however, the value is treated as a constant, namely 11 ton per ha per year for the USA (Pagiola, 1994a). As a result, there is widespread criticism on the T-value, both on technical and economic grounds.

On technical grounds, the critique is basically two-fold. First, the T-value is ambiguous as it is based on the rate of topsoil formation, and not on the actual rate of soil formation

[3] In addition, Turner *et al.* (1993) distinguish the 'best available technology not entailing excessive costs'. 'Excessive' is mainly used in relative terms, in comparison to the benefits achieved or in relation to the nature of the economic activity.

[4] Blyth and McCallum, 1987; Phipps, 1987; Seckler, 1987; Carlson and Zilberman, 1993; Barbier and Bishop, 1995.

from consolidated parent materials - a much slower process (Crosson *et al.*, 1985).[5] It is the latter rate that is the controlling factor in long-term soil renewal (Nowak *et al.*, 1985). Second, 'the relationships among soil quality, erosion, and productivity are far too complex and variable among soils and regions to be captured in a single rule of thumb for the entire US.' (Crosson, 1997). This obviously is even more problematic when applied to other countries and continents (*ibid.*).

The main economic argument against the T-value standard is that it is a purely physical on-site concept that fully ignores the costs and benefits of conservation. It requires conservation measures *now* on all soils where erosion exceeds T (Crosson *et al.*, 1985). Especially the observance of the strict definition of T - based on actual soil formation - would imply an enormously high cost, both in lost current output and in measures to control erosion (*ibid.*). Some authors have suggested the need to include economic considerations - both on-site and off-site - in the T-value. This would make the T-value more site-specific and dynamic, incorporate trade-offs and allow for a more accurate targeting of conservation (Griffin and Stoll, 1984; Nowak *et al.*, 1985).

Assessing soil conservation

Defining soil conservation is a necessary first step upon assessing soil conservation, but there are more hurdles to overcome. The economic assessment of soil conservation encounters all the problems that pertain to the analysis of soil erosion (Chapter 2). Soil conservation also introduces some new problems. For instance, with erosion one can 'wait and see'; with conservation one needs to act now and see. Soil conservation represents a capital investment that does not generate a new income stream, but reduces the rate of decay of an existing income stream (Collins and Headley, 1983). Further, this investment is generally high and implies a long payback period (high gestation period) - especially in the case of physical structures (Swader, 1994; de Graaff, 1996). As a result, while the investment costs of soil conservation are readily determined, measuring the benefits is often more problematic (Barbier and Bishop, 1995).

Soil conservation reduces the cumulative on-site damage by soil erosion. However, in many instances this damage was largely imperceptible in the first place, making it equally difficult to observe the benefits of its control (Pimentel, 1987). In the case of rapid erosion-induced yield declines, the potential conservation benefits must be commensurately greater (Stocking, 1988, 1993; Barbier and Bishop, 1995). However, rapid yield declines simultaneously imply that most agricultural land may already be degraded, and thereby reduces the benefits of any subsequent conservation efforts. It therefore is vital to consider the stage of erosion: the earlier soil conservation is initiated the greater the benefits (Chisholm, 1987a; Stocking, 1988).

Soil conservation also counterbalances the ephemeral costs of erosion, *e.g.* in terms of retaining water and nutrients. Whenever soil moisture is a limiting constraint, water-conserving effects can have a profound positive effect on yields (Pimentel, 1987; Bishop

[5] *E.g.*, Pimentel (1987) estimates soil formation to amount to only 1 Mg ha^{-1} yr^{-1} in the USA, whereas soil loss averages 18 Mg ha^{-1} yr^{-1}.

and Allen, 1989; Hudson, 1993; Shaxson, 1993). These short-term benefits can be significant, and are relatively more visible than the cumulative on-site benefits.

The economic implications of the conservation scenario are determined by available technology, resources, preferences and institutions. Different conservation measures exist, each with their characteristic resource needs. The implications of these resource needs are highly site-specific. For instance, low cost stone bunds appear to be an effective solution in Burkina Faso (Reij, 1994). However, the same measure may not be so cost effective in areas where stones are scarce. In addition, property rights are influential, as access to the stone resource is becoming increasingly restricted - *e.g.* it is no longer possible for village A to collect stones in village B territory.

The economic implications of conservation are also subject-specific. Soil erosion through current activity taxes future generations; conservation does the reverse. Alternatively, one may view conservation as the redistribution of resource use rates into the future, whereas erosion would be a redistribution of use rates towards the present (von Ciriacy-Wantrup, 1968). Private and social interests are likely to differ in terms of reflecting intergenerational equity considerations. Spatial externalities and other market failures (*e.g.* imperfect information) will only strengthen the divergence between private and social interests (Upstill and Yapp, 1987). Similarly, the implications typically also vary between individual economic agents.

The conservation effort thus adds another layer to the already rampant site-specificity, both in biophysical and socio-economic terms. The assessment of soil conservation indeed poses considerable analytical challenges that have been tackled in varying ways. The different analytical approaches can be broadly grouped under two main schools of economic analysis: (i) the evaluation school and (ii) the adoption school. The *evaluation school* basically tries to quantify the economic impact of different soil conservation scenarios. The *adoption school* tries to explain and predict the divergences in soil conservation behaviour between economic agents. Each school therefore focuses on different aspects of soil conservation and is to a certain degree complementary to the other.

3.2 Evaluation school

One approach to the analysis of soil conservation is to quantify its economic implications - here labelled as the *evaluation school.* Such an analysis helps to answer the question whether soil conservation is warranted in a given situation. It also helps to assess trade-offs - both between conservation alternatives as between conservation and alternative investments. In the end, it helps to determine a course of action.

For adequate economic evaluation one needs adequate data, but soil conservation is shrouded in a thick cloud of uncertainty. The temporal, spatial and locational dimensions complicate the analysis and generate severe data limitations.[6] Conceptualising the relationships is easy enough, although actually quantifying them is quite another matter

[6] Rausser, 1980; Blaikie and Brookfield, 1987; Chisholm, 1987a; Seckler, 1987; El-Swaify, 1994; de Graaff, 1996; Eaton, 1996.

(Crosson *et al.*, 1985). Much progress has been made in describing the interaction of natural and human production systems, but the picture is still patchy and imprecise; data are scarce and models are imperfect (Bishop and Allen, 1989). This in turn leads to 'informed guesswork' (Blaikie and Brookfield, 1987:97; Scoones *et al.*, 1996). It also implies the danger of 'asymmetry of valuation', where important (environmental) costs and benefits are ignored simply because they are difficult to measure (Pearce, 1993 in Harrington *et al.*, 1995).

Upon quantifying the economic implications of soil conservation, two analytical choices must be made. First, one must decide on the mode of costing erosion. Second, one must decide on the mode of economic analysis. These choices will be subsequently discussed, each choice being influenced by the data limitations.

3.2.1 Costing erosion

Several approaches can be used to cost erosion. In this regard the typology developed by Turner *et al.* (1993) with respect to costing the environment is useful - broadly categorising methods on the basis of the use or non-use of a demand curve (Table 3.1).[7] The present subsection discusses these approaches in relation to the costing of soil erosion.

Table 3.1 Monetary evaluation methods of the environment (Turner *et al.*, 1993: 115)

Demand curve approaches	Non-demand curve approaches
- Expressed preference methods *(contingent valuation method)*	- Dose-response approach
	- Replacement cost
- Revealed preference methods *(hedonic pricing method; travel cost method)*	- Mitigation behaviour
	- Opportunity cost approach

Expressed and revealed preference methods

The expressed preference method (*e.g.* willingness to pay) is a direct demand curve approach, the revealed preference method an indirect demand curve approach. Demand curve approaches have the advantage of providing a welfare measure. Both methods could potentially be applied to costing erosion. A contingent valuation study (an expressed preference method) could conceivably asses the downstream users' willingness to pay for reduced erosion-related pollution; and assess upstream farmers' willingness to accept compensation for using soil conservation. A hedonic pricing study (a revealed preference method) could conceivably try to assess the premium market value of conserved land compared to eroded land.

Hedonic pricing requires a functioning land market that recognises degradation and conservation. King and Sinden (1988) applied hedonic pricing in Australia and concluded

[7] There are a number of other typologies. For example, Hufschmidt *et al.* (1983 in de Graaff, 1996:64) distinguish valuation approaches on the basis of the type of market prices used: (i) conventional; (ii) implicit (*e.g.* hedonic pricing); and (iii) artificial (*e.g.* contingent valuation).

that the land market seems to be working to support on-farm, soil conservation efforts. However, this will not necessarily be the case in view of typically imperfect information. Soil degradation in itself is not always obvious, and there is a need to disentangle several other factors such as location, personal preferences, institutions and government policy (Blyth and McCallum, 1987). Particularly in developing countries, land markets are poorly developed and property rights may be insecure. In such instances hedonic pricing has limited operational value for assessing soil conservation (Enters 1998).

Demand curve approaches have up to hereto been relatively ignored in terms of costing erosion (for other applications see Lohr and Park, 1994; Bejranonda, 1996). In part this is related to some of the above problems. The approaches themselves are subject to some inherent methodological problems, which are likely to be compounded by the complexity and uncertainties surrounding erosion (*e.g.* see Turner *et al.*, 1993:120-127; Verkoijen, 1994).

Dose-response approach

The dose-response approach links a biological response to an environmental stress on the basis of a production or damage function (Walker, 1982; Turner *et al.*, 1993). It provides a means to estimate (i) the damage incurred by non-action and (ii) the averted damage of mitigating action. The dose-response approach is frequently used to assess the on-site effect of soil erosion, with soil erosion being the 'dose' and the productivity effect the 'response'. Conceptually this seems straightforward, but in practice it is far from so. Chapter 2 (see 2.3) already reviewed some of the complications that arise in assessing this relationship. Although modelling can take into account the several factors and interactions at play, its use is severely constrained by data availability. Instead, most dose-response studies use proxies for soil erosion, including topsoil depth, physical soil loss, time or some other affected soil characteristic. The main drawback is that such proxies are typically imperfect: they only provide a partial and/or rough measure of the 'dose'. Further, even proxies can suffer from data limitations.

Figure 3.1 illustrates one hypothetical model that relates yield to declining topsoil depth (as proxy for soil erosion) over time.[8] For topsoil depths exceeding X_1 yield is not affected, but as topsoil depth declines beyond X_1 yield starts to collapse. As topsoil depth is a direct function of soil loss, it implicitly suggests that not all soil loss is equally damaging in terms of yield loss - *e.g.* soil loss reducing topsoil depth from X_0 to X_1 will have no effect on yield, *ceteris paribus*. Likewise, it implies that soil conservation maintaining soil depth

[8] The underlying topsoil-yield relationship tends to be depicted without explicitly considering the time dimension - *e.g.* Walker, 1982; Walker and Young, 1986; Blyth and McCallum, 1987; Anderson and Thampapillai, 1990; Carlson and Zilberman, 1993; de Graaff, 1993; van Kooten, 1993. Walker (1982) has illustrated the topsoil-yield function empirically with data from the USA, using the function: $Y_D = Y_0 + Y_1(1 - e^{-bD})$; where Y_D: actual yield; Y_0: base yield (when D=0); Y_1: potential yield loss due to erosion; D: topsoil depth; and b: coefficient. $(Y_0 + Y_1)$ = potential yield on deep topsoil (Walker and Young, 1986). Pagiola (1994b) derived a linear relationship in Kenya: $Y = Y_0\text{-}bx$; where Y: yield; Y_0: initial yield; x: soil depth removed (cm); and b: regression coefficient.

above the declining point X_1 will have a no effect on yield. In such a case, farmers will have little incentive to incur expenditures in order to avoid soil loss (Carlson and Zilberman, 1993; van Kooten, 1993).

Under limited or no fertiliser amendments yields are often highly related to topsoil depth (Pierce, 1991:42). Although the relationship is intuitive, care should be taken with its interpretation as it singles out only one factor, assuming others to be constant. However, a number of those other factors may simultaneously be affected by soil erosion and can equally have a profound effect on yield. Indeed, topsoil depth says little about the water loss through run-off and the preferential depletion of fertility and organic matter that generally have a more devastating effect. In this regard, Lal (1988 in Pimentel *et al.*, 1995) reports that a narrow focus on changes in soil depth significantly underestimates the impact of soil erosion.

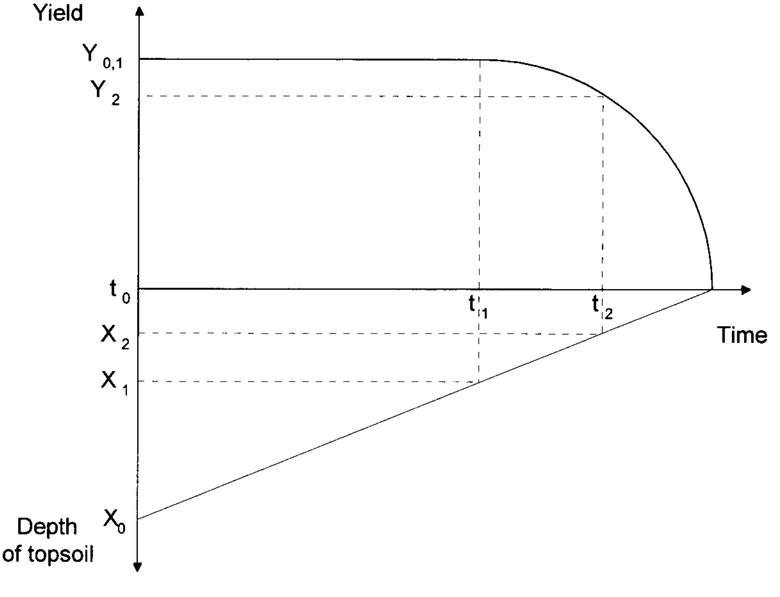

Figure 3.1 Hypothetical damage function

The (cumulative) soil loss-productivity relationships described by Lal (1981) provide another frequently cited example of dose-response functions. His exponential regression equations[9] are based on empirical data for maize and cowpea in Nigeria, but have been frequently used by others (Ehui *et al.*, 1991; Bishop, 1995; Eaton, 1996). However, Pierce and Lal (1994:244) warn that the extent to which the results of site and management specific studies can be extrapolated to other regions and conditions may be limited. This is

[9] $Y = Y_0 * e^{-bx}$ where Y: yield; Y_0: initial yield on uneroded land (x = 0); x: cumulative soil loss; and b: regression coefficient (Lal, 1987a:334; Bishop, 1995:40).

supported by Bojö's (1996) review, which highlights that studies extrapolating Lal's original findings stood out with relatively high productivity losses. Extrapolations and approximations should be taken with care as they can reduce overall precision and introduce bias (Pagiola, 1994a). The more so in view of the underlying complexities and site-specificity.

Others have simplified the dose-response relationship into a time-productivity link, assuming yields to decline due to erosion by some specified constant. The decline is either assumed to be linear (Alfsen *et al.*, 1996) or exponential (McIntire, 1994).[10] However, again the empirical base for deriving the 'constant' is arbitrary. In this regard, Alfsen *et al.* (p.134) rely on expert opinion and do acknowledge this 'qualified and partly subjective assessment'. In the case of McIntire it is not entirely clear where the assumed constant comes from. Even less clear is his assumption for an expected yield increase with conservation (*i.e.* in addition to off-setting the erosion-induced yield reduction). Indeed, sometimes it is simply assumed that without conservation measures production would gradually decline and that with measures production would remain constant or even increase. Yet these assumptions can be quite fallacious (de Graaff, 1996; see Annex B).

The dose-response approach is the most frequently used approach in the economic analysis of soil conservation. Yet one of the major problems to this remains the fact that there generally are no clear dose-effect relations due to non-linearities and synergetic effects, discontinuities, thresholds and lags (Dietz and van Straaten, 1994; Perman *et al.*, 1996). Site-specificity and data limitations do not help in this regard. Indeed, the dose-response link is typically the most crucial yet weakest link in studies that assess the cost of erosion (Bishop and Allen, 1989; Bojö, 1992).

Replacement cost

The replacement cost technique tries to estimate the cost of replacing or restoring a damaged asset (Turner *et al.*, 1993:114). It can therefore be interpreted as a means to estimate curative costs. It can be applied to assess both on-site and off-site costs of soil erosion. On-site it tends to revolve around the rehabilitation costs of eroded soils. Off-site applications include the costs of water treatment to offset erosion-related pollution; or the costs incurred in restoring the live-storage capacity of dams. It is a valid approach in situations where it is possible to argue that the remedial work must take place because of some other constraint (*e.g.* environmental standards; sustainability constraints - *ibid.*).

A specific application in relation to the on-site costs of soil erosion is the nutrient replacement approach (*e.g.* Stocking, 1988; Bishop and Allen, 1989; Kejela, 1992; Pimentel *et al.*, 1995).[11] This approach calculates the cost of replacing the nutrients lost through erosion by chemical fertilisers and other means. Stocking (1988) has estimated that the financial cost of fertiliser to replace eroded nitrogen and phosphorous in Zimbabwe amounts to US$ 25-60 ha^{-1} yr^{-1}, depending on implemented soil conservation measures.

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[10] $Y_t = Y_0 * e^{-kt}$ where Y_t: yield year t; Y_0: initial yield Y (t=0); k: constant representing loss of crop yield from erosion; and t: time (McIntire, 1994).

[11] The approach is also applied to assess the costs of other forms of chemical soil degradation, particularly soil mining (*e.g.* van der Pol, 1992; Kuyvenhoven *et al.*, 1996).

Bishop and Allen (1989: 45-46)[12] have come up with substantially more conservative estimates in Mali of US$ 3 ha^{-1} yr^{-1} for average nutrient loss (NPK), whereas correcting for plant availability this amounts to less than US$ 1 ha^{-1} yr^{-1}.[13] Solorzano *et al.* (1991 in Sanders *et al.*, 1995:31) estimate replacement costs for eroded nutrients (NPK) in Costa Rica to amount to around 10% of annual agricultural value added.

The nutrient replacement cost approach appears to be relatively straightforward when nutrient loss data are readily available and nutrients are a binding constraint (Bojö, 1996). However, it is controversial as it is an imperfect proxy of the total on-site cost of soil erosion. Indeed, in some ways it is likely to overestimate, in others to underestimate, the true cost.

The approach may *overestimate* the on-site costs as it applies soil conservation in the absolute sense: all nutrient loss is considered undesirable and needs to be compensated (Pearce and Warford, 1993). However, the marginal productivity impact of nutrient loss varies across nutrients, crops, soils and management levels. Indeed, nutrients may well not be limiting for crop productivity, whereas plants typically need a 'balanced' supply of nutrients.[14] Further, the form in which nutrients are lost implies different degrees of availability to plants (Stocking, 1988). In addition, not all nutrient loss is lost completely due to deposition elsewhere on agricultural land (Crosson, 1985). The approach also ignores other remedial approaches that may well be more cost effective (Pagiola, 1994a; Enters, 1998).

The approach may *underestimate* the on-site costs of erosion as it singles out only one aspect of the incurred degradation: it is only a partial reflection of the total on-site impact. Fertility replenishment may therefore not be enough to compensate all of the erosion-induced productivity loss (Lal, 1987b). For instance, Bishop and Allen (1989) find that the value of nutrient losses is lower than the corresponding value of yield losses (as estimated through the dose-response approach). The degree of underestimation is likely to be related to whether the eroded nutrients are (or become) a limiting factor. The issue is compounded by the fact that nutrient losses usually diminish as erosion proceeds nonetheless (Sanders *et al.*, 1995:31): nutrients are generally concentrated in the top layer and are subject to preferential erosion-induced depletion.[15] Furthermore, the approach typically ignores the economic damage (if any) incurred between the time of actual loss and its replacement.

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[12] Based on $Y = b X^a$ where Y nutrient loss; X soil loss; a and b: regression coefficients (Bishop and Allen, 1989).

[13] For comparison, in Southern Mali van der Pol (1992:25) has valued the average net nutrient loss from agriculture (*i.e.* the balance of influx and outflux, the latter including erosion, volatilisation, leaching and crop uptake) at US$ 59 ha^{-1} (replacement cost based on fertilisers). Erosion is flagged as an important cause of nutrient loss, contributing 17% of total nitrogen exports. Assuming the latter is representative for the overall nutrient loss through erosion, this suggests erosion costs US$ 10 $ha^{-1}yr^{-1}$.

[14] In this regard Gaffney (1965 in van Kooten and Furtan, 1987) refers to the expendable surplus. It indeed is unlikely that somebody would replace *all* nutrients (Stocking, 1988).

[15] For instance, in Zimbabwe the average eroded sediments were 2.5 times richer in nutrients than the soil from which the sediments were derived - *i.e.* the enrichment ratio (Stocking, 1988).

The replacement cost approach is therefore not without its problems, particularly when applied to the erosion-induced nutrient loss. It is an imperfect proxy for the actual on-site cost of soil erosion and care must be taken in its interpretation.

Other approaches

Other non-demand curve approaches include mitigation behaviour and the opportunity cost approach. *Mitigation behaviour* is based on aversive expenditures: *i.e.* preventive costs. It can be applied to assess both on-site and off-site costs of soil erosion. Applied on-site, it could assess the cost of meeting soil-loss tolerance (T) values (see Box 3.1). Applied off-site, it could assess the cost of upstream soil conservation in order to attain a predefined level of downstream pollution (*e.g.* in terms of sediment or nutrient loadings).[16] Mitigation behaviour will generally be some form of standards-based conservation, using the most cost effective way of meeting the conservation standard.

The *opportunity cost approach* circumvents the controversial valuation of the environmental benefits and costs. Instead the benefits of the degrading activity are used as benchmark for what environmental benefits would have to surpass to make the activity *not* worthwhile. This is therefore not a valuation technique, but more of a decision making aid (Turner *et al.*, 1993: 116). It could conceivably be applied to soil erosion. For example, the benefits in relation to erosive land use within a watershed could be used as benchmark to mirror the joint downstream impacts within the same watershed. Alternatively, the costs of soil conservation within the watershed could be used as benchmark. Both could conceivably help in deciding on the need for intervention.

Discussion

After reviewing the above valuation methods, it is clear that each measure is imperfect in some way. Moreover, the different measures are not directly comparable. Typically they only provide a partial - yet occasionally overlapping - measure of the true cost of soil erosion. Further, most measures specifically address one of the three envisaged soil erosion scenarios: ignore, prevent or cure. Their application also may reflect different - implicit or explicit - definitions of conservation (*i.e.* absolute, standards-based, efficient or optimal). This opens up the scope for varying results. Indeed, the choice of the valuation technique strongly influences the estimated total cost of erosion (Grohs, 1994).

Yet in terms of valuing erosion, it may not be a one or the other choice. It is conceivable that a calculation of the full cost of erosion may need to use one costing method for the on-site effects and another for the off-site. Even when addressing only the on-site or off-site cost of erosion, one may need to consider the use of different methods. Conservation typically implies a reduction of erosion, instead of actual elimination - *e.g.* because conservation measures are imperfect. In such a case an estimation of the full on-site cost of erosion may require both a dose-response approach and mitigation behaviour - although care should be taken to avoid double-counting.

[16] Conceivably one could also include the costs of aversive structures to trap sediment or deviate run-off. However, such measures are both aversive (they prevent further downstream damage) as curative (they offset some of the upstream effects).

In conclusion, the economic valuation of environmental costs and benefits is typically imperfect (Turner *et al.*, 1993; Bulte, 1997). Notwithstanding, invariably some valuation explicitly laid out for scrutiny is better than none - as none can mean some implicit valuation shrouded from public scrutiny (Turner *et al.*, 1993:109).

3.2.2 Mode of analysis

Various economic evaluation methods exist that can be used to assess soil conservation. One possible breakdown distinguishes between discrete and continuous methods. The *discrete* approaches basically try to quantify the economic impact of a specific predetermined set of conservation scenarios (*e.g.* cost-benefit analysis). In the *continuous* approaches, the set of scenarios is conceivably unlimited (*e.g.* optimisation models). The present subsection will briefly review those that are of particular relevance.

Cost-benefit analysis

Cost-benefit analysis (CBA) provides a method to define and compare the costs and benefits of various management scenarios (Zerbe and Dively, 1994). It thereby allows available biophysical and economic information to be integrated into a single, consistent analytical framework (Pagiola, 1994a). It has been variously applied to soil conservation.[17] Such applications generally distinguish between a 'without-case' where erosion continues unabated, and a 'with-case' where some kind of conservation measure is implemented.

When properly done, CBA provides a useful tool to assess soil conservation (Stocking, 1988; Bojö, 1992; McIntire, 1994; Pagiola, 1994a). Unfortunately, its actual application to soil conservation leaves many things to be desired. There certainly are limits to CBA - both empirical and theoretical (Helmers, 1977; Hanley and Spash, 1993; van Pelt, 1993; Zerbe and Dively, 1994; de Graaff, 1996). These are compounded by the specific features of soil conservation. The listing of cost items is usually a rather straightforward exercise. However, the benefit side is substantially more problematic. For instance, the greatest on-site benefits relate to the averted yield loss, but information for accurate quantification is typically lacking (see Subsection 3.2.1).

The use of discounting in soil conservation CBA is another controversial issue, particularly for non-economists. The environmental critique revolves around the perceived bias against soil conservation. Discounting is seen to particularly 'penalise' the future benefit stream of soil conservation investments, whereas current investments costs remain relatively unaffected. However, discounting remains justified in relation to the social rate of time preference and the opportunity cost of capital (Zerbe and Dively, 1994).[18] Furthermore, it is often forgotten that there is no unique relation between discounting and

[17] For instance, Bojö (1992) reviewed 20 soil conservation CBA studies. He concluded that the number of available studies was rather limited, with the majority from the 1980s and applied retrospectively. Lately, the World Bank has substantially contributed to that set (Lutz *et al.*, 1994a; Current *et al.*, 1995). For two frequently cited examples see Wiggins, 1981; Veloz *et al.*, 1985.

[18] These would yield the same rate in a perfect economy with no transaction costs, no uncertainty or risk, and no taxes (*ibid.*).

environmental degradation in general, and soil erosion in particular (Pearce *et al.*, 1990; Pearce and Warford, 1993).[19]

One particularly useful application of CBA to soil conservation has been developed by Walker and associates (Walker, 1982; Walker and Young, 1986). In their damage function approach they assess on an annual basis the present value of future income impacts from delaying the adoption of conservation.[20] *I.e.* in each period the decision is taken to adopt or defer the soil conserving practice, thus presenting a way of altering the timing of the investment (Eaton, 1996). Conceivably, the formulation is flexible enough to take into account subsequent changes in prices and technology.

Optimisation models

An optimisation model basically maximises a specified objective function subject to a number of constraints. It has been variously applied to soil conservation to derive an optimal conservation strategy. One frequent approach uses *mathematical programming*, either in a static (*e.g.* Seitz *et al.*, 1979; Zinser *et al.*, 1985; Deybe, 1990; Carcamo *et al.*, 1994) or dynamic setting (*e.g.* Miranowski, 1984; Baffoe *et al.*, 1987; Orazem and Miranowski, 1994). The static models typically have a soil loss constraint, which subsequently can be tightened or slackened to assess the impact of more stringent conservation standards. However, according to Rausser (1980:1094), the 'management of the soil resource is inherently dynamic, and thus static constructs modified by various bells and whistles provide little insight'. Static models indeed fail to recognise the endogenous incentives for soil conservation: the higher the erosion-induced yield loss the bigger the incentive for adoption (Miranowski, 1984; Miranowski and Cochran, 1993). The dynamic models typically do include some form of erosion-induced productivity loss.

Stochastic programming incorporates stochastic elements into the optimisation model. It presents a form of sequential and adaptive modelling more consistent with farmer behaviour. However, it has only sporadically been applied to soil conservation (*e.g.* Lopez-Pereira *et al.*, 1994). This may relate to the 'curse' of dimensionality: the model grows exponentially with the number of states and stages included (*ibid.*). This is a major drawback of mathematical programming approaches in general: the additional states (including dynamic elements) greatly increase the complexity of the model.

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[19] Consequently, the results of lowering the discount rate are ambiguous. Although the discounted environmental benefits from conservation indeed would be larger, current economic activity would simultaneously be stimulated, resulting in uncertain aggregate environmental effects.

[20] The damage function is $\delta_t = \Pi_e - \Pi_c$; where δ_t is the value of the damage function at time period t, Π_c is the net present value of changing to the conservation practice in the current period; and Π_e is the net present value of continuing with the erosive practice for the current period and changing to the conservation practice in the subsequent period. In formula:

$$\Pi_e = P\,Y_e(t,D_{t-1}) - C_e(t,D_{t-1}) + \Sigma^{T-1}{}_{i=1}\,[Y_c(t+i,D_t) - C_c(t,D_t)] * (1+r)^{-i}$$

$$\Pi_c = P\,Y_c(t,D_{t-1}) - C_c(t,D_{t-1}) + \Sigma^{T-1}{}_{i=1}\,[Y_c(t+i,D_{t-1}) - C_c(t,D_{t-1})] * (1+r)^{-i}$$

where P: price of crop; Y is crop yield; D: depth of topsoil (end of current period); C: production cost; T: time horizon; r: discount rate; subscript c: conservation practice; subscript e: erosive practice (Walker and Young, 1986; Eaton, 1996).

Multi-criteria programming[21] provides another approach to make optimisation models more realistic. In most 'standard' applications, models optimise one objective, typically maximising utility (efficiency). Yet in the real world, multiple objectives are the rule rather than the exception. Multi-criteria programming allows for the simultaneous optimisation of more than one objective. However, its application to soil conservation is relatively limited (*e.g.* Ramirez and Martinez, 1995). An essential feature is the need to apply weights to each objective, and this can have far reaching implications for the outcome.

Optimal control is a frequently applied approach to model soil conservation (and natural resource management in general). The most influential application to soil conservation is by McConnell (1983). His model maximises the net value of the farm[22], with input use as control variable and soil depth as state variable.[23] An earlier application by Burt (1981) used the proportion of land under wheat as decision variable and topsoil depth and organic matter content as state variables. Notwithstanding, it is McConnell's model that has been variously adapted.[24]

Optimal control methods determine the privately optimal path of soil degradation (or optimal cropping strategy to employ; etc.) in each period of time as a function of prices and biophysical conditions (van Kooten, 1993). However, a major shortcoming of such dynamic optimisation techniques is that they still are only applied in abstract stylised settings under specific assumptions (Pagiola, 1994a). In part this is related to the limitations of formal models for describing complex phenomena (Eaton, 1996). Yet some of the assumptions are rather stringent - leading Kiker and Lynne (1986) to state that McConnell assumes away many of the real issues. Even McConnell (1983:84) himself acknowledges that the 'model is a substantial, but plausible, simplification of the complex process'.

One of the controversial assumptions is the use of soil depth as state variable. As mentioned above, this represents a gross simplification, although additional state variables increase the complexity of the model (Sanders *et al.*, 1995). Another controversial assumption is that farmers are able to directly control the amount of erosion on their fields (van Kooten, 1993). Another major controversy relates to the assumed perfect markets and perfect foresight (Kiker and Lynne, 1986; Blyth and McCallum, 1987). Furthermore, such

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[21] Multi-criteria programming is a subset of multi-criteria analysis (MCA). MCA is an umbrella-term for numerous multi-criteria approaches, including both continuous and discrete applications. For an overview of multi-criteria programming see Romero and Rehman, 1989; for a brief summary and application see Erenstein and Schipper, 1993. For a comparison of CBA and MCA see van Pelt, 1993 and de Graaff, 1996.

[22] Sum of the net present value of returns to crop production over the planning period and the present value of the terminal value of the land. Yet if markets work well, the increased value of land is simply a reflection of the discounted value of raised yields (Bojö, 1992).

[23] In formula: Max $\int_0^T e^{-rt} [\ p\ g(t)\ f(s,x,z) - cz]dt + R[x(T)]\ e^{-rT}$ subject to $x^{\circ}(t) = k - s(t)$ and $x(0) = x_0$; where p: output price; g(t): neutral technical change; s(t): soil loss; x(t): soil depth; z(t): index of variable inputs; c: input price index; T: time horizon; R(x): terminal value; r: farmer's discount rate; k: exogenous addition to soil base; x_0: initial soil depth (McConnell, 1983).

[24] Barbier, 1990; Barrett, 1991; van Kooten, 1993; Miranowski and Cochran, 1993. For other optimal control applications to soil conservation see Sanders *et al.*, 1995; Bulte and Soest, 1997.

models are generally very data demanding for any empirical validation, thereby limiting their application in developing countries (Carlson and Zilberman, 1993; van Kooten, 1993).

Other approaches

There are a number of other approaches (both discrete and continuous) that can be used to assess soil conservation. However, other discrete approaches typically aid decision-making instead of providing an in-depth economic analysis. For example, *cost-effectiveness analysis* focuses on achieving objectives at least cost, or alternatively, the maximum contribution to the objectives at a fixed cost (Gittinger, 1982; Edwards, 1987; de Graaff, 1996:55). Similar to the opportunity cost approach, it thereby circumvents the controversial valuation of the environmental benefits and costs. The objective will generally be some form of standards-based conservation. Other approaches include planning without valuation (*e.g.* environmental impact assessment); planning with valuation and inclusion of standards; discrete forms of multi-criteria analysis (MCA); planning balance sheets; and the shadow project approach (see de Graaff, 1993).

Most of the economic modelling approaches to soil conservation have relied on partial-equilibrium models. A couple of recent studies have applied general-equilibrium models. Alfsen *et al.* (1996) developed a model for Nicaragua to highlight the social cost of erosion-induced productivity loss - though excluding off-site costs and albeit on a weak statistical basis. Coxhead and Jayasuriya (1995) developed a hypothetical developing country model to explore implications of policy changes (tax and tariff) on upland resource allocation and, by implication, on the rate of erosion. However, neither case is particularly strong in terms of costing erosion[25] - which could have been expected when applying a macro approach to a problem still bogged down at the micro level.

Discussion

Discrete approaches like CBA typically address the question whether changing to a particular conservation scenario is efficient. Continuous approaches like optimisation models go one step further, and try to identify the optimal conservation scenario within the constraints imposed to the model. In a sense, they respectively reflect the efficient and optimal interpretations of soil conservation.

Formal models help in highlighting the implications and coping with the complexity of analytical problems. They provide a powerful tool to identify key trade-offs and single out the impact of specific factors (Eaton, 1996). Models are simplified representations of systems. Thus, the fact that a model leaves out certain aspects of reality is not in itself a criticism. It is, of course, essential that what is left out is of secondary importance (Stiglitz, 1987). Models are never more accurate than the assumptions upon which they are based - the robustness of inferences thereby depends critically on the underlying assumptions (Barlowe, 1974; Deaton, 1995).

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[25] This is kind of contrary to the claim made in the title of Alfsen *et al.* (1996). Coxhead and Jayasuriya (1995:632) circumvent the issue of on-site and off-site costs of erosion and simply assume (albeit quite correctly) that annual food crops tend to be more erosive than 'well-established' perennial crops on sloping uplands.

The economic evaluation of soil conservation aptly highlights the analytical dilemma of choosing between the messy world of empirical verification and the cleaner, safer world of pure deduction or mathematical optimisation (Taylor *et al.*, 1986). Relevant models of soil conservation require assumptions and technical relationships that correspond to empirical realities. Indeed a lack of empirical rigor risks loss of economic relevancy. Yet emphasising the empirical, one risks getting bogged down in all the detail and complexity.

A better scientific understanding of all the underlying complexities of soil conservation certainly will help. However, even if an economic evaluation would be empirically valid, the adoption of soil conservation measures would still be uncertain. Only in the case that farmers were operating under perfect markets with the sole objective of maximising efficiency would such an economic analysis suffice (Pagiola, 1994a: 34). Therefore, an adequate understanding of the socio-economics of soil conservation is also needed - the field of study of the adoption school.

3.3 Adoption school

Another approach to the analysis of soil conservation is to assess the divergences in conservation behaviour between economic agents - here labelled as the *adoption school.* Such an analysis helps to explain the reasons behind the differential adoption of soil conservation. It thereby helps to assess the actual trade-offs faced by economic agents. It also helps predict future conservation behaviour and highlight the corresponding policy implications. In the end, it should enhance the effectiveness of conservation intervention.

The extreme socio-economic site-specificity of soil conservation both warrants and entangles this line of research. Indeed, the advances so far are patchy. The research problems are exceedingly complex and uni-causal models generally founder (Blaikie and Brookfield, 1987; SRAPTF, 1993). Most adoption models have not explained farmers' behaviour well or are not very useful (Miranowski and Cochran, 1993; Camboni and Napier, 1994). Therefore, despite considerable effort there still is very little known about who conserves the soil (Lockeretz, 1990).

Lockeretz (*ibid.*) provides a critical review of the major shortcomings of the soil conservation adoption literature. Some problems are methodological, others analytical - such as the difficulty in defining and measuring conservation adoption (Miranowski and Cochran, 1993). Another major problem is the difficulty of comparing and interpreting results over studies (SRAPTF, 1993). Most studies relate to specific regions and one point in time, and generally use different methodologies and present their results in a different format. The empirical problems of studying soil conservation adoption in particular, are compounded by the complexity of explaining farm household behaviour in general, particularly in developing countries.

What does seem clear is that many factors potentially influence the adoption of soil conservation practices at the farm level (SRAPTF, 1993; Shaxson, 1993; Camboni and Napier, 1994; Napier *et al.*, 1994b). The subsequent subsections briefly review these in terms of technology, the farm household and prevailing institutions. Though the factors are discussed separately, most of them interact[26] and together determine conservation behaviour.

3.3.1 Technology factors

Technology enters the adoption decision in two distinct ways. First, conservation technology is not homogeneous. Second, current production technology may have different implications for a given conservation technology.

Different conservation technologies exist, with corresponding implications for (i) efficiency; (ii) feasibility; (iii) complexity; (iv) predictability; and (v) divisibility (Reardon and Vosti, 1992; Napier and Sommers, 1993). The *efficiency* of technologies is likely to be affected by the timing and magnitude of initial investment, recurrent costs and corresponding benefits - which are all technology-specific. The *feasibility* of technological options typically depends on the required supporting environment - *e.g.* in terms of the provision of specific equipment or inputs. *Complexity* increases the learning costs for farmers, whereas *predictability* reduces the risks associated with adoption. *Divisibility* - or the contrary, lumpiness - has a twofold effect. First, if the technology is divisible a farmer can experiment and adopt in incremental steps thus reducing both risk and the level of economic investment needed. Variety of designs and the emergence of markets for hired services can potentially mitigate lumpiness of technology (Feder *et al.*, 1985). Second, the technology may require a certain scale of implementation that may transcend the farm boundary and thereby require collective action, thus complicating the adoption process.

The implications of a given conservation technology are also affected by current production technology. On the one hand, conservation and production technology may not be entirely compatible - *e.g.* terraces at a width that prohibits mechanised land preparation. This implies the need to adapt at least one of the two technologies upon conservation adoption. On the other hand, conservation and production technology may also be complementary - *e.g.* soil conservation also implies reduced runoff of inputs. The complementarity also gives rise to a paradox: conservation competes with productive investment for resources, but also can increase the returns to productive investment (Reardon, 1995; 1998).

Consequently, both conservation and production technology can have a profound influence on the adoption of soil conservation. The technology aspect of soil conservation will be elaborated in Chapter 4.

3.3.2 Farm household factors

The farm household is the ultimate decision maker in terms of land use and therefore soil conservation. The adoption decision is therefore likely to reflect the resource endowments and preferences of the farm household.

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[26] *E.g.* the composition of farm household assets tend to reflect farm household preferences and the institutional setting; the marked time preference of farm households tends to reflect scarce resources and the institutional setting; etc.

Farm household resources

Farm households only have a limited set of resources (land, labour and capital). Soil conservation requires the use of resources - either directly in terms of investment and maintenance requirements (*e.g.* capital and labour) or indirectly in terms of foregone production (*e.g.* land to locate structures). However, these conservation requirements are likely to compete with alternative household uses in terms of production and consumption. Therefore, resource availability constrains the feasible set of activities.

Given a set of resource constraints, both the absolute level and timing of resource requirements are of importance. For instance, the household's labour used for production and consumption activities is likely to be divided between on-farm, off-farm, home, social and leisure activities. Labour needed for conservation activities implies displacement from one or more activities and thereby imposes an opportunity cost in terms of utility foregone. The timing of the labour needs influences the magnitude of these opportunity costs. This opportunity cost will be high during peak periods of agricultural on-farm work and other - on-farm and off-farm - employment opportunities (Kerr and Sanghi, 1993). Consequently, the slack agricultural season tends to correspond with much off-farm activity (Reardon and Vosti, 1992; Erenstein and Cadena, 1997).

Inadequate consideration of labour is a common cause of failure in soil conservation schemes (Stocking and Abel, 1992). Labour can be a critical constraint and inadequate consideration of the opportunity cost of time can substantially underestimate the cost of labour-intensive conservation measures (Hudson, 1988a). Something similar applies to capital. Farm households typically face binding capital/liquidity constraints implying a correspondingly high opportunity cost.

Specific internal resource constraints may be eased by the exchange between economic agents - institutional set-up permitting. External inputs are normally used to increase the productivity of scarce factors (Kuyvenhoven *et al.,* 1996). Such exchange is likely to somehow align internal and external opportunity costs for the resources in question. In the end, however, household activity remains constrained by its overall resource availability.

It is often hypothesised that farm resources are positively correlated with adoption in general, and soil conservation in particular. In this regard farm size has received substantial attention. Even seemingly neutral technology may entail significant set-up costs and this tends to discourage adoption on small farms. However, size of holding is a surrogate for a large number of potentially important yet confounding factors (Feder *et al.*, 1985). A larger holding is typically associated with access to financial and technical support systems as well as economies of scale (Napier and Sommers, 1993). The effect of farm size can be particularly important in association with institutional imperfections (*e.g.* in credit market). Farm size also tends to affect preferences (*e.g.* attitude towards risk; Pomp, 1994).

Farm household resources have both quantitative and qualitative dimensions. However, aggregate indicators of resource availability often fail to reflect such quality differences, although these can have important implications for the adoption decision. The quality aspect is particularly relevant for the land resource, being dependant on the soil proper and the wider environmental setting - both in bio-physic and socio-economic terms (Barlowe, 1974; Schipper, 1996). Land quality has a profound influence on conservation adoption, as it affects both the need for conservation and its opportunity cost.

The adoption decision is also linked to human capital - *i.e.* the knowledge and skills embodied in the household members. Human capital influences the learning costs - a potentially large and fixed cost of adoption. These costs are likely to vary over households depending on their knowledge base and skills (*e.g.* learning ability; management capacity). In this regard Stiglitz (1988) distinguishes between (i) learning by doing and (ii) learning to learn. Learning by doing stresses the investment in knowledge upon technology adoption. This implies that it may pay to adopt a given technology in a dynamic setting when on static considerations alone it would not. Learning to learn stresses the investment in skills. This implies it may pay to adopt a technology neither for its current or prospective returns, but for the benefits which will accrue in the adoption of future technologies.

A body of literature revolves around farmers' awareness of soil erosion, which relates back to its enigmatic nature. Such research generally assumes that a precondition for action is the awareness of the problem (Jolly *et al.*, 1985; Herweg, 1993; Sombatpanit *et al.*, 1993). Some models therefore try to depict the decision-making process by resolving the awareness issue first and subsequently looking into actual conservation behaviour (Ervin and Ervin, 1982; Gould *et al.*, 1989). Awareness may thus be a necessary but not a sufficient condition for conservation (Napier and Sommers, 1993). In this regard, Sinden and King (1990) note that while the stewardship motivation and personal factors encourage perception and recognition of a problem, economic factors promote actual adoption.

Consequently, the availability of land, labour and capital resources can have a profound influence on the adoption of soil conservation. Of particular relevance are the resultant opportunity costs.

Farm household preferences

The conservation decision is co-determined by the farm household's preferences as reflected in their objectives and attitudes. Farmers generally pursue a set of objectives - for instance, to provide for food and other household needs, to avoid becoming indebted, to obtain acceptable returns for the applied resources, and to achieve an adequate balance between work and leisure. Relevant attitudes include time preference, risk preference, and stewardship motivations. Both objectives and attitudes are inherently subjective and specific for each household, but jointly determine the preferred set of production and consumption activities. The household will seek to choose the combination of these activities which will maximise utility, given the constraints imposed by available resources, technology and institutions.

Within the process of maximising utility, the conservation objective competes with the other objectives for limited resources. This is, in fact, the heart of the soil conservation problem (Barbier and Bishop, 1995:137). Other objectives tend to subdue the conservation objective, particularly in the case of resource-poor farmers in developing countries (Douglas, 1993). For numerous such farmers sheer survival today is generally a more pressing problem than conservation of the resource base for a distant future (Blaikie, 1985; Conway and Barbier, 1990; Stonehouse and Protz, 1993; Reardon and Vosti, 1995). 'The immediate problem is how to keep the family fed during the next six months' (Hudson, 1988a:5) and many cannot look further than the next harvest (Napier *et al.*, 1991; Hudson, 1993; de Graaff, 1996). Most operate with year to year or shorter planning horizons

(Swader, 1994). Therefore, the issue is not that resource-poor farmers do not care about tomorrow or resource conservation. The issue is that they have limited ability to do anything about conservation if it diverts resources from the process of meeting today's needs (Turner *et al.*, 1993).

Yet, even when basic survival is assured, other demands are still likely to subdue soil conservation considerations. In this regard, Reardon and Vosti (1995) distinguish between welfare poor and investment poor. A farm household may be above the welfare poverty line, but still not invest in conservation, having other priorities for the limited resources. It is generally acknowledged that developing country farmers tend to be risk-averse, have short planning horizons and hence high discount rates (see Anderson and Thampapillai, 1990:11-13 for various references). Farmers are generally practising a form of 'myopic optimisation' resulting in a strong preference for short-term effects (Feder *et al.*, 1985; Lovejoy and Napier, 1988:111). This contrasts starkly with the several years normally needed to achieve significant benefits from traditional conservation investments (Napier *et al.*, 1991). Within the farmer's limited but reasonable time horizon, conservation may simply not be attractive (Wolman, 1985; Bojö and Cassells, 1995).

One may even wonder whether farmers actually consider conservation as one of their objectives. More likely, farmers tend to view conservation not as an end in itself, but only as a means to an end (Stonehouse and Protz, 1993). In any event, soil conservation seldom appears near the top of farmers' list of priorities - even in those instances where the results of erosion are highly visible (Shaxson, 1993). Such erosion-prone areas often coincide with economic marginality, and the corresponding productivity and marketing problems may well relegate soil conservation to a lower priority.[27]

Obtaining an acceptable return from the applied resources may well be one of the objectives of a farm household. If a problem is perceived, but the recommended action does not lead to appropriate rewards, farmers are unlikely to adopt it (Meyer, 1988; Biot and Xi, 1993; Lingard, 1994; Sanders *et al.*, 1995). Therefore, one would expect adoption of soil conservation to correlate well with private returns, as it seems to do both in developing as developed countries (Thomas *et al.*, 1983; Conway and Barbier, 1990:154; Pagiola, 1994b. See Napier, 1991:134 for various references). Yet it is often forgotten that such economic rather than conservation considerations dominate farm management decisions.

This is the more problematic as conservation measures are generally costly (Sanders, 1988; Pagiola, 1994b; Sanders *et al.*, 1995). The critical question therefore becomes if the benefits make these costs worth bearing. If damage from erosion is slight and/or cost of conservation is high, the return to conservation is unlikely to be attractive (Pagiola, 1994b). In fact, the returns on soil conservation investment have generally been low; whereas many practices only provide positive returns in the long term - if at all.[28]

[27] This is not to say that farmers would not be willing to invest in soil conservation. Chapter 4 (Subsection 4.3.1) considers some lessons from autonomous soil conservation.

[28] Seitz and Swanson, 1980; Batie, 1986; various references in Swanson *et al.*, 1986; Shaxson *et al.*, 1989; Herweg, 1993; various references in Stonehouse and Protz, 1993:31; Camboni and Napier, 1994; Napier *et al.*, 1994b.

Failure to consider the *potential* returns to conservation measures can lead to futile searches for constraints to adoption (Pagiola, 1994b: 173). It makes a rather big difference whether conservation is potentially attractive but constrained, or simply not attractive weighed against alternative investment opportunities (Kerr and Sanghi, 1993). Although the returns to conservation weigh heavily in adoption decisions, it is not the only factor that farmers consider (Anderson and Thampapillai, 1990; Biot and Xi, 1993; Faeth, 1994). A positive return to conservation is typically a necessary but not sufficient condition for its adoption (Lutz *et al.*, 1994b:287; Pagiola, 1994b; Reardon and Vosti, 1997).

The risk implications are another particularly important factor in the conservation adoption decision. Farmers are typically risk-averse, yet conservation typically poses a risk dilemma as it affects risk in two opposing ways. On the one hand, soil conservation reduces risk. Soil conservation halts the decay of an income stream: it is a preventive investment that avoids an undesirable and uncertain future outcome (Rogers in Jolly *et al.*, 1985). Further, soil conservation tends to reduce agricultural production risks by conserving water - often a limiting factor (Anderson and Thampapillai, 1990; Reij, 1994).

On the other hand, soil conservation increases risk. It is generally acknowledged that innovations - whatever their nature - entail risk.[29] In the case of soil conservation this is exacerbated by the time-scale and observability problem (Reardon and Vosti, 1992). In addition, soil conservation represents a further investment within the agricultural sphere. At the household level, investment in portfolio diversification may well have more favourable risk implications (Sadoulet and de Janvry, 1995). This gives rise to yet another paradox: soil conservation may conflict with risk management, particularly in the most fragile environments, as it is here that the desire to diversify out of agriculture will be strongest (Reardon and Islam, 1989 in Reardon and Vosti, 1992; 1997). A complicating factor is that risk preference is difficult to measure and is closely associated with other factors, leading to identification difficulties in empirical associations observed in cross-sectional data (Feder *et al.*, 1985; Norris and Batie, 1987 in Anderson and Thampapillai, 1990).

Consequently, both objectives and attitudes can have a profound influence on the adoption of soil conservation. Of particular relevance is the compatibility of conservation with utility maximisation. Compatibility is more likely when implementing conservation implies short-term returns and reduces risk.

3.3.3 Institutional factors

Institutional factors provide an important set of external conditioning variables for the conservation decision. Institutions are variously defined. Lin and Nugent (1995:2306-7) define an institution as a set of 'behavioural rules that govern and shape the interactions of human beings, in part by helping them to form expectations of what other people will do.' Hoff *et al.* (1993:1) consider an economic institution to be 'a public system of rules that define the kinds of exchanges that can occur among individuals and that structure their

[29] Feder *et al.* (1985) distinguish between subjective risk (*e.g.* yield is more uncertain with an unfamiliar technique) and objective risks (*e.g.* in relation to weather and availability of inputs).

incentives in exchange.'[30] It is therefore somewhat of an umbrella term that includes formal and informal rules of conduct at all levels, encompassing both market and non-market exchanges.[31]

The standard neo-classical analysis assumes that the required institutional arrangements for the efficient allocation of resources exist,[32] and thereby concentrates on technology, resources and preferences. However, in the analysis of soil conservation in developing countries this is inappropriate, as both the problem and the setting imply substantial divergences. Soil conservation itself is characterised by the existence of externalities and imperfect information (see Chapter 2; and Sections 3.1 and 3.2). Similarly, developing countries are characterised by incomplete markets and insecure property rights (Feder and Feeny, 1993; Hoff *et al.,* 1993; Lin and Nugent, 1995). The importance of the institutional side of soil conservation, particularly in developing countries, is increasingly acknowledged.[33]

Market imperfections

The market is an institution that makes available to interested parties the opportunity to negotiate courses of action (Dasgupta and Mäler, 1995). The existence, structure and performance of markets thereby influences farm household behaviour. Yet in the case of soil conservation in developing countries the set of markets is typically incomplete and their structure and performance imperfect.

Factor market imperfections affect the adoption decision directly. For instance, soil conservation is embodied in the land resource. To recapture soil conservation investments upon selling the land requires a functioning land market to recognise such investments (Kuyvenhoven *et al.,* 1996) - *i.e.* land values should reflect the value of the averted long-term erosion-induced productivity losses (Miranowski and Cochran, 1993).[34] A functioning labour and capital market may allow the household to alleviate resource constraints that could otherwise prohibit the implementation of conservation. Institutional interrelationships

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[30] According to Bromley (1982b: 839), 'institutions are collective conventions and rules that establish acceptable standards of individual and group behaviour.' Hayami and Ruttan (1985:94) consider institutions as the rules 'that facilitate co-ordination among people by helping them form expectations which each person can reasonably hold in dealing with others'.

[31] However, in this respect institutions are *not* organisations, though organisations are defined by institutions (Bromley, 1982b). Some confusion arises from the fact that this distinction is by no means universal. Indeed, institutions are frequently equated with organisations.

[32] Namely: 1. Complete set of markets; 2. Perfectly competitive markets; 3. No externalities; 4. No public goods; 5. Fully assigned property rights; 6. Perfect information; 7. Producers maximise profit, consumers utility; 8. Long-run average costs are non-decreasing; 9. No transaction costs; 10. All relevant functions satisfy convexity conditions (Perman *et al.*, 1996:93).

[33] Bromley, 1982a; Halcrow *et al.*, 1982; Southgate *et al.*, 1984; Blaikie, 1985; Nowak *et al.*, 1985; Batie, 1986; Lovejoy and Napier, 1986; Blaikie and Brookfield, 1987; Garcia-Barrios and Garcia-Barrios, 1990; Napier, 1991; Baum *et al.*, 1993; Carlson and Zilberman, 1993; Sfeir Younis and Dragun, 1993; Napier *et al.*, 1994a.

[34] Southgate (1994) doubts whether that is really possible in developing countries, citing amongst others bureaucratically-induced transactions costs.

may affect the adoption decision indirectly. For instance, a functioning labour market may alleviate a missing credit market as off-farm work substitutes for credit (Reardon *et al.*, 1994).

Credit market imperfections are of particular relevance to the conservation decision. Without access to credit, the investment requirements may be prohibitive. But even with access to credit, high interest rates are likely to make their use for conservation unattractive. This disproportionately affects resource-poor farmers, with typically restricted access to mainly informal credit sources at high rates. However, such high interest rates also tend to reflect high rates of default, high correlation among defaults and the high cost of screening applicants and pursuing delinquent borrowers (Stiglitz, 1993).

In addition, there are a number of potential credit market constraints specifically hampering soil conservation investments (Reardon and Vosti, 1992; 1997). The very spatial and temporal externalities postpone repayment and increase the risk of default. In addition, conservation investments typically do not create loan collateral, in contrast to most productive or consumptive investments. Conservation work is also commonly carried out in stages, not all at once (Kerr and Sanghi, 1993). The difficulties in handling productive credit for farmers, are therefore likely to be compounded for conservation credit.

Markets also do not function efficiently in the case of non-excludable public goods. In this regard, the public good nature of information particularly affects adoption decisions. Early adopters convey useful information to their neighbours, particularly when these actions are directly observable as is the case with soil conservation measures. This typically reduces the cost of acquiring information and may induce copying behaviour (Stiglitz, 1993; Pomp, 1994).

Various other institutional factors contribute to the existence of market imperfections - *e.g.* imperfect information, externalities and transaction costs. The role of property rights is assessed hereafter. However, whatever their nature, market imperfections limit the household's efficiency in allocating resources to soil conservation.

Property rights

Property rights are one of the most frequently highlighted institutional factors influencing soil conservation adoption (Bromley, 1982a, 1982b; Edwards, 1987; Napier, 1992; Southgate, 1994; Sanders *et al.*, 1995). 'Economic theory suggests that insecure property rights lead to a premature depletion of resources. If a farmer cannot capture the future gains that arise from conservation decisions, he or she will have no incentive to conserve' (Batie, 1982: 37). In the extreme, farmers without security of tenure are interested in maximising their short-term investment in seed, fertiliser and labour for the crop that is in the ground (Barbier, 1990).

There are different types of property rights: (i) private; (ii) state; (iii) communal (*i.e.* with conventions governing use); and (iv) open access (*i.e.* without conventions). Conventional wisdom holds that soil erosion/degradation is most likely under open access as no one will have the incentive to invest in soil conservation. Communal management of resources can be successful - notably when institutional arrangements adequately relate private incentives to collective benefit and impose the necessary sanctions from within to prevent free-riding (Turner *et al.*, 1993:219). However, most instances of communal management of the soil resource for agricultural purposes emphasise usufructuary rights.[35] These generally provide weak - if any - incentives to adopt soil conservation[36] (Southgate *et al.*, 1984; Southgate, 1994; Sanders *et al.*, 1995). An additional problem of usufructuary rights is the impossibility to use the land as collateral - being an inalienable resource - for loans to finance soil conservation investment (Anderson and Thampapillai, 1990; Atwood, 1990; Feder and Feeny, 1993; Sanders *et al.*, 1995). Communal management can also break down under various strains. Therefore from a soil conservation perspective, preference is generally given to private property rights.

(Private) property rights can also be transferred, either by ceding them fully and permanently in the case of selling or partially and temporarily in the case of leasing out. The case of tenancy - *i.e.* landlord-tenant combination in contrast to owner-operators - is of particular relevance to soil conservation.[37] The (temporal) separation of ownership and operation implies the need to share the costs and benefits of conservation investments and thereby gives rise to transaction costs (*i.e.* the costs of acquiring information, negotiating a contract and enforcing it - Upton, 1996).

If the sharing is unequitable in the first place - in terms of who benefits and who pays - it is bound to discourage the implementation of conservation measures. A tenant may have little incentive to conserve if he cannot capture the benefits from his investments (Napier *et al.*, 1991; Stahl, 1993). For conservation to be attractive to the tenant the payback period needs to fall within the time he expects to rent the land (Pagiola, 1994a). In this regard the stability and length of his tenure are crucial (Ervin, 1986; Sanders, 1988). Alternatively, compensation by the landlord to the tenant for land improvements could ostensibly make up for differentials (Wiggins, 1981); or conversely, landlords may insist on tenants adopting conservation.[38]

A landlord may also have the incentive to underinvest as tenants will capture some benefits (Ervin, 1986). Other constraints reflect imperfect information and the landlord's preferences and resources (Kerr and Sanghi, 1993:276-77). Landlords that do not cultivate themselves may well be unaware of the erosion problem or do not consider it worth worrying about. In some instances they do not have the resources to cultivate their land, let alone to invest in soil conservation. In other instances - notably absentee landlords - they have alternative income sources with presumably higher returns than farming and/or may hold land as a source of long-term security. Landlords may also actually oppose conservation enabling conditions - such as long-term leases or allowing tenants to make major land improvements - if they fear this facilitates tenants laying ownership claims in future.

Ervin (1986) has reviewed some of the empirical evidence to assess whether there is any truth to the conventional wisdom that tenancy is associated with less conservation effort.

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[35] For instance, Latin America's 'comunas' and Mexico's 'ejidos' before the constitutional reforms of Article 27.

[36] Or other productivity-enhancing investments for that matter.

[37] von Ciriacy-Wantrup, 1968; Lee and Stewart, 1983; Barlowe, 1958 in Blaikie, 1985; Ervin, 1986; Napier and Sommers, 1993.

[38] Depending on the bargaining power of each party and the perceived sharing of costs/benefits.

However, he highlights the empirical ambiguity surrounding the relation and concludes that it is impossible to test rigorously without simultaneously controlling tenure conditions and other factors influencing soil conservation decisions. Yet tenancy as such may not be the limiting factor. Instead, it is increasingly acknowledged that it is the security of rights that matters (*e.g.* Messer, 1987). Further, the *de facto* and not the *de jure* rights are of relevance (Feder and Feeny, 1993; Scoones *et al.*, 1996).

But secure property rights alone do not imply soil conservation (Southgate *et al.*, 1984). Securing property rights - *e.g.* through effective land reform in Latin America - may actually increase soil erosion through the resulting intensification (Crosson, 1983 in Anderson and Thampapillai, 1990). Also, property rights are of limited use in resolving erosion-induced pollution - as long as it is impossible or at least very costly to determine contribution from the non-point source (Edwards, 1987). In fact, insecure property rights may be less of a problem than originally thought as all soil conservation measures with high returns have a short pay-back period anyway (Lutz *et al.*, 1994b). In other words, a long pay-back period implies low returns which in turn implies low adoption rates - irrespective of security.

Other institutional issues

Soil conservation occasionally requires *collective action* by farmers when the measure transcends farm boundaries. Indeed, there may exist scale economies in multi-farm conservation practices. However, this simultaneously implies a more substantial overall investment and an increased need for co-operation - which is not cost free. The cost of organisation and monitoring may not justify undertaking the required group action. A related problem is free riding, as benefits and costs may well be distributed unevenly among the affected people. This provides incentives to undermine the system and institutions are needed to equate marginal entry costs and benefits. Equity may thus become a prerequisite to efficiency (Carlson and Zilberman, 1993; Kerr and Sanghi, 1993).

An important characteristic of institutions is their dynamic nature. Alternative (non-market) institutions may evolve in response to market imperfections. The omnipresence of the family farm as basic agricultural production unit reflects one particular institutional adaptation: it provides functions to make up for missing markets (*e.g.* insurance; Stiglitz, 1988). Non-market institutions can provide good substitutes for markets - *e.g.* in the form of sophisticated contracts (McIntire, 1993). Such institutions may help to overcome information problems, but can also aggravate them. They may also give rise to economically unprofitable institutions that may persist as a result of a mutually sustaining network of social sanctions (Hoff *et al.*, 1993). In the end, both the original market imperfections and eventual institutional adaptations restrict farm household behaviour and thereby influence the adoption decision. In fact, there is a two-way relationship between institutions and adoption. On the one hand, institutions may constrain or facilitate adoption. On the other, adoption may induce institutional change. This reverse causality occasionally makes it difficult to assess the corresponding determinants and effects.

Notwithstanding the potential for institutional change, institutional factors encompass a set of external conditioning variables that can have a profound influence on the adoption of soil conservation. Of particular relevance are the market imperfections and the corresponding institutional adaptations. The security of rights can be influential in this respect.

Discussion

There are numerous factors in relation to technology, resources, preferences and institutions that potentially influence conservation behaviour. Different researchers have emphasised different aspects. For instance, the advocates of the diffusion model tend to see adoption behaviour as strongly influenced by information and past experiences (Hansen *et al.*, 1987; Napier, 1991). Advocates of the farm structure model emphasise the role of the farm household's resources. However, such perspectives are bound to be complementary (Nowak, 1987). No doubt most factors play a role, and their relative importance is likely to vary over time and space (SRAPTF, 1993).

The different factors have a profound influence on the incentives and capacity to invest in soil conservation (Reardon and Vosti, 1997). The implications of soil conservation will necessarily vary over farm households - at least if the analysis adequately reflects the specific constraints and opportunities faced by the individual farmer. Therefore, a particular conservation technology is not equally attractive for all farmers within a given region (Kerr and Sanghi, 1993). Even minor variations in biophysical and/or socio-economic conditions are likely to induce variations. As a result one would not expect to observe complete adoption in any region (Pagiola, 1994b:173). The diversity of farm circumstances thereby tends to undermine generalisations about soil conservation behaviour (Anderson and Thampapillai, 1990).

Understanding such divergences between farm households is of crucial importance for government policy. Government intervention typically tries to alter one or more of the different factors in an attempt to ensure soil conservation. For instance, government services provide information (*e.g.* through education, extension, mass media, etc.) to alter farmers preferences (*e.g.* by raising awareness). Similarly, governments provide conservation technology or address market imperfections. However, an incomplete understanding of the complex soil conservation problem risks addressing only symptoms or providing partial solutions. In this regard, an adequate understanding of the socio-economic side of soil conservation will be crucial in revealing the correct policy implications. Chapter 4 will specifically address some of the policy and technology implications that derive from the foregoing analysis.

3.4 In conclusion

The present chapter addressed the economic analysis of soil conservation. Soil conservation averts the damage inflicted by soil erosion. Consequently, the analysis of conservation mirrors many of the issues and controversies encountered in the analysis of soil erosion (see Chapter 2). There are two important additional issues. First, the conservation effort itself adds another layer to the already rampant site-specificity, both in biophysical and socio-economic terms. Second, soil conservation requires investment now at a readily determined cost, whereas benefits remain largely uncertain and difficult to measure.

The analysis is confounded by different interpretations of conservation - namely absolute, standards-based, efficient and optimal. The different interpretations imply different degrees of erosion control with significant implications for the analysis. Absolute and optimal conservation remain largely hypothetical in view of the costs and complexities involved respectively. In practice, the implementation of soil conservation tends to be standards-based in view of the prevailing uncertainty, whereas economic analysis tends to assess the efficiency implications.

The assessment of soil conservation poses considerable analytical challenges that have been tackled in varying ways. The different analytical approaches can be broadly grouped under two main schools of economic analysis: (i) the evaluation school and (ii) the adoption school. Each school focuses on different aspects of soil conservation and to a certain degree is complementary to the other.

The *evaluation school* basically tries to quantify the economic impact of different soil conservation scenarios. However, such attempts are curtailed by stringent data limitations. A first analytic choice relates to the mode of costing erosion; a second choice to the mode of economic analysis.

Alternative approaches for costing erosion include the dose-response approach, replacement cost, mitigation behaviour, opportunity cost approach and demand curve approaches (*e.g.* contingent valuation and hedonic pricing). The dose-response approach is the most frequently used. Notwithstanding, the complexity of the underlying soil erosion process implies there generally are no clear dose-effect relations. The dose-response link is typically the most crucial yet weakest link in these studies. The replacement cost approach is occasionally used as alternative but is not without its problems either, particularly when applied to the erosion-induced nutrient loss. In fact, each measure is imperfect in some way. Compounding the issue, the different measures are not directly comparable. Many only provide a partial - yet occasionally overlapping - measure of the true cost of soil erosion. Further, each measure reflects different soil erosion scenarios (*i.e.* ignore, prevent and cure), whereas their application may reflect different - implicit or explicit - definitions of conservation (*i.e.* absolute, standards-based, efficient or optimal). Although all existing methods are typically imperfect and open to criticism, following a method which is open for external debate is preferable to covering the difficulties.

The most frequently used modes of analysis include cost-benefit analysis (CBA) and optimisation models, with substantial differences between the two. CBA is a discrete approach and mainly revolves around the efficiency interpretation of soil conservation. Optimisation models provide a continuous approach more in line with the optimal interpretation of conservation. The choice is influenced by the data limitations and the nature of analysis. Although models provide a powerful analytical tool, their strength in the end hinges on the underlying assumptions. The economic evaluation of soil conservation thereby eloquently highlights the analytical dilemma of opting for a 'messy' empirical or 'clean' theoretical approach.

The *adoption school* tries to explain and predict the divergences in soil conservation behaviour between economic agents. However, the extreme socio-economic site-specificity of soil conservation both warrants and entangles this line of research. The numerous factors that potentially influence the adoption decision of the farm household include resources, preferences, technology, and institutions.

The availability of land, labour and capital resources constrains the farm household's feasible set of activities. Implementing soil conservation may thereby imply substantial opportunity costs. The household's objectives and attitudes determine whether these costs are compatible with utility maximisation. Compatibility is more likely when implementing conservation implies short-term returns and reduces risk. In part this will depend on technology factors: neither conservation or production technology is homogeneous. This implies significant differences exist between the different conservation technologies themselves; as well as their technological compatibility with current production practices. The compatibility of conservation with utility maximisation will also depend on institutional factors, which encompass a highly influential set of external conditioning variables. Of particular relevance for institutional compatibility are the market imperfections and the corresponding institutional adaptations. The security of rights can be influential in this respect.

The different factors have a profound influence on the incentives for, and capacity of, farm households to invest in soil conservation. The relative importance of each factor is likely to vary over time and space. Understanding such divergences between farm households is of crucial importance in devising effective and efficient government policy and conservation technology - an issue elaborated in Chapter 4.

CHAPTER 4

SOIL CONSERVATION: POLICY AND TECHNOLOGY IMPLICATIONS

Soil conservation has long received substantial policy interest. Public conservation interventions go back to the 19th century in the USA and early 20th century in tropical colonies - receiving a substantial boost after the Dust Bowl storms of the 1930s in the USA's Midwest (Camboni and Napier, 1994; Pretty and Shah, 1997). During the last half century, extensive efforts and matching resources have been underway worldwide to conserve soils.

But intervention so far has proven largely unsuccessful: 'The history of soil and water conservation so far is not a success story' (Biot and Xi, 1993:167); the resolution remains frustratingly beyond our grasp (Lockeretz, 1990); 'The problem persists despite the billions spent on it' (Carter, 1977); many soil conservation programs have fallen far short of expectations (Pagiola, 1994b); Africa shows a dismal record of soil conservation (Fones-Sundell, 1992); the list of disappointing results could go on and on.[1] Since the end of the 1970s, the frequent failure of soil conservation intervention is increasingly noted (Roose, 1993). 'By most performance measures, conventional conservation programmes have been remarkable failures' (Pretty and Shah, 1997:48).

This suggests that the mode of intervention has been neither effective nor efficient. This is even more problematic in developing countries, as erosion is potentially more damaging and the resources to mitigate it scarcer. From the preceding chapters emerges that soil conservation may well warrant intervention, but that this is unlikely to be straightforward in view of the complexity of the problem. This chapter discusses implications for policy intervention and conservation technology development. The first section briefly discusses the rationale for intervention. The second section assesses the traditional approach to soil conservation in terms of modes of intervention and traditional conservation technology. The third section then delineates new directions for conservation intervention and conservation technology development. The fourth section introduces some promising technological options, specifically crop residue and cover crop mulching. The last section provides a concluding summary.

4.1 Justification for public intervention in soil conservation

Soil conservation is characterised by numerous market failures, including imperfect information, spatial and temporal externalities, and the potential for economies of scale and irreversible damage. These failures are likely to be exacerbated in developing countries by

[1] See for instance McConnell, 1983; Southgate *et al.*, 1984; Wolman, 1985; Buttel and Swanson, 1986; Swanson *et al.*, 1986; Walker and Young, 1986; Blaikie and Brookfield, 1987; Sanders, 1990; Faeth *et al.*, 1991; Napier, 1991; Napier *et al.*, 1991; Douglas, 1993; Kerr and Sanghi, 1993; Roose, 1993; Greenland *et al.*, 1994.

typically missing, incomplete and imperfect markets. The question then is whether the public sector can be expected to offer effective interventions.

For some, the mere existence of market failures implies the need for public intervention. For others, particularly absolute conservationists, intervention is a matter of common sense.[2] However, intervention in soil conservation is only justified if the expected benefits of intervention to society are larger than the related costs.[3] In other words, intervention should be less costly than the market failure it is designed to correct (Hunter, 1993). Market failure therefore only identifies the potential area for intervention: *i.e.* it is a necessary but not sufficient condition for public intervention (Stiglitz, 1987:44).

To assess whether intervention is justified the on-site and off-site effects need to be quantified and valued, although this is problematic (see preceding chapters). Indeed, the decision to intervene is confounded by the complexity of soil conservation and the corresponding imperfect information and limitations for intervention. In practice, the decision is therefore likely to be controversial.

Table 4.1 highlights some of the arguments for and against public intervention in soil conservation in relation to on-site and off-site effects. Some liberals have argued that if erosion really would impose severe on-site productivity costs, it would be in the farmers' self-interest to conserve his resource (Crosson, 1997). The counter-argument frequently relates to conservation being privately unattractive in the face of its investment nature. Conservation advocates also highlight imperfect information: if one does not perceive the need, there will be little incentive to conserve. Yet, others still find the evidence of serious on-site damage inconclusive. Another major argument revolves around the reversibility issue. Degradation will be more costly if it is irreversible. Yet, opinions are divided about whether soil erosion really is irreversible. Concerns about national interests also enter the debate. Soil erosion undermines the future national food security as well as rural livelihoods, the latter exacerbating rapid rural-urban migration. But others rebuff this by indicating the ever expanding international trade and the need to free labour from the agricultural sector to further development elsewhere (Southgate, 1994). Or that intervention induces adverse selection: conservation efforts serve as a magnet that will keep people in fragile areas best left alone (Anderson and Thampapillai, 1990:24).

Off-site costs have regularly been flagged as warranting intervention - but are equally controversial. Some will highlight substantial social costs such as the reduced economic lifetime of costly hydroelectric dams and irrigation infrastructure. Or the need for expensive water-treatment plants; or the havoc created by floods. Others will not hesitate to point out that most sediment is deposited before it actually does any harm. Or that there are few downstream users anyway; or that the sediment enriches the downstream floodplains. Likewise, one could argue that the off-site damage is costly to revert, but the same appears to be true for prevention.

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[2] *E.g.*, Herweg (1993:400) states that if soil erosion in Ethiopia 'will certainly bring only more poverty and higher vulnerability to famine, the need for protection does not have to be argued upon'.

[3] Edwards, 1987; Panayatou, 1992 in Sanders *et al.*, 1995; Hunter, 1993. Further, all advocates of efficient conservation.

The controversies highlight the problematic quantification and valuation of on-site and off-site effects. The handling of downstream externalities has proven particularly difficult, and claimed downstream benefits of soil conservation have often proved to be illusory (Anderson and Thampapillai, 1990). This suggests that soil conservation intervention should be justified in the first place on on-site grounds, and that off-site benefits should only be included when destination and time profiles are clear and appropriately discounted for probabilities of occurrence.

Table 4.1 Arguments for and against soil conservation intervention

	Arguments for	Arguments against
On-site	– privately unattractive (investment nature)	– self-interest
	– imperfect information ('hidden' costs)	– inconclusive evidence
	– irreversible damage	– reversible damage
	– in national interest (food security; rural-urban migration)	– not in national interest (market integration; wider development; adverse selection)
Off-site	– serious damage (siltation; water quality; hydrological cycle)	– limited damage (deposition; few downstream users; new productive land)
	– costly to revert	– costly to prevent (non-point source)

The controversies over intervention can be partially resolved by targeting those areas were inaction would be particularly costly - so-called 'hot spots' (Scherr and Yadav, 1996). The extreme site-specificity of both problem and solution suggest that blanket approaches will be highly inefficient. To assure efficiency, targeting would obviously need to consider both on-site and off-site impacts (Nowak *et al.*, 1985; Ribaudo, 1986; Stults and Strohbehn, 1987). Yet, adequate targeting is problematic (Eleveld and Halcrow, 1982). For adequate on-site targeting one should focus on those soils that are not beyond salvation but are subject to a clear potential erosion-induced productivity loss (Seckler, 1987). Adequate off-site targeting is even more problematic. Soil erosion is a major cause of non-point source pollution, making the linkage of any particular source to downstream damage virtually impossible (Griffin and Stoll, 1984; Phipps, 1987).

These arguments underline the problem of addressing imperfect information for a government likely to face similar dilemmas (Stiglitz, 1987; 1988). The gains from intervention may well be limited if it replaces market failure with government failure, or if it induces market failures elsewhere (Perman *et al.*, 1996). Consequently, caution is needed in assessing the need for intervention. Similar caution is needed upon structuring intervention such that intended objectives will be achieved (Stiglitz, 1987; 1988). The link between the reasons for intervention and actual government policy may be tenuous - often exacerbated by political considerations. The government is not a benevolent homogeneous body, but subject to problems of public choice, incentives and vested interests (Hoff *et al.*, 1993).

For public intervention to be justified it should outperform the market: *i.e.* the social benefits of intervening in soil conservation should outweigh the social costs. If past conservation intervention in developing countries proof to be any guide, the prospects of doing so are dim. There simply is no clean, easy avenue for public intervention in soil conservation (Swader, 1994).

4.2 Assessing traditional public intervention in soil conservation

Soil conservation is perceived differently by land users on the one hand, and government and conservationists on the other. Table 4.2 highlights one such dichotomy of views – conservationists *versus* farmers. The traditional soil conservationist emphasises conservation, takes a long term view and a regional perspective that includes both on-site and off-site effects. The farmer in contrast emphasises productivity, has a substantially shorter planning horizon and a perspective that puts his farm central. The traditional approach to conservation intervention - implicitly or explicitly - recognises the market failures underlying soil conservation. Farmers are seen to underinvest in conservation, and the government, knowing better, tries to redress that. Intervention is based on the premise that conservation technology works - it is just a matter of getting farmers to adopt. However, the traditional mode of conservation intervention has not been very successful. The present section therefore assesses traditional conservation intervention, first in terms of approach, second in terms of technology.

Table 4.2 A dichotomy of views

	Conservationist	Farmer
Emphasis	Conservation	Productivity
Planning horizon	Long term (cumulative degradation, investment)	Short term (making ends meet)
Focus	Regional (externalities)	Farm (no externalities)

4.2.1 Traditional modes of intervention

The traditional approach to conservation intervention generally set out to persuade, induce and/or coerce farmers into adopting soil conservation.[4] Persuasion alone on grounds of stewardship, environmental concern, social good and the like was never likely to be very

[4] Others have labelled these respectively: normative re-educative (norms); empirical-rational (self-interest); and power-coercive (sanctions) (Bultena and Hoiberg, 1986; Lovejoy and Napier, 1988).

effective in the face of private costs (Nowak, 1988; Sanders, 1988). That leaves the two acknowledged approaches to correct market failures: economic incentives and direct regulation (Turner *et al.*, 1993).

Economic incentives and direct regulation

The economic incentive approach potentially includes various market-based options. With respect to soil conservation, economic incentives have traditionally focused on subsidies. Subsidies take different forms, including direct handouts (*e.g.* cash, food, inputs, capital goods), subsidised inputs (*e.g.* credit) and different degrees of cost-sharing. The direct regulatory approach exemplifies command and control and is largely based on standards and the like. With respect to soil conservation it generally stipulates the do's and don'ts, attaching penalties to non-compliance.

The economic and regulatory approach therefore largely correspond with positive and negative incentives. Both try to rectify market failure by raising the attractiveness of conservation, or conversely, increasing the costs of inaction. As such they aim to internalise externalities - albeit imperfectly. Indeed, instead of a full internalisation, the used measures seem to focus on stimulating more socially-benign private behaviour. For instance, the polluter-pays principle would imply penalties rather than subsidies (Edwards, 1987). Yet agriculture has been relatively spared of this principle for various reasons, including political as well as logistical considerations.

The conservation history in the USA is a case in point. The USA experience is characterised by a long-standing political reluctance to subject farmers to regulatory measures (Buttel and Swanson, 1986; SRAPTF, 1993). Instead, various types of financial inducement have been used,[5] including (i) cost-sharing (farmers and government share the costs of conservation); (ii) conservation reserves (farmers receive compensation for the temporary retirement of highly erodible cropland); and (iii) cross-compliance (farmers receive agricultural support conditional upon implementing stipulated conservation measures) (Batie, 1986; Buttel and Swanson, 1986; Sanders *et al.*, 1995; Camboni and Napier, 1994; Burns, 1994).

Several issues complicate the use of incentives and sanctions. The non-point nature of soil erosion is not very helpful in those instances where spatial externalities are of concern. To link policies (incentives or sanctions) to the level of discharge would imply potentially prohibitive monitoring and enforcement costs; *i.e.* it is virtually impossible to efficiently internalise the externality. It is possible to link policies to related variables: *e.g.* production activities; input use; management practices. Yet by operating on related variables the relationship is often imperfect, whereas there are many things a farmer can do that will reduce external diseconomies. Feasible policies will necessarily be imperfect, inevitably

[5] Soil conservation programs in the USA typically have multiple political objectives (Griffin and Stoll, 1984; Batie, 1986; Blaikie and Brookfield, 1987). Such programs received a boost from the concern with rural poverty and a fear of major social upheaval during the Great Depression. In fact, many soil conservation programs were mainly used to improve farmers' income. However, such additional objectives are likely to reduce their actual conservation effectiveness (Batie, 1986).

involving inefficiencies and rough justice (Griffin and Stoll, 1984; Edwards, 1987; Phipps, 1987).

Assessing economic incentives

The use of incentives in developing countries is often seen as a fair and easy way to spur farmers into socially-desired conservation behaviour. However, the soil conservation literature highlights that their effective use is fraught with difficulties. Incentives should only be a means to an end (Swader, 1994); but there is a real danger of *disarticulation* between means and end, especially in those instances where the incentive is overly attractive. The use of food-for-work to construct conservation measures in Ethiopia is a case in point (Sanders, 1988; Hudson, 1991; Herweg, 1993). In other instances the relationship incentive-purpose is not always clear or is simply ignored (de Graaff, 1993). In this regard Ashby *et al.* (1996) mention a credit program for planting live barriers in Colombia - 50% of recipients never actually planted them.

Another - albeit related - danger is that incentives only achieve *temporary* adjustments. Incentives may persuade farmers to modify their behaviour only as long as they continue to receive such assistance (Lutz *et al.*, 1994b; Carter, 1996; Scoones *et al.*, 1996). Such fragile adoption is more likely whenever the short term attractiveness of conservation hinges on the incentives or where considerable maintenance is required (Swanson *et al.*, 1986; Herweg, 1993; Sombatpanit *et al.*, 1993). The cost of continuous incentives is likely to be prohibitive, whereas inducing farmers into temporary adoption is unlikely to be efficient.

Yet incentives often introduce such a *bias*. Incentives are typically given for construction of structures, and not for their maintenance (Lutz *et al.*, 1994b). Likewise, incentives tend to distort technological choice. For instance, the food-for-work schemes in Ethiopia were heavily biased toward labour-intensive conservation measures (Bojö and Cassells, 1995). Similarly, conservation cost-sharing in the USA provided for 50% of construction costs of structures, whereas management practices were excluded (Griffin and Stoll, 1984). Such construction incentives typically are one-time-only outlays and do not require annual monitoring - as maintenance and management practices would. They also achieve more visible results with corresponding implications for political prestige. Although construction incentives may appear efficient in the short run, they can actually hamper long run efficiency.

The traditional use of incentives indeed is likely to be *inefficient*. Incentives should only be used there where needed, *i.e.* when it is socially profitable to do so (Kerr and Sanghi, 1993). For this there is a need to determine who needs to be motivated, based on the divergence between social and private returns (Nowak *et al.*, 1985; Lutz *et al.*, 1994b). Incentives for conservation may not be necessary if farmers themselves can perceive an immediate economic gain from adoption (Barbier, 1990). Yet blanket approaches with conservation incentives are the rule rather than the exception.

Incentives may also be *perverse* and counterproductive (Sanders, 1988; Stocking, 1993; Lutz *et al.*, 1994b). They are frequently associated with a paternalistic government, which induces a receiver mentality that seems to paralyse own initiative and creativity (Herweg, 1993). In extreme cases it may even induce degradation so as to qualify (Lutz *et al.*, 1994b). Incentives also undermine the farmers' identification with the conservation measures and decreases their sense of involvement and responsibility (Hudson, 1991). The incentive itself may also displace - crowd out - local initiatives or budding markets (de Graaff, 1993).

Lastly, incentives are never free and thus require *revenue*, which is to be raised by taxes elsewhere (Edwards, 1987). Taxing the beneficiaries of soil conservation could conceivably be one option, but in developing countries possibilities for such income transfers are limited - whether over space or time (de Graaff, 1993). Such expenses are likely to be large, yet unlikely to be popular in view of the general restraint on the public purse (SRAPTF, 1993).

Assessing legal sanctions

The use of sanctions in developing countries presents its own difficulties. The *lack of enforcement* of existing measures is definitely a more fundamental problem than the lack of legislation *per se* (Blaikie, 1985). History has repeatedly shown that environmental laws are of little value if they are not enforced. Yet this is not uncommon in developing countries. Kenya's law to prohibit use in any way of land with slopes over 35% is a case in point: it is indeed widely violated (Thomas, 1988; Pagiola, 1994b). This also illustrates the need to strike a balance between realism and idealism (Hudson, 1988a:6). Enforced land use change should only be attempted as a last resort - if at all (Hurni, 1988).

Obviously related to the lack of enforcement is the *inability to enforce* (Blaikie, 1985; Laing and Ashby, 1993; Pagiola, 1994b). Mandatory conservation approaches entail high implementation costs, in the form of administration, monitoring and enforcement (Sanders *et al.*, 1995). Government agencies in developing countries generally lack sufficient means to enforce, or an adequate enforcement mechanism for that matter (Stahl, 1993; Swader, 1994; de Graaff, 1996). Regulatory agencies - if existent at all - are traditionally poorly staffed and informed (Turner *et al.*, 1993). The logistics of coercion are not to be taken lightly.

Sanctions, where they are necessary, are most effectively applied through local institutions where such remain (or can become) viable. Coercion by a remote authority lacking local knowledge is a poor second-best, though often unavoidable (Blaikie and Brookfield, 1987:249). With site-specificity rampant, uniform regulation and enforcement inevitably also involves *inefficiencies* and rough justice (Turner *et al.*, 1993:144; Swader, 1994).

Coercion is a most delicate aspect of intervention. Yet often it is handled so crudely that it was *counter-productive* (Blaikie and Brookfield, 1987). The forcing of soil conservation measures on unwilling farmers is laying the groundwork for major obstacles in the future (Stocking, 1993). Such imposition is likely to enhance, rather than reduce, farmers' resistance to conservation (Shaxson, 1993). Past coercive efforts in developing countries - by colonial or independent administrations - have invariably been deeply unpopular and created resentment, distrust and antagonism (Blaikie, 1985; Blaikie and Brookfield, 1987; Stocking, 1993).

Discussion

The use of incentives and sanctions appears to be fraught with difficulties in developing countries. In fact, experience shows a generally doubtful effect of employing high-subsidy approaches to soil conservation as this tends to undermine lasting conservation effectiveness (Shaxson, 1993; Stocking, 1993). Most of the past public interventions never questioned the underlying premise that conservation technology works. Indeed, there frequently has been a rising sense of exasperation among conservationists because farmers are slow or even unwilling to accept and implement widely known technical recommendations. This entails the danger to adopt increasingly authoritarian means (Shaxson, 1993). Yet, what exactly are the characteristics of this infallible technology? The subsequent subsection addresses this question.

4.2.2 Traditional conservation technology

Conservation interventions have traditionally emphasised barrier-type physical structures. Indeed, it is difficult to get away from the image of soil conservation being done by anything else than implanting physical works (Shaxson, 1993). Barrier-type conservation emphasises run-off control. This mainly revolves around cross-slope structures that literally raise barriers against run-off, controlling its movement and limiting its erosive capacity by retention, dispersion and/or drainage (Shaxson *et al.*, 1989). The cross-slope barriers divide the natural slope length of a hillside into shorter segments. They typically include bench terraces and conservation banks.[6] Bench terraces also reduce the slope steepness, either instantly upon construction or progressively over time. Barrier-type conservation traditionally emphasises the construction of physical structures. Increasingly it also includes vegetative structures ('live barriers'), such as contour hedgerows (agro-forestry, *e.g.* Kiepe and Rao, 1994) and grass strips (*e.g.* vetiver). Some crop management practices like contour cropping are also forms of (micro-)barrier-type conservation.

One of the biggest drawbacks of traditional conservation technology is the characteristically poor private returns (Wiggins, 1981; Blaikie and Brookfield, 1987). It is increasingly recognised that physical structures are expensive to build and maintain whereas they add little to the productivity of the land in the short run (Roose, 1988; Shaxson *et al.*, 1989; de Graaff, 1993; Douglas, 1993). In fact, they are generally characterised by *lower* land productivity (compared to without-case) in the first years due to:

- *Loss of useful soil surface to locate the structure:* The effective productive area may be reduced by 7-20% - depending on the type of structure and slope (G/Michael, 1992; Herweg, 1993; Roose, 1993; Pagiola, 1994b). Such loss can be partially compensated by growing useful species on the raisers/bunds (*e.g.* fodder grasses; fruit trees - Pagiola, 1994b). However this may present new trade-offs in view of possible competition with the main crop and pest ecology (*e.g.* rodent infestation - Thomas, 1988);
- *Soil disturbance:* Construction generally involves disturbance of the soil and may bring unproductive soil to surface (Lutz et al., 1994b; de Graaff, 1996). This loss is generally only temporary and to a large extend can be off-set by careful 'cutting and filling' of soil;
- *Interference with land management:* Structures interfere with management operations, especially when these are (semi-)mechanised (G/Michael, 1992; Lutz *et al.*, 1994b).

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[6] Each comes in different shapes and sizes. See Shaxson *et al.* (1989:47-48) for an overview.

Taking into account management considerations generally implies a trade-off in terms of conservation effectiveness (*e.g.* adapted spacing of bench terrace raisers).

Terraces typify the generally poor private returns of physical structures (Jolly *et al.*, 1985; English and Krog, 1987; Barbier, 1990).[7] They are costly both in terms of construction and foregone productive area - whereas both cost components are a positive function of slope. With increasing slope the actual construction costs rises (Wiggins, 1981; Stocking and Abel, 1992) as (i) more structures are needed per unit area (steeper slopes imply an increasing density of structures); and (ii) construction *per se* (per unit barrier length) is generally more costly. The productive area lost to structures rises as result of their increasing density.

The returns to terracing could potentially be improved by opting for progressive formation instead of actually constructing the terrace in one operation. Progressive formation revolves around only raising barriers as sediment traps - in the form of permeable micro-barriers or banks of earth or stone. It subsequently relies on gravity and time to do most of the earth-moving to eventually form the terraces. This process may be enhanced by normal tillage practices in-between the barriers, potentially leading to nearly level terraces in seven years (Hudson, 1988b). The original investment needed is substantially lower and easier to adopt (Shaxson *et al.*, 1989). Yet at the same time, the process is obviously slower, thereby further postponing the soil and water conservation benefits.

Consequently, even the returns to progressive terracing may remain relatively unattractive from the private viewpoint. Pagiola (1994b) presents an illustrative case study of progressively build ('fanya juu') terraces in Kenya. He incorporates the area loss to locate the structure[8] and assumes the without-case to shutdown after 19 years as production without conservation would become unprofitable (*i.e.* without conservation the land would then be abandoned). Notwithstanding, only by the seventh year does the with-case start to outperform the without-case, whereas the break-even point does not occur until half a century later. However, in another instance in Kenya, such terracing in combination with other components was sufficiently attractive (Tiffen *et al.*, 1994).

The returns to physical conservation structures are also adversely affected by the recurrent maintenance costs, which can be substantial (Sheng and Meiman, 1988; Napier *et al.*, 1991). For instance, in the above example of progressively build terraces annual maintenance costs amount to 12% of the initial construction outlays (Pagiola, 1994b). Without maintenance structures can fall into disrepair and become ineffective, and on occasions even accelerate soil erosion (Sanders, 1988; Shaxson *et al.*, 1989; Pretty and Shah, 1997).

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[7] Paradoxically, terraces have historically been a widely accepted and implemented measure. However, in a number of instances this can be explained by the benefits and costs of terracing at the time. This issue is taken up in Subsection 4.3.1 when deriving lessons from autonomous soil conservation. It does reiterate that the economics of soil conservation are location specific, *i.e.* dependent on the state of the biophysical and socio-economic environment.

[8] *I.e.* a yield trend that corresponds with scenario A in Annex B.

Biases in traditional conservation technology

The traditional emphasis on physical structures is one sort of technological bias in conservation intervention. In fact, it is a reflection of a number of underlying and interacting biases that have constrained the technology development process so far.

Conservation bias - Conservation technology development has traditionally fixated itself on conservation. However, such a conservation-first approach tends to favour technical effectiveness over economic efficiency (Lutz *et al.*, 1994b). This risks ignoring a number of trade-offs. For instance, less effective conservation measures may be substantially cheaper and easier to implement for the farmer (*ibid.*; Kerr and Sanghi, 1993). To the farmer these socio-economic dimensions are crucial.[9]

Developed country bias - Various researchers have highlighted the need for appropriate technology in developing countries. Whether Schumacher's (1973) 'Small is beautiful' or Todaro's (1981) false-paradigm model is taken, the basic premise is that technologies designed in developed countries to suit their conditions should not be unthinkingly imported into developing countries where conditions are different (Gill, 1993:9). Yet this message fails to sink through in the field of soil conservation. Most conventional theory on soil conservation started in the USA under circumstances very different from the rest of the world (Hudson, 1988b; Reijntjes *et al.*, 1992:74). Nonetheless, the transfer of techniques of soil erosion measurement, conservation technologies and policies from the USA to developing countries continues unabated (Blaikie and Brookfield, 1987). However, these may not be directly transferable without considerable modification (Lovejoy and Napier, 1988; Laflen and Onstad, 1994; Napier *et al.*, 1994b; Hudson, 1995:204).

Favourable land bias - There has been a tendency to neglect the steep lands: research stations are typically located in relatively flat areas and most soil conservation research has been done on flat or rolling land with a maximum slope of 20% (Lal, 1988). Steep lands are generally considered too marginal for farming: 'There is no way of avoiding or defeating gravity, and on steep slopes with high rainfall, cultivation will inevitably cause more erosion than there would be in the undisturbed state' (Hudson, 1988a:6). Yet in developing countries this is largely an irrelevant ideal. Land is going to be used for farming regardless of its slope or quality (Thomas *et al.*, 1983). Therefore, the question is how can this be achieved at the least social cost. Yet the past neglect of the steep lands does not help in that

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[9] Kerr and Sanghi (1993) present an illustrative example. They compare contour-based with boundary-based bunds for soil and water conservation in India. The technicians recommend the contour-based systems, being technically superior. Farmers however preferred to opt for their indigenous bunds along the field borders. Such boundary bunds served to demarcate property and were operationally more convenient for ploughing. In addition, this reduced the required co-operation to only those adjacent farmers sharing a common boundary. However, these considerations are by no means universal: *e.g.* in West Africa contour bunds are much more readily accepted (Reij, 1994).

matter, as little research information is available (Lal, 1988). In fact, steep land is frequently not even considered in soil conservation recommendations.

Paradigm bias - Up to recently, there has been a genuine lack of innovation in the conservation technology development process. Instead of more radical fundamental changes, the same old technological approach was used. Griffin and Stoll (1984) have labelled this disjointed incrementalism, Stocking (1987) simply sees it as an inertia that prevents perceptible analysis and innovative answers. Although it would have been useful to clean the slate now and then, this is easier said than done (Lockeretz, 1990). Conservationists - like all humans for that matter - are largely prisoners of their own historical development.

Discussion

Traditional conservation technology has contributed to the lack-lustre success of conservation intervention. The issue is not that the technology is fundamentally wrong, but rather that it is unsuitable for particular conditions (Hudson, 1991); whereas adapting conditions to suit conservation technology - through economic incentives or legal sanctions - has proven to be difficult. Therefore, a new approach to conservation intervention is needed.

4.3 New directions for public intervention in soil conservation

The lack-lustre success of the traditional conservation-first approach is increasingly recognised and explained. The formulation of conservation policies, the development of conservation technologies, and the implementation of policies is generally firmly in the hands of the public sector. Yet farmers have the final say in the adoption decision. And for a variety of reasons, have typically elected not to adopt the prescribed soil conservation measures (Lovejoy and Napier, 1986; Napier, 1991). For soil conservation intervention to ever become effective, the differences between private and social viewpoints must be understood and reconciled (Shaxson *et al.*, 1989; Kerr and Sanghi, 1993). But how can one harmonise the views of conservationists with those of farmers? The present section addresses the implications for the mode of conservation intervention and conservation technology development.

4.3.1 New directions for implementation

The success of soil conservation intervention is likely to be enhanced by incorporating a number of relatively straightforward principles - which will be introduced hereafter. A useful point of departure is acknowledging the diverging viewpoints of conservationists and farmers. Indeed, even if both parties are aware of soil erosion and the need to control it, their perception of the problems and approaches to solving them will diverge.

Incorporating socio-economic considerations

Traditionally soil conservation is perceived as a technical field. Attention thereby focused on the engineering/technology/resource aspects of conservation, rather than on the people aspects (SRAPTF, 1993; Gould, 1994; Swader, 1994). But the reasons why technically effective conservation measures are proving to be so problematic in the real world lie squarely within the realm of social science. Yet only a decade ago there still had been remarkably little in the way of either empirical or methodological work on the socio-economics of soil conservation (Blaikie and Brookfield, 1987).

That farmers should fail to adopt technically effective soil conservation practices, has long been a source of puzzlement and frustration for conservationists (Pagiola, 1994b). There is now a growing realisation that conservation is as much about socio-economic processes as physical ones, and that the major constraints are not technical but socio-economic (Blaikie, 1985; Lovejoy and Napier, 1988; Sanders, 1988). Therefore, a critical ingredient for addressing soil conservation is to understand why farmers behave as they do and how they will respond (SRAPTF, 1993). This obviously calls for multidisciplinary and/or interdisciplinary approaches.

Some researchers see soil erosion as a basic symptom of a deeply embedded, more structural socio-economic crisis (Meyer, 1988; Sanders, 1990; Roose, 1993). In this view, a technocratic approach to soil conservation may be of little use as long as it does not address the real socio-economic roots of the problem (Blaikie, 1985; Sheng and Meiman, 1988; Fones-Sundell, 1992). Such roots tend to be linked to poverty, inequity and institutional issues rather than soil erosion *per se*. Farmers do not degrade land resources as an objective; but are forced to do so out of necessity. Unequitable land distribution is the major underlying force that has displaced people to the hills, where the slopes are steep, soils are thin and the erosion hazard is great (Stocking, 1988). Yet identifying and resolving the real problems why farmers are forced to misuse land are bound to be politically sensitive.

'No amount of research and appropriate extension will persuade farmers to conserve their resources if powerful economic incentives are driving them in the other direction' (Conway and Barbier, 1990:113). Conservation intervention will remain ineffective unless it proves to be genuinely helpful to the farmers (Cook, 1988:22). Yet throughout developing countries there is still insufficient understanding of - and thereby the tendency to ignore - the interplay of socio-economic factors that can make or break soil conservation (Barbier and Bishop, 1995).

Farmers typically pursue a set of multiple objectives within the constraints imposed by available resources, technology and institutions. In this regard, conservation technology is only part of the picture. To harmonise the conservationist and farmer perspective there is a need to go beyond purely technological considerations - and include the farm households' preferences, resources and institutional setting. The discussion of the adoption school (see 3.3) already reviewed the respective implications for the adoption decision and these will not be repeated here. However, such adoption studies highlight how conservation fits - or does not fit - in particular socio-economic settings. It thereby provides useful policy lessons for conservation intervention.

The traditional approach takes technology as given and tries to adapt one or more of the other variables. Such intervention could address specific institutional imperfections - *e.g.* by securing property rights; by providing information and/or credit services; by stimulating institutional change. However, in isolation each is unlikely to be sufficient. For intervention to be effective there is a need to ensure an overall enabling environment that favours conservation behaviour. This will tend to run far wider than what is traditionally perceived as the field of soil conservation. For instance, there may be a need to alleviate priority constraints first before farmers are likely to consider conservation. Occasionally, providing an enabling environment may be sufficient to address soil conservation. In this regard, a generally reasonable government policy environment contributed to make land improvement worthwhile and thereby stimulated autonomous conservation investment in Kenya's Machakos district (Tiffen *et al.,* 1994).

Lessons from autonomous soil conservation

Upon harmonising the conservationist and farmer perspective it is useful to assess what can be learned from farmers in terms of soil conservation. Farmers have managed their soil resource for millennia and generally speaking are still in business. In some instances, farmers have themselves constructed relatively obvious and expensive terraces - whether the terraced rice fields in South-East Asia or the ancient terraces in the Mediterranean and the Himalayas. In others, conservation may not directly revolve around such visible structures. In fact, many indigenous conservation measures (Kerr and Sanghi, 1993; Reij *et al.,* 1996) tend to be ignored by traditional conservationists.

But why do some farmers autonomously 'conserve' whereas others remain ambivalent even after substantial government efforts? Boserup (1993) has already posited the role of population density in agricultural intensification. Hayami and Ruttan (1985) see agricultural adjustment and intensification in response to changing factor proportions. Conservation behaviour is likely to reflect similar considerations. Rising population density is indeed seen as an important precondition for investment in soil conservation (Scoones *et al.*, 1996): higher density induces land scarcity - *i.e.* land rather than labour becomes the key constraint. For instance in Kenya's Machakos district, population pressure helped induce terracing and investment in land improvement (Tiffen *et al.*, 1994).

Land scarcity is not the only conservation-inducing variable. The main reason farmers are willing to invest in soil conservation in semi-arid regions is the water conservation this implies. This potential entails the existence of short term benefits, allowing farmers to rapidly recap their investment. Experience in the Sahel indeed highlights that the most rapidly adopted conservation techniques are those that emphasise water-harvesting (Scoones *et al.*, 1996). The terraces used for irrigated rice in South-East Asia primarily also reflect water management considerations - and not soil conservation *per se*. The major lesson from farmers' autonomous conservation efforts is that these typically alleviate binding constraints in terms of land quantity and/or quality.

The fact that conservation can be induced by other considerations than soil conservation *per se* gives rise to two issues. First, it raises an interesting paradox. Terraces are occasionally concentrated in those areas where they are least needed from a soil conservation point of view. For instance, three-quarters of terraced land in the USA were in the semiarid plains (AFT, 1984 in Crosson, 1985). Water and not soil conservation was probably the main motivating factor. In addition, the costs of establishment was less substantial (being a positive function of slope).

Second, farmers may disadopt particular conservation measures whenever the original constraint that induced their use cedes to be binding - or can alternatively be alleviated. For instance, farmers have traditionally used different ingenious fertility-management strategies to prevent wider soil degradation (*e.g.* crop rotation/fallowing systems). However, land pressure and the advent and declining prices of chemical fertiliser made many farmers abandon such low external input measures. Similarly, external changes may undermine the incentive to maintain soil conservation structures - *e.g.* depopulation of the country side and the subsequent neglect of ancient terraces in the Mediterranean region. On the other hand, conservation may by then already have become institutionalised (*i.e.* standard practice and part of the local folklore of agriculture - Shaxson, 1993).[10]

Need to emphasise soil productivity

There has been a gradual shift in the theory and practice of soil conservation during the 1980s and now new thinking is in vogue. The new philosophy emphasises soil productivity, instead of the soil resource *per se*. The primary purpose is not to prevent soil erosion at any cost, rather to maintain and improve the soil's productive capacity (Shaxson *et al.*, 1989; Stahl, 1993; Sanders *et al.*, 1995). It thereby is a more integrated approach that advocates good land husbandry (Hudson, 1988a, 1992; Shaxson *et al.*, 1989, 1997).[11]

The new approach is increasingly gaining ground on the traditional conservation-first approach. Shifting the viewpoint from merely conserving soil to that of maintaining and enhancing productivity widens the horizon. One can start with improving farming and only include physical structures as the last resort (Hudson, 1988a, 1992). Whereas the better the farming, the less traditional conservation measures are required (Shaxson, 1993). Practices not classically labelled as soil conservation are also re-evaluated for their conservation potential.

'The surprising thing is that it has taken us so long to put all the parts of the jigsaw together' (Hudson, 1995:205). Particularly as the components for the new approach have been around for a very long time. Yet only recently is it being acknowledged that conserving water and fertility, not soil *per se*, is the crucial link to short term productivity and sustainability.[12] Conserving and enhancing soil productivity is bound to be more in line with farmers' interests than traditional soil conservation. And being in line with people's preferences is frequently one of the ingredients for successful intervention (Chambers, 1983; Conway and Barbier, 1990:137; Douglas, 1993).[13]

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[10] For instance, Sanders (1988) describes a case in Lesotho where - although contour conservation works fell in disrepair - the remnants of these works forced farmers to farm along the contour. In time this became the established practice.

[11] Land husbandry has been variously defined and interpreted, but the dictionary sense implies the economic management of land.

[12] In this regard, Sanders *et al.* (1995) suggest that soil conservation technologies have generally been misnamed as such, emphasising dull conservation instead of lustrous productive opportunities. Hudson (1995:204) even suggests that 'if the present trend continues 'soil conservation' may become a pejorative term'.

[13] Conway and Barbier (1990:137) even single out soil conservation intervention as the prime example of the contrary: they have rarely satisfied farmers' priorities and hence have foundered.

Need for flexibility and local involvement

Soil conservation has traditionally been tackled in developing countries in a top-down fashion with little local involvement. It is now increasingly acknowledged that little to no involvement of farmers is a recipe for conservation failure. When farmers are not convinced, do not feel responsible, and/or do not see any advantage to soil conservation, there is little chance that they will subsequently maintain the conservation measures (Shaxson *et al.*, 1989; Kerr and Sanghi, 1993; Bojö and Cassells, 1995; de Graaff, 1996; Pretty and Shah, 1997). In fact, some structures may not be compatible with the farmers' preferences, and may therefore be purposively sabotaged if not demolished (Herweg, 1993).

Conservation policies also tend to apply universal approaches (de Graaff, 1993). However, these fail to account for locational differences resulting in low effectiveness and high costs (Stonehouse and Protz, 1993). Marginal areas such as steep lands tend to have the highest erosion potential: yet next to being typically fragile, such marginal lands also tend to be extremely heterogeneous and inaccessible (Harrington, 1993). It is impossible to develop a ready-made technological solution that will suit the extensively subdivided and tremendously diverse farms in developing countries. Instead, intervention needs to be flexible and adaptable - *e.g.* by providing the necessary technological options that can be adapted to the local context. This is obviously best done with the necessary farmer participation. This also requires a change of mindset for all involved. For instance, many engineers still tend to be outraged by any disruption of design (Scoones *et al.*, 1996; Pretty and Shah, 1997).[14]

Farmers are increasingly considered part of the solution rather than the problem (Shaxson *et al.*, 1989; Pretty and Shah, 1997). Sustainable intervention in soil conservation requires the involvement of all stakeholders in a continuing process of learning and action. Participation is typically interactive and empowering, both a necessity and practical. Participation also creates ownership of technology, an essential feature for a lasting change process.

Participatory approaches also fit in - *i.e.* are politically appropriate and practically necessary - with wider trends of democratisation, decentralisation and the retreat of the state (Scoones *et al.*, 1996). In some instances, conservation responsibilities have been passed on to the local or village level (Roose, 1993; de Graaff, 1996). In others, a localised watershed approach is being tried on a pilot scale (PSSM, 1994b; Ravnborg and Ashby, 1996) - although the enabling implementation costs have proven to be substantial. Notwithstanding, investing in local institutions with legal authority can be a viable and cheap alternative (Feder and Feeny, 1993). There is a need to realise the distance between rhetoric and reality when it comes to participation. Many different interpretations of 'participation' exist (Pretty, 1995), and many types of so-called participation will threaten rather than support institutional sustainability. Furthermore, participatory approaches are not uncomplicated (Chambers, 1983; Chambers *et al.*, 1989; Scoones *et al.*, 1996; Pretty and Shah, 1997).

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[14] For a typical illustration of engineers criticising farmers for tinkering with the original design see Bannister and Nair (1990).

Discussion

The key to successful conservation intervention lies in harmonising the views of conservationists with those of farmers. Therefore, understanding and addressing the farmers' preferences and constraints is crucial. A multidisciplinary, participatory and flexible approach with the necessary feedback loops is helpful in this regard. Further, the emphasis should be on soil productivity, instead of soil conservation *per se*, and on ensuring an enabling environment that favours conservation behaviour. A promising complementary step would be to incorporate *ex ante* farm household and institutional considerations in conservation technology development.

4.3.2 New directions for technology development

The conflicting private and social viewpoints with respect to soil conservation make it unlikely that conservation technology developed from a purely social conservationist perspective is entirely in line with the private preferences and constraints. Therefore, still needed are conservation technologies that match the farm household and its institutional setting rather than just the natural environment (Stocking and Abel, 1992). The technological challenge that remains today is still substantial and addresses the duality of production and conservation (Shaxson, 1988:16; Napier *et al.*, 1994b).[15] There is a need to develop dual-purpose technological options that are acceptable to both conservationists and farmers - *i.e.* that present acceptable trade-offs, that are both efficient and effective.

Economic considerations for conservation technology development

Traditional conservation measures are characterised by their typically low private returns: the combined result of a high initial investment, distant benefits and typically high discount rates. An attractive private return is increasingly recognised as necessary to make conservation compatible with the farm households' utility maximisation (Blaikie and Brookfield, 1987:73; Castro F. *et al.*, 1993; Kerr and Sanghi, 1993; Stahl, 1993). The most obvious ways to ensure this are to: (i) increase conservation benefits and bring them forward in time; (ii) lower conservation costs and push them backward in time; and/or (iii) lower private discount rates. The first two options have direct implications for conservation technology development, whereas the latter is more structural and should (temporarily at least) be taken as an exogenous factor. Whenever farmers exhibit high rates of discount, research should focus on short term returns (Walker and Young, 1986). There are a number of considerations for conservation technology development that are likely to enhance the compatibility of conservation with utility maximisation. These are reviewed hereafter, first in terms of the output side of conservation technology, than in terms of input requirements.

Conservation is more likely to be compatible with the households' utility maximisation whenever the conservation technology's outputs are:

[15] Technology that adequately addresses the productivity-conservation duality is variously labelled: *e.g.* productivity-enhancing, resource-conserving technology (Erenstein, 1996); 'win-win' technology (*ibid.*); overlap technology (Reardon and Vosti, 1992).

1. *Short term:*[16] In developing countries, farmers' planning horizons are short. Short term corresponds with the next growing season, or at most the next twelve months. Benefits should be realised within this time span. Soil conservation *per se* has seldom (if ever) been shown satisfactorily to achieve this (Shaxson, 1993:119).[17] However, water conservation holds more promise for such an immediate pay-off;
2. *Tangible and relevant*: A less eroded soil as such is of little use to farmers; nor are they likely to be moved by the interests of downstream benefactors (Ravnborg *et al.*, 1996). However, increased yields, higher incomes, and reduced input needs are more likely to contribute to the households' utility maximisation (Harper and El-Swaify, 1988; Sanders, 1988, 1990). Promising options enable farmers to meet a pressing need or provide an opportunity to improve production/income - *e.g.* by enhancing the return on a scarce production factor (Laing and Ashby, 1993);
3. *Worth the candle*: [18] Farmers are human and subject to their own historical bias. They will adhere to their established pattern unless the foregone benefits are sufficiently large for them to consider making the necessary changes. Farmers tend to find changes acceptable if they present a benefit:cost ratio of at least 1.5-2.0 (*i.e.* a marginal rate of return of 50-100% - CIMMYT, 1988:34). Similar rates of return may well be needed for them to positively consider conservation technologies. Such requirements seem quite demanding in their own right - but they seem to be a sheer impossibility if the technology would require some form of foregone benefits. Indeed, farmers frequently find foregone benefits unacceptable - unless they are more than off-set[19] (Wenner, 1988 in Fones-Sundell, 1992; Hudson, 1991, 1993);
4. *Competitive:* Potential returns to conservation may well not be enough. Notably, if they are dwarfed by alternative investment opportunities.[20] In this regard, Kerr and Sanghi (1993) mention that farmers who own and operate both irrigated and rainfed land appear to invest little in their rainfed plots. Soil conservation efforts on the dryland may not match productive investment opportunities in irrigated land. Therefore, such farmers may consider land of low productivity not worth conserving - even if it were potentially attractive to do so;
5. *Institutionally feasible*: Benefits should largely accrue to the investor. Whenever institutional arrangements allow others to capture a substantial share of the benefits, private interest will wane. The prime example is the short-lease tenant without any assurance that he can recap his conservation investment;

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[16] Hudson, 1988a; Moldenhauer and Hudson, 1988; Shaxson *et al.*, 1989; Hudson, 1991; Sanders, 1990; Douglas, 1993; Herweg, 1993; Kerr and Sanghi, 1993; Stocking, 1993; Southgate, 1994.

[17] With reference to Annex B: required is the D scenario. Typically soil conservation corresponds with the A or C scenario.

[18] Kirkby, 1973 in Blaikie and Brookfield, 1987; Wade and Heady, 1979 in McConnell, 1983; Bojö, 1987 in Stocking, 1993; Hudson, 1991 in Shaxson, 1993:119; Douglas, 1993:12.

[19] This seems to be one of the major drawbacks of physical conservation structures such as terracing. They impose a loss of land without adequate balancing benefits in the short term.

[20] Conservation is unlikely to be attractive if these alternative investments compete for the same resources, thus increasing their opportunity cost.

6. *Predictable*: Farmers in developing countries are risk averse. The more predictable the benefits, the lower the risks of the technology. Any increase in risk may not be acceptable. Instead, technology should preferably reduce risk (Hudson, 1991, 1993; Douglas, 1993:12; Stocking, 1993).

Similarly, conservation is more likely to be compatible with the households' utility maximisation whenever the conservation technology itself is:

1. *Cheap:*[21] Cheap technological options are characterised by low resource requirements and/or drawing on resources with relatively low opportunity costs. Conservation technology should add little extra burden to the critical factors of production - land, labour, and capital (Stocking, 1993). A low cash requirement is a typical prerequisite (Hudson, 1993). Opportunity costs are likely to be influenced by the timing and the nature of resource requirements (*e.g.* in relation to the gender division of labour);
2. *Simple:*[22] Changes imply learning costs. The simpler the change, the better. Farmers are likely to be overwhelmed by complex technologies or complete technological packages;
3. *Divisible:* At the inter-farm level, divisibility allows farmers to adopt individually - thereby reducing transaction costs. At the intra-farm level, it allows farmers to adopt incrementally - thereby reducing risk and spreading investment needs (Harper and El-Swaify, 1988; Kerr and Sanghi, 1993). In case the technology is scale neutral, both would conceivably reduce the adoption costs;
4. *Easy to maintain* (sustainable): Preference should be given to those measures that can be sustained without outside help and that require little maintenance (Moldenhauer and Hudson, 1988). The concept of regular maintenance tends not to be well developed among developing country farmers (Hudson, 1988b:127). The technology should preferably be sustainable with limited additional effort and resources (Douglas, 1993:12). These considerations would be less of an issue if the practice itself is so attractive that it quickly becomes institutionalised (Shaxson,1993);
5. *Compatible with the farm system*: A compatible measure fits in easily with other components of the farm system - *i.e.* it would require few adaptations to be effective. The new technology tends to compete for the same resources with other farm household activities. Ideally, the opportunity costs of the affected resources already reflect this (and thus the cost of the measure). In other instances the adaptations may impose additional costs not yet reflected;
6. *Institutionally feasible*: The measure should preferably fit within the local institutions as institutional change can provide a significant barrier. In this regard, locally used practices might well be more acceptable than alien ones as they already fit into the social fabric (Hudson, 1993; Kerr and Sanghi, 1993; Stocking, 1993). Yet clearly local

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[21] Blaikie and Brookfield, 1987; Lal, 1987a; Hudson, 1988; Napier, 1991; Castro *et al.*, 1993; Moldenhauer and Douglas, 1993:12; Stahl, 1993; Stocking, 1993; Lutz *et al.*, 1994b; Southgate, 1994.

[22] Lal, 1987a; Harper and El-Swaify, 1988; Moldenhauer and Hudson, 1988; Nowak, 1991; Castro F. *et al.*, 1993; Douglas, 1993:12; Lutz *et al.*, 1994b.

practices alone are not enough - otherwise there would have been no problem (Blaikie and Brookfield, 1987);

7. *Flexible*: A flexible measure does not impose a straightjacket. It thereby leaves scope for future developments. Flexibility in terms of potential reversibility or adaptability is an attractive feature in view of uncertainty.

Discussion

Increasing benefits and lowering costs is bound to increase the return to conservation and thereby it's utility. Yet there is no such thing as a free lunch and such a win-win scenario simply looks too good to be true. Some essential questions remain unanswered. What (if any) are the trade-offs in terms of conservation effectiveness? *I.e.* is it possible to assure a high return while keeping options technically (conservation) effective? What (if any) are the trade-offs between the different components of the 'wish list'? It seems highly unlikely that all of the items of the wish list can be achieved simultaneously without some trade-offs between them and/or the conservation effectiveness.

Some authors are pessimistic about such trade-offs. Napier (1991) stresses the need for inexpensive and simple conservation measures, yet concludes that often these will not adequately control erosion. According to Herweg (1993:408) the solution can never be simple, since the problem is not simple either: 'Most of the time it can only be stated what must be avoided, not what really can be done'.

Other authors are simply realistic. For instance, Lutz *et al.* (1994b:291) opine that research is not likely to produce a breakthrough technology that will solve all conservation problems. Improvements are likely to be more piece-meal. Kerr and Sanghi (1993) see only limited opportunities to combine conservation with quick increases in productivity - but these should be exploited to the extent possible. Stocking (1993) has highlighted the scarcity of appropriate (farmer-friendly) conservation options, although conditions make conservation imperative. He sees appropriate conservation technology as the greatest challenge facing the development of sustainable agricultural systems in developing countries. 'One of the main challenges for future agricultural research will be to develop ways to increase yields while keeping environmental costs within socially acceptable limits' (Crosson, 1997:31).

A given practice can be classified in different ways depending on how, where and by whom; and few technologies are inherently 'good' or 'bad' (Reardon and Vosti, 1997). Yet those that adequately span both fields are bound to be limited as well. What is more, there is bound to be a lack of consensus of what technology adequately satisfies both needs (Napier *et al.*, 1991). And there may even be a danger that the reversal of conservation-first to productivity-first tilts the balance too far towards production and the short term.

Trade-offs are part of the real world and there is no reason to expect the conservation - productivity duality to be exempted. Yet trade-offs, though a challenge, do not pose an insurmountable barrier. With some give and take it should be feasible to find an acceptable middle-road between the traditional conservation-first approach and the absolute neglect of soil conservation. The critical word though is 'acceptable' - not only acceptable to the conservationist, but above all, acceptable to the farmer.

4.4 Promising technological options

Does economically attractive, conservation effective technology exist at all? There certainly seem to be some promising best-bet options - particularly in the field of cover-type conservation, which emphasises crop management practices. Such measures combine the greatest likelihood of productive opportunities with a minimum of investment and maintenance (Stocking, 1993).

Cover-type conservation

Cover-type conservation emphasises protection against rainfall (and wind). This mainly revolves around producing and maintaining an effective protective layer close to the soil surface. The layer also tends to raise an effective micro-barrier against run-off. An adequate ground cover - in terms of timing and density - is very conservation effective. It largely prevents both detachment and transport of the soil, ensuring that both soil and water remain where they are needed (Shaxson, 1993). Ground cover is increasingly recognised as a crucial soil conservation component.[23]

Compared to a bare soil, a uniform ground cover close to the surface will lead to less detachment, more infiltration and less run-off and to a large degree prevent erosion (Hudson, 1988b:124; Roose, 1988; Shaxson *et al.*, 1989). In this perspective, soil erosion (by water) appears to be a drainage problem and rainwater management becomes the primary aim (Herweg, 1993). The reduction of runoff should thereby precede attempts to control its flow (Shaxson *et al.*, 1989:23). In this regard, an effective ground cover is likely to be more effective than the traditional barrier-type measures (Lal, 1988:49; Shaxson *et al.*, 1989; Sombatpanit *et al.*, 1993). Indeed, such structures are more of an end-of-pipe intervention. By then, the soil has already been exposed to splash-erosion and run-off has been generated by a lack of infiltration. In contrast, cover-type measures address the conditions that are conducive to generate such runoff and erosion in the first place (Shaxson, 1993) - *i.e.* prevent soil detachment and increase infiltration over the entirety of the cropping area.[24]

It has long been known that ground cover greatly reduces and may even eliminate soil erosion, with research going back to the late 1930s (*e.g.* Duley, 1939 in Moldenhauer *et al.*, 1994; Allmaras *et al.*, 1991). The conservationist rationale for leaving steep lands untouched under their natural vegetative cover is a direct recognition of the need to maintain cover. The problem has traditionally been how to grow crops in the presence of such a protective layer (Langdale *et al.*, 1994; Moldenhauer *et al.*, 1994:37), but the original difficulties have increasingly been overcome.

In fact, ground cover is increasingly recognised in terms of its productive potential. Less run-off due to cover not only implies less erosion, it also implies more plant available water and nutrients. In many instances water is a potentially limiting factor at some point in the

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[23] Shaxson *et al.*, 1989; Conway and Barbier, 1990:88; Flach, 1990; Sombatpanit *et al.*, 1993; Stocking, 1994; Pimentel *et al.*, 1995:1121.

[24] *I.e.*, cover-type conservation is an area-wide measure, whereas barrier-type conservation a linear measure, with on-going degradation in-between the barriers (Stroosnijder, pers. comm.).

crop production cycle. Whenever this is the case, such water conservation potentially provides a productive boost. Further, there tends to be a self-reinforcing feedback as more biomass production implies yet more cover.[25] In this regard, production and conservation are not antagonistic but mutually reinforcing (Shaxson *et al.*, 1989; Shaxson, 1993).[26] Farmers and conservationists therefore 'have several interests in common, although each group looks at these interests from different perspectives' (Shaxson *et al.*, 1989:33).

The problem is that most annual crops provide insufficient cover during the early growth stages, and none at all prior to emergence. Cultivated lands are typically bare at the on-set of the rains. Soils are therefore fully exposed to the erosive elements. Mulch - *i.e.* material that provides ground cover - could conceivably provide the needed cover to bridge this critical period. But where does the mulch come from?

Mulch sources

The mulch can be provided by various sources, be either dead or alive; produced *ex* or *in situ*; be a by-product or produced purposively. Figure 4.1 provides a schematic overview of the different options of soil cover for agricultural production. The scheme is based on the spatial and temporal separation between the production of the cover and agricultural produce:

A. Ex situ mulch: Mulch can be produced *ex situ* and imported to the site (cut-and-carry), implying a (horizontal) spatial separation between the production and the use of mulch. In view of the expenses involved this is generally not an option for agriculture with extended areas and low-value produce. Applications are generally limited to small-scale and/or high-value enterprises (*e.g.* horticultural crops). The mulch can be produced purposively by industrial or biological means (see Lal, 1989). Alternatively it may be generated as a by-product from *ex situ* production processes and as such provide a means of disposal (*e.g.* wood-chip mulch in municipal gardens in developed countries).

B. In situ produced mulch: Mulch can be produced *in situ* prior to crop establishment. This provides a temporal separation between cover and crop production. Examples include the slash/mulch systems in Central and South America, which compare with slash-and-burn systems (see Annex A) with the exception that the slash is not burned but kept as mulch; and that the fallow period is more variable (Thurston *et al.*, 1994). Thurston (1994) reviews some of the literature describing slash/mulch systems with multi-year fallows. In more sedentary systems the opportunity cost of land tends to make the mulch-producing period substantially shorter, and generally limited to the off-season.[27] Such systems tend to rely on fast growing legumes (green manures/cover crops) for lush growth and fertility

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[25] Whether the feedback is indeed self-reinforcing depends on the resulting net water balance.

[26] However, under very marginal conditions such reinforcement can also backfire. A particularly poor crop stand implies little cover, which implies more run-off and erosion, which implies less biomass and cover, etc. (Hudson 1971 in Eaton, 1996; Herweg, 1993).

[27] Farmers in northern Honduras provide an interesting exception. They have successfully grown cover crops during the main season and grown maize during the second minor season. In this case farmers took advantage of seasonal differentials in produce prices and the opportunity cost of labour (Buckles *et al.*, 1994, 1998; Sain *et al.*, 1994).

enhancement. Next to slashing, such cover crops could also be liquidated by other means such as herbicides.

C. *In situ live mulch*: Mulch can also be alive as in the case of a low growing intercrop. This generally provides an altitudinal separation between cover and main crop. Such practices are relatively common with wide-spaced high-rising perennial crops in the humid tropics (*e.g.* with grass or a green manure as cover crop). Intercropping of cereals with beans and other intercrops conceivably also could fall in this category. However, such productive intercrops are generally established at the same time as, or after, the cereal crop. As such they provide little cover during the critical on-set of the growing season. Being alive, there are a number of additional considerations such as competition for water and nutrients (and possibly light and space when the altitudinal separation is not complete).

D. *In situ residue mulch*: Mulch can be generated as a residue from *in situ* production systems, typically including crop and weed residues from the previous cycle. In this case the cover and produce production overlap completely - albeit that the cover produced in one season is only used as such in the subsequent growing seasons. This typically includes crop residue mulching - or conservation tillage - systems.

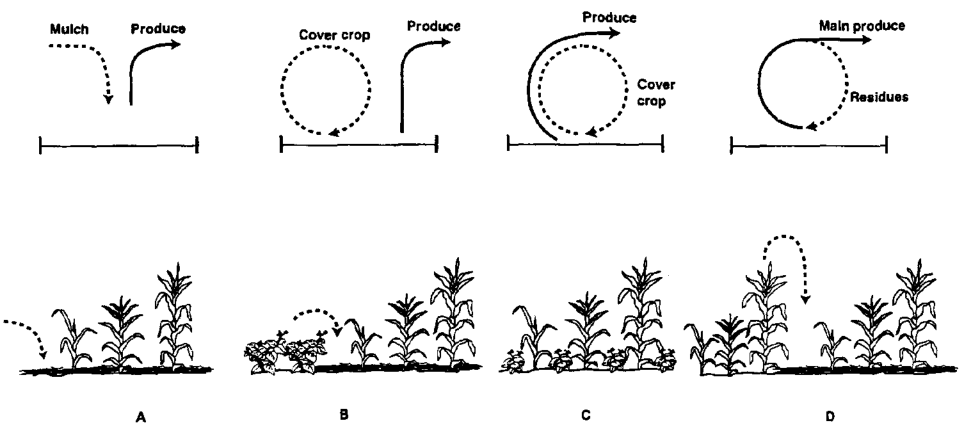

Figure 4.1 Options for providing ground cover in agricultural production (A. *Ex situ* mulch; B. *In situ* produced mulch; C. *In situ* live mulch; D. *In situ* residual mulch)

The above is only one categorisation emphasising the temporal and spatial dimension. Potentially some additional hybrid and/or overlap systems could be distinguished. For instance, a relay system where the cover crop is established into an existing agricultural crop (combining option B and C).[28] In much the same way, several relay-cropping systems

[28] Buckles and Barreto (1996) provide a comparative overview of the different sole (option B), relay (B-C) and intercropping (C) options for green manures/cover crops.

of different productive crops exist (combining C and D; *e.g.* maize-beans in Chiapas, Mexico; maize-sorghum in El Salvador; maize-cassava in Costa Rica). Some agro-forestry systems use the tree prunings as mulch. In the case of contour hedgerows these systems use a spatial separation within the same field (conceivably combining A and C). In view of the multitude of systems it is not entirely surprising that mulching means different things to different people (Thurston, 1992).

Due to the emphasis on soil cover, the different options are relatively similar in terms of soil conservation. Bigger differences loom in terms of productivity implications. Maintaining the mulch as cover requires a number of changes in land management, and changes generally imply costs. The two more promising alternatives are cover crop mulching (option B and C above) and crop residue mulching (or conservation tillage, option D). Both fall under the umbrella term 'land husbandry' and both rely on a renewable resource to conserve the relatively non-renewable soil resource (Shaxson *et al.*, 1989; Langdale *et al.*, 1994). Table 4.3 summarises some of the distinctive issues that pertain to each - which will be briefly elaborated hereafter.

Table 4.3 Comparison of cover crop and crop residue mulching

	Cover crop mulching	Crop residue mulching
Considerations	– Inherently renewable – Market independent	– Mixed nature: both renewable and non-renewable – Market dependent
Productive effect	– Fertility boost (fertiliser saving - 'green gold') – Potentially water conserving – Potentially labour saving	– Cost/labour saving ('liquid gold') – Water conserving
Limitations		
– Biophysical	– Water availability	– Biomass availability
– Socio-economic	– Opportunity costs land, labour and fertiliser	– Opportunity costs residues, labour and herbicides

Cover crop mulching

Cover crop mulching offers potential as low external input and sustainable agriculture (LEISA - Reijntjes *et al.*, 1992). This option generally draws heavily on local resources and relatively little on external inputs such as fertiliser, herbicides and other capital goods. The fact that cover crops are easily propagated (generally by seed) adds to this independence. Both the cover crop itself and the nutrient source it provides are inherently renewable.

Cover crops are typically leguminous and therefore nitrogen fixers.[29] Mucuna (*Mucuna sp.*, velvet bean) is one such example.[30] A sole crop of mucuna with good nodulation can

[29] Non-leguminous cover crops include *e.g.* grasses and small grains (Reeves, 1994).

capture from 60 to 200 kg N ha^{-1}, whereas mixed stands may capture about 40% less (IITA, 1994). Leguminous cover crops therefore have a substantial fertiliser-substituting potential. This manuring aspect has led farmers in Benin to nickname it 'green gold' (*ibid.*).

Cover crops have a controversial effect on the water balance. They conserve water by maintaining the soil covered but at the same time consume water during their growth. The corresponding productivity effect largely depends on how the water balance evolves over time (especially during the main crop's critical stages). Cover crops are not very promising in those instances where they compete with the main crop for the same water (or other scarce resource for that matter). The outlook is rosier in those instances where the cover crops tap into otherwise slack reserves (*e.g.* as a relay crop using residual moisture insufficient for a second crop). The potential of cover crops is therefore typically greater in the relatively humid areas where competition for water is not a major issue.

Cover crops conceivably can also have a labour saving effect in low external input systems. Cover crops smother weeds and thereby potentially reduce land preparation and weed control costs (Sain *et al.*, 1994; Buckles and Barreto, 1996).[31] This is an attractive feature for rotational systems (option B above). However, in systems with more overlap between main and cover crop (like intercropping - option C; or relay cropping - combination of B/C) the labour savings are less conclusive. What is more, they may even increase labour needs. This is largely the result of making the management of the main crop more cumbersome and possibly demanding additional operations (*e.g.* to reduce competition between main and cover crop). Not surprisingly, farmers prefer late over early cover crop establishment in case of relay/inter cropping (*e.g.* not before 40-60 days after maize establishment - Buckles and Erenstein, 1996:13).

Cover crops also need to be established someway, and however minimal, this implies some cost.[32] In addition, cover crops occupy land - conceivably displacing other potential inter or sole crops (Bunch, 1994; Reeves, 1994; Buckles and Barreto, 1996). The overall economic attractiveness for the farmer largely depends on the opportunity costs of land, labour and nitrogen fertiliser (Erenstein, forthcoming).

In this respect it is noteworthy that the use of cover crops in high external input food crop systems is generally limited. Frye and Blevins (1989) indeed note that the agro-ecologic potential of cover crops in these systems is substantially greater than their economic potential. Yet in some of these currently high input systems, cover crops have been used in the past. Buckles (1995:15-17) has highlighted the use of mucuna as dual-purpose green manure and fodder crop in the USA in the first half of the 20th century. Mucuna was typically intercropped with maize. Its area peaked at around two million ha in 1917 (Coe, 1918 in *ibid.*) and continued to occupy 0.5-1 million ha up to the mid-1940s.[33]

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[30] Other examples include *Canavalia sp.*, *Centrosema pubescens, Pueraria sp.* and *Psophocarpus palustris* (wild winged bean) (Rijn, 1982; Buckles and Barreto, 1996; Erenstein, forthcoming).

[31] Although this biological control can turn the cover crop into a pernicious weed (Rijn, 1982).

[32] Earlier research has contemplated the use of growth retardants on cover crops, conceivably reducing both competition and establishment costs (Rijn, 1982; Wilson and Akapa, 1983).

[33] Admittedly, the peak acreage only represented about 1% of total USA arable acreage at the time (US Census of agriculture in Hayami and Ruttan, 1985:480). However, the cover crop acreage

After W.W.II it's area declined and eventually disappeared from the statistics. Buckles relates this to the declining prices of chemical fertilisers and the advent of soybean. These factors may indeed have contributed to lower the benefit side, by providing substitutes for both the fertiliser and fodder aspect. However, probably equally important were the rapidly increasing opportunity costs of growing mucuna during the post war years. Maize productivity rocketed after being virtually stagnant in the pre-war years, amongst others due to the advent of hybrid maize and higher input use (Hayami and Ruttan, 1985:481). This productivity increase would largely be forfeited if mucuna was maintained as an intercrop in maize. In addition, labour and subsequently land prices increased substantially (*ibid.*:482-3).

Such historical cases provide interesting anecdotes and lessons for the current developments in developing countries (without implying a growth-stage theory). Especially, as the increasing commercialisation of agriculture in developing countries (notably in Asia and Latin America) may imply a similar transition out of low external input systems (Pingali, 1997). Yet in the meantime cover crops may provide a viable technological alternative for millions of farmers still constrained to their low external input systems.

Crop residue mulching

Crop residue mulching simply draws on the residues of previous productive activities to provide the ground cover. It thereby circumvents the necessity to actually grow a separate cover crop and the costs this implies. Yet to maintain the residues as mulch several adaptations are still needed - *e.g.* physical soil disturbance has to be limited so as not to destroy the cover. Crop residue mulching generally resorts to the use of herbicides to substitute for the weed control effect of physical tillage.[34] Depending on the opportunity costs, such substitution can generate substantial cost savings. Indeed, while herbicides are not without their problems, they are widely attractive in developing countries as a means of reducing labour spent on weed control (Blaikie and Brookfield, 1987:230). This labour-saving aspect has led farmers in Mexico to treasure herbicides as if it were 'liquid gold' (McMahon, 1996).

The use of herbicides implies the use of non-renewable resources and market integration by default (and the corresponding need for cash). By implication, crop residue mulching is characterised by a higher external input use than cover crop mulching. In view of this, crop residue mulching is less popular with environmentalists and LEISA proponents. In manual systems, sceptics only see a humane factor of production (labour) being replaced by an inhumane one (pesticides). In mechanised systems, some only see fossil fuel (a non-renewable resource) being substituted by a fuel derivative (herbicides). The net effect on the energy balance may indeed be marginal (Lal *et al.*, 1990). Crop residue mulching therefore does not really help to foster the desired change from exhaustible to renewable resources (Turner *et al.*, 1993; Dietz and van Straaten, 1994; Perman *et al.*, 1996). Notwithstanding,

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tended to be concentrated in the Southeast (Tracy and Coe, 1918 in Buckles, 1995:16), thus comprising a substantially bigger share in those localities.

[34] However, not necessarily so. In Africa non-herbicide-based systems exist or are being developed, reflecting high herbicide:labour price ratios (Erenstein, forthcoming).

crop residue mulching has expanded rapidly in modern high external input food crop systems, especially in the USA and Australia.

Crop residue mulching has an uncontroversial water-conserving effect. In this regard, it has a potential comparative advantage over cover crop mulching in those areas where water is a limiting factor. Yet at the same time, low water availability implies low biomass production. Consequently, the potential of crop residue mulching in semi-arid areas may well be constrained by the combined effect of low biomass supply and high alternative demand for the same residues (*e.g.* as fodder).

Conceivably cover crop and crop residue mulching could also be combined (Power, 1987; Frye and Blevins, 1989). Depending on the situation, this could make mulching more attractive. For instance, herbicides could be used to kill the cover crop (Frye and Blevins, 1989). Or cover crops could make up for any shortfall in available residual biomass.[35]

Discussion

Conservation technologies that emphasise productivity are likely to be more attractive from a private viewpoint. Cover-type conservation such as crop residue and cover crop mulching offer such prospects. However, there is a need to scrutinise the eventual trade-offs between productivity and conservation. Although a promising alternative, it seems unrealistic to expect that ground cover is the panacea for soil conservation, or that any single technology is the single best option for every situation (Reijntjes *et al.*, 1992:64; Kerr and Sanghi, 1993; Stocking, 1994). There simply are 'no universally applicable conservation treatments' (Hudson, 1988b:117). Yet successful and useful tools tend to generate wide application, including extrapolation to areas where it is not really suitable (*ibid.*:119).

Crop residue mulching has already proven itself in developed countries and this has strengthened the interest for its application in developing countries. The experimental evidence for this technology in developing countries looks promising. But how does this technology actually fit in the farm household and institutional setting in developing countries? What (if any) are the actual trade-offs that farmers face? To assess these questions in more detail there is a need for empirical evidence and better understanding of farmer conditions. Indeed, there is a constant need for feedback to keep the conservation technology development on track, and assess how theory relates to empirical reality. More research into the decisions and practices of farmers 'is perhaps one of the few areas in which more research may provide genuinely useful insights for more realistic soil conservation programs' (Blaikie, 1985:67). Farmers will only adopt conservation when it is compatible with their utility maximisation - and this is more likely when conservation measures provide a positive return. Yet, unless there is a good understanding of the farmers' preferences and constraints can one actually judge on the economic merit of such practice. The next part assesses the case of the crop residue mulching technology, and

[35] However, cover crops could also exacerbate biomass shortfalls. For instance, Herrera *et al.* (1993) highlight the potential of cover crops to increase the palatability of residues as fodder. Such a combination conceivably increases the extraction of residues and decreases the prospects of crop residue mulching. Indeed, it would increase the opportunity cost of conserving the residues as mulch.

develops and applies a conceptual framework to assess the technology from the farmer's perspective.

4.5 In conclusion

The present chapter assessed the implications for policy conservation intervention and conservation technology development. The complexity of the problem seems to both warrant and entangle public intervention. The problem is characterised by market failure - a necessary, but insufficient, condition for intervention. Intervention is only justified if the expected benefits of intervention to society are larger than the related costs. However, the problematic quantification and valuation of the on-site and off-site dimensions of the problem tend to make intervention decisions controversial. This is compounded by potential government failure - in itself likely in view of imperfect information.

Soil conservation is perceived differently by farmers and government/conservationists. The traditional approach to conservation intervention is based on the premise that conservation technology works - it is just a matter of getting farmers to adopt. In this regard, intervention typically relied heavily on economic incentives and legal sanctions. However, both are fraught with difficulties in developing countries and have typically not been very successful.

Traditional conservation technology has contributed to the lack-lustre success of conservation intervention. Emphasis has traditionally been on barrier-type physical structures. However, such measures are characterised by poor private returns. They typically require substantial investment and maintenance, and lower land productivity in the short term. Only in the event of severe quantitative or qualitative land constraints are such measures likely to be compatible with the farm households' utility maximisation and have they led to autonomous conservation adoption.

Traditional conservation approaches emphasised resource conservation and thereby tended to ignore the farm household and institutional setting of the problem. Yet farmers have the final say in the adoption decision and their participation is indispensable. For conservation intervention to become effective and efficient, there is a need to harmonise the views of conservationists with those of farmers. The recent shift in soil conservation towards maintaining and enhancing soil productivity, instead of conserving the soil resource *per se*, is a necessary step in the right direction. In addition, understanding and addressing the farmers' preferences and constraints is critical. A multidisciplinary, participatory and flexible approach with the necessary feedback loops is helpful in this regard.

The challenge is to make conservation compatible with the farm households' utility maximisation. One promising approach is to ensure an enabling environment for farm households that favours conservation behaviour. A complementary approach is to incorporate farm household and institutional considerations in conservation technology development. There are a number of economic considerations that are likely to make conservation technology development more effective. These considerations are rather stringent as they imply the need for limited costs and yet immediate benefits - as well as ensuring conservation effectiveness. However, there are also trade-offs between conservation and productivity, thereby posing a considerable challenge to the development of acceptable dual-purpose technologies.

Cover-type conservation is increasingly recognised for its conservation - productivity potential. Ground cover largely prevents soil erosion, whereas it has considerable productive potential in terms of water and fertility conservation. The cover - or mulch - can come from various sources - but crop residue and cover crop mulching are two particularly promising options. However, it seems unrealistic to expect that mulching is the panacea for soil conservation. Indeed, there is a need to assess how this dual-purpose technology actually performs and fits in the varied empirical setting of developing countries.

Intermezzo

A decade ago Miranowski (1986) already indicated that research that develops new conservation technologies and lowers the cost of conservation was the best long-run conservation policy. The present chapter tends to support this view. However, economically attractive conservation measures may not only be attractive from a private viewpoint. Indeed, such options are potentially also more attractive from a social point of view. Society at large would indeed benefit if public funds would be better spent and the soil resources managed more efficiently (Kerr and Sanghi, 1993). Three particular issues warrant highlighting.

First, mulching measures seem to be more efficient (both socially and privately) than physical structures – the more so, as they seem to be at least equally effective in halting erosion. Physical structures may be difficult to justify economically - not only privately but also socially - in view of the substantial investment required, distant benefits and the current resource constraints of most economies. Costs associated with mulching are mainly of a recurrent type – and thereby smear out the costs over the years. With equal benefits, such measures are subsequently less adversely affected by discounting and may potentially present more favourable social and private returns.

Second, conservation embodied in technologies that are privately attractive side-steps the whole negative externalities issue (Jolly *et al.*, 1985). With conservation in the self-interest of farmers, they will be more likely to adopt conservation autonomously. This reduces the need for government to intervene in soil conservation. Consequently, implementation costs can be drastically slashed, and there is less need for external 'incentives' or other subsidies to lure farmers (Napier *et al.*, 1991:375). The same applies to administrative and enforcement costs (Hunter, 1993). Even promotional costs will be substantially reduced as voluntary adoption opens up efficient farmer-to-farmer transfer (Chambers *et al.*, 1989). In addition to reducing costs, self-interested compliance is bound to be more effective (Phipps, 1987; Hunter, 1993).

Third, there is still a cloud of uncertainty surrounding the actual seriousness of the soil erosion problem. In fact, there will always exist substantial uncertainties about future world food demand, production technologies, and resource productivity (Miranowski, 1986). In view of the uncertainty, three policy options are generally perceived (Turner *et al.*, 1993:274): (i) One could do nothing, and merely wait and see how serious the problem really is; (ii) One could adopt no-regrets measures that are economically attractive in their own right even without considering uncertain benefits; or (iii) One can adopt a precautionary approach, preferring to be rather safe than sorry. Whereas options (i) and (iii) will always generate heated debate,[36] option (ii) is widely acceptable to both sides. Mulching is a potential no-regrets option. Indeed, mulching conceivably provides an economic return in the short term. In addition, by its very nature it makes any eventual over-investment in conservation less costly (low investment, easily reversible).

Yet at the same time a no-regrets option seems to imply a currently Pareto-inefficient situation. For instance, a no-regrets option suggests current gains are possible without future losses. But if this is possible, why have these options not been exploited already? A closer empirical examination of such potential options is warranted and could conceivably provide valuable insights for appropriate policies (Perman *et al.*, 1996). The second part specifically assesses crop residue mulching as promising dual-purpose alternative.

[36] A case in point is the debate about global warming.

PART II:

The Case of Crop Residue Mulching

CHAPTER 5

THE CROP RESIDUE MULCHING (CRM) TECHNOLOGY

Crop residue mulching (CRM) has been identified as a promising dual-purpose technological option: it is effective in conserving soil and can enhance productivity. But what exactly is this technology? How does it conceivably achieve its dual potential of resource conservation and productivity enhancement? This chapter defines and reviews the technology, emphasising its technical aspects. The first section deals with definitional issues and presents a short historical and geographical perspective. The second section discusses the implications for conservation and productivity. The third section introduces the residue balance - which combines crop residue production and use. The subsequent two sections look into some of the wider implications of CRM. The fourth section looks at the complexity of the technology itself and the challenges this implies to all parties concerned. The fifth section reviews some of the market imperfections inherent to the technology and the new trade-offs these imply. The last section provides a concluding summary.

5.1 CRM: definition and perspective

Mulch is a protective layer on the ground surface, at the soil-atmosphere interface. It thereby protects the soil from natural elements (rain, wind, sun) and regulates the soil ecology (water, air, temperature). Mulch occurs naturally in undisturbed environments - *e.g.* leaf litter in forests, organic residues in grasslands - but is generally adversely affected by human interference such as traditional crop management practices. Mulching tries to emulate nature by applying additional and/or maintaining the original mulch material. In the case of crop residue mulching use is made of crop residues.

Crop residue mulching (CRM) can be defined as a technology whereby *at the time of crop emergence at least 30% of the soil surface is covered by organic residue of the previous crop.* The three pertinent technical issues covered in the definition are: (i) the question of timing; (ii) the cover threshold; and (iii) the origin of the mulch. The *timing* issue relates to the limited crop cover at the onset of the season - and the correspondingly high erodibility of the soil. From a conservation point of view this is the critical time, although a year-round cover is still preferable. Further, land preparation activities directly affect the quantities of residues remaining on the soil surface, and at the time of crop emergence land preparation is complete. The 30% *threshold* was originally chosen in the USA "to achieve an approximate 50% soil erosion (wind and water) reduction relative to a soil surface without residue cover" (Allmaras and Dowdy, 1985:198). Notwithstanding, the threshold is rather arbitrary and higher levels of soil cover imply even greater reductions of soil erosion. The *origin* of the mulch has varying implications for the soil resource and soil/crop management. The reliance on organic residues from the previous crop distinguishes CRM from other forms of mulching (such as cover crop mulching, see 4.4). Although CRM can conceivably also be applied to the production of perennial crops, it is particularly relevant for annual crops, where crop cycles are short and land preparation and crop establishment are regular practices. The definition of CRM reflects technical and conservation considerations only. Indeed, it is a standards-based conservation technology (see 3.1). Whether it is efficient to fulfil this standard remains to be seen.

Crop residue mulching is better known as 'conservation tillage'. However, there is substantial controversy and confusion around this latter term. Indeed, "a classic problem affiliated with conservation tillage over its years of development has been its definition" (Pierce, 1985:4). One may posit - in analogy with sustainability - that there are as many interpretations of conservation tillage as there are practitioners (Erenstein, 1997a:188). So why the confusion? Part of the confusion relates to the various interpretations of 'conservation' (Conservation of what? Of soil, water, crop residues?). Another part of the confusion relates directly to the word 'tillage'.[1]

A first problem with tillage is that it puts too much emphasis on physical soil tillage. This seems adequate in the production systems of the USA, where the term originated. There, incorporation through tillage was the principal destination of the residues (Sandretto and Bull, 1996). Reducing tillage typically implied substantial quantities of residues remained as mulch. Indeed, CRM often occurred by default upon adopting no tillage or reduced tillage practices (Heimlich, 1985). However, in developing countries, tillage is only one of the various factors that determines potential residue availability as mulch. Availability is co-determined by other residue management practices (*e.g.* pre-plant burning and extraction), residue production and weathering (Erenstein, 1997a). What is more, in many production systems in developing countries there is traditionally no tillage at all (Akobundu, 1987).

A second issue with tillage is that there are so many types (including a wide range of available implements and practices). Although this in itself is not a problem, it does easily confound the discussion. The more so as there is no consensus on terminology. There are numerous terms that are variously defined, either referring to a specific practice or a (sub)set. Some of these terms (partially) overlap, and occasionally are used interchangeably (Mannering and Fenster, 1983).[2]

Conservation tillage is a generic umbrella term that includes several tillage practices and systems (Mannering and Fenster, 1983; Lal, 1989:163; Carter, 1994:5; CTIC, 1994). Consequently, it is variously interpreted. For instance, Dickey *et al.* (1987) have highlighted that farmers seemed to associate conservation tillage with not using the mouldboard plough. Articles in renowned journals have added to the confusion. Gould *et al.*

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[1] Tillage refers to the manipulation of soil by an implement powered by humans, animals or machines (Gupta *et al.*, 1991).

[2] The Conservation Technology Information Centre (CTIC, 1994) provides one set of frequently used definitions, distinguishing between (1) no till; (2) ridge till; (3) mulch till; (4) reduced till (15-30% cover); (5) conventional till (<15% cover). Conservation tillage (>30% cover) groups items (1-3); crop residue management (>15% cover) groups items (1-4). Other classifications and terms overlap to a varying degree - zero till, direct drilling and slot plant would fall under item (1); clean till and plough till under (5). However, there is no consensus in relation to some terms - *e.g.* numerous interpretations of reduced and minimum till abound (Allmaras *et al.*, 1991:55). For instance, Rahm and Huffman (1984) equate reduced tillage with not using the mouldboard plough (*i.e.* non-inversion tillage).

(1989) equated conservation tillage with reduced tillage. Lee and Stewart (1983; 1985; Heimlich, 1985) considered it as either minimum tillage or crop residue management.

Adding to the confusion is the refining of definitions over time. Indeed, early definitions of conservation tillage tend to be more abstract and emphasise tillage and relative erosion. For instance, the Soil Conservation Society of America (1982; Mannering and Fenster, 1983; Violic, 1989b) defined conservation tillage as "any tillage sequence that reduces loss of soil or water relative to conventional tillage; often a form of non-inversion tillage that retains protective amounts of residue mulch on the surface". A first problem with this definition is that it is very broad. It includes all tillage practices that conserve soil and water, including those with low or no residue levels. A second problem is that it is fuzzy. Being 'relative to conventional tillage' has the disadvantage that 'conventional' varies over time and space.[3] Current definitions are more operational and tend to emphasise the soil cover threshold of 30% (Lal *et al.*, 1990; CTIC, 1994).[4] Some authors use or cite both the abstract and operational definition (Unger, 1990; Allmaras *et al.*, 1991; Figueroa and Morales, 1992:6; Carter, 1994:5).

Using the same term with varying definitions over time and space is bound to generate confusion. To circumvent the conservation tillage controversy other names have surfaced. A number of alternatives still emphasise the tillage aspect - *e.g.* no till; minimum till; direct sowing - with the consequent confusion and potential neglect of the mulch aspect. Other definitions are wider and tend to see mulch as implicit - *e.g.* land husbandry (Shaxson *et al.*, 1989; Hudson, 1992; Hudson and Cheatle, 1993) and conservation farming (Moldenhauer and Hudson, 1988; Wijerwardene and Waidyanatha, 1989; Moldenhauer *et al.*, 1991).

Another popular contender is *crop residue management*,[5] and refers to a year-round system that includes all field operations that affect the amount of residue (CTIC, 1994; Sandretto and Bull, 1996). It correctly emphasises crop residues. The problem though remains that it is unspecified: it simply is too broad. Indeed, all practices affecting residues are forms of management - whether extraction, incorporation, or other means of disposal. Some of these residue management practices may not be compatible with the retention of residues as mulch (Cornish and Pratley, 1987). In addition, crop residue management has already been variously defined (*e.g.* by CTIC, 1994 - see footnote 2).

The alternatives put forward do not fully resolve the controversy and confusion surrounding conservation tillage. The present study therefore proposes *crop residue mulching* (CRM) as the most adequate term for the technology. It is less confounded by controversy and correctly emphasises the pertinent issues - *i.e.* the presence of a mulch that provides soil cover and the origin of that mulch.

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[3] SCSA (1982) define conventional tillage as "the combined primary and secondary tillage operations performed in preparing a seedbed for a given crop in a given geographical area".

[4] Up to 1982, the CTIC used a threshold of 20% (Dickey *et al.*, 1987:432).

[5] SWCS, 1991; CTIC, 1994; Hatfield and Stewart, 1994; Moldenhauer *et al.*, 1994; Sandretto and Bull, 1996. Alternatively, managing agricultural residues (Unger, 1994).

Historical and geographical perspective

The crucial feature of CRM is the presence of sufficient crop residues at the right time to ensure an adequate soil cover. However, over the centuries agriculture has traditionally emphasised the opposite: *i.e.* the need for a clean seedbed. Numerous farmers in developing countries still rely on pre-plant burning of vegetative debris for this purpose. So, have farmers in developed countries in the past. However, with the advent of tillage opportunities over the last two centuries,[6] incorporation of residues became an increasingly adequate way of disposal. Tillage is perceived to also provide a number of other benefits, including (temporary) weed control and the creation of a favourable environment for crop sowing and emergence (*e.g.* Kuipers, 1991; Hoogmoed, 1999).[7] Both tillage and burning practices conflict directly with CRM. Indeed, the retention of mulch actually requires relatively little or no disturbance of the soil and the elimination of burning. The problem has traditionally been how to economically achieve this.

The discovery and commercial development of herbicides provided part of the solution. During the W.W.II, post-emergence herbicides were discovered (2,4-D and MCPA). Other herbicides followed in the 1950-60s - including triazines and ureas (Rijn, 1982; Violic, 1989a). With time, herbicides increasingly provided an economic substitute for the weed control function of tillage (Unger, 1990:58). Another crucial component for mechanised agriculture was the development in the post-war years of planting equipment (direct seed drills) that could adequately sow through the mulch (Phillips, 1983; Violic, 1989b). Both the herbicides and planting equipment allowed for the successful establishment of crops under CRM. With further fine-tuning of the technology and favourable market developments, CRM became an increasingly attractive economic alternative for crop production on well drained soils in the USA from the 1970s onward (Allmaras and Dowdy, 1985:216).

Economic returns ensured that the promotion of CRM practices was not ignored in the USA. The Conservation Technology Information Centre (CTIC, 1994) estimates that 35% of USA cropped land was under CRM in 1993, up from 26% only four years before, although expansion flattened thereafter. CTIC subdivides CRM into three categories: no till, ridge till and mulch till (all >30% soil cover; Figure 5.1).[8] Within these, no till has shown the most pronounced increase. In 1996, it made up about 15% of US cropped land, corresponding with 42% of the CRM area. In 1989, the no till share was respectively 5% and 19%. CRM in the USA tends to be concentrated amongst maize, sorghum and soybean (all row crops),[9] especially in areas where double cropping is feasible.[10]

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[6] The mouldboard plough was only invented at the end of the 18th century and used after 1830 (Violic, 1989a). Tillage developed further with the advent of the steam and petrol engine.

[7] The scientific merits and dismerits of tillage are disputed, however. Faulkner pioneered the discussion with his epic "Plowman's Folly" (1943), claiming that there was no scientific justification for ploughing the soil.

[8] CTIC implements an annual comprehensive "national crop residue management survey" (*e.g.* CTIC, 1994). The data set is directly comparable from 1989 onwards (Sandretto and Bull, 1996).

[9] Epplin and Tice (1986) suggest two reasons for the preferential use of CRM on maize compared to wheat. Maize farmers had relatively more experience with herbicides; and it was substantially easier to adapt maize seed drills. In addition, crop-mulch interactions could be influential (*e.g.* crop

Most of the available CRM literature documents the advances of research and use in the USA - generally perceived to be the cradle of this technology.[11] Notwithstanding, actual use of CRM has been reported in various corners of the world - although adoption levels are less well documented and care is needed in interpreting such data in view of the terminology problem. Use of CRM practices seems to be increasingly common in semi-arid Canada (Cannell and Hawes, 1994) and Australia (Cornish and Pratley, 1987; Freebairn *et al.*, 1993). CRM also seems to be spreading in Latin America - particularly in Brazil, as well as Argentina, Chile, Paraguay, Mexico and Central America (for references see Derpsch, 1998; Wall, 1998; Erenstein, forthcoming). In Africa and Asia reports have tended to emphasise CRM research, including the pioneering work of IITA in West Africa (Greenland, 1975; Lal, 1976; Akobundu and Deutsch, 1983).[12]

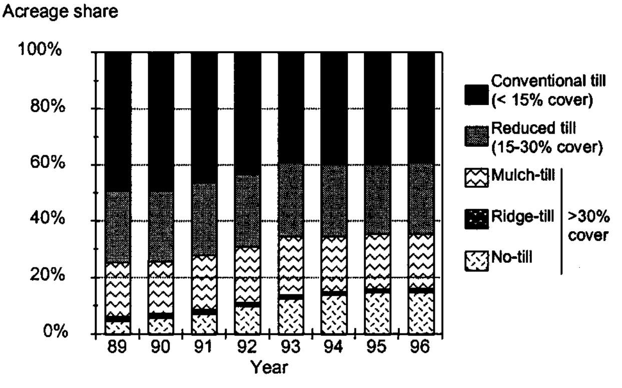

Figure 5.1 Development of tillage systems on arable land in the USA (source: CTIC in Sandretto, 1996)

Europe provides a stark contrast to North America in terms of CRM research and adoption. Soil erosion problems in (Western) Europe tend to be less obvious. There is also a need to remove at least some residue in view of biophysical limitations[13], resulting in

geometry and phyto-sanitary aspects).

[10] At least half the double cropped area with aforementioned crops used CRM (CTIC, 1994).

[11] Early papers with wide circulation include Triplett and Doren, 1977 and Phillips *et al.*, 1980. Books include Phillips and Young, 1973; Phillips and Phillips, 1983; Rice, 1983; d'Itri, 1985; Sprague and Triplett, 1986; Carter, 1994; Hatfield and Stewart, 1994; Unger, 1994.

[12] For references in relation to Africa see Erenstein, forthcoming. For further details see reviews in Unger and McCalla, 1980; Lal, 1989; Unger, 1990; Cannell and Hawes, 1994. Reviews focusing on no till include Rijn, 1982; Derpsch, 1998; Köller *et al.*, 1998; Wall, 1998. For an early overview by crop and region see Watson and Allen, 1985. For historical detail see Wiese, 1983; Shear, 1985.

[13] *E.g.* sub-optimal soil temperatures, high soil moisture, slow decomposition, and prevalent

potential yield loss (Lal, 1989:109; Cannell and Hawes, 1994). In addition, there is a greater reluctance to use herbicides and soils tend to be 'older' (Stroosnijder, pers. comm.). The lack-lustre appeal of CRM in this part of the Old World is noteworthy. It adequately illustrates that the technology is not a panacea. It also provides a sobering dose of realism, as one would expect more similarity - both biophysically and socio-economically - between Europe and North America, than between developing and developed nations.

CRM is not a simple add-on technology. For most farmers, its adoption would imply major changes in crop establishment and management of weeds and residues. In addition, fertiliser, pest and disease management may require adaptation. CRM, therefore, is not an easily transferable, single component technology. Instead, it is a complete package of cultural practices (Pierce, 1985; Lal, 1989:163; Lal *et al.*, 1990). Such a package is not likely to fit in seamlessly into the widely varying production systems in developing countries. The appropriateness of CRM thus depends on both biophysical and socio-economic factors and their interactions (Lal, 1985; 1989:177, 184; 1991). Therefore, the CRM knowledge base developed in the USA, Canada and Australia is not directly transferable to developing countries. Instead, one would expect the need for substantial adaptive research (Thomas *et al.*, 1983).

5.2 CRM effects at the crop level: Conservation and productivity

CRM is potentially a dual-purpose technology that combines conservation and productivity effects. This potential relates to CRM's effects on: (i) soil conservation; (ii) soil ecology; (iii) crop yield; and (iv) labour and capital productivity. Crop residue mulch *conserves the soil*: it provides a protective layer to the soil surface that is extremely effective in halting soil erosion. Crop residue mulch also conserves water and in itself is a soil amendment, thereby altering the *soil ecology*. These alterations tend to ameliorate the soil environment for crop growth and thereby tend to stabilise, and possibly even enhance, *crop yield*. The retention of the mulch implies changes in crop management, and these may favourably alter *labour and capital productivity*. The present section briefly reviews these implications.

5.2.1 Soil conservation effects

The resource conserving effect of CRM revolves around soil cover. The two major processes of water erosion are the loosening of soil particles by rain splash and the washing away of soil particles by water runoff. The corresponding control strategies are maintaining good soil cover (to absorb raindrop impact), increase resistance against overland flow and maximising soil infiltration (to reduce the amount and speed of runoff - Shaxson *et al.*, 1989). An effective layer of crop residues provides these mechanisms, as well as adding organic matter to stabilise soil structure (Figure 5.2).

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anaerobic conditions.

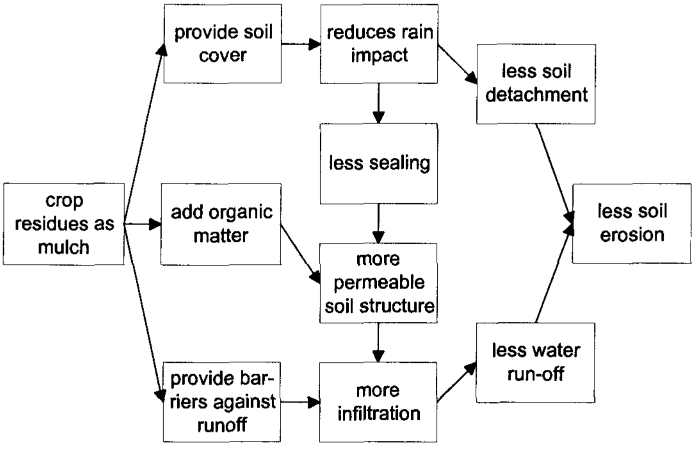

Figure 5.2 The soil conservation effect of crop residue mulching

The resulting reduction in soil erosion is impressive (*e.g.* Table 5.1) and has been repeatedly observed both in temperate and tropical environments.[14] Erosion declines asymptotically to zero as cover increases, though the exact form may well be site-specific (Quadrant I of Figure 5.3).[15] Depending on such locational issues, 30% of uniform soil cover may generate a reduction in soil erosion - compared to exposed soil - from 50% to 80% (Allmaras and Dowdy, 1985; Shaxson *et al.*, 1989). Quadrant I of Figure 5.3 highlights two issues. First, a near complete soil cover can conceivably almost eliminate soil erosion (Lal *et al.*, 1990; Moldenhauer *et al.*, 1994). Second, the reduction of soil erosion in response to an increase in cover is subject to diminishing returns. However, without considering the conservation costs and benefits it remains impossible to say anything about the optimal cover level. The 30%-threshold is therefore rather arbitrary - both from a conservationist and economic point of view. Notwithstanding its arbitrariness, the present study uses the 30%-cover threshold as conservation standard. The case studies can then focus on whether it is efficient to fulfil this standard.

[14] Shaxson *et al.*, 1989; Lal *et al.*, 1990; Alegre *et al.*, 1991; Khybri, 1991; Langdale *et al.*, 1994; Moldenhauer *et al.*, 1994; Stocking, 1994.

[15] Based on $E = 100 * e^{-\beta C}$ where E: relative erosion (% of bare soil erosion); C: soil cover (%); β: location specific coefficient (Alberts and Neibling, 1992 in Moldenhauer *et al.*, 1994). Illustrative values of β include 0.025 and 0.05 (*ibid.*); 0.035 (RUSLE data, USDA in Moldenhauer *et al.*, 1994:38); approximately 0.0575 (Shaxson *et al.*, 1989:36). Quadrant I of Figure 5.3 depicts a β of 0.05.

Table 5.1 Mulch effects in Zimbabwe (on-station trials, average 1988-95)

	Domboshawa (758 mm annual rainfall)				Makoholi (463 mm)	
	Well-drained soil		Poor-drained soil			
	Clean till	Mulch till	Clean till	Mulch till	Clean till	Mulch till
Maize yield (Mg ha^{-1})	3.2	4.0	3.1	3.0	2.9	3.6
Runoff (mm)	71	15	109	46	54	14
Soil loss (Mg ha^{-1})	5.3	1.0	6.1	1.0	9.6	0.9

Source: various sources in Elwell (1995)

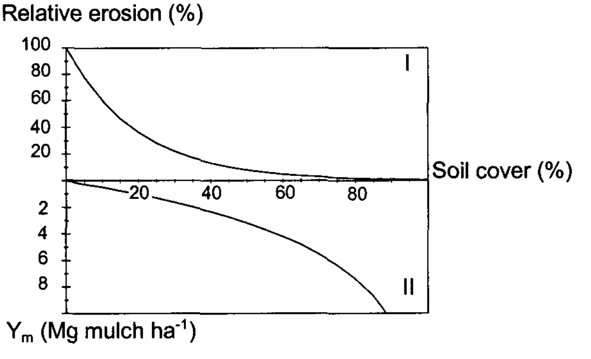

Figure 5.3 Two-quadrant graph showing the relationship between relative erosion and soil cover in Quadrant I; and soil cover and amount of mulch [Y_m] in Quadrant II (see text for sources)

The amount of residues needed to fulfil the conservation standard varies, depending on factors such as crop, variety and residue management practices.[16] Further, the quantities of residue needed to enhance soil cover increase exponentially (Quadrant II of Figure 5.3).[17] Approximately two Mg of maize residue ha^{-1} are necessary to obtain 30% soil cover in Meso America (Tripp and Barreto, 1993). Larger amounts of residues do conserve soil better, but increasing quantities of residue are required for additional improvements in soil conservation (Table 5.2).

[16] Maize residues can provide varying degrees of cover depending on their state: *e.g.* cover is relatively high for new residues, low for intensively grazed residues (Scopel and Chavez, 1996).

[17] Based on $C = (1 - e^{-\alpha R}) * 100$ where C: estimated soil cover (%); R: residue quantity (Mg ha^{-1}); α: crop specific residue cover factor (Gregory, 1982 in Allmaras *et al.*, 1985; Kok and Thien, 1994). Quadrant II of Figure 5.3 depicts an α of 0.219 - reflecting maize residue in Meso America (estimated from Tripp and Barreto, 1993).

Table 5.2 Effects of variable mulch rates on water and soil loss in Nigeria (forest-savanna transition zone, Apr-Oct 1977)

Mulch rates (Mg rice straw ha^{-1})	Runoff(%)	Soil loss (Mg ha^{-1})	Marginal conservation effect [Mg soil] [Mg mulch]$^{-1}$
0	75.4	9.6	
2	43.4	2.3	3.7
3	15.2	0.5	1.8
6	5.4	0.1	0.13
12	0	0	0.017

Source: De Vleeschauwer *et al.*, 1980 in Carsky *et al.*, 1998.

5.2.2 Soil ecology effects

The effects of CRM on the soil environment are not limited to conserving the soil *in situ*. The presence of the mulch at the soil-atmosphere interface has profound effects for the entire soil ecology, including soil moisture; soil temperature; soil physical properties and structure; soil fertility; and soil life (Lal, 1989; Carsky *et al.*, 1998). However, with the soil being a complex environment, many of these effects are intertwined.

CRM has a profound water conserving effect: the very process that conserves the soil also implies more infiltration of rain water and less runoff (Figure 5.2, Tables 5.1 and 5.2). Therefore more water is retained in the soil profile, where it remains potentially available for crop growth (Featherstone *et al.*, 1991; Dalrymple *et al.*, 1992; Moldenhauer *et al.*, 1994). The presence of the mulch also reduces soil temperature oscillations and reduces evaporation losses.

CRM also has profound effects on soil fertility. Tropical soils typically have a low inherent fertility, where plant available nutrients and organic matter are concentrated in the topsoil. The conservation effect of mulch helps maintain this *in situ*, whereas the mulch itself typically adds to the low stock of soil organic matter. Organic matter is a key component for sustainable and productive use of soils (Pieri, 1989), that links back to its favourable effect on the soil's erodibility, cation exchange capacity and water holding capacity.

CRM favours the activity of soil biota (*e.g.* soil fauna like earthworms and termites) by providing a readily available food source and creating a more favourable soil habitat (Mando, 1997; Carsky *et al.*, 1998). In turn, the activity of soil biota contributes to improved soil physical and chemical properties. Although the effects of soil biota are considered favourable for the soil itself, their very activity actually contributes to the disappearance of the mulch layer (*i.e.* weathering).

5.2.3 Crop yield effects

The growth of plants is primarily a function of biophysical conditions, including (i) defining conditions (carbon dioxide; radiation; temperature; crop attributes), (ii) limiting conditions (water and nutrients) and (iii) reducing conditions (weeds; pests; diseases; pollutants - Rabbinge and van Ittersum, 1994). Therefore, for crop growth it is not the soil as such that matters, but the soil's influence on these conditions. The implications for CRM are substantial. CRM drastically changes the soil ecology: it simultaneously influences the soil temperature, the availability of water and nutrients, and the incidence of reducing agents (Rijn, 1982; Lal, 1989; Unger, 1990). The marginal yield effect will depend on the extent these changes influence the constraint(s) for crop growth. This makes the yield effect of CRM site-specific - and somewhat difficult to disentangle in view of the numerous interactions (Lal *et al.*, 1990; Sandretto and Bull, 1996).

The water conserving effect of CRM can induce a substantial yield increase when drought stress is an issue. But the same effect can actually be detrimental when it exacerbates poor drainage and water logging conditions (Rice, 1983; Lal *et al.*, 1990; Table 5.1). Nonetheless, water shortage, rather than excess, tends to constrain crop growth. In fact, an immediate yield boost (if any) upon adopting CRM tends to be linked to the enhanced rainwater use efficiency (Shaxson *et al.*, 1989). The positive effect is most evident in areas with moisture stress during the cropping cycle (Rijn, 1982; Thomas *et al.*, 1983; Lal, 1989). It is frequently observed in relatively dry environments, although even humid areas may experience occasional moisture stress (Williams, 1988; Pierce and Lal, 1994; Scopel, 1995b).

CRM conceivably generates a self-reinforcing feedback whenever water is a limiting factor (Figure 5.4). This is of special interest in relatively dry areas, where water availability constrains biomass production and thus the availability of residues as mulch. However, there are two caveats. First, to achieve the water conserving effect one needs to conserve enough residues in the first place (Erenstein, 1997b). Second, other conditions than water may subsequently constrain crop growth (*e.g.* nutrients in the Sahel).

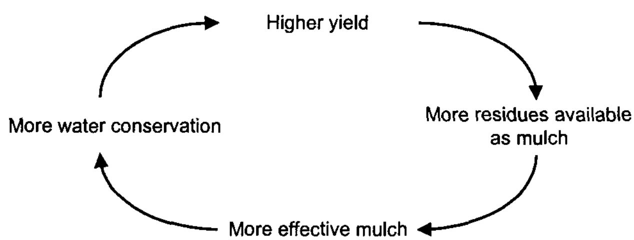

Figure 5.4 The upward spiral of crop residue mulching when water is a limiting factor

The organic matter contributed by CRM can have different short-term yield implications, typically hinging on the quality of that organic matter as reflected by the C:N-ratio. Leguminous crop residues typically have a low C:N-ratio and tend to ameliorate N-availability. Alternatively, cereal crop residues typically have a high C:N-ratio and may actually exacerbate N-stress by temporary N-immobilisation.

Mulch also shields the soil surface against solar radiation, thereby buffering soil temperature fluctuations. This can alleviate soil temperature stress in the warmer environments, yet at the same time slows the necessary warming up of the soil in cooler environments (*e.g.* highlands; Western Europe - Rijn, 1982; Lal *et al.*, 1990).

CRM also affects the incidence of crop weeds, pests and diseases. Mulches are known to control weed growth, typically by smothering them and/or through allelopathic effects (Akobundu, 1987). The effect of CRM on pests and diseases is varied. Crop residues may actually carry-over inoculum from the previous crop. It thereby favours not only harmful pests, but also their natural enemies (predators and parasites), which helps to establish a new equilibrium (Rijn, 1982; Thurston, 1992). Furthermore, the presence of the mulch may reduce the transmittal of plant diseases by rain-splash (Thurston, 1992). With contradictory evidence, it remains ambiguous whether residues are detrimental or beneficial in this respect (Akobundu, 1987; Ortega, 1989; Unger, 1990). The issue is that many weeds, pests and diseases respond uniquely to the CRM-induced alterations in the crop-soil ecosystem (Forcella *et al.*, 1994).

The yield effect of CRM also varies per crop. For instance, CRM tends to have favourable effects for row crops that inherently provide limited vegetative cover (Sandretto and Bull, 1996). CRM is also not suited for all crops (Akobundu, 1987). For example, root and tuber crops generally respond favourably to intensive tillage (Howeler *et al.*, 1993).

The short-term yield effect is therefore variable over space and time - depending on the mulch, crop and site-specific characteristics. Experiences so far have highlighted positive, neutral and negative short-term yield responses to CRM - although overall, the immediate impact is weak (McIntire *et al.*, 1992:79). After a multi-year transition period, the yield effects tend to be neutral to positive (Logan *et al.*, 1991; Kapusta *et al.*, 1996). Indeed, some productive benefits accumulate over time as mulching arrests soil degradation processes and gradually improves the soil in biological, chemical and physical terms.

Other effects may not necessarily accumulate, but still need a multi-year perspective. For instance, the water conserving effect of mulch may have little tangible effect on yields on well drained soils in most "normal" years. Nonetheless, it is particularly beneficial and obvious on well drained soils in dry years, with the important benefit of reducing production risk and yield oscillations (Lal, 1989; Violic *et al.*, 1989). Alternatively, the water conserving effect is particularly detrimental on poorly drained soils in wet years (or wet periods).

Of the biophysical mulch effects discussed so far, the crop yield effect is the most crucial for farmer acceptance - yet it is also the one most difficult to predict in view of the site-specificity. As a rule of thumb it seems advisable to assume that crop yield levels will not differ significantly under CRM in the short term, unless there are substantial indications to the contrary. However, yield oscillations tend to be reduced, and over time, yield levels are more adequately maintained.

5.2.4 Labour and capital productivity effects

CRM's productivity effects are not limited to crop yield. In order to maintain the mulch, CRM typically implies a major overhaul of crop management practices. This inherently alters the crop production technology. The effects for labour and capital productivity are two-fold. First, it typically implies factor substitution and thereby alters factor requirements. Second, it alters input use efficiency.

The implied *factor substitution* is to a large extent dependent on the actual production technology. For instance, mechanised agricultural systems have traditionally emphasised intensive tillage. CRM foregoes intensive tillage in order to conserve the mulch layer. It thereby tends to substitute herbicides for tillage and adapts the sowing operation. Such changes implied substantial labour and capital savings in the USA.[18] In manual agricultural systems, traditional land preparation and weeding are very labour intensive. By substituting herbicides for such laborious measures, CRM can imply substantial labour savings. The production technology actually being used is a function of available technological options, preferences, resources and institutions, *i.e.* is location and time dependent. Consequently, the exact factor implications of CRM will vary over space and time.

Factor substitution can alleviate crop management bottlenecks - particularly during land preparation and/or weeding. In land abundant situations this can ostensibly allow for an increase in the area that can be adequately handled. Alternatively, it may enhance the timeliness of crop management and thereby favourably affect productivity. CRM potentially also offers more flexibility in terms of crop establishment (*e.g.* less time needed for land preparation; enhanced workability in mechanised systems).[19] This typically reduces the turnaround time between crops. Occasionally, this may allow for an increase in land-use intensity by enabling the cultivation of a second crop (further aided by the enhanced availability of residual moisture under CRM).

CRM alters *input use efficiency* by affecting the inputs' (i) mode of application; (ii) mode of action; and/or (iii) effective loss. The retention of mulch directly affects the mode of application - for instance, by limiting the available options, or by making the application process itself less efficient. The altered soil ecology can affect the mode of action of the input. CRM also affects the effective loss of input through runoff, leaching and volatilisation. Depending on the technological level, these effects can have repercussions for labour and capital input. Depending on the processes at play, the net effects can be positive or negative.

Efficiency considerations are particularly relevant to fertiliser use in general, and nitrogen (N) fertiliser in particular. N may be temporarily immobilised by the microbial biomass with CRM - especially when the C:N ratio of the residues is high. This may result in a lower N availability for the crop until a new equilibrium is established (Barreto, 1989).[20] The initial years may thus require an investment into the revolving fund of nutrients in the form of a higher N dosage - though the reverse may be true in later years (Rijn, 1982; Shenk *et al.*, 1983; Barreto, 1989; Moldenhauer *et al.*, 1994). In addition, there tends to be an interaction between CRM and application rates during the initial years (Figure 5.5). At low nitrogen application levels, conventional (no mulch) systems typically outyield CRM. However, as N rates are increased, the response curves intersect and CRM

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[18] Rice, 1983; Crosson, 1985; Harman and Wiese, 1985; Unger, 1990; Moldenhauer *et al.*, 1994; Sandretto and Bull, 1996.

[19] The net effect on the flexibility of weeding is uncertain though. By substituting herbicides for tillage, CRM limits the array of weed control options, increasing the dependency on chemical weed control (Scopel, pers. comm.).

[20] On the other hand, P is more effectively available under CRM (Moldenhauer *et al.*, 1994).

starts to outyield (Logan *et al.*, 1991). A crossover point (X^* in Figure 5.5) of around 80-100 kg N ha^{-1} has been reported for maize in the USA and Central America (Phillips *et al.*, 1980; Zea and Bolaños, 1997). N efficiency also varies over N source, as ammonia volatilisation can be substantial when applied superficially. Splitting N application may increase efficiency (Barreto, 1989). Fertiliser efficiency considerations are further compounded by the interaction with the water conservation effect of CRM. This reduces runoff losses and increases crop response due to higher plant available water.

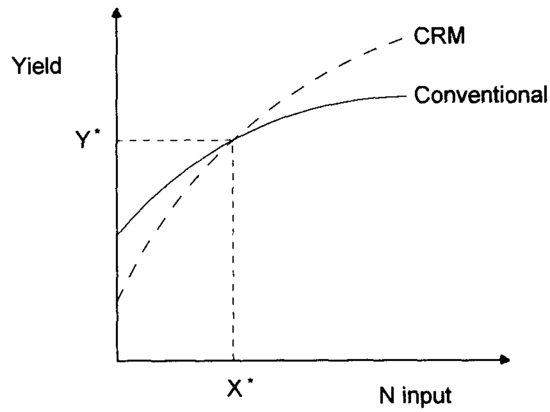

Figure 5.5 Response of crop to N fertiliser with different production technology

Efficiency considerations also apply to other inputs - both labour and capital. For instance, the presence of the mulch may reduce actual herbicide efficiency (Akobundu, 1987). CRM may also require higher seed rates to ensure an adequate crop stand (Rice, 1983; Figueroa and Morales, 1992:7). Altered input use efficiency implies the need to adapt input usage, or alternatively, may have repercussions for crop yield. The net efficiency effect varies over inputs, space and time - and is subject to numerous interactions. This adds to the site-specificity of factor substitution. The overall factor productivity effect of CRM is thereby very location dependent.

Discussion

From a conservation point of view, the critical component of CRM is the presence of crop residues as mulch. This mulch is responsible for the soil conservation effect and the alteration of the soil ecology. From a farmer's point of view, the productivity effects are of particular interest: mulch tends to stabilise, and occasionally even enhance, crop yield, and also implies factor substitution and input use efficiency effects. Whether the factor productivity effects are actually economically attractive is bound to be site-specific, being dependent on technology, preferences, resources and institutions.

The factor productivity effects are likely to be decisive for farmer acceptance. For instance, the implied factor substitution contributed to CRM's cost-reducing potential in the short term in the USA - which is regularly flagged as the determinant of its success there

(Magleby *et al.*, 1984 in Miranowski and Cochran, 1993; Buttel and Swanson, 1986; Miranowski, 1986; Gajewski *et al.*, 1992a:34). CRM proved to be economically attractive even without considering long-term productivity effects and spatial externalities (Fletcher and Seitz, 1986). The conservation benefits apparently were of secondary interest (Allmaras and Dowdy, 1985; Allmaras *et al.*, 1991). In fact, much of the CRM area in the USA is actually located on land that is not particularly erodible (Crosson, 1985).

The factor saving potential of CRM presents a dilemma. To be attractive to the farmer, the conservation technology needs to address short-term productivity interests. Yet when farmers' overemphasise productivity concerns, this may actually smother the conservation aspects. This may not be an issue when the conservation aspect is inseparably linked to the productivity aspect - *i.e.* the two are embodied in the same component. However, there is a real danger of disarticulation whenever this is not the case.

The conservation and crop yield effects are largely embodied in the same component: *i.e.* in the mulch. But the factor productivity effect is not. It generally depends on the factor saving potential of some of the underlying management changes. Some of the more attractive changes may therefore be implemented as such, without actually ensuring retention of sufficient residues as mulch. For instance, farmers may adopt herbicides and/or reduced tillage practices for being economically attractive in their own right. However, by themselves such changes may be a necessary, but not sufficient condition for CRM adoption - an issue highlighted by the residue balance.

5.3 Residue balance at the crop level

CRM requires the retention of sufficient residues as mulch. Yet, numerous factors influence the availability of residues - both in terms of residue production as by generating competing residue destinations. The effects of all these factors can be linked in a residue balance. This is the physical balance of residues for a specific location, equating the production with aggregate residue use. The residue balance serves as an analytical aid. Indeed, by grouping the different components it highlights the potential biophysical bottlenecks for CRM and where changes would be needed. Subsequently valuing the required changes allows for the economic assessment of CRM.

The residue balance may be expressed as:

$$P = U_E + U_B + U_I + U_W + U_M \qquad (5.1)$$

where:

P: production of residues;

U_E: residues extracted;

U_B: residues burned *in situ*;

U_I: residues incorporated;

U_W: residues lost due to weathering;

U_M: residues retained as mulch.

The present section reviews the different components of the balance, starting with the production side (P), then the utilisation side (U's), and ending with the implications for CRM.

Residue production

Crop residue production is basically a function of (i) biomass production; and (ii) the harvest index. Crop *biomass production* is determined by the biophysical environment, including defining, limiting and reducing conditions (Rabbinge and van Ittersum, 1994). Crop attributes are an important defining condition. For example, a cereal crop (*e.g.* maize) potentially produces more biomass than a leguminous crop (*e.g.* beans). Agronomic practices may alleviate limiting and reducing conditions through yield increasing and yield protecting measures respectively (*ibid.*). Socio-economic variables largely determine the actual use of such practices.

The *harvest index* expresses the agricultural commodity yield (*e.g.* maize grain) as a fraction of total crop biomass.[21] The remaining biomass is generally perceived as a by-product and typically remains in the field as crop residue (*e.g.* maize stubble). The harvest index for cereals such as maize is relatively constant for a given variety. Therefore, for such a variety, residue production is a constant fraction of total crop biomass. The harvest index does vary greatly among crop varieties. For example, a maize landrace may have a relatively low harvest index of 30%, while an improved variety may have an index of 50%. Thus, for a given level of biomass production, residue production will generally be substantially higher with a landrace than with an improved variety.

The production of crop residues ignores the potential contribution of weeds. However, weeds can occasionally provide a substantial contribution to annual biomass production (Thomas, 1988; Scopel, pers. comm.). This may particularly underestimate actual organic residue production (*i.e.* crop and weed) in less intensive crop production systems (*e.g.* when weed control is incomplete and/or crop biomass production is limited).

Figure 5.6 depicts crop residue production in response to input use in its first two quadrants. It uses a standard production function (yield - input) as starting point in Quadrant I. The form of the production function is determined by biophysical factors and reflects the product of biomass production and harvest index.[22] Quadrant II links grain and residue production - a linear transformation based on a constant harvest index. The subsequent subsection highlights that produced crop residues are not necessarily available as mulch due to the existence of other uses. Quadrant III depicts the distribution of the residues produced over various competing uses, with the remnant remaining as mulch.[23] Socio-economic

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[21] In grain crops: $HI = Y_g * (Y_g + Y_r)^{-1} * 100$. Where HI: harvest index (%); Y_g: grain yield (Mg ha^{-1}); and Y_r: residue yield (Mg ha^{-1}).

[22] The production function depicted in Quadrant I could be further refined by specifying yield as function of input uptake and adding a further quadrant (IV) depicting input use efficiency (linking input uptake to application - Rabbinge, pers. comm. See for instance Wit, 1992).

[23] Actually depicted in Quadrant III of Figure 5.6 is a fictive situation where crop residues are subject to weathering (10% weathering index), extraction (2 Mg ha^{-1}) and reduced tillage (50% incorporation index). When residue production exceeds 6.5 Mg ha^{-1} sufficient residues would remain

factors enter Figure 5.6 in two distinct ways. First, they influence residue production directly through the choice of crop and input levels (Quadrants I and II). Second, they co-determine residue use (Quadrant III).

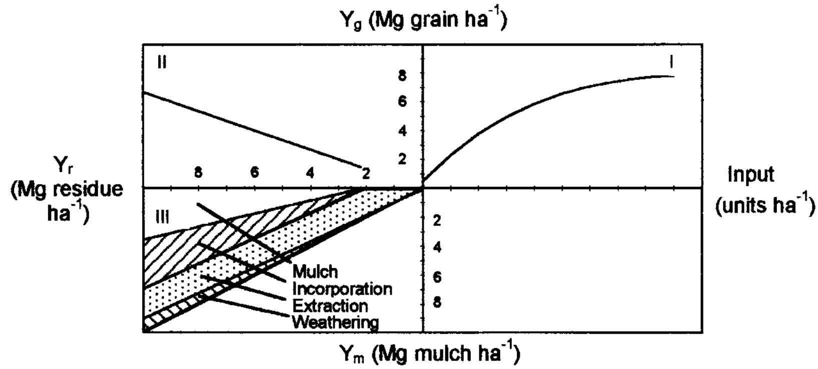

Figure 5.6 Three-quadrant graph showing the relationship between input use and grain yield [Y_g] in Quadrant I; grain and residue yield [Y_r] in Quadrant II; and residue yield and residue uses, with the remnant remaining as mulch [Y_m] in Quadrant III (adapted from Sain, 1996)

Residue utilisation

Residue production does not translate simply into its availability as mulch. In developing countries, residues have several uses (or destinations) that directly affect their availability as mulch. These uses may vary considerably between and even within regions, but typically include extraction, burning, incorporation and weathering.

Extraction - Crop residues are generally considered as agricultural by-products. However, in developing countries they have several productive uses and frequently are important sources of fodder, fuel, and/or construction material.[24] Such uses are reported for various regions, including Africa[25], Asia[26] and Latin America.[27] The intensive use of crop

as mulch.

[24] Rijn, 1982; Blaikie and Brookfield, 1987:30; Hurni, 1988; Bolton, 1991; Ofori, 1991; Unger *et al.*, 1991; Greenland *et al.*, 1994; Renard, 1997.

[25] Including West Africa (Hayward *et al.*, 1980; Bonsu, 1981; Hullugalle and Maurya, 1991; Laryea *et al.*, 1991; Baidu-Forson, 1994; Thiec, 1996) and East Africa (Thomas, 1988; Laing and Ashby, 1993; Pagiola, 1994b). For an overview see de Leeuw, 1997.

[26] Including Pakistan (Byerlee and Khan, 1992; Dove and Carpenter, 1992; Hussain and Erenstein, 1994); India (Laryea *et al.*, 1991; Kelley *et al.*, 1993); China and Bangladesh (Smil, 1987; Briscoe, 1992; Dazhong, 1993 in Pimentel *et al.*, 1995).

[27] Including Bolivia (Hanrahan, 1994; Wall, 1994); Central America (Choto and Sain, 1993); Mexico (Erenstein, 1997a).

residues in developing countries is in stark contrast with developed nations, where they generally have few economic uses (Heimlich, 1985; Cannell and Hawes, 1994). The relative importance of each use varies geographically and by crop, as does the degree of extraction. Residue use as fuel or construction material involves the harvest of residues - *i.e.* the physical export of these from the field. Residue use as fodder may involve (stubble) grazing or actual harvesting for later use. In general, when done, the harvest of residues is thorough, leaving little in the field.

Pre-plant burning - Crop residues may be burned *in situ*[28] prior to planting by the farmer or a third party - either intentionally or accidentally. Reasons for intentional burning include land clearing, fertility enhancement, weed/pest management, pasture management, hunting and well-being (Erenstein, forthcoming). The first three are particularly relevant for CRM. Burning traditionally provides a fast way to clear the agricultural field of residual biomass and thereby facilitates further land preparation and planting (Akobundu, 1987). Burning is also perceived to boost soil fertility.[29] It also provides a fast way of controlling various weeds, pests and diseases, both by eliminating them directly as altering their natural habitat (*e.g.* mulch as hide-out for snakes and rodents - Akobundu, 1978; 1987; Thurston, 1992; Ravnborg *et al.*, 1996). Burning is still widespread in developing countries. It also was a traditional practice in the developed countries,[30] but has increasingly disappeared. In some European countries, burning of residues is now illegal (Cannell and Hawes, 1994). In general, burning can be very effective for disposing of residues. However, it may be less effective when residue humidity is high or when there are limited or unevenly distributed residues (causing a non-uniform burn).

Incorporation - In arable[31] crop production, land preparation generally implies physical tillage before planting. The main purpose of this operation is to create a clean, uniform seedbed that facilitates crop establishment. To achieve this, the topsoil is typically inverted, thereby incorporating the residues remaining on the soil surface. The degree of incorporation varies over tillage systems - depending on such issues as implements, intensity and traction source (*i.e.* manual, animal traction or mechanised).[32]

Weathering - Even if not used for any specific purpose, the amount of residues diminishes over time due to weathering. This encompasses natural processes such as decomposition and erosion of residues. The rate of residue decomposition is largely influenced by ecological factors (moisture, temperature, and biological activity) and the nature of the residues (fragility, C:N ratio). Residue erosion by water and/or wind may be important in areas with steep slopes and/or strong winds. Weathering is a year-round on-going process, but the interval between harvest and the establishment of the subsequent crop

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[28] In contrast with burning *ex situ* as a fuel source (see residue extraction above).

[29] However, burning has a differential impact on soil fertility. It increases the short-term availability of some nutrients (*e.g.* P and K) and reduces soil acidity, but leads to a loss of other nutrients (*e.g.* N and S) and organic matter (Akobundu, 1987).

[30] For instance in the USA (Bolton, 1991); in Australia (Felton *et al.*, 1987).

[31] Arable is used here and elsewhere in the sense of fit for (semi-)mechanised tillage.

[32] ACC and CTIC (1994) have developed a residue scorecard that illustrates residue incorporation rates by implement and fragility of residues for mechanised systems. Kok and Thien (1994) have developed a simple computer model that calculates the same. Also see Allmaras *et al.* (1985:363).

is particularly relevant for CRM. Weathering is also more obvious between growing seasons as it is less masked by continuing biomass production. Weathering rates are largely exogenous but can be substantial and may largely eliminate existing crop residues - *e.g.* in areas with high termite activity[33] and/or prolonged exposure between growing seasons.

Most residue uses (with the exception of mulching) are irreversible, exclusive, and therefore dependent on the chronological order. For example, if burning has eliminated most residues, subsequent incorporation during ploughing will be minimal. However, in case of not burning, incorporation could be substantial. Indeed, some of the residue uses are near perfect substitutes for each other in terms of eliminating residues (see Box 5.1).

Box 5.1 Substitution possibilities for residue elimination

The zero till experience in the UK highlights the existence of substitution possibilities for rèsidue elimination. During the 1970s, zero tillage for small grains became increasingly popular. However, zero tillage eliminates the possibility of residue incorporation, whereas small grains generate substantial amounts of residue, which when left as mulch increase wetness and make crop management more difficult. Most farmers therefore simply burned them (substituting burning for incorporation). Subsequent public environmental concern severely curtailed the possibilities of burning. Consequently, farmers reverted to incorporation - thereby practically eliminating zero tillage from the UK (Cannell, 1981; Cannell, 1985 in Kuipers, 1991; Cannell and Hawes, 1994).

Implications for CRM

Mulching is the residual claimant - *i.e.* it is formed with the residues that are left over after the other uses. The residue balance (equation 5.1 above) stipulates that the sum of all residue uses equates (*in situ*) production for each location. Consequently, the other uses, as well as production, in general determine residue availability as mulch. So if a farmer wants to start retaining sufficient residues as mulch, he will have to adapt the other variables of the residue balance to make it compatible with CRM.

Let U_M^* denote the amount of residues required to surpass the 30% soil cover threshold (*e.g.* in Meso America, $U_M^* = 2$ Mg maize residue ha^{-1}). The residue balance can therefore be reorganised into the following condition for CRM (using the same notation as equation 5.1):

$$P - (U_E + U_B + U_I + U_W) \geq U_M^* \qquad (5.2)$$

If this condition is satisfied at the time of crop emergence, sufficient residues are retained to qualify as CRM. If it is not, either residue production (P) will have to increase or its alternative uses (left hand sum of U's) have to decrease in order to qualify as CRM. However, the possibility to modify each of these variables varies. For instance, weathering

33 Rijn, 1982; Wilson and Akapa, 1983; Bonsu, 1985; Thomas, 1988; Pagiola, 1994b; Mando, 1997.

is difficult to reduce given that it is an autonomous process and a direct result of the forces of nature.[34] In fact, weathering may even increase when residues are left *in situ* (*e.g.* when it triggers an increase in termite activity - Mando, 1997).

In some instances, residue production is considered excessive and farmers prefer to maintain some form of residue elimination - *e.g.* complete burning of wheat straw in the UK (Box 5.1) and Brazil (Castro *et al.*, 1993:354). To circumvent the issue, the possibility of partial burning of residues is now contemplated as a CRM-compatible alternative in residue excess situations (Felton *et al.*, 1987; Harris, 1996).[35]

In some semi-arid areas, levels of *in situ* residue production are so low that CRM appears doomed from the start (Unger *et al.*, 1991).[36] Conceivably, there is the option of importing sufficient residues into the field from an *ex situ* source (see 4.4).[37] In fact, farmers' use of cut-and-carry mulch for production agriculture has sporadically been reported - *e.g.* in Burkina Faso and Madagascar (Reij, 1994; Slingerland and Masdawel, 1996; Charpentier, pers. comm.). However, the major problem of mulch is the large quantities needed. *Ex situ* sources therefore impose a substantial cost in terms of transporting and handling (Wilson and Akapa, 1983; Thurston, 1992). Only occasionally are such costs sufficiently offset by substantial productive benefits.[38] In general though, *ex situ* mulch is not economically feasible on a production scale for staple food crops (Akobundu, 1987; Lal, 1989:94; Baidu-Forson, 1994).

Alternatively, increasing *in situ* residue production may look like an attractive proposition. However, it is relatively futile as long as mulching remains the residual claimant and other uses (such as burning, incorporation and weathering) are a function of total biomass. *Ceteris paribus*, this implies that an increase in production would result in an increase in such uses.

In general, it is not residue production, but residue use that tends to constrain mulch availability. CRM will therefore typically need to emphasise reducing the aggregate amount of residues eliminated through the other uses. This may imply numerous management adaptations. In this respect, CRM is generally incompatible with pre-plant burning and ploughing. In addition, further reductions may be needed in other competing residue uses. In fact, CRM resembles a basket of complementary management practices. As local factors determine both production and use of residues, the actual management changes needed to retain sufficient residues are site-specific.

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[34] Although the farmer may influence the weathering process somewhat. For instance, selecting a crop with non-fragile residues; using a non-destructive harvesting method; and limiting the time the residues are exposed to weathering (*e.g.* by altering the planting date - Erenstein, 1997a).

[35] For instance, in the Yaqui Valley of Northern Mexico partial burning of wheat straw is ensured by burning the residues in the early morning (high humidity) and prior to chopping (Harris, 1996).

[36] What is more, semi-arid areas tend to combine low residue production with high demand for residues as fodder - further limiting the potential of CRM (see Erenstein, forthcoming).

[37] Residue import could easily be included in the residue balance. *E.g.*, by dis-aggregating the P-term to reflect *in situ* (P_I) and *ex situ* (P_E) production.

[38] For instance, in Burkina Faso application of 6 Mg ha^{-1} *ex situ* mulch required 180 labour days ha^{-1}. Sorghum yields were however boosted from 140 to 774 kg ha^{-1} (Slingerland, 1998).

5.4 Technological complexity

One of the drawbacks of CRM is its inherent complexity. In some ways, it thereby makes an already complex situation even more so. This has implications at all levels of research and implementation, from the farmer up to the government official. Several underlying and interacting problems reflect this complexity.

The terminology problem - The controversy and confusion surrounding 'conservation tillage' (see 5.1) is directly related to the complexity of the technology. And with researchers still bickering over terminology, opinion is equally divided amongst other practitioners.

The adoption problem - Instead of a simple component technology, CRM involves a set of management practices. Substitution possibilities between different modes of residue elimination call for a joint consideration of all relevant management practices. The adoption of CRM by farmers is far from straightforward.

The measurability problem - The 30%-cover threshold determines CRM adoption. But how to obtain a reliable-yet-cost-effective estimate of soil cover? Experience in the USA has highlighted that farmers frequently overestimate such cover levels (Nowak and Korsching, 1983 in Nowak *et al.*, 1985; Dickey *et al.*, 1987) - though the terminology problem may be partly to blame. Field measurements are more objective but also more resource demanding (Box 5.2).[39] Other compounding issues are the time dimension of the estimate (preferably at crop emergence), the spatial dimension (partial or total coverage, both within a field and within the farm), and the fact that adoption of CRM is a multistage process. Indeed, one can distinguish partial adoption in terms of both area as well as CRM components. Measuring adoption of CRM is therefore not clear-cut, but rather fuzzy. The issue is further compounded when applying a retrospective view. This complicates the evaluation and visibility of the adoption process. Adding to the measurability problem is the reversibility of adoption.[40]

The ambiguous adoption threshold - Although specific, the 30%-cover threshold is rather arbitrary (see 5.2). This issue is compounded by the fact that it classifies adoption according to a dichotomous rather than a continuos variable. This is the more problematic in view of the asymptotic decline of relative erosion. Indeed, a soil cover of say 15%, would not be classified as CRM, yet still achieves a substantial reduction of erosion relative to an entirely bare soil. This further enhances the fuzziness of measuring the impact of adoption (*e.g.* see Figure 8.1).

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[39] The described aids focus on estimating the residue remaining as mulch. However, the residue balance (see 5.3) also distinguishes between the different destinations. The latter are not usually harvested or measured in any way, but can be estimated through empirical relationships. In this respect, the residue balance generally only provides a rough approximation.

[40] In view of the measurement difficulties to assess CRM adoption, data collection itself is probably a major source of error - much like other land degradation research for that matter (Stocking, 1987). In a number of ways the measurability problem is comparable to that encountered when assessing extension (Birkhaeuser *et al.*, 1991).

The causality problem - CRM is a dual-purpose technology. Therefore, either productivity and/or conservation considerations can motivate CRM adoption. Conservationists may like to emphasise the conservation rationale. Reality may well be otherwise, with farmers emphasising productivity, with conservation as added benefit. Emphasis on the productivity aspects can help explain incomplete, partial adoption of CRM practices. However, proving causality may well be difficult and tenuous - the more so as the explanatory linkages move further away from the site-specific characteristics of the soil conservation problem (Blaikie, 1989). A further complication is that motivation alone is not sufficient: whatever the motivation, there may be different available options to achieve the same goal (conservation or productivity).

The conservation decision rarely is a yes-no choice (SRAPTF, 1993). Instead, conservation adoption is a complex concept with several dimensions. "Understanding such a complex subject presents formidable research challenges" and "most research projects on farmers' conservation behaviour have been modest in scope compared to the complexities of the problem." (*ibid.*: 6). Conceivably, the same is true for the present study.

Box 5.2 Aids to estimate residue cover

Several aids to assess the degree of soil cover exist. These include:

- *field-based measurements:* A relatively simple (yet time demanding) technique is the transect-line methodology. This assesses the presence of residues at selected points along a demarcation string (Kok and Thien, 1994; Shelton *et al.*, 1994). Numerous other field-based measurement techniques exist, mostly developed in the USA. Morrison *et al.* (1993) provide an overview. Stocking (1994) describes techniques to measure vegetative cover;
- *photo comparisons:* Field conditions are compared with photos of known residue cover as reference (Felton *et al.*, 1987; Tripp and Barreto, 1993; Kok and Thien, 1994; Erenstein and Cadena, 1997);
- *empirical relations:* Using empirical constants derived elsewhere, residue cover can be estimated indirectly from a limited data set - *e.g.* based on quantity and type of residue (Gregory, 1982 in Allmaras *et al.*, 1985; Kok and Thien, 1994; - also see footnote 17).

Measures vary in terms of accuracy and cost. The preferred measure is therefore situation dependent.

5.5 Externalities and imperfect information

Soil conservation typically offsets the temporal and spatial externalities imposed by soil erosion. One may therefore expect that a soil conserving technology has a unequivocally positive social and environmental impact. However, the co-existence of several market imperfections implies that alleviating one may actually exacerbate another. The social and environmental impact of a conservation technology therefore depends on the net aggregate effect. CRM presents similar trade-offs. Its soil conserving potential is generally undisputed and the corresponding positive externalities will not be reiterated here. More controversial is its high dependence on herbicides - and the new problems this may impose.[41] The present section emphasises those market imperfections that are of specific relevance to the CRM technology, particularly in terms of externalities and imperfect information.

Externalities

The off-site effects of CRM are not straightforward. On the one hand CRM may *reduce* risks of surface water pollution by reducing both soil erosion and runoff. On the other, it may *increase* those risks through its reliance on herbicides and the surface application of agro-chemicals (Lal, 1991). Fawcett *et al.* (1994) highlight that, on average, CRM actually reduced herbicide runoff in the USA. However, herbicide runoff may be equal or increased in case of heavy rainfall soon after application; or when infiltration is limited (*ibid.*). Herbicide runoff also depends on soil adsorption. The soil tightly adsorbs some herbicides (*e.g.* paraquat and glyphosate).[42] Such herbicides do not form a significant threat to surface water as long as soil erosion is seriously controlled - as in the case of CRM. However, most herbicides are not tightly adsorbed by the soil, and are therefore liable to runoff loss (Fawcett *et al.*, 1994).

CRM and the resultant higher water infiltration may increase risks of leaching biocides and fertiliser (*e.g.* nitrates) - and thus of polluting groundwater. However, the evidence for this is not conclusive and the processes complex. In any case, biocide concentrations tend to be substantially higher in surface water than in shallow groundwater (Papendick *et al.*, 1991; Fawcett *et al.*, 1994). In developing countries, even less is known about the retention, biodegradation and movement of agrochemicals in surface and subsurface waters (Lal, 1989:160). This is especially problematic as rural people in developing regions often use surface water directly (Akobundu, 1987; Anderson and Thampapillai, 1990).

CRM also affects atmospheric pollution. On the one hand, it increases volatilisation of superficially applied fertiliser (NH_3) and biocides (Lal, 1989:161). On the other, it implies the temporary immobilisation of CO_2 - a green-house gas contributing to global warming - by maintaining the crop residues on the soil surface. Alternative crop residue management practices include incorporation into the soil - whereupon mineralisation and CO_2 release is accelerated - or pre-plant burning - whereupon CO_2 release is immediate. CRM thereby can convert annual cropping from a net source of CO_2 to a net sink (Kern and Johnson, 1993). As farmers forego the use of fire the emission of particulates is also drastically reduced. Times of widespread pre-plant burning traditionally give rise to severe air pollution problems.

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[41] However, herbicide use is not limited to CRM. For instance, in the USA there seems to be a heavy dependence on herbicides *regardless* of tillage and residue management (Lal, 1989). Consequently, CRM does not *necessarily* increase agricultural chemical requirements and costs (Bull, 1991 in WRI *et al.*, 1992; Fawcett *et al.*, 1994; Sandretto and Bull, 1996). This is contrary to what was expected in some of the early works (*e.g.* Christensen, 1984). Nonetheless, the herbicide dependence conflicts with current trends to make agriculture 'greener', particularly in Europe.

[42] Once paraquat reaches the soil, it is strongly adsorbed by soil colloids and becomes inactive (Wauchope *et al.*, 1985; Tasistro, 1989a,, 1989b; Violic *et al.*, 1989b). However, its prolonged and intensive use by some farmers in Latin America makes one ponder if there really is no soil health cost.

By foregoing the use of fire, CRM also greatly reduces the risk of wildfires and the subsequent damages these impose on ecosystems and property (Ravnborg *et al.*, 1996). For example, in the Mexican State of Chiapas, burning of residues was identified as the major cause of forest fires (Sandoval, 1994). In fact, protecting forest resources was part of the rationale for a recent law that severely restricts burning as a land preparation measure in the state.

CRM therefore brings into play a number of environmental implications that not only transcend the farm boundary, but also transcend the traditional externalities associated with soil conservation. However, the net environmental impact remains fuzzy and controversial. Valuing such impact in economic terms to assess the social implications is even more problematic. Indeed, such valuation is subject to the methodological difficulties reviewed in Part I and will be highly site-specific.

Imperfect information

Imperfect information implies that not all implications of a decision are known at the time of making that decision. That is, there may be a time lag between making a decision (*e.g.* applying a new technology) and the realisation of its full costs.[43] These costs are real but unknown to the decision maker at the time of decision. The human health costs of agrochemical use are particularly relevant in this regard, as CRM tends to rely on the use of herbicides.

Pingali and associates have highlighted the health impact of biocide - especially insecticide - use in the Philippines by costing biocide-related illness and the associated loss in farmer productivity (Rola and Pingali, 1993; Antle and Pingali, 1994; Pingali and Roger, 1995; Pingali and Gerpacio, 1996). When farmers' health costs are internalised, the economic balance shifts to natural control (Rola and Pingali, 1993; Faeth, 1994). Evidence of biocide-related health costs in other developing countries is incomplete, but anecdotal evidence suggest that they are seriously under-reported (Conway and Barbier, 1990).

Two issues tend to confound the debate on health costs. First, not all biocides are equally hazardous. For instance, as a group, insecticides are substantially more dangerous than herbicides.[44] Second, distinctions between biocides are muddled by nomenclature. *Pesticide* is used in both a narrow and a wide sense. In the narrow sense, it denominates killing agents of detrimental animals (insects, rodents, birds, etc.). In the wide sense, it is synonym for biocide - *i.e.* an umbrella term for all killing agents (including those to combat detrimental animals, diseases, and weeds).[45]

Most modern herbicides are organic compounds relatively non-toxic to man and animals - belonging to class III and IV of the toxicity rating scale (Marsico, 1980:78; Akobundu, 1987; Violic *et al.*, 1989b).[46] Notwithstanding, *there is no such thing as a completely safe*

[43] Princen (1997) has labelled this 'shading' in terms of casting a shadow or obscuring an image.

[44] Biologically, humans have more in common with insects than plants. As biocides affect biologic processes, the dangers of insecticides are concomitantly greater.

[45] This is a direct legacy of the confounding use of the word 'pest' itself - also being used both in the wide and narrow sense.

[46] The scale distinguishes 4 classes: I Highly toxic; II Moderately toxic; III Slightly toxic; and IV

herbicide (Kasasian, 1971).[47] Furthermore, it is the dose that makes the poison (Ottoboni, 1984 in Akobundu, 1987). Toxicity reflects the inherent harmful effect of a chemical.[48] Of more concern, is the *hazard* it imposes: *i.e.* the risk of harm associated with its use. Indeed, toxicity frequently reflects exposure to acute doses. In contrast, farmers are exposed regularly to small doses over long periods. Such cumulative effects are inevitably more difficult to recognise (Kasasian, 1971).

Within a particular category of biocides the dangers differ. Pingali and Gerpacio (1996) highlight that the predominant insecticides in Asia are of the highly hazardous types, mainly as they are substantially cheaper than the safer alternatives. Herbicide use tends to suffer the same fate in developing countries, with farmers opting for cheaper yet more dangerous alternatives. For instance, paraquat (a broad-spectrum herbicide) is very popular in Latin America. But paraquat is one of the most dangerous herbicides (class II), with very serious toxic effects in mammals (Barnes, 1976; Akobundu, 1987). Glyphosate - another broad-spectrum herbicide but in toxicity class IV - is safer to handle than paraquat but also more expensive (Akobundu, 1987; Violic, 1989b).[49] In this regard, paraquat may be viewed as a merit good - not subject to market or government failure, but to preference failure (Opschoor, 1994).

The on-farm dangers of biocide use are well established in developed countries - to the point that the use of many chemicals is severely curtailed (Princen, 1997). Yet, some of the banned chemicals are freely available in developing countries. Compounding the issue, the hazards of biocide use are concomitantly greater due to (i) limited human capital; (ii) lax safety measures; and (iii) the mode of application. The safe and effective use of modern chemical inputs imposes a high information demand (Runge, 1990 in Princen, 1997). For example, herbicide use requires adequate knowledge of basic properties of products and application requirements. In developing countries, farmers often lack this capacity (Tasistro, 1994). Hence the need to condense complex messages into several simple usage rules (Pingali and Gerpacio, 1996). The hot tropical climate makes the wearing of full protective clothing impracticable in many developing countries (Kasasian, 1971; Akobundu, 1987). Many farmers ignore the minimum safety standards for application and storage. Indeed, safety measures in developing countries are notoriously lax (Princen, 1997). Biocides are generally applied with a backpack sprayer in developing countries. This mode of application is more hazardous than mechanised motorised application (Akobundu, 1987). High weeds and steep slopes may further complicate safe application.

Many farmers in developing countries have learned about agrochemical use by doing (Erenstein, 1996).[50] By now, many Mexican farmers have experienced biocide-related

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Practically non-toxic (Akobundu, 1987:321). Herbicides are less dangerous than frequently thought - *e.g.* aspirin and table salt also fall in toxicity class III (Kasasian, 1971; Akobundu, 1987; Avery, 1996).

[47] By definition all biocides are toxic to some form of living organism (Akobundu, 1987).

[48] One can distinguish between acute, sub-chronic, chronic and delayed toxicity (Akobundu, 1987).

[49] Although the expiration of its patent in 1991 has put a downward pressure on its price.

[50] This has wider ramifications than human health costs only. Indeed, there may be real efficiency gains by using herbicides more efficiently and effectively. There may also be other environmental

intoxication symptoms - *e.g.* up to 45 % of farmers in the Fraylesca area of Chiapas (van Nieuwkoop *et al.*, 1994:46). The use of carbofuran - a highly toxic insecticide - as seed treatment is especially notorious. Some Mexican day labourers attempt to internalise the health cost by demanding a 33% surcharge whenever they have to sow with this chemical (Erenstein *et al.*, 1998).

Therefore, the human health costs of biocide use in general, and herbicide use in particular, are likely to be more severe in developing countries. Further, biocide-related health costs are not limited to the farmer applicator. There is a greater accessibility and exposure to chemicals for the entire farm household, and domestic accidents are common (Pingali and Gerpacio, 1996).[51] Hence, the need to address imperfect information.

Discussion

With the reliance of CRM on herbicide use, environmental and health costs are worthy of attention. However, the labour saving potential of herbicides can be exceptionally attractive. Indeed, herbicides have spread substantially faster than CRM. The ideal herbicide would fulfil its purpose (*i.e.* weed control) efficiently and effectively, without imposing a hazard for the user's health or the wider environment (*e.g.* by breaking down into harmless substances immediately after use - Tasistro, 1989b). Such an ideal herbicide may not yet exist - at least at an affordable price for developing country farmers. But with the advent of CRM world-wide - and in the USA in particular - new chemicals that better meet the needs of the farmer and the environment are increasingly being developed and marketed (Laflen and Onstad, 1994). Therefore, the prospects for CRM's net social and environmental effect are likely to improve.

5.6 Concluding summary

The present chapter reviewed the crop residue mulching (CRM) technology. CRM can be defined as a technology whereby at the time of crop emergence at least 30% of the soil surface is covered by organic residue of the previous crop. The present study proposes CRM as the most adequate term for the technology in view of the substantial controversy and confusion surrounding existing terms, particularly conservation tillage.

CRM is a dual-purpose technology that combines conservation and productivity effects. Its conservation potential hinges on the presence of the crop residues as mulch. This mulch provides a protective layer to the soil surface that is extremely effective in halting soil erosion and also amends the soil ecology. Its productivity potential is two-fold. First, the mulch tends to stabilise, and occasionally even enhance, crop yield. Second, it implies factor substitution and input use efficiency alterations. Whether the productivity effects are actually economically attractive is bound to be site-specific, being dependent on technology, preferences, resources and institutions.

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costs in relation to 'misuse', as when farmers clean backpack sprayers in streams.

[51] *E.g.* due to temporary storage in other (non-labelled) containers; the re-use of empty biocide containers (Barnes, 1976; Akobundu, 1987).

The conservation and crop yield effects are largely embodied in the same component: *i.e.* in the mulch. However, the labour and capital productivity effects are not. Farmers may therefore adopt the more attractive factor saving changes, without actually ensuring retention of sufficient residues as mulch. Indeed, a number of crop management practices are a necessary, but not sufficient condition for CRM adoption.

All necessary conditions can be grouped in the residue balance. This stipulates that the sum of all residue uses equates (*in situ*) production for each location. Mulch is the residual claimant - *i.e.* the difference between residue production and the sum of alternative residue uses (extraction, pre-plant burning, incorporation and weathering). Adoption of CRM requires adapting the variables of the residue balance so as to make it compatible with CRM - *i.e.,* ensure enough residues are retained in order to satisfy the 30%-cover threshold. The changes needed to satisfy the threshold are site specific: local factors determine both production and use of residues. Actual adoption may imply numerous management adaptations. Therefore, although CRM is considered to be a technology, it resembles more of a basket of management practices that are complements.

In fact, the technology is inherently complex - the existence of complementary practices being only one particular example. Other issues that compound the assessment of the technology include terminology, measurability, causality and the ambiguous adoption threshold. In addition, CRM also embodies some new market imperfections that undermine its potential as dual-purpose technology. First, CRM gives rise to new externalities - both positive and negative - that make its net environmental impact fuzzy and controversial. Second, CRM exacerbates imperfect information - particularly in relation to the health costs associated with its reliance on herbicides. The herbicide-related environmental and health costs are particularly worthy of attention. Indeed, farm households increasingly adopt herbicides in view of the labour saving potential - regardless of CRM or the hazards associated with their use.

CRM is a standards-based conservation technology. Whether it is actually privately efficient to satisfy the conservation standard remains to be seen. To help answer this question, Chapter 6 develops a framework to assess the socio-economic implications of CRM adoption.

CHAPTER 6

A CONCEPTUAL FRAMEWORK TO ASSESS THE SOCIO-ECONOMICS OF CRM

The current chapter presents a conceptual framework to assess the socio-economic implications of using the crop residue mulching (CRM) technology in developing countries. Available data in relation to CRM tend to be biased towards biophysical aspects, mainly reflecting experimental data sets. Socio-economic aspects are typically underreported and/or neglected. However, socio-economic aspects tend to determine land and technology use. The conceptual framework therefore assesses the implications of CRM-based crop production within the context of the farm household and the institutional setting.[1]

The farm household can be variously viewed. A particularly convenient way is to see it as a system, where the farm household is an envelope of various productive and consumptive activities. Each individual activity can be viewed as a subsystem - *e.g.* crop production; livestock production; non-agricultural enterprises; and home(stead) activities. In turn, the farm household itself is part of the wider biophysical and socio-economic environment (see Figure 6.1).

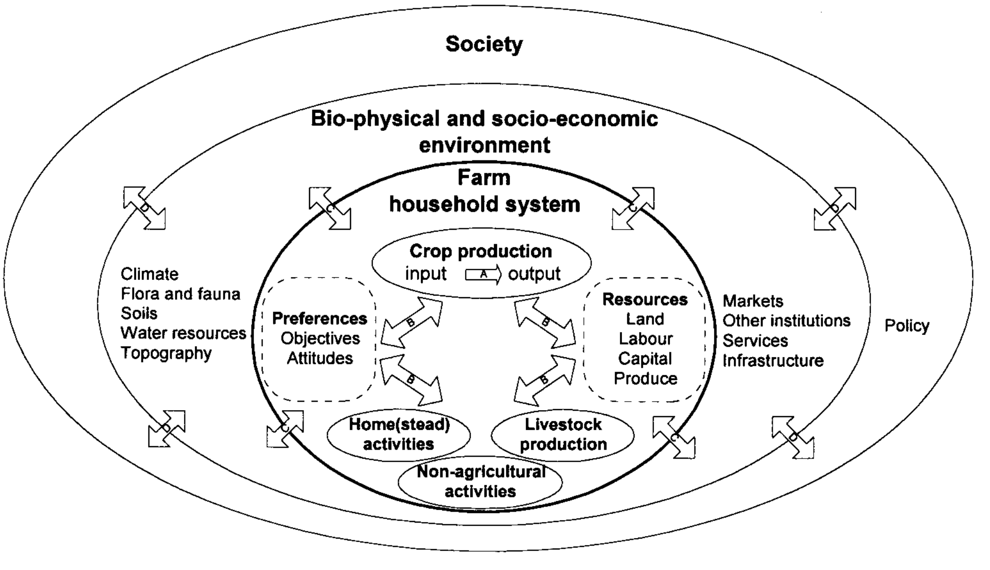

Figure 6.1 The farm household system (adapted from Bosman *et al.*, 1997)

[1] The framework thereby contributes to the adoption school of economic analysis of soil conservation (see Chapter 3, Section 3.3). It specifically outlines how (production) technology, farm household and institutional factors influence the farm household decision whether to adopt this particular (conservation) technology.

Farm household decisions are conditioned by (i) internal and (ii) external variables. *Internal conditioning variables* include the farm household's preferences and resources. Preferences encompass the household's set of objectives and attitudes. Resources encompass the farm household's endowment of land, labour, capital[2] and stocks of agricultural produce. The wider biophysical and socio-economic environment encompasses a number of *external conditioning variables*. Biophysical variables include climate, natural flora and fauna, soils, water resources and topography. Socio-economic variables include markets, non-market institutions, services and infrastructure. In turn, society can be viewed as an additional shell which influences - and is influenced by - the biophysical and socio-economic environment in which the farm household operates. Government policy is one societal variable that has a profound influence on the socio-economic variables.

The numerous system components are variously linked - both between and within the different tiers of the system. The linkages make a number of components mutually dependent - albeit in different degrees. This makes some system components inherently dynamic as they constantly adapt to internal and external changes. Simultaneously, it makes others inherently static - as they remain subdued by overarching conditioning variables.

The farm household is allocating resources on a daily basis. The balance outcome of these production and consumption decisions alters the household's resource base over time, and thereby determines the continuity of production and consumption into the future (Moll, 1992).

Imperfect institutional arrangements are a predominant feature of developing countries. Markets for production factors and products are typically incomplete and their structure and performance imperfect (*e.g.* credit and insurance markets tend to be absent and/or imperfect, Reardon, 1997). The institutional imperfections have a profound influence on farm household decision making, as reflected internally by the choice of assets, activities and technology; and externally by the household's participation in markets (Moll, 1989).

Typically, farm households in developing countries are only partially engaged in factor and product markets (Ellis, 1988). Consequently, the farm households' choice of enterprise and technology tend to reflect resource endowments. For instance, households utilise mainly family labour in farm production, whereas the seasonality of agriculture implies its use is very irregular throughout the year. This results in high marginal returns for relatively scarce factors (Moll, 1992) - typically capital, but potentially also land and labour.[3] Limited participation in product markets - as buyer and seller - implies enterprise choice is in part conditioned by the households' consumption requirements. Indeed, many farm households try to ensure food security through self-sufficiency.

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[2] Capital refers here to all assets other than land and (agricultural) produce. Based on their primordial value (production, consumption or liquidity), assets can be categorised as (i) productive (*e.g.* capital goods; human capital); (ii) consumptive (*e.g.* consumer goods); and (iii) liquid (*e.g.* cash; debts/claims and credit reserve - Moll, 1992).

[3] Labour scarcity is typically associated with a combination of other binding factor constraints and the seasonality of agriculture. For instance, the area actually cultivated under low-external input systems may well be constrained by the labour available for land preparation or weeding.

Most farm households in developing countries have a limited resource base, whereas their factor proportions are co-determined by institutional imperfections - *e.g.* high transaction costs in converting assets; limited access to credit and insurance markets. This, combined with risk aversion, ensures that households typically maintain a substantial share of their resource base as relatively safe but low productive assets (*ibid.*). These assets form a reserve for unforeseen consumption needs (*e.g.* illness).

Notwithstanding institutional imperfections, the rural economy in developing countries has increasingly commercialised. For the farm household, commercialisation implies an increasing market orientation, substitution of external for internal inputs, and a gradual decline of integrated farming systems towards specialised enterprises (Pingali, 1997). It also induces institutional change as family links weaken and contractual rather than reciprocal terms increasingly define social transactions. Commercialisation is generally not a frictionless process and may have significant equity and environmental consequences (*ibid.*; Garcia-Barrios and Garcia-Barrios, 1990).

The present chapter provides a framework to assess how CRM fits in the farm household system. It thereby follows a stepwise expanding analysis (Bosman *et al.*, 1997). The first section delimits itself to the crop activity level. It delineates the implications for crop production in physical terms - *i.e.* how CRM alters the crop production function and thereby input and output levels. The second section places the CRM-based crop activity within the context of the farm household. It delineates the implications for other farm household activities in terms of resource use. The third section delineates the influential nature of the wider environment in which the farm household operates - thereby emphasising the institutional setting. The subsequent two sections bring together the above implications and come to an overall assessment of CRM. The fourth section does so for a private assessment - *i.e.* the farm household's viewpoint. The fifth section does so for a social assessment - *i.e.* society's viewpoint - and thereby derives the corresponding policy implications. The sixth section presents a number of methodological considerations for the application and validation of the framework. The last section provides a concluding summary. The framework can be variously applied - as will be illustrated empirically in the subsequent chapters.

6.1 Crop system implications

CRM inherently alters the physical production function (relation A in Figure 6.1) and thereby affects both crop system output and input. Chapter 5 already reviewed the implications for sustainability and productivity (Section 5.2) and residue management (Section 5.3). These issues will only be summarised here. Emphasis will be on assessing crop management implications and the corresponding changes in physical input and output levels. Figure 6.2 conceptualises the implications that will be discussed hereafter.

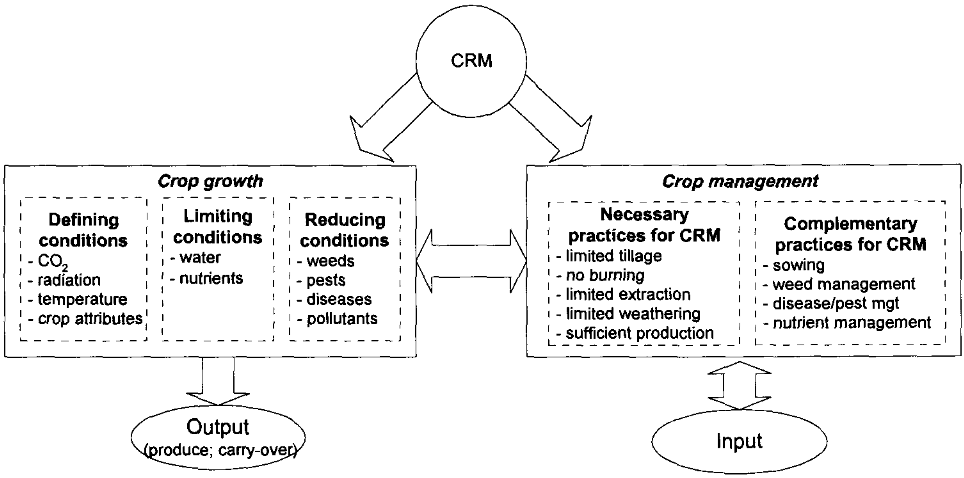

Figure 6.2 Crop system implications of CRM

Necessary practices for CRM

CRM implies the retention of sufficient residues on the soil surface to surpass the 30%-cover threshold and thereby form an effective mulch. The residue balance (see 5.3) stipulates that aggregate residue use equates (*in situ*) production. With mulch as the residual claimant, a set of necessary conditions for CRM can thereby be derived:

- *Limited incorporation:* The amount of residues incorporated during tillage should be limited. Hence, the emphasis on reduced and zero tillage in CRM-based production systems. Ploughing is generally incompatible with CRM because it is so efficient in incorporating residues;
- *No burning:* Residues should not be burned as residue management and/or land preparation practice;
- *Limited extraction:* The amount of residues extracted as fodder, fuel and/or construction material should be limited. Intensive residue harvesting and/or grazing is generally incompatible with CRM;
- *Limited weathering:* The amount of residues lost to weathering (decomposition; erosion) should be limited. Fragile residues and/or an 'aggressive' ecology (*e.g.* hot and humid; high levels of consumption by soil biota) may imply incompatible weathering losses;
- *Sufficient residue production:* Residue production should be sufficient so as to retain enough residues to surpass the 30%-cover threshold in the subsequent cycle. Marginal crop production conditions and/or crop characteristics may imply incompatible levels of residue production.

Two issues warrant highlighting. First, the necessary conditions are only sufficient for CRM if the entire set is simultaneously satisfied. Second, except the no-burning condition, individual conditions are not absolute entities. Instead, they are relative entities dependent on the other residue balance components and thereby site-specific.

The necessary conditions can be mirrored against the actual situation. Discrepancies thereby indicate the crop management adaptations needed to meet the necessary conditions for CRM - *i.e.* necessary for its adoption. The actual adaptations needed depend on the current location-specific practices and residue production. Most necessary practices follow directly from the necessary conditions and may include reducing tillage, eliminating burning and/or reducing extraction. The protection of residues may be a necessary practice whenever it is a third party that burns and/or extracts the residues (*e.g.* by maintaining a fire-break; by fencing the field; by chopping residues to make subsequent collection more difficult - Matthews, 1998).

Low residue production levels may be a result of crop characteristics. CRM may then imply the need to adapt crop choice - or alternatively, CRM would be limited to those cropping patterns with sufficient residue production. Incompatible weathering and residue production levels that are ecologically determined are generally more problematic to address (*e.g.* areas that are (semi-)arid or have high termite activity). They thereby tend to curtail the possibility of CRM adoption.

Complementary cultural practices for CRM

Necessary practices ensure the retention of sufficient residues. In turn, these changes may imply other complementary adaptations in order to be able to grow a crop and/or maintain yield levels. Such complementary crop management practices may include adaptations to sowing and the management of nutrients, weeds, pests and diseases.

Sowing - CRM implies a seedbed covered with residues. This inherently complicates the sowing operation, although the exact implications depend on the used sowing implement and traction source. Some manual and animal-drawn implements may not require adaptation, but sowing does generally become more difficult and more time consuming.

In arable systems, two mechanised sowing options are potentially compatible with CRM. The first option uses a direct seed drill to establish the crop through the mulch. Such drills are specially designed for CRM and can be used on un-tilled (but arable) soil. The second option uses a conventional seed drill and implies the need to maintain at least some form of tillage. This option may thereby still incorporate a substantial portion of the residues (*e.g.*, two passes with a disk harrow will incorporate half the residue present - ACC and CTIC, 1994). This can be an issue, especially in areas where mulch availability is already limited. Further, even low residue levels may still hamper the functioning of the seed drill.

Weed management - CRM curtails the intensity of soil tillage and use of pre-plant burning. It thereby foregoes the corresponding weed control effect these measures would have achieved. CRM typically relies on herbicides to substitute for such physical measures. The corresponding factor implications depend on actual production technology, the new herbicide technology and site-specific factors. For instance, chemical weed control implies the use of herbicides, an application implement (*e.g.* a backpack sprayer) and water for its application. In turn, labour needs for application and water haulage depend on herbicide type, application technology[4] and site-specific factors (*e.g.* field characteristics; the location of the water source).

The reliance on herbicides for weed control makes their effective use imperative (Sandretto and Bull, 1996). However, herbicide use is knowledge intensive: it requires adequate knowledge of basic properties of products and application requirements (Ward *et al.*, 1987; Hurni, 1988; Tasistro, 1994). For instance, some herbicides are incompatible with certain crops. The choice of main crop, intercrop and/or subsequent crop may therefore limit the choice of herbicides (*e.g.* preclude the use of residual herbicides like atrazine and 2,4-D - Tasistro, 1989a; Violic *et al.*, 1989b). The knowledge intensity also implies that human skills are likely to have a profound influence on herbicide use efficiency.

CRM itself also affects herbicide use efficiency - for instance, due the presence of the mulch. Further, CRM affects the incidence of weeds (in terms of species and numbers). First, mulch inherently alters the soil ecology and thereby weed growth (*e.g.* a substantial mulch may in itself have a weed controlling effect). Second, the implied changes in weed management feed back into weed incidence. For instance, the increased reliance on herbicides can induce changes in weed patterns (Rijn, 1982; Akobundu, 1987). Also, CRM conceivably allows for a more timely and effective weed management and can thereby gradually deplete the weed seed bank. CRM thus simultaneously affects (i) the incidence of weeds, and (ii) weed management (Figure 6.3). Furthermore, these effects are interrelated and have an intertemporal dimension.

Pest and disease management - Many of the weed management considerations also apply to pest and disease management. Incorporation and burning of crop residues frequently are used as phytosanitary measures, whereas CRM curtails their use. By retaining the crop residues, CRM may enhance the carry-over of both pest organisms and their natural enemies. In fact, many pests respond uniquely to the CRM-induced alterations in the crop-soil ecosystem (Forcella *et al.*, 1994). CRM thus simultaneously affects the incidence and management of pests and diseases (Figure 6.3).

Nutrient management - CRM affects nutrient management by altering (i) nutrient availability; and (ii) fertiliser use efficiency. CRM retains the crop residues as mulch - instead of extracting, burning or incorporating them. This inherently alters *nutrient availability* through the corresponding effects on the soil ecology and the release, immobilisation and loss of nutrients. CRM profoundly alters *fertiliser use efficiency* by affecting the (i) mode of application; (ii) mode of action; and/or (iii) effective loss (see 5.2.4). The two effects are interrelated and have an intertemporal dimension.

[4] For instance, backpack sprayers use large volumes of water (*e.g.* 200 l ha^{-1}) compared to ultra-low volume (ULV) and very-low volume (VLV) sprayers (*e.g.* 10-30 l ha^{-1} - CFU, 1997).

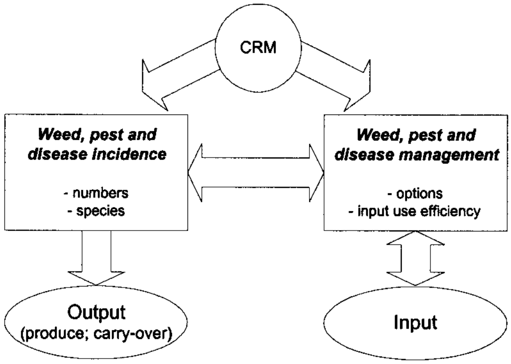

Figure 6.3 Implications of CRM for incidence and management of weeds, pests and diseases

Input-output implications

The necessary and complementary practices for CRM alter the input into the crop system, particularly in terms of labour, capital and crop residues. The factor alterations reflect both substitution and input use efficiency considerations. Further, these changes are inherently site-specific depending on biophysical and technological factors.

The factor input alterations have both a quantitative and qualitative component. CRM alters the absolute quantity of labour input: its overall effect tends to be labour saving. However, this is the net result of two opposing forces. CRM may imply labour savings for some practices (*e.g.* land preparation and weeding), but increases for others (*e.g.* protecting crop residues and sowing). This gives rise to the qualitative component. First, the seasonality of agriculture implies these changes alter the labour calendar. Second, an eventual gender-based division of labour may imply differential labour implications.

CRM has similar quantitative and qualitative implications for the capital input. It implies increases for certain capital components (*e.g.* herbicides; knowledge), and decreases for others (*e.g.* tillage implements). For other physical inputs the implications are ambivalent (*e.g.* pesticides; fertilisers; sowing implements).

CRM is complex and knowledge intensive - especially when compared to conventional (no mulch) systems (Nowak *et al.*, 1985; Rickson *et al.*, 1993; Kok and Thien, 1994; Stocking, 1994). For it to be effective, the farmer needs to possess a number of managerial skills to cope with this complexity. Or alternatively, possess the learning ability and invest the necessary time to adequately develop these skills. Further, CRM tends to reverse long established cultural practices and thereby may conflict with traditional knowledge systems. Many farmers frequently have to overcome a mental hurdle upon changing from traditionally 'clean' to so-called 'trash'-farming. The inherent complexity and learning processes imply input use efficiency is likely to improve over time.

The output of a crop system encompasses two components. The most obvious component is the *physical produce*: the season's production of the main agricultural product (*e.g.* grain) and possible by-products (*e.g.* crop residues). In addition, there is a *carry-over component*. Each crop season affects the soil resource (positively and/or negatively) and thereby alters the resource's productivity in the subsequent seasons. CRM affects both output components.

In terms of crop produce, CRM affects: (i) yield level; and (ii) yield stability. CRM profoundly alters the biophysical conditions affecting crop growth (left-hand side of Figure 6.2; Section 5.2). Therefore, the net effect on the *yield level* of main and by-products in the short term is uncertain and inherently site-specific (being dependent both on the biophysical conditions and their eventual adaptation through complementary crop management practices). In many instances the net effect on main product yield will be negligible, unless CRM alleviates - or exacerbates - a binding constraint for crop growth. CRM does tend to enhance *yield stability* when water is limiting through its inherently water conserving effect.

In terms of the carry-over component, CRM affects: (i) soil conservation; and (ii) soil ecology. CRM has a profound *soil conserving* effect, which implies yield levels will be more adequately maintained over time. By inherently altering the *soil ecology*, CRM affects the dynamics of the various biophysical conditions affecting crop growth (*e.g.* water, nutrients, pests).

Discussion

CRM typically implies a major overhaul of the crop system, affecting both output and input levels. These biophysical implications are interdependent and dynamic, and thereby inherently site-specific, varying both over space and time. An illustrative example of carry-over is the case of the crop residues. For a given cycle, the necessary practices for CRM - and thereby input implications - are directly dependent on the residue output of the previous cycle. Whether the changes implied by CRM are in the interest of the farm household depends on the other system components - both within and outside the farm household. The subsequent sections will review the implications of the input-output changes for the different system components.

6.2 Resource implications for the farm household

CRM-based crop production alters the flow of resources that are drawn from and contributed to the pool of farm household resources. Next to the crop system where CRM is applied, the farm household typically encompasses various other productive and consumptive activities - *e.g.* livestock production; non-CRM based crop production; non-agricultural enterprises; and home(stead) activities. How do the CRM-induced changes affect these other farm household activities? Figure 6.4 conceptualises some of the implications. Some of the CRM-induced changes are likely to enhance the farm household's productive and/or consumptive possibilities, others to compete with existing activities. These implications are inherently site-specific being dependent on the nature of the other farm household activities. The present section analyses these implications in relation to production factors and crop produce.

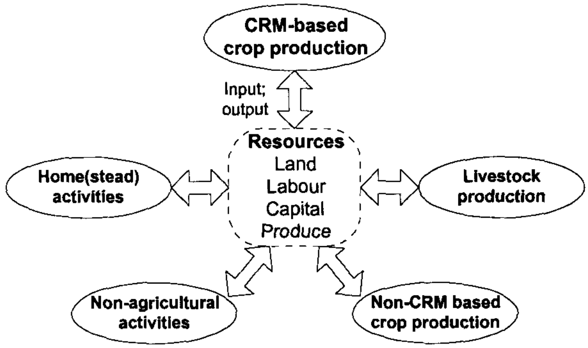

Figure 6.4 Implications of CRM for farm household resources

Land-related implications

The land-related implications of CRM for the farm household are confined to livestock production and non-CRM based crop production (Table 6.1).[5] Four distinct implications can be identified. First, the application of CRM alters the land resource itself through its carry-over effects in terms of soil conservation and soil ecology. It thereby inherently alters the quality and the productive capacity of the resource over time. This affects the productivity of subsequent land use activities on that land - including non-CRM and/or non-crop based activities.

Second, CRM may curtail subsequent land use options on CRM land. The implications of CRM transcend the specific crop cycle where it is applied. It typically implies the need for a year-round land use management that is compatible with CRM. This may directly affect other household activities that otherwise could have used the same land. For instance, in developing countries crop land is often used as pasture land during the dry season (an issue elaborated below upon discussing crop residues). Further, residue retention may conflict with established crop rotations (*e.g.* the emergence of a chickpea catch-crop was adversely affected by the presence of maize stubble in Jalisco, Mexico - Mendoza *et al.*, 1992).

Third, CRM may enhance land use options on CRM land. For instance, it may widen the conceivable crop choice by lengthening the time actually available for crop growth - *e.g.* by conserving water and providing a more flexible and timely crop establishment. Further, by reducing the turnaround time between crops it may enable the cultivation of a second crop. Also, by foregoing the use of pre-plant burning perennial species can be more easily integrated (*e.g.* agro-forestry).

[5] The farm-household implications for the land and other resources can be likened to the structure of a linear programming model (Moll, 1992). The rows of Table 6.1 could be specified as resource constraints; the columns as the input/output vectors. Still lacking would be the contribution to and the specification of the objective function.

Fourth, CRM may alter land use on non-CRM land, particularly in land extensive systems. CRM reduces the need for periodic fallowing, by more adequately maintaining the productive potential of the land resource. This frees land that otherwise would have been fallowed for alternative use. CRM may also alleviate crop management bottlenecks - particularly for land preparation and weeding - and thereby enable an extension of the crop area.

Table 6.1 Utilisation of production factors and crop produce by farm household enterprises

	Farm Household Activity				
	CRM-based crop production	Livestock production	Non-CRM based crop production	Non agricultural activities	Home(stead) activities
Land	Crop land	Pasture and forage land	(Other) Crop land	-	-
Labour	Crop management	Livestock management	(Other) Crop management	Work	Leisure; reproduction/care
Capital	Working capital; implements	Working capital; herd investment	Working capital; implements	Working capital; capital goods	Daily consumption; consumer durables
Crop produce [a]	Residue as mulch	Grain and residue as fodder	-	-	Grain as food; residue as fuel & construction material

[a] Assumes a cereal crop and thereby equates grain with main-product, crop residues with by-product.

Labour-related implications

The labour-related implications of CRM for the farm household cut across all activities: all activities draw on labour for production and/or consumption purposes (Table 6.1). Three distinct implications can be identified.

First, CRM has a quantitative effect on the labour available for other activities. Overall, CRM-based crop production tends to be labour saving and thereby frees labour for alternative use (productive or leisure). Second, CRM has a qualitative effect in terms of the labour calendar and an eventual gender-based division of labour. These effects may disproportionately affect other activities by exacerbating and/or alleviating the aggregate workload over time and/or gender. Third, CRM may also alter the actual labour input of other activities. By retaining the residues as mulch, CRM typically augments the labour spent on the extraction of alternatives to substitute for the residues. For instance, in the case of using residues as household fuel, CRM may imply a substantial increase in labour needs for fuel collection (*e.g.* in Niger, where it disproportionately affected women - Matthews, 1998). In much the same way, CRM may imply a substantial increase in labour needs for livestock production (*e.g.* time spent on fodder collection and/or herding).

Capital-related implications

The capital-related implications of CRM for the farm household also cut across all activities: all activities draw on capital for production and/or consumption purposes (Table 6.1). Three distinct implications can be identified.

First, CRM may imply additional demands for short-term finance (*e.g.* to pay for herbicides). These demands are likely to compete with the demands of other activities (*e.g.* working capital; daily consumption) for typically scarce cash and other liquid assets. Second, CRM also may imply additional demands for long-term finance (*e.g.* to finance investments in herbicide application equipment; sowing equipment; fencing). Such demands are again likely to compete with the demands of other activities (*e.g.* capital goods; consumer durables). Third, CRM may alter the use of capital goods already owned by the farm household. Dependent on the other farm household activities, some assets - *e.g.* plough; conventional seed drill; other tillage implements - may be less intensively used or simply become redundant. Other assets (*e.g.* herbicide application equipment; human capital) are likely to be more intensively used.

Crop produce related implications

The crop produce related implications of CRM for the farm household revolve around the internal use of crop produce for livestock production and/or human consumption purposes (Table 6.1). Two distinct implications can be identified. On the one hand, CRM alters the crop produce yield - in terms of level, oscillation and trend - both for main and by-products. This tends to stabilise the pool of crop produce available for internal use over time. It thereby reduces the need to maintain buffer stocks of produce or other assets against productive shortfalls. On the other, CRM adds to the existing internal demands for the crop residues. This restricts the amount of residues available for other internal uses - which may conflict with established activities.

In a number of instances, crop residues are used as source of household fuel and construction material. According to some estimates, at least half of China's crop residues are removed and burned as household fuel (Smil, 1987; Dazhong, 1993 in Pimentel *et al.*, 1995). For Bangladesh that figure may even be 90% (*ibid.*). Farm households with livestock frequently use crop residues as a source of fodder. The intensity of such use is highly site-specific, depending *inter alia* on the livestock component and the availability of crop residues and other fodder sources (*e.g.*, pasture; forage crops). Annex C presents a simple model to highlight the implications of such crop-livestock interaction.

6.3 Institutional setting

The implications of CRM-based crop production transcend the internal dynamics of the farm household. The institutional setting of the farm system has a profound influence on the technology - *e.g.* by determining resource rights, prices and accessibility. The institutional environment thereby includes a number of external conditioning factors that may either enable or constrain the application of CRM. Alternatively, CRM may require and/or induce institutional change. The present section discusses those implications that are of particular relevance, particularly residue rights and markets, burning arrangements, factor markets, and institutional interrelationships.

Residue rights and markets

The prospects of limiting the extraction of crop residues depend on the local residue rights. In developing countries, crop residues are occasionally subject to open access.[6] *I.e.*, after the harvest of the main crop, anyone can collect residues for *ex situ* use and/or graze them *in situ*.[7] Residues can also be common property (or 'club goods' - Upton, 1996:43-4), with conventions to regulate residue use (for instance, access for community members only; a maximum number of livestock per member; etc.), or private property.[8]

Communal and open access obviously poses problems for CRM, as the amount extracted is no longer under direct control of the farmer. Conceivably though, a common property regime could stipulate regulations that would enable residue retention. The would-be adopters would however face costs in getting these institutionalised, monitored and enforced. Furthermore, such regulations are bound to be problematic to enforce. For instance, livestock tends to graze a given area disproportionately, thereby blurring a distinction between purposeful and accidental over-grazing.

Would-be adopters could also try to assert private rights - *i.e.* opt out of a communal setting. The farmer may consider restricting the access of livestock to his fields by fencing them off. However, the feasibility of such opting-out depends on the institutional setting (*e.g.* Will others respect the enclosure? What, if any, are the social costs that the farmer incurs?). In the end, the transaction costs in establishing and enforcing rights may impose a substantial entry barrier for CRM. At the same time, opting-out of communal property settings is likely to put substantial strains on the institution.[9]

Communal rights often prevail when rights are difficult to define and enforce (Dasgupta and Mäler, 1995). Technical, demographic and/or market changes can make it increasingly attractive to exert private rights. They thereby tend to accelerate the transition of common property to private (Feder and Feeny, 1993; McIntire, 1993). For instance, barbed wire - invented a little more than a century ago - provides a widely available and economic form of property demarcation (Sanders *et al.*, 1995). Restrictions on crop residue use are increasingly common in developing countries, especially where residues are relatively

[6] However, the rivalness in consumption implies residues are not pure public goods (Turner *et al.*, 1993; Dasgupta and Mäler, 1995).

[7] This implies a temporal separation of property rights - *i.e.* rights to the actual crop is private, rights to the residues of the same is open. This contrasts with the more common spatial separation (Feder and Feeny, 1993; Hudson, 1993).

[8] Communal and free grazing has been variously reported in developing nations - *e.g.* in Africa (Sanders, 1988; Ofori, 1991; Baidu-Forson, 1994; Thiec, 1996); India (Wade, 1986 in Turner *et al.*, 1993; Laryea *et al.*, 1991); and Mexico (Erenstein, 1997a). It was also used in developed nations in the past (Campbell and Goody, 1986 in Feder and Feeny, 1993; Blaikie and Brookfield, 1987).

[9] The first opt-outs tend to be those that benefit least from the current setting. In terms of CRM and communal grazing, these are the farmers with few livestock. Their withdrawal quickly leads to increasing livestock pressure on the remaining areas. In turn, this may induce others to opt out too.

scarce. However, numerous intermediate variants are conceivable between the absolute extremes of open access and private property (*e.g.* see McIntire *et al.*, 1992:123).

Established residue rights can give rise to stubble grazing contracts and the emergence of a residue market. In Mexico for instance, surplus residues are frequently sold as fodder, generally as standing stubble.[10] Arrangements and prices vary, depending on the region (*e.g.*, aggregate demand for and production of residues) and on plot specific factors (*e.g.*, location, fencing, water availability, and perceived amount of residue). The implications of the residue market for CRM are however not straightforward. On the one hand, it may *constrain* CRM as it provides an option to market surplus residues and thereby obtain immediate income. On the other, it may *enable* CRM as it conceivably increases the logistic feasibility of residue retention. Indeed, the existence of a residue market frequently implies that fields are already fenced and that private residue rights are respected. Furthermore, residues are not very nutritious as fodder source (Unger *et al.*, 1991). With an increasing commercialisation of the livestock sector, forage that is more nutritious may increasingly substitute for residues (Pingali, 1997; Williams *et al.*, 1997). Alternatively, commercialisation allows for an increasing use of amendments to enhance the fodder value of residues (Renard, 1997).

CRM is likely to generate a pecuniary externality[11] in the local residue market.[12] Figure 6.5 gives a graphical representation with S being the local supply curve of residues, and D the local demand curve, resulting in a price of p. A farm household's decision to adopt CRM implies that part of the residues will be maintained on-farm as mulch, and consequently less will be supplied to the market. The advent of CRM therefore results in a leftward shift of the residue supply curve, depicted by S', with residue prices rising to p'. The actual extent of the price rise is related to the extent of the leftward shift of S and the elasticities of supply and demand (*i.e.* the respective slopes). The upward pressure on residue prices will however dampen the advent of CRM, as the opportunity cost to retain residues as mulch becomes higher.

Figure 6.5 also highlights the existence of choke-off prices for both demand and supply. Let us assume that the demand curve is largely based on the willingness to pay for residues as fodder source. It is likely that above price p^*, demand for residues is choked-off as other forage sources will substitute for residues (aided by the fact that residues have low nutritional value). Alternative fodder sources may thus provide a backstop technology that imposes a ceiling upon the purchase price of residues as fodder.[13] In turn, the supply curve S is also likely to exhibit a choke-off price: below price p^{**} farmers do not find it

[10] Residues may also be sold once harvested and/or processed (*e.g.* as bundles, bales or grounded).

[11] *I.e.* the decisions made by one entity, influences the prices faced by others (Gittinger, 1982).

[12] Residue markets tend to be very localised in view of the bulky nature of residues. However, trading between different residue markets occasionally does happen. For instance, in irrigated areas in central Mexico residue supply tends to swamp demand. The resulting low price induces some residue deficit areas to import residues from these areas.

[13] Alternatively, residue surplus areas could provide a backstop supply - depending on transport costs and purchase price (see previous footnote).

worthwhile to supply residues.[14] Such a choke-off price is likely to increase with the advent of CRM and farmers learning about the merits of leaving residues and the dismerits of stubble grazing.[15] The actual values of p, p^* and p^{**} are likely to have profound effects on the functioning of the residue market and the potential of CRM in particular.

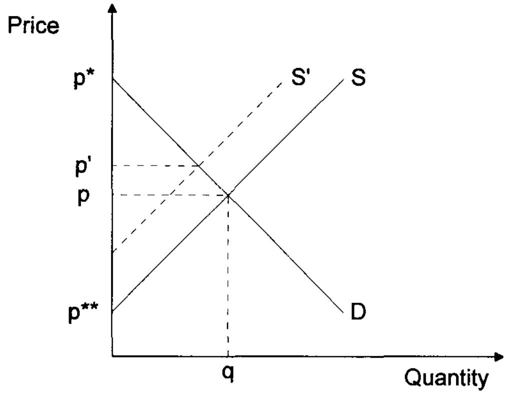

Figure 6.5 The residue market

Burning arrangements

Not burning crop residues is a necessary condition for CRM. However, when an individual farmer stops burning, this may not be sufficient to satisfy this condition. As long as one of his neighbours continues burning, there is the risk that his mulch will accidentally catch fire. Farmers indeed distinguish between purposeful and accidental burning (Ravnborg *et al.*, 1996; Erenstein, 1997a). Satisfying the condition of no burning may thus require:

- collective action in the form of his neighbours also abandoning burning;
- his neighbours taking precautions to prevent fire spilling out of their fields; and/or
- the farmer implementing protective measures to prevent fire spilling into his field.

The local convention in relation to pre-plant burning of residues stipulates the prevailing rights and duties of individual farmers. It thereby implicitly determines who needs to invest the necessary effort in preventive measures (*e.g.* the time and energy to build a firebreak). The prospects of using CRM thus depend on the local convention, and whether this is respected.[16] Furthermore, such conventions may change over time - *e.g.* depending upon established practice. For instance, Ravnborg *et al.* (1996) highlight a case of successful

[14] The author indeed encountered some instances in Mexico where farmers resorted to the purposeful elimination of their residues (by ploughing or burning) after failing to negotiate an acceptable residue price.

[15] *E.g.*, soil structure is likely to be adversely affected by the associated trampling (Shaxson, 1993).

[16] For instance, in the Tuxtlas region of Southern Veracruz, Mexico, some of the first farmers to abandon burning opted for the last option. Yet some of these farmers reported that, notwithstanding protective measures, their residues were burned intentionally by others whom disapproved.

institutional change with regard to the practice of burning in a Colombian watershed. The fact that the change made sense in the local context and allowed for eventual burning if so desired, probably helped in ensuring success.

Land rights and markets
CRM has inter-temporal implications for the land resource (in terms of subsequent productive capacity and land use options). CRM is therefore likely to be influenced by the type of rights the farmer has over the land resource, and particularly the security of those rights. Further, functioning land markets - sale and rental - that recognise such implications are also likely to be influential. CRM typically also implies compatible crop residue management over subsequent seasons. In this regard, short-term land rental can be particularly problematic for CRM: in the case of seasonal rent, a prospective tenant adopter is entirely dependent on the previous land user(s).

Labour market
CRM alters the labour input into crop production. The labour market can provide the farm household the necessary flexibility to cope with these changes (*e.g.* by providing the option to smoothen labour peaks and troughs). The labour market also determines the local wage rates for day labour, and thereby influences the costs and/or savings of these changes. In turn, CRM may occasionally generate a pecuniary externality in the local labour market. Particularly when CRM implies the advent of labour-saving herbicides, it may substantially reduce labour input in the early agricultural season (land preparation and weeding). However, the pecuniary effect will largely depend on the relative magnitude of the labour saved and the eventual alternatives to apply the freed labour.

Capital markets
CRM alters the capital input into crop production. It may depend on various markets to provide these inputs. For instance, CRM tends to substitute herbicides for tillage. It thereby depends on the input market for the provision of these inputs. Similarly, CRM may depend on the equipment market for the provision of new equipment (*e.g.* herbicide application equipment; sowing equipment). Farm households may not be able to finance the CRM-related capital demands internally. Adoption may thereby depend on the functioning of financial markets. CRM is also knowledge intensive and thereby depends on access to the necessary information sources (*e.g.* knowledgeable farmers; input dealers; providers of tractor services; extension services).

Provision of the capital inputs *per se* may not be enough, as accessibility - in terms of time, price, place and packaging - can still be a major issue for farm households. For instance, original packaging may make certain physical inputs lumpy and costly. Re-packaging inputs into smaller and more affordable units thereby tends to enhance accessibility for these farmers.[17] Similarly, rental markets make lumpy equipment divisible

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[17] However, re-packaging can also be problematic - *e.g.* when using inadequate containers or providing inadequate labelling. Improper packaging can be a major source of biocide contamination in developing countries (Akobundu, 1987).

and thereby more accessible (Benites and Ofori, 1993). Rental markets for equipment are common in most developing countries, particularly for various tractor services. However, rental markets also bring dependence. Indeed, the farmer depends on the providers for a timely and effective service - and in addition, upon their equipment.

In developing countries, the set of capital markets is typically incomplete and their structure and performance imperfect. Imperfect markets tend to adversely affect prospective adopters - *e.g.* by augmenting the costs of acquiring the necessary capital. Missing markets may imply the need to create new markets - *e.g.* markets for new inputs/equipment. Traders in new markets often impose high initial margins as risk premium - in conjunction with eventual economies of scale and monopoly rents. This may imply that early adopters invest in establishing marketing infrastructure (Pomp, 1994). As the new market becomes wider and more competitive, prices are likely to decline and availability to improve. Occasionally, missing markets can also be circumvented through other institutions and/or markets.

Institutional interrelationships

Hereto the different institutions were reviewed individually. However, in developing countries markets are occasionally interlinked[18] or otherwise interrelated. For instance, in Mexico land rental for annual cropping is often interlinked with residue transactions. A frequent arrangement is that the landlord reserves the right to stubble grazing.[19] This obviously poses an institutional conflict for CRM, as the amount extracted is no longer under direct control of the farmer.[20] Alternatively a prospective tenant adopter may need to refrain from interlinking or convince the landlord into limiting his extraction - incurring transaction costs and possibly, compensation costs (in the form of a compensatory rent increase).

CRM typically implies the use of external inputs. The farm household therefore needs to transact some other internal resource in exchange. Occasionally these transactions are interlinked (*e.g.* the trader that supplies external inputs receives a specified amount of grain in return). Alternatively, it implies the farm household needs to participate in another market - typically (but not necessarily) the crop produce market (*e.g.* by selling the surplus produce not needed to cover household consumption needs). The functioning of agricultural produce markets can thereby be another influential factor for CRM.

To actually finance the acquisition of the necessary external inputs (*e.g.* herbicides in the early season until repayment at harvest time), the farm household may require some source of credit or liquidity. However, failures in financial markets are widespread in rural developing economies, thereby often making the farm household dependent on other markets to finance the acquisition of inputs. Off-farm employment can provide farm

[18] *I.e.* transactions between two parties over several markets are simultaneously fixed, with the terms of one transaction contingent on the terms of the another (Hoff *et al.*, 1993:6).

[19] A similar institution is reported in Panama (Pereira *et al.*, 1997).

[20] In such instances, the CRM condition may be adapted into (using the same notation as equation 5.2, and with subscript T denoting tenant, L landlord):

$$P - (U_E^T + U_B + U_I + U_W) > (U_M^* + U_E^L) \qquad (6.1)$$

With U_E^L exogenous, the room for manoeuvre to satisfy condition (6.1) is further constrained.

households the means to earn the necessary cash income to finance farm expenditures (Reardon, 1997). In the case of herbicide-based CRM this can give rise to a triangular relationship (Figure 6.6). Herbicides can free household members to work off-farm (herbicides substitute for farm labour), whereas the cash income from off-farm work enables herbicide acquisition.

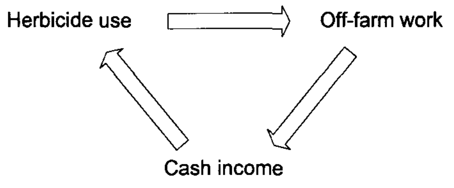

Figure 6.6 The triangular herbicide relation

Off-farm work can be a major source of household income and can profoundly alter the household's resources - particularly in the case of temporary or permanent out-migration of household members. For instance, it tends to affect the household's endowment of labour and capital assets (*e.g.* capital goods; cash; credit reserve[21]; and human capital[22]). In turn, these changes tend to affect the households participation in other markets. Indeed, remittances can fuel the rural economy and accelerate the commercialisation of agriculture.

6.4 Private assessment

For a private assessment of the implications of the adoption decision for the farm household, technological, resource, institutional and preference considerations need to be incorporated. The previous sections highlighted how CRM alters the crop production technology and the intra-household flow of resources, and how these changes are conditioned by the institutional setting. Figure 6.7 summarises these implications and their interrelationships graphically. To assess whether the implied changes are in the interest of the farm household, the household's preferences need to be incorporated.

[21] *I.e.* the potential volume of credit that lenders are prepared to supply on the basis of their perception of the borrowing capacity of the household (Moll, 1992).

[22] Migration affects human capital in two opposite ways. First, it can be a source of new skills and knowledge. Second, it can lead to the loss of the human capital embodied in the out-migrants (*e.g.* Bocco, 1991).

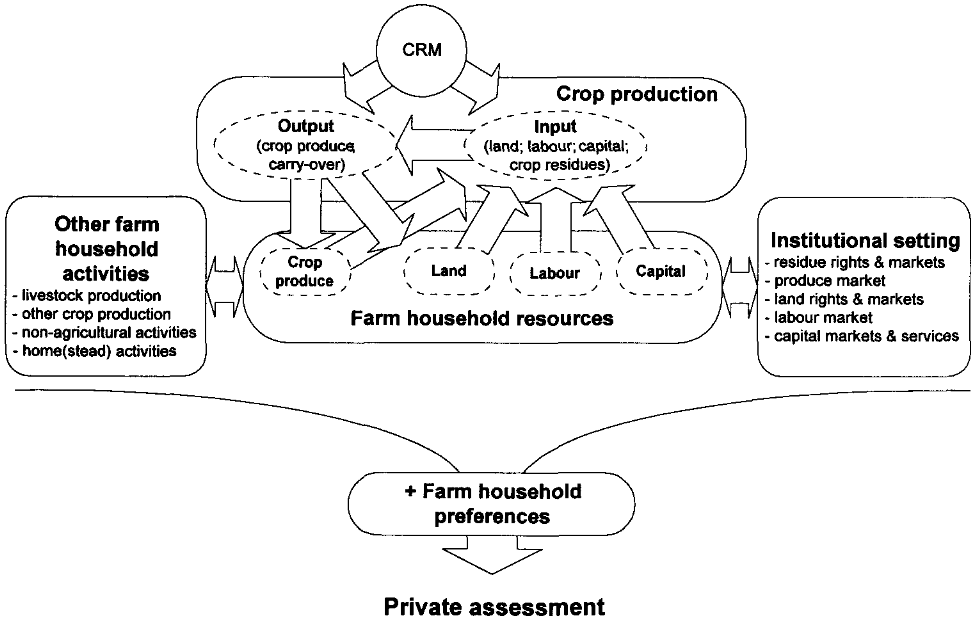

Figure 6.7 Overview of factors affecting private assessment of CRM

Farm household preferences

Farm households in developing countries generally maximise utility by pursuing a set of multiple objectives, are risk averse and have a pronounced time preference. These preferences (both objectives and attitudes) are conditioned by available resources, technology and institutions. CRM is not likely to alter farm household preferences *per se*. However, preferences are important internal conditioning factors for the adoption of CRM.

The pronounced time preference implies that the household's planning horizon is short and its discount rate high. Immediate returns are therefore particularly influential in the private assessment of the technology. *I.e.* substantial investments and/or delayed benefits will severely curtail the economic prospects of CRM. The potential to reduce costs and increase yields will enhance the prospects of CRM.

The pronounced risk aversion implies households are occasionally willing to forego income in order to reduce risk. However, soil conservation technologies tend to raise a risk dilemma as they conceivably both decrease and increase risk (see 3.3.2). CRM is subject to similar considerations. At the crop production level CRM tends to reduce risk.[23] It has a pronounced yield stabilising potential, which decreases production risk *ex ante* - particularly

[23] Risk-averse farmers may be willing to accept lower average crop yields with CRM provided these are less variable.

in drought-prone areas. This is partly offset by CRM's complexity, which may increase production risk in the initial years of use.[24]

At the farm household level, CRM also implies risk trade-offs. The yield stabilisation enhances the household's income certainty and food security. Further, by freeing family labour for off-farm activities it can facilitate income diversification. Alternatively, CRM may increase market exposure and thereby risk of default *ex post*. CRM's resource demands can also limit income diversification. The risk trade-off is particularly pronounced when CRM competes directly with livestock production (*e.g.* for scarce residues). Livestock production often provides the necessary portfolio diversification. It also can have important benefits in terms of financing and insurance in view of absent/imperfect markets (Bosman *et al.*, 1997).

Utility maximisation implies that the farm household is likely to adopt CRM when it enhances the household's (expected) utility. This is more likely when adoption implies substantial private returns. In fact, obtaining an acceptable return from the applied resources may well be one of the objectives of the farm household. The critical question therefore becomes whether the household's marginal benefits (utility) of adopting CRM make the marginal costs (disutility) to satisfy CRM's conservation standard worth incurring. The actual value of the altered resource flows is critical in this respect.

Valuation

In order to assess the utility trade-offs faced by farm households, the CRM-induced changes need to be valued. This valuation is compounded by market imperfections and the typically partial market engagement of farm households. Consequently, market prices are either not readily available or not necessarily representative. In fact, valuation depends on inherently household specific internal and external variables. For instance, the value of labour use changes depends *inter alia* on the household's marginal utility of leisure and the degree of integration in labour markets (*e.g.* households may not participate, be net contractors of labour, or net suppliers).[25] CRM's labour implications thus have a differential impact over households. Similarly, the cost of herbicide use (input acquisition, application and financing) varies over households, depending *inter alia* on household resources and access to input and financial markets.

Characteristic for CRM is its reliance on crop residues as mulch. The correct valuation of this resource is therefore critical. Crop residues have different uses with corresponding values. For instance, residues have (i) production value (*e.g.* as fodder and/or construction material); (ii) consumption value (*e.g.* as household fuel); and (iii) soil conservation value (*e.g.* as mulch and/or soil amendment).[26] Production and consumption values usually reflect

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[24] Feder *et al.* (1985) have labelled these objective and subjective risk, respectively.

[25] The participation of the farm household in the day-labour market (as employer and/or employee) is closely associated with the well-being of the household. Indeed, such participation can be used as an indicator of the latter (*e.g.* see Ravnborg and Ashby, 1996).

[26] The conservation value implies that even when extraction is CRM-compatible, the opportunity cost of extracting the crop residues is not zero. By extracting, the farmer foregoes the marginal benefit from the residues as soil amendment and/or mulch (albeit dependent on the residue balance).

scarcity and/or qualitative considerations. For instance, the production value of crop residues as fodder tends to be high when fodder sources are relatively scarce - *e.g.* areas with (semi) arid climates and/or high livestock densities.[27] The same value is also higher for legume than for cereal residues in West Africa (Thiec, 1996); and for maize than for wheat residues in Mexico (*e.g.* Bravo *et al.*, 1993).

The production and/or consumption value of crop residues can be substantial, comprising an important share of the total value of crop production in high value scenarios (Table 6.2). The productive and consumptive value to a large extent determines the degree of crop residue extraction. In turn, extraction levels determine the actual opportunity cost of the residues retained as mulch. Whenever extraction levels are already compatible with CRM, this opportunity cost is negligible. When the extraction level is not compatible, the opportunity cost depends on the primary source of extraction - *i.e.* internal; external without compensation; external with compensation (see Table 6.3).

Table 6.2 Value of crop residues in high value scenarios

Crop and country	Grain:stover Price ratio	Stover contribution to gross production value	Source
Sorghum, India	5.5-6.9	32-38%	Kelley *et al.*, 1990
Sorghum, Ethiopia	2.0-2.5	35-48%	McIntire *et al.*, 1988 in McIntire *et al.*, 1992
Maize, Pakistan	2.0-2.5	29-33% [a]	Byerlee *et al.*, 1989
Maize, Mexico	2.5	29-41%	Bravo *et al.*, 1993

[a] Contribution ranges from 29-57% when it includes green thinnings prior to harvest.

Table 6.3 CRM's opportunity cost of crop residues as determined by residue extraction

Extraction level	Primary source of residue extraction	Corresponding opportunity cost
CRM compatible [a]	Internal or external	Negligible
CRM non-compatible	Internal	Cost of alternative procurement; or cost of reducing internal demand
	External without compensation (*e.g.* open access; communal)	Cost of asserting ownership (*e.g.* costs of protection + enforcement)
	External with compensation	Revenue foregone + transaction costs

[a] Compatibility is co-determined by the other components of residue balance.

[27] Scarcity of fodder can also induce partial crop biomass harvesting *prior* to the harvest of the main produce. For instance, in certain areas of Mexico farmers remove part of the maize plant above the ear for fodder once the grain reaches physiological maturity (so-called "topping"). In northern Pakistan farmers thin their immature maize stands for fodder purposes (Byerlee *et al.*, 1989; Byerlee and Khan, 1992). Use of thinnings/weeds has also been reported in Africa (McIntire *et al.*, 1992).

When CRM conflicts with internal demand, the prospective adopter may need to secure an alternative source (*e.g.* obtain fodder and/or fuel off-farm; increase on-farm residue production).[28] Reducing internal demand typically implies a high opportunity cost and is not likely to be attractive. McIntire *et al.* (1992) provide an indicative comparison of altering the allocation of crop residues over crop and livestock production in Niger, Nigeria and Ethiopia. They concluded that shifting crop residues from grazing to mulching would only increase income in the Nigerian case, in view of a crop response to mulching, a substantial production of crop residues and the low production value of crop residues as fodder.

When CRM conflicts with external demand, existing residue rights have a profound influence on the opportunity cost of the mulch. In case access to the residues is open or communal, the opportunity cost revolves around the cost of exerting private property rights. In case the residue rights are private, the opportunity cost revolves around eventual income foregone and transaction costs (*e.g.* the cost of ensuring that sufficient residues remain in case of 'partial' sale).

Private returns

The magnitude of the underlying biophysical changes and their corresponding (private) valuation co-determine the assessment of CRM from the farm household viewpoint. Private costs and benefits of applying CRM thereby determine its private return. This return will reflect the same household specificity that is inherent in both the underlying variables. Further, as CRM implies factor substitution, returns are profoundly influenced by relative costs. In manual systems, the potential of herbicides is to a large extent determined by the relative costs of labour and herbicide use. In contrast, in mechanised systems the potential of herbicides is to a large extent determined by the relative costs of tillage and herbicide use.

Scale implications are also likely to influence private returns. CRM may entail substantial learning costs (Logan *et al.*, 1991; Napier *et al.*, 1991; Harrington, 1994) - especially in developing countries. It also may entail lumpy investments in implements and residue protection measures (firebreaks; fencing), with corresponding economies of scale. These create differential start-up costs by size of farm and crop system.

The private assessment of the CRM-induced changes conveys the underlying trade-offs for the farm household. In general, opportunity costs are likely to be high whenever CRM's resource demands compete directly with the farm household's other established productive or consumptive activities. For a positive return in such instances, CRM needs to outperform the competing activities' contributions to the objective set. Further, established activities reflect the farm household's adaptation to the internal and external conditioning variables. Some of these conditioning variables are also likely to constrain CRM, and thereby tend to raise the underlying costs of adoption. In the end, the private assessment of CRM determines the adoption decision of the farm household.

[28] For a number of such alternatives, including ways to make residue extraction and mulching more compatible, see Unger *et al.*, 1991; Powell and Unger, 1997;.

6.5 Social assessment

The framework hereto emphasises the private viewpoint - being the major determinant for the farm household decision to apply or not apply CRM to crop production. However, the adoption decision of the individual farm household has wider implications for society. Therefore, a social assessment is needed to assess whether the aggregate social benefits and costs of applying or not applying CRM are in the interest of society.

Society at large and individual economic agents are likely to assign different values. First, taxes and subsidies ensure a divergence between private (financial) and social (economic) prices. Second, market/institutional imperfections drive a wedge between the private and social perspective. Chapter 5 (Section 5.5) already highlighted that CRM has wider implications in terms of externalities (*e.g.* soil conservation; non-point source pollution) and imperfect information (*e.g.* health and environmental costs). Scale issues also play a role as CRM cuts across individual farm households and institutions. For instance, CRM has a number of intricate backward and forward linkages with potential multiplier effects in the local markets.

Society is heterogeneous: it encompasses diverging farm households and other economic agents. This makes clashes between private interests of individual economic agents and between private and social interests likely. For various reasons, CRM is likely to be beneficial for some agents, and detrimental for others. For instance, CRM has profoundly distinct implications for the crop and livestock sectors. Application of CRM also requires a minimum resource set - *e.g.* access to land (though not necessarily owned), residues, cash and equipment (owned or rented). This may not be the case for those with the least resources.[29] This is the more worrying in view of trends that seem to concentrate the poorest groups in ecologically fragile zones (Barbier and Bishop, 1995). Further, CRM relies on labour-saving herbicides and may thereby reduce employment opportunities for the poorest (Miller and Burrill, 1978). The poorest in rural areas are frequently day-labourers, who only have their labour resource to provide for their needs. CRM therefore has implications for both inter-generational and intra-generational equity. An overall social assessment needs to determine the potential conflicts of interest and trade-offs.

In conclusion, a divergence between the private and social assessment of CRM-based crop production is likely. The question then arises whether policy could influence farm households so as to align their behaviour with social interest.

Assessment of policy intervention

Divergence between private and social interests is a necessary though not sufficient condition for policy intervention (Zerbe and Dively, 1994). The marginal cost of policy intervention should never exceed the social cost of inaction - *i.e.* policy action should not cost more than the market failures it is set to correct. Policy assessment therefore needs to (i) assess the case for intervention; and (ii) assess the mode of intervention. The case for intervention revolves around the divergences between the private and social assessment. The mode of intervention analysis should assess the policy instrument in terms of effectiveness

[29] Carter (1996) reports a similar issue for alley farming.

(impact) and efficiency (costs and benefits) considerations. In the end, the policy assessment should indicate whether intervention by a specific policy instrument is warranted.

Several potential policy interventions are conceivable depending on the private, social and policy assessment (see Figure 6.8). Policy intervention could *create an enabling environment* for CRM. This is particularly relevant when CRM is both privately and socially attractive. Potential private returns is a necessary but not a sufficient condition for CRM adoption. There is a set of external conditioning variables that can either enable or constrain CRM. For instance, necessary institutions may be missing and/or incompatible institutions may be present. This typically imposes additional costs upon the prospective adopter and/or may require institutional change. Institutional change is induced when the potential benefits of change outweigh the costs. However, institutional rigidity implies institutions do not always evolve smoothly (Lin and Nugent, 1995). Hence, policy intervention can play an important facilitory role.

There are a number of ways in which policy can help create an enabling environment. First, it can address information problems through research and extension services (*e.g.* funding CRM adaptive research and demonstrations). Second, policy can address missing or imperfect markets (*e.g.* through targeted intervention and by helping set up the required financial and equipment services). The development of physical infrastructure also has an influential role, as it is closely related to the exposure to information and the functioning of markets. Third, policy interventions can establish and enforce rights (*e.g.* residue; land tenure). For instance, recent legislation in Lesotho now considers crop residues as private property: it cancelled communal grazing rights and now allows a land user to forbid access by other people's animals (Hudson, 1991). However, there can be a thin line between creating an enabling and an antagonistic environment. For instance, one soil conservation program in Tanzania went to the extreme of enforcing a complete destocking of the area (Mndeme, 1992). Policy intervention is more likely to create an enabling environment when it builds on the necessary local involvement.

CRM-based crop production may also bring into play some new market imperfections (*e.g.* externalities; imperfect information - see 5.5). Policy intervention could *address* these *new market imperfections* - particularly relevant when CRM is privately attractive, but not socially. For instance, in the case of herbicide-related health and environmental issues, policy interventions include taxation (*e.g.* of hazardous herbicides), regulation and dissemination of information.

Policy intervention could also *raise* the *utility* of CRM adoption, or conversely, the disutility of non-adoption - particularly when CRM is socially attractive, but not privately. The utility of CRM could be enhanced by an array of economic incentives (*e.g.* subsidies for inputs, equipment and/or services). Such incentives are likely to be more cost-effective when they are narrowly targeted - *i.e.* made conditional upon CRM adoption. The disutility of non-adoption could be raised by an array of legal sanctions. For instance, recent legislation in Chiapas, Mexico now restricts the use of pre-plant burning (Erenstein and Cadena, 1997; Erenstein *et al.*, 1998). In such instances, the intervention problem resembles traditional soil conservation intervention. It is therefore subject to similar limitations that affect the use of economic incentives and legal sanctions in soil conservation in general (see 4.2.1).

Policy intervention could also *seek conservation alternatives* to CRM. This is particularly relevant when CRM is neither privately nor socially attractive - provided that soil erosion is an economic problem. Alternatively, CRM could be socially attractive, but policy intervention to make it privately attractive too costly. In either case, CRM should (temporarily at least) be dropped from the local portfolio of conservation alternatives. Policy could provide the necessary funds to identify more appropriate conservation alternatives. Such research should incorporate the necessary farmer participation from the start.

Lastly, *no policy intervention* can be proposed for the time being. Such an outcome is conceivable when policy instruments are not likely to be effective or efficient.

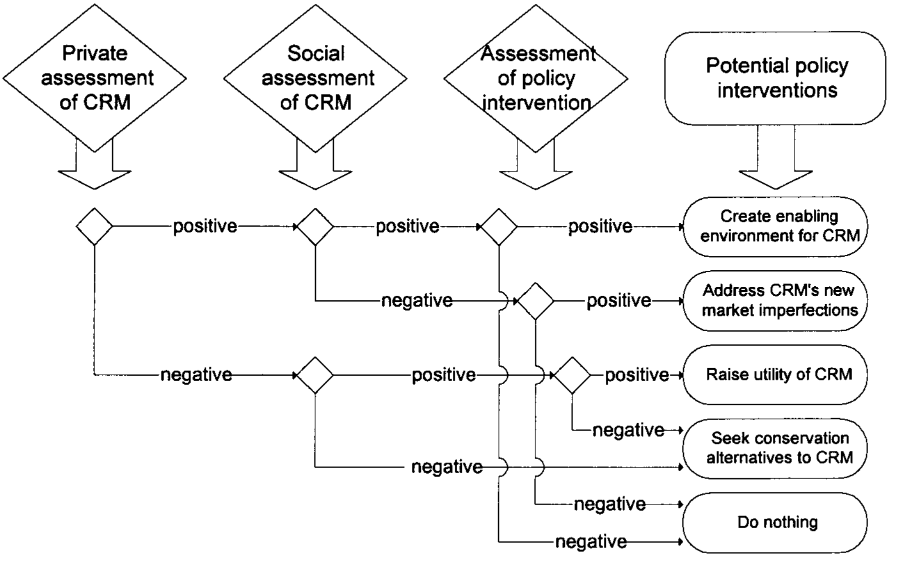

Figure 6.8 Flow chart to derive potential policy interventions for CRM
(legend: diamond is assessment nexus; arrows leaving diamond to the right imply a positive assessment; arrows leaving diamond downwards imply a negative assessment)

Identifying the appropriate policy intervention is far from straightforward (Stiglitz, 1988) and site-specific (Reardon and Vosti, 1995). Policy is only one amongst several forces acting on the decision making process of the farm household. Policy itself is also constrained by the prevailing socio-economic environment in developing countries. Market-based interventions are compounded by the characteristic partial market engagement of farm households, and the imperfect nature of these markets. Legal interventions are compounded by major enforcement problems.

It can therefore be useful to distinguish between broad and targeted policy interventions. Targeted policies could specifically address CRM issues. However, broad policies may be required to tackle some of the overarching constraints - *i.e.* to create an enabling environment for farming in general (*e.g.* stable macro-economic conditions; developed rural infrastructure; access to functioning agricultural produce and factor markets; security of tenure; decentralisation; access to functioning extension and research services - Bojö and Cassells, 1995; Reardon, 1998). Once an overall enabling environment is ensured, targeted intervention may well be more efficient and predictable than broad interventions. Nonetheless, targeted intervention is still likely to be complex and have unforeseen consequences (Reardon and Vosti, 1997) - especially in view of the technological complexity of CRM (also see 5.4).

6.6 Methodological issues in technology assessment

The previous sections developed a conceptual framework to assess the socio-economics of using the CRM technology - hereafter referred to as the technology assessment (TA) framework. The present section discusses some methodological issues inherent to its application and validation.

Application of the technology assessment (TA) framework

Applying the TA framework provides valuable insight about the functioning and aptness of CRM. In particular, it identifies the existing constraints - if any - for farm households to use CRM-based crop production. It also helps determine whether CRM actually is a privately attractive conservation alternative. This enables deriving the corresponding implications for research, extension and policy. The TA framework can be applied to different settings and in different modes. In terms of setting, a distinction can be made between *ex ante* and *ex post* CRM application.[30] In terms of mode, a distinction can be made between chronological, contemporary and mixed applications (Table 6.4).

Table 6.4 Forms of applying the TA framework

	Setting of application	
Mode of application	*Ex ante*	*Ex post*
Chronological	Forward looking for given farm type (*e.g.* A_t *versus* A_{t+n})	Backward looking for a given adoption type (*e.g.* C_{t-m} *versus* C_t)
Contemporary	Comparison of different farm types (*e.g.* A_t *versus* B_t)	Comparison of different adoption types (*e.g.* C_t *versus* D_t)
Mixed (chronological & contemporary)	Prospective comparison of farm types [*e.g.* (A_t *versus* A_{t+n}) *versus* (B_t *versus* B_{t+n})]	Retrospective comparison of adoption types [*e.g.* (C_{t-m} *versus* C_t) *versus* (D_{t-m} *versus* D_t)]

Legend: A and B denominate specific farm types - *e.g.* A: farms with livestock; B: farms without. C and D denominate specific adoption types - *e.g.* C: adopters of CRM; D: non adopters. t refers to the time of analysis. For a given area and technology, t (*ex ante*) < t (*ex post*).

[30] The dichotomy *ex ante versus ex post* is fuzzy when applied to the adoption of a technology where the possibility of partial adoption exists - as is the case with CRM based crop production. *Ex ante* refers here to any analysis prior to significant adoption, *ex post* thereafter.

The chronological application of the TA framework as such requires no further adaptations in either an *ex ante* or *ex post* setting. Both instances would distinguish between the implications for crop production, farm household and institutional setting, and provide a private and social assessment. The main difference would be the time of analysis: the *ex ante* setting is inherently forward looking (prospective), the *ex post* setting backward looking (retrospective).

Conceivably, the chronological application of the TA framework as such is more apt in an *ex ante* setting. First, it would potentially allow all relevant data to be collected. Second, it implies no confounding of cause and effect of CRM adoption. Third, it enables a timely assessment of the private and social viewpoint and corresponding policy implications. However, *ex ante* application is inherently constrained by data availability - *e.g.* in terms of an uncertain future and limited to no local time series. Data limitations are particularly problematic when CRM's risk implications are likely to be important. *Ex post* application has the benefit of hindsight, but tends to suffer from other data limitations (*e.g.* missing baseline data; memory bias of recall data).

The contemporary application of the TA framework requires some additional analytical steps - particularly in terms of distinguishing types (*e.g.* farm types; adoption types) and subsequently including these in the analysis. A purely contemporary application (*i.e.* single mode, no chronological aspects) is more relevant for an *ex post* setting, which will therefore be emphasised hereafter. Three distinct additional steps can be identified for the contemporary application in an *ex post* setting: (i) adoption classification; (ii) comparison of indicators by adoption class; and (iii) multivariate analysis.

The first step encompasses the *adoption classification*. The application of the TA framework identifies the necessary practices for adoption, which subsequently can be used to identify the corresponding adoption strata/classes. The resulting typology can be clarified with such aids as an adoption matrix, a flow chart or a Venn diagram. Categorising the (sample) population in terms of these strata provides the adoption pattern of CRM (for a given time and location).

Classifying CRM adoption however presents a number of issues (see 5.4). The *ex post* case studies classify adoption based on the crop residue management practices applied to a given place (the largest maize field cultivated by the sample farm household) prior to a given time (crop emergence in year X). This thereby forfeits insight into the intensity of adoption of the farm household. However, this simplification is a direct result of the measurability problem of CRM adoption. Further, CRM adoption hinges on a number of necessary practices. The various combinations amongst these already imply a substantial number of adoption strata. For instance, necessary practices might affect pre-plant burning, tillage intensity and extraction. If each is independent and is categorised dichotomously (*i.e.* CRM compatible and non-compatible), this gives rise to eight conceivably combinations (*i.e.* adoption strata). Only one of these is a total adopter, and only one a complete non-adopter - the remaining six being partial adopters. There are clearly trade-offs upon maintaining each of these as a separate adoption stratum - notably in terms of the capacity to analyse, present and comprehend such a breakdown. A substantial regrouping may indeed be advantageous.

The second step encompasses the *comparison of indicators* from the TA framework over adoption strata. The comparison typically includes univariate analysis of relevant indicators - including crop production input-output data; farm household resources; farm household activities; and the institutional setting. It also allows for a comparative assessment of economic returns. The purpose of these comparisons is two-fold. First, it helps establish which adoption factors were particularly influential - *i.e.* explain the observed adoption patterns. Second, it helps determine the consequences of adoption. The cause-effect relationship with adoption varies per indicator - some are inherently causal, others effect-related and yet others have a mixed nature (*i.e.* reverse causality).

The third step encompasses a *multivariate analysis* using logistic models. This allows for the joint consideration of selected indicators from the framework - including structural and institutional variables - upon explaining the adoption decision. A confounding factor is the typically high correlation between some of the indicators.

Finally, Figure 6.9 provides a methodological overview for the application of the TA framework. For expositional purposes, the preceding discussion focused on single mode application - *i.e.* either chronological or contemporary. Data and resources permitting, a mixed application - including both chronological and contemporary comparisons - provides a better insight, irrespective of whether the setting is *ex ante* or *ex post*. However, in the end the preferred mode of application should depend on the envisaged objective for applying the TA framework.

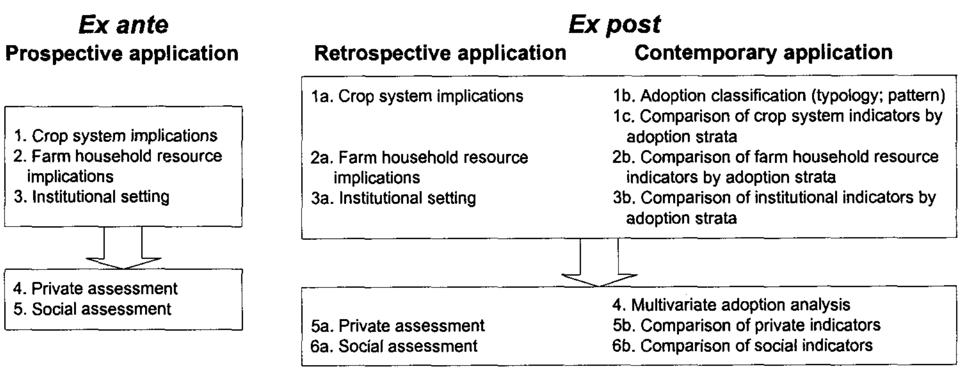

Figure 6.9 Methodological overview of TA framework applications

Validation of the TA framework

The TA framework is built on a number of hypotheses. It stipulates that a number of interrelated variables at different levels potentially affect the CRM adoption decision. Application of the TA framework to empirical settings - both *ex ante* and *ex post* - allows us to assess the validity and applicability of the framework as analytical tool. For instance, it generates insight in the relevancy of its indicators and may highlight the need for possible adaptations (*e.g.* omitted variables; unforeseen factors/relations). By definition, the validation of the outcome of the framework is restricted to the *ex post* setting.

In an ideal world, the TA framework would be first applied *ex ante* to a particular setting, and subsequently be validated *ex post*. This would enable the compilation of a baseline, the identification of a control group and a with-without comparison. Time and budgetary constraints typically curtail the prospects of such an elaborate assessment. The present study thereby chooses for a compromise. It applies the TA framework both in an *ex ante* and an *ex post* setting - but to different cases.

The followed approach has some distinct advantages. First, it shortens the time needed for the application of the framework in both an *ex ante* and *ex post* setting for validatory purposes. Second, it allows for a wider coverage of biophysical and socio-economic conditions. This provides a more representative picture, reduces the likelihood of omitting relevant variables, and allows drawing more general inferences. The approach thereby enhances the assessment of the framework.

The present approach also has some distinct disadvantages. A major drawback is that it curtails the prospects of framework validation. First, the different cases are not directly comparable. Second, the simultaneous implementation already enables framework fine-tuning. Further, the selection of *ex post* cases is inherently constrained to sites were adoption is apparent. This implies the danger that such sites may be biased by an underlying variable - *e.g.* sites where the problem was serious enough to warrant initial research and extension efforts; or the solution apt enough to warrant substantial adoption.

The actual choice of *ex ante* and *ex post* cases reflects three considerations. First, they reflect the active presence of research collaborators in the area. Second, they reflect contrasting situations in terms of biophysical and socio-economic conditions. Third, the *ex post* cases reflect the existence of significant levels of adoption. The cases were thereby chosen purposively and are not necessarily representative of the wider region.

Data issues

Each individual case study is based on a farm household survey.[31] In addition, data from local on farm experiments and relevant secondary sources are used. In an *ex ante* setting, these data enable the prediction of likely CRM-induced consequences. In some instances the predictions are largely unambiguous and conclusions can simply be drawn. In other instances, certain ambiguous predictions would need to be verified *ex ante* - *e.g.* through (further) complementary experimentation on location. This is particularly an issue when significant CRM-induced effects on crop system output are expected - *e.g.* in terms of yield level and variability.

Ex ante studies can provide baseline data for future reference. Some quantitative indicators could thereby prove useful for future monitoring and evaluation. However, compiling such information requires resources and careful deliberation of the indicators to

[31] To economise space only the salient and pertinent features of each study will be highlighted. The interested reader is referred to the cited background papers (*i.e.* original case studies) for a more detailed account. These are available upon request from CIMMYT's Natural Resources Group.

be included. A qualitative feasibility study is therefore essential in the run-up to a comprehensive quantitative *ex ante* study. In the end, some form of hybrid might well be the most effective and efficient solution - *i.e.* a more holistic qualitative study followed by a focused quantitative study.

Ex post studies use the survey data to test the hypothesised relations. This is done through a with-without comparison in either a chronological (before-after comparison) or a contemporary (adoption strata comparison) setting. However, in most instances this testing is imperfect in view of (i) 'noise'; (ii) absence of a control group; and (iii) absence of baseline data. CRM survey data imply two sources of *noise*.[32] First, they are exposed to the confounding signals from non-controlled variables. Second, measuring CRM adoption is inherently fuzzy. CRM is a complex, multifaceted management practice - confusion over terminology, ambiguous thresholds, partial adoption and variations over time and space do not help (see 5.4).[33]

The case studies tend to lack an adequate *control group* for a with-without analysis, thereby making any before-after or adoption-strata comparison imperfect. This confounds the contribution of CRM with that of other associated variables. Consequently, some of the observed adoption consequences remain ambiguous.

Absence of *baseline data* further augments the difficulty to interpret observed differences (if any). Occasionally, reverse causality makes it difficult to interpret cause and effect. This is especially problematic where the results seem to confirm one's prejudices (Stocking, 1987). For instance, are the higher yields of adopters a result or the cause of adoption? Without baseline data this remains ambiguous - as cause (higher initial yields implies more residues are potentially available as mulch) and effect (CRM potentially implies higher yields) are intricately linked (*e.g.* see Figure 5.4).

The temporal coverage of a single survey is typically limited.[34] Without baseline data, this further complicates assessing the actual consequences of adoption. Some authors have stressed the need for more longitudinal studies (Byerlee *et al.*, 1991; SRAPTF, 1993) to monitor and document adoption processes. Such studies could indeed more adequately address the dynamic nature of the adoption process and its consequences. However, one should not underestimate the logistics of monitoring - adequate monitoring is a resource demanding process and early inconsistencies expensive to revert. An objective identifier for the units to be monitored is essential, and in this regard the advent of global positioning systems looks promising (although more conventional means also merit more use).

Last, the case studies focus on the private viewpoint - *i.e.* try to assess the private implications of the adoption decision. In view of the typically high time preference and short time horizons of (resource-poor) farm households it thereby focuses on immediate

[32] Survey data also have other shortcomings (see *e.g.* Chambers, 1983; Gill, 1993).

[33] Verification of residue quantities in the field (see Box 5.2) potentially reduces the fuzziness of determining CRM adoption. However, this potential depends on a number of procedural conditions, including clear and objective guidelines for those performing the assessment. Such verification also imposes substantial additional timing and financial burdens.

[34] The Central-Chiapas *ex post* case is somewhat of an exception as it concerns a monitoring study, but still provides only two points in time.

consequences. Similarly, it focuses on on-farm effects that are of relevance to the farm household. The cases assume that meeting the CRM conservation-standard (*i.e.* >30%-cover) ensures soil conservation effectiveness. The emphasis on the private viewpoint implies that the social assessment and identified policy implications are of an indicative nature only.

6.7 Concluding summary

The present chapter presented a conceptual framework to assess the socio-economic implications of farm households using CRM-based crop production practices in developing countries. The farm household is a system that comprises various productive and consumptive activities and is located within a wider biophysical and socio-economic environment. Farm household decisions are conditioned by the internal and external variables.

CRM implies a 'basket' of management practices whose implications permeate throughout the farm system. The conceptual framework follows a stepwise expanding analysis of these implications along a three-tier hierarchy: crop production, the farm household and the institutional setting. CRM typically implies a major overhaul of the crop system, affecting both input and output levels. The input implications are conditioned by the necessary and complementary practices. Necessary practices ensure sufficient residues are retained to surpass the 30%-cover threshold. Complementary practices may be needed in order to be able to still grow a crop and/or maintain yield levels. The output implications are conditioned by CRM's effect on crop produce (yield level and stability) and seasonal carry-over (soil conservation and ecology). These biophysical implications are far from straightforward and inherently site-specific, varying both over space and time. The input and output implications are indeed interdependent and dynamic.

The biophysical changes in the crop system alter the internal flow of resources within the farm household. Some of the CRM-induced changes are likely to enhance the farm household's productive and/or consumptive possibilities, others to compete with existing activities. For instance in terms of land, CRM alters both land productivity and land use options. CRM also has implications for the use of labour (availability for and use by other activities), capital (use of finance and capital goods) and crop produce (production and use). These implications are again inherently site-specific being dependent on the nature of the other farm household activities.

The implications of CRM also transcend the farm household. The institutional setting has a profound influence on the technology, as it includes a number of external conditioning factors that may either enable or constrain its use. Alternatively, CRM may require and/or induce institutional change. In order to actually retain residues as mulch, residue rights and markets and burning arrangements are particularly influential. The inter-temporal nature of CRM implies that land rights and markets also play a role. Labour and capital markets are important in view of the CRM-induced changes in factor inputs. Market failures may imply that some transactions are interlinked or otherwise interrelated.

In the end, the farm household's decision to adopt hinges on whether CRM enhances the household's (expected) utility. This is more likely when adoption implies substantial private returns, a function of the magnitude and value of the underlying biophysical changes. Influential factors in this respect are the farm household preferences, opportunity costs/benefits, relative costs and scale implications. Consequently, private returns to adopting CRM are likely to be household-specific.

The private and social assessment of CRM are likely to diverge in view of institutional imperfections, taxes/subsidies and heterogeneity. Numerous policy interventions are conceivable to address such divergences. For instance, policy measures could create an enabling environment for CRM; address market imperfections inherent in CRM; raise the utility of CRM; or seek conservation alternatives. The adequacy of the different policy interventions is site-specific. In fact, policy intervention is only warranted when the social benefits of applying a particular policy instrument outweigh its costs.

The technology assessment (TA) framework can be used both in an *ex ante* and an *ex post* setting - its use being prospective in the former and retrospective in the latter. In terms of mode, application can be chronological, contemporary and mixed. Chronological application closely follows the stipulated framework. Contemporary application encompasses three distinct additional steps: (i) adoption/farm household classification; (ii) comparison of indicators by adoption class/farm types; and (iii) multivariate analysis.

Both *ex ante* and *ex post* application of the TA framework to empirical settings allows for its validation. Validation of the outcome of the framework is limited to *ex post* settings. However, the validation process tends to be imperfect when applied to individual case studies, in view of 'noise', the absence of a control group and the absence of baseline data. The subsequent chapters will apply the TA framework to empirical cases from Meso America. Chapter 7 will do so in an *ex ante* setting, Chapter 8 in an *ex post*. Finally, Chapter 9 addresses the partial application of the TA framework.

CHAPTER 7

EX ANTE APPLICATION OF THE TECHNOLOGY ASSESSMENT FRAMEWORK

Chapter 6 developed a technology assessment (TA) framework to evaluate the socio-economics of crop residue mulching (CRM). The present chapter will apply the TA framework in an *ex ante* fashion: *i.e.* assess the potential adoption of the technology in specific empirical settings. It will do so for two case studies in Mexico. The cases depict two particularly contrasting situations in terms of biophysical and socio-economic conditions. The first case - Southern Jalisco (Figure 7.1) - analyses the prospects of CRM-based maize production in a commercial, market-oriented agricultural system. The area is mid-altitude with a semi-arid to sub-humid climate. The agricultural landscape is flat to rolling and the rural economy is reasonably developed. The second case - Southern Veracruz (Figure 7.1) - analyses the prospects of CRM-based maize production in a remote, home consumption oriented agricultural system. The area is low-altitude with a (sub)humid climate and rugged topography. The rural economy is undeveloped.

The contribution of each *ex ante* case study is two-fold. First, it provides prospective insight into the potential functioning and aptness of CRM in specific empirical settings. Second, it provides insight into the *ex ante* applicability of the TA framework. The first section deals with the Southern Jalisco case study, the second with Southern Veracruz. The last section draws conclusions with respect to the technology and the TA framework.

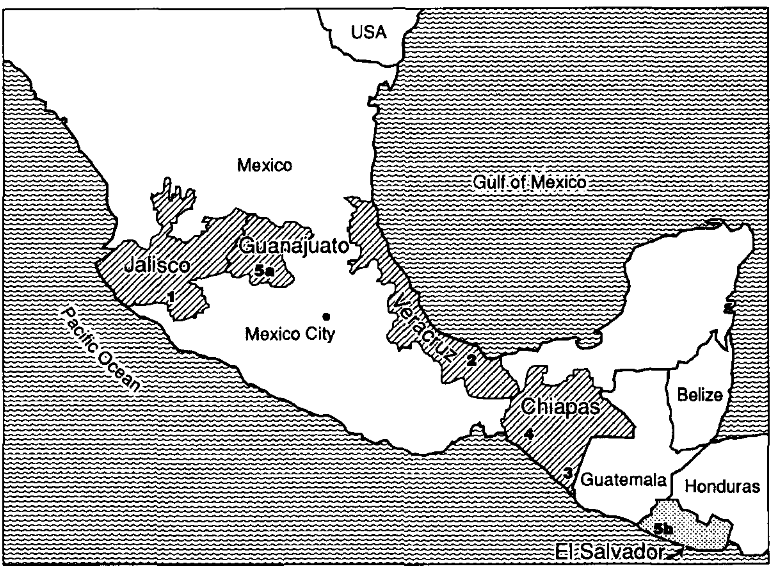

Figure 7.1 Location of the case study areas in Meso America
Chapter 7: 1. Southern Jalisco; 2. Southern Veracruz;
Chapter 8: 3. Chiapas Highlands; 4. Central Chiapas;
Chapter 9: 5a. The Bajio; 5b Guaymango.

7.1 The potential of CRM-based maize production in Southern Jalisco, Mexico[1]

The Southern Jalisco study area is located in central-west Mexico. Its agricultural-based rural economy is quite developed. Crop production is market-oriented, with a substantial use of mechanisation and external inputs. Agriculture is predominantly rainfed, which implies a single cropping season in the summer and a prolonged dry season in winter. The area is mid-altitude (1,000 - 1,500 m), and encompasses a high (600-1,000 mm yr^{-1}) and low (400-600 mm yr^{-1}) rainfall zone. Crop and livestock production is mainly located on flat to rolling arable land. Steeper slopes tend to be under brushwood, giving way to pine forests at higher altitudes. CRM adoption levels in the study area are minimal (about 1% in 1994).

The selection of the study area reflects an on-going collaborative (INIFAP, CIRAD and CIMMYT) CRM-related research project in the area (*e.g.* Scopel, 1995b; 1996; 1997). The project has several long-term on-farm trials located within the area, reflecting contrasting agronomic conditions. Predictions of the biophysical effects of CRM in the area are derived from these trials. The socio-economic data were primarily collected through a formal single visit survey of 141 farmers at the onset of the 1995 summer cropping season.. The survey used a random sample, stratified by community and land tenure with a sampling fraction of 7.5%. Overall, survey data collection required an estimated 4 man months. The following subsections assess the potential of CRM-based maize production following the steps specified in the TA framework.

7.1.1 Crop system implications

Maize is the main crop in the local farming system. Introducing CRM would substantially affect maize production in physical terms. Therefore, the emphasis will be on assessing crop management implications and the corresponding changes in physical input and output levels.

Necessary practices for CRM

CRM-based crop production requires a compatible residue balance so as to retain sufficient residues to surpass the 30%-cover threshold (*i.e.* a mulch of >2 Mg maize residue ha^{-1}). In the case of maize, both residue production and weathering levels are potentially compatible (in regular years). In view of major yield differences between the high and low rainfall zones, there is a need though to distinguish between the two zones.

The current residue balance for a 'typical' maize field[2] is estimated based on the prevalent practices (Table 7.1) and a number of assumptions.[3] The 'current' columns in

[1] This case study is based on Erenstein (1997b) and Erenstein *et al.* (1997). Credit is due for the various collaborators from INIFAP (Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico) and CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France).

[2] Typical in the sense of representative and most common in terms of field characteristics and management practices. As with any typology, some approximate this better than others.

[3] Maize yields, land preparation practices and residue extraction reflect average/typical levels reported for each zone. Assumes average yield in regular years; a harvest index of 40% in high

Figure 7.2 depict the results for each zone.[4] The current residue balance highlights that the quantity of residues remaining as mulch is minimal: typically most residues are extracted or burned.

The residue balance can be made CRM-compatible by including the necessary practices - *i.e.* no burning, limited incorporation and limited extraction. The current residue balance however masks the effect of tillage. Land preparation is generally mechanised (88% of farmers) and tillage intensive. Consequently, no burning is a necessary but typically not sufficient condition for CRM adoption. Especially in the high rainfall zone, incorporation would largely substitute for previous burning in terms of residue elimination.[5]

Table 7.1 Overview of current and CRM-based residue management practices in the Southern Jalisco study area

	Current residue management[a]		CRM-based residue management	
Practice	High rainfall zone	Low rainfall zone	No till option	Reduced till option
Pre-plant burning	Yes (55%)[a]	Yes (55%)	No (preventive fire break)	No (preventive fire break)
Tillage	Intensive (59%)	Reduced (77%)	No	Reduced
Residue extraction	Yes (94%)	Yes (96%)	Yes	No
Mulch	No (98%)	No (100%)	Yes	Yes

[a] Percentage refers to survey population implementing specified practice (Erenstein, 1997b).

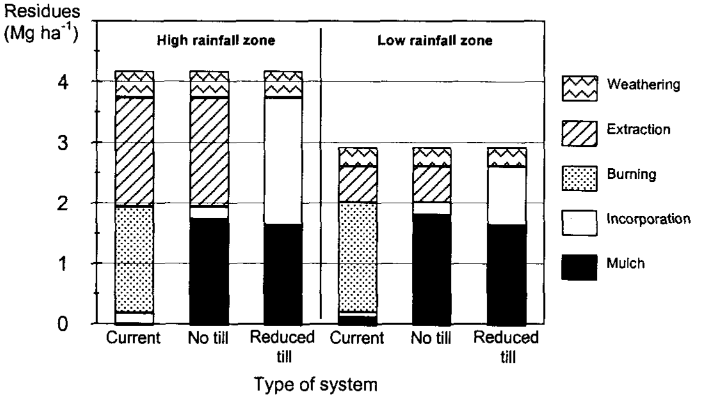

Figure 7.2 Current and prospective CRM-based residue balances in the Southern Jalisco study area

rainfall, 30% in low rainfall zone; and a weathering index of 10%. Assumed incorporation/-elimination indices: ploughing 80%; harrowing 30%; sowing 10%; burning 90%.

[4] The different residue uses are stacked in each column, whereas by definition the different uses add up to the local residue production.

[5] The data suggest that pre-plant burning is especially common where farmers perceive a need to somehow eliminate residues. No burning is already common in areas with intensive tillage and/or limited residue production.

Two residue management scenarios can be envisaged that would be broadly compatible with CRM: (i) a no till system with limited residue extraction; and (ii) a reduced till system without residue extraction (Figure 7.2).[6] The no till option implies two necessary changes (Table 7.1): (a) residues are not burned; and (b) all soil tillage prior to establishment is eliminated - *i.e.* the crop is drilled directly into the soil. The reduced till option implies three necessary practices (Table 7.1): (a) residues are not burned; (b) tillage intensity prior to establishment is curtailed (*i.e.* soil is not inverted and the number of passings with disc harrow is limited to two); and (c) residue extraction is eliminated.[7] In order to protect the residues against accidental burning, both options imply the recurrent need to construct a firebreak. Most fields (80%) are already fenced - providing the possibility to protect the residues from extraction in the reduced till option.

Complementary cultural practices for CRM

CRM would also imply a number of complementary practices. The no till option drastically alters the *sowing* operation as it requires the use of a direct seed drill that can sow in an untilled mulched soil. The reduced tillage option conceivably could maintain the current sowing practice (dependent on rainfall zone, either mechanised or with animal traction) - albeit that sowing would require more time (Table 7.2).

Reducing (or eliminating) tillage implies an increased reliance on herbicides to achieve satisfactory *weed management*. Herbicide use is already widespread in the high rainfall zone (Table 7.2), implying limited adaptations (in terms of dosages, products and number of applications). In the low rainfall zone herbicide use is less common and adaptations are more substantial. Furthermore, intercropping (especially with squash) is more common in this zone thereby posing a herbicide-intercrop compatibility problem.

There is some anecdotal evidence that no burning might increase the incidence of some pests in the area (notably *Phyllophaga spp.* and *Cercospora zeae-maydis*). However, for now CRM does not seem to imply substantial alterations for *pest and disease management*.

CRM also does not seem to require substantial alterations in terms of *nutrient management*. Chemical fertiliser use is near universal, with an average $N:P_2O_5:K_2O$ dose of 157:43:5. Current N-application rates reduce the possibility of a N-immobilisation related yield loss under CRM - even in the low rainfall zone (Table 7.2). The exact implications of CRM for fertiliser use efficiency are unclear though. Farmers rely predominantly on ammonium-based fertilisers as N-source - which may increase the danger of volatilisation.

[6] Admittedly, none of these options actually surpasses the two Mg maize residue ha^{-1} threshold required for CRM. Strictly speaking, only zero till with *reduced* extraction would be compatible under the current assumptions. Note, however, that values are of indicative nature only and ignore the contribution of weeds. Scopel and Chavez (1996) actually contemplate the use of a 1.5 Mg residue threshold in areas with residue scarcity. Further, the depicted residue balances reflect the situation faced by a prospective adopter. Upon adoption, the water conservation effect may subsequently increase residue production where water is a limiting factor (particularly in the low rainfall zone).

[7] This corresponds with the empirical data: 19% of the farmers combined reduced tillage with no burning, yet only 1% actually reported retaining sufficient mulch.

This may be offset though by the farmer's practice of splitting fertiliser application and CRM's water conservation effect.

Table 7.2 Overview of current and CRM-based crop management practices in the Southern Jalisco study area

	Current crop management[a]		CRM-based crop management	
Practice	High rainfall zone	Low rainfall zone	No till option	Reduced till option
Sowing	Mechanised traditional (55%)	Animal traction (64%)	Mechanised direct	Original practice but slower
Weed management				
- prior crop emergence	Mixed, including herbicides (78%)	Physical (68%)	Herbicides	Mixed, including herbicides
- after crop emergence	Mixed, including herbicides (83%)	Mixed, including herbicides (55%)	Mixed	Mixed
Intercropping	No (79%)	Yes (64%)	No [b]	No [b]
Pest/disease mgt.	Mixed, including biocides (56%)	Mixed, including biocides (32%)	Biocide	Biocide
Nutrient management	Chemical fertiliser (98% use, average 170 kg N ha^{-1})	Chemical fertiliser (91% use, average 89 kg N ha^{-1})	Chemical fertiliser (>80 kg N ha^{-1})	Chemical fertiliser (>80 kg N ha^{-1})

[a] Percentage refers to survey population currently implementing practice. [b] Or reliance on non-residual herbicides only. Source: derived from survey data - Erenstein, 1997b; Erenstein *et al.*, 1997.

Input-output implications

The necessary and complementary practices for CRM alter the input into the crop system, particularly in terms of labour, capital and crop residues. The exact implications depend both on the rainfall zone and CRM option (Table 7.3). In the high rainfall zone, CRM has minor implications for labour input - partly in view of the current mechanisation and external input levels. In the low rainfall zone, CRM slightly augments labour input - particularly for the reduced till option. The capital input mainly reflects the substitution of herbicides for tillage, and the implications for the sowing operation. In addition, the reduced till option implies foregoing the extraction of residues.

CRM is complex and knowledge intensive, but does not seem to impose major learning costs for farmers in the area. First, most farmers already had substantial experience with herbicides by 1995 (Figure 7.3).[8] Second, nearly half of the farmers were aware of the

[8] Although experience does not necessarily imply an effective and efficient use. Further, overall learning costs will never be zero as the farmer still has to adapt himself to the CRM technology (and possibly the technology to his specific circumstances).

technology (*i.e.* had actually heard of it and could indicate some of its merits and demerits). Such farmers tended to associate the technology with enhanced soil fertility and soil conservation, but also expressed some concern over pest problems.

Table 7.3 Output-input levels in current and prospective CRM-based maize production in the Southern Jalisco study area

	High rainfall zone			Low rainfall zone		
	Current	No till	Red. till	Current	No till	Red. till
Output						
- Maize grain (kg ha^{-1}) [a]	2,800	ditto	ditto	1,250	2,000	2,000
- Maize residues (kg ha^{-1}, estimate)[b]	4,200	ditto	ditto	1,875	3,000	3,000
- Intercrop (US$ ha^{-1}) [c]				100	foregone	foregone
Recurrent & labour input						
- Burning or firebreak (day ha^{-1})	2 (burn)	2 (break)	2 (break)	2 (burn)	2 (break)	2 (break)
- Maize residues (kg ha^{-1} prior to tillage, estimate) [d]	200	2,000	3,800	200	2,000	2,600
- Ploughing (operation)[e]	1	0	0	0	0	0
- Discing (operation) [e]	2	0	1	1	0	1
- Mechanised seed drill (op.)[e]	1		1.2			
- Direct-seed drill (op.)[e]		1			1	
- Animal input sowing (op.)				1		1.25
- Sowing labour (day ha^{-1})				2		2.5
- Seed (kg ha^{-1})	19	ditto	ditto	15.5	ditto	ditto
- Pre-emergence herbicide (l ha^{-1})	1.8	2.5	2.0	0.6	2.5	2.0
- Other herbicide (l ha^{-1})	0.8	2.0	1.6	0.3	2.0	1.6
- Application herbicide (day ha^{-1})	2	2.5	2	0.8	2.5	2.0
- Physical weeding (op.)	1	ditto	ditto	1	ditto	ditto
- Fertiliser ($N:P_2O_5:K_2O$; kg ha^{-1})	170:46:6	ditto	ditto	90:33:0	ditto	ditto
- Insecticide (l ha^{-1})	8.5	ditto	ditto	4.6	ditto	ditto
- Application fertiliser & insecticide (day ha^{-1})	3.8	ditto	ditto	3.6	ditto	ditto
- Mechanical harvesting (op.) [e]	1	ditto	ditto			
- Manual harvesting (day ha^{-1})				4.2	6.7	6.7
- Mechanised shelling (Mg grain)				1.25	2.0	2.0

Current data based on survey averages (Erenstein, 1997b; Erenstein *et al.*, 1997); CRM-based data are deducted. Ditto is same as current. Blank entries are zero or not relevant. [a] Maize yield increase reflects a yield adjustment of 80% (CIMMYT, 1988) of on-farm trial results. [b] Based on harvest index - 40% high rainfall, 30% low rainfall zone. [c] Foregone intercrop yield reflects incompatibility with used herbicides. [d] Estimate from residue balance. Pre-tillage residue quantities need to be higher for reduced till option to compensate for incorporation. [e] Tractor input includes driver.

Current maize yields (farmer reported, for a regular year) average 3 Mg ha^{-1} for the high rainfall zone, and 1.25 Mg for the low rainfall zone. Water tends to be a limiting factor for crop growth in the latter zone. Experimental results corroborate CRM's potential to boost water limited yields. With a two Mg mulch, grain yield in the low rainfall zone may increase from 1.25 to 2.2 Mg ha^{-1} under experimental conditions - a 75% increment (Scopel, 1995a; 1996). At the same time, CRM does not significantly alter the yield level in the high rainfall zone (*ibid.*).

Rainfall is particularly erratic in the low rainfall zone, although the high rainfall zone also occasionally experiences pronounced dry spells. Therefore, CRM's water conserving effect has the potential to enhance yield stability in both areas.[9] CRM is also shown to have favourable carry-over effects in terms of soil conservation, soil water reserves and physical soil structure in the area (*ibid.*).

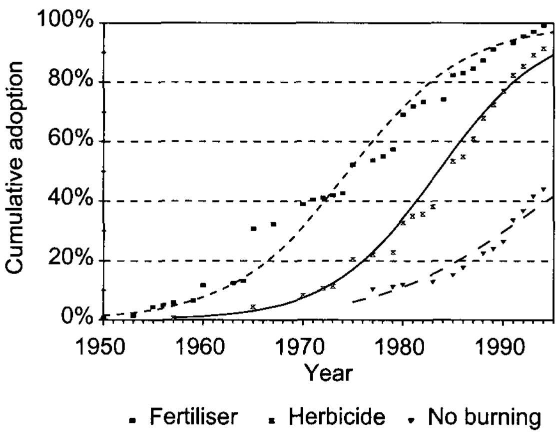

Figure 7.3 Diffusion of some management practices in the Southern Jalisco study area (actual points refer to survey data; logistic curves estimated thereupon[10])

7.1.2 Resource implications for the farm household

The typical components of the local farm household system include crop production, livestock production, other productive and household activities. Different farm types can be distinguished, but across farm types, crop production is characterised by the prevalence of

[9] Experimental evidence does highlight that there are limits to CRM's yield stabilising potential (*ibid.*). CRM may limit the drought-incurred yield loss when the dry spell is short and intense (but long enough to adversely affect the conventional clean till crop). However, with a prolonged dry spell, even CRM's additional water reserves eventually run out. With an extreme drought, both the CRM as the clean till crop may end up desiccated and produce a negligible grain yield - although CRM's crop residue yield will still tend to be higher.

[10] Based on $Y_t = K * [100 * (1+e^{a-bt})]^{-1}$ where Y_t cumulative adoption at time t; K upper bound of adoption; a and b regression constants (CIMMYT, 1993). *E.g.* for herbicides K=100%; a=368.4; b=0.1857; R^2=0.98 (Erenstein, 1997b).

maize (Table 7.4).[11] In the 1994 cropping season its cultivation was near universal (95% of survey households) and occupied 79% of average arable area; whereas other crops (including forage, vegetables and fruits) occupied 6%. Permanent pastures occupied 15% of average arable area. Livestock production is widespread: 66% of households had cattle and 12% small stock (pigs; sheep). For half the farm households this comprised a substantial activity (*i.e.* more than the equivalent of 5 adult cows). About a third of these could be typified as dairy farms (18% of households), the remaining as mixed farms with cattle for meat or dual purpose. On-farm agricultural income is frequently supplemented with income from other activities, such as off-farm work in the region (41% of households), out-migration of family members to the USA (38%) and non-agricultural activities (25%). The household encompasses an average of 6 people. The present subsection briefly assesses the main resource-related implications of CRM-based crop production for the other farm household activities.

Table 7.4 Comparison of land-related indicators over farm types in the Southern Jalisco study area

	Small scale crop farms	Small scale mixed farms	Large scale crop farms	Large scale mixed farms	Dairy farms	Prob.
Arable area (ha)						
- Maize area	5.6 a	7.0 a	46.1 b	35.6 b	37.6 b	.00
- Pasture area	0.8 a	1.5 a	6.6 b	7.3 b	9.2 b	.00
- Fodder crop area	0.0 a	0.1 a	0.3 a	1.8 ab	2.5 b	.06
- Other crop area	0.6	0.3	2.4	1.8	0.6	NS
Non-arable area (ha)	4.1	5.8	11.5	4.7	13.8	NS
Sum (*i.e.* farm area)	11.0 a	14.7 a	63.1 b	51.2 b	63.8 b	.00

Source: Erenstein *et al.* (1997). Data followed by different letters differ significantly - Duncan (.10), within row comparison. Summation discrepancies due to rounding.

Factor related implications

CRM-based maize production has two main *land*-related implications. First, crop rotations emphasise the cultivation of a single annual maize crop on a continuous basis. This implies CRM-based maize production would have few direct effects on other crop production activities. It also makes it more likely that effects in terms of soil ecology and soil conservation accumulate over time. Overall, these effects are likely to enhance maize productivity. Second, CRM restricts the use of crop stubble as pasture between subsequent cropping seasons - particularly in the case of the reduced till option. This issue is elaborated upon discussing crop residue use, but may imply that the household needs to extend the area under annual (permanent) pasture.

CRM-based maize production does not really alter the *labour* input or timing. However, the dominance of maize implies small changes can still have a significant impact on-farm household labour use. This impact is likely to be accentuated by the pronounced seasonality.

[11] Farm size varies substantially across farm types, with an overall average of 39 ha but a median of only 17 ha.

Further, the reliance on herbicides implies that timing is increasingly important. CRM may therefore still displace some household labour from alternative use (productive or leisure).

The *capital*-related implications of CRM-based maize production depend on a combination of factors, including tillage option, rainfall zone and equipment level. The tillage option and rainfall zone determine the corresponding changes for herbicide and implements use (tillage; sowing). In turn, these changes have a different financial impact on a farm household depending on whether it owns a tractor. Only one third is (co-)owner - with ownership concentrated amongst the large scale and dairy farms. For tractor owners, CRM's financial implications are two-fold. First, CRM affects long-term finances. Particularly in the case of the no till option, CRM implies investment in a direct seed drill whereas existing tillage implements may become obsolete. Second, CRM affects short-term finances as it increases the use of herbicides. For non-tractor owners, CRM mainly affects short-term finances, as external herbicides substitute for external services. Additional demands for short-term and long-term finances are likely to compete with the other productive and consumptive demands. With the use of herbicides already widespread and long established, access to herbicide application equipment is not an issue.

Crop produce related implications

Both maize grain and residues are used internally by the farm household. On average, 16% of the household's grain production in a regular year is used for internal consumption (divided equally over human and animal consumption). Residues are widely used as internal fodder source. Mixed and dairy farms have a substantially higher internal residue pressure than crop farms (Table 7.5). Residues are often the main fodder source during the dry season for meat and dual-purpose cattle, and are therefore particularly important for mixed farms. Residues are used less intensively on dairy farms - in part reflecting their low nutritious value. Dairy farms typically supplement residue use with better quality fodder sources - including alfalfa, improved pasture, concentrates and a more intensive use of maize grain. Access to irrigation typically allows dairy farms to produce their own fodder on a year-round basis.

The implications of CRM-based maize production are twofold. First, CRM stabilises the internal pool of crop produce over time in both zones, as well as enhancing it in the low rainfall zone. Second, the reduced till option curtails the use of residues as fodder. This particularly conflicts with established practice on mixed farms.

Table 7.5 Comparison of livestock-related indicators over farm types in the Southern Jalisco study area

	Small scale crop farms	Small scale mixed farms	Large scale crop farms	Large scale mixed farms	Dairy farms	Prob.
Herd size (AU)[a]	2.3 a	19.5 b	1.6 a	31.7 c	51.7 d	.00
Internal pressure on residues (AU ha^{-1})[b]	0.42 a	1.83 c	0.19 a	0.97 b	2.41 c	.00

Source: Erenstein *et al.*, 1997. Data followed by different letters differ significantly - Duncan (.10), within row comparison. [a] Animal unit, equivalent of one adult cow. [b]Calculated as household animals that graze residues divided by the household's cultivated area with basic food crops (AU ha^{-1})

7.1.3 Institutional setting

The local institutional setting is relatively developed, with markets for produce and production factors. Physical infrastructure is reasonable, thereby providing year-round access to the main town in the area (Cuidad Guzmán). This town is the main commercial hub with good access to other markets, including Guadalajara - Mexico's second biggest city. The present subsection briefly assesses the relevant institutional issues.

Crop produce rights & markets

Two types of *crop residue* rights prevail in the area - private and communal. Private rights are predominant and are generally respected. They are typically protected by having individual fields fenced-off with barbed wire. Communal rights may be protected through a common contour fence around adjoining fields. In these instances, adjoining farmers - varying from two individuals to entire communities - frequently jointly manage their residue extraction and/or transactions. The prospective adopter with communal rights faces an institutional entry barrier, in terms of either requiring collective adoption or opting-out and erecting additional fences.

The area has a well-developed residue market, with 36% of the farm households reportedly selling and 28% buying. As expected, net household sales correlate negatively with internal fodder demands: selling being predominant amongst crop farms, buying amongst mixed and dairy farms. About two-thirds of residue transactions proceed in the form of standing stubble, with the remainder in processed form (milled or baled). The average transaction price for standing stubble amounted to US\$ 34 ha^{-1}. Current transactions give the buyer the right to all the residues within a stipulated period.[12]

The two CRM options are likely to have different implications for residue rights and markets. The reduced till option implies the need to forego residue extraction. Widespread use of this option is likely to increase the market price of residues. The no till option does allow for extraction. However, average extraction levels already put considerable strains on the possibility to satisfy the mulch threshold in a regular year (let alone, in a less-than-regular year). Therefore, the prospective adopter of the no till option may want to sell some surplus residues but ensure sufficient residues are left to form a mulch. This requires adapting the residue transaction and implies additional transactions costs - *e.g.* by stipulating that the seller retains the right to two Mg of residues ha^{-1} and the buyer observes the duty to leave sufficient residues. Such institutional change is likely to be constrained by the widespread ownership of livestock.

Pre-plant *burning* is still the prevalent practice in the area, but is rapidly being abandoned (Figure 7.3:161). With the current trend it looks likely that no-burning will become the established practice. This would imply that CRM adopters no longer need to invest in annual firebreaks.

[12] With as outmost bounds the grain harvest (of the crop that provides the residues) and the land preparation for the subsequent crop.

Factor rights & markets

About three-quarters of the farm households own their *land*, comprising both *ejidatarios* and 'small proprietors'.[13] The inter-temporal implications of CRM are unlikely to be a major issue for these households in view of secure tenure. The inter-temporal nature is more problematic for the quarter of the households that rent in their land. Renting in of land seems to relate to economies of scale, as it tends to be common amongst the households with greater farm size.

Farm households mainly rely on family *labour* but also actively participate in the local labour market. Nearly two-thirds of households reported renting in and about one-third renting out agricultural day-labour. Nearly one fifth of the households reported having permanent farm labourers. The typical local wage rate for agricultural day labour was US$ 7.35 day^{-1}, irrespective of activity.

The main town in the area is the base for *capital* markets and services, including providers of inputs, equipment, rental services, official credit and extension. Some services are also readily available outside the main town - *e.g.* provision of physical inputs. Prospective adopters may thereby be able to access most of the required capital goods. More problematic is the direct seed drill for the no till option. Farmers that were aware of the technology indeed identified the availability of direct seed drills as a major issue. The area has a well-developed market for general tractor services (especially in the high rainfall zone), and most farmers without tractors contract these. However, the rental market for direct seed drills in the area is still nascent. This has a number of implications for prospective adopters of the no till option.

A nascent market corresponds with limited availability and typically high cost - in view of risk premiums, economies of scale and eventual monopoly rents.[14] Early adopters may thereby invest in establishing a rental market. As the new market becomes wider and more competitive, prices are likely to decline and availability to improve - much like has happened in the USA (Moldenhauer *et al.*, 1994). Rental services also offer opportunities for the advent of CRM. Each direct seed drill will be accessible to a greater number of farmers. Entry barriers are also substantially reduced by lowering (i) experimentation costs (*e.g.* no need to invest in equipment); and (ii) learning costs (*e.g.* the service provider with his accumulated hands-on experience is present). Further, the provider having already made

[13] The distinction goes back to the land reform that followed the Mexican Revolution. Small proprietors were private landholders, labelled "small" because of the imposed maximum area per owner. *Ejidatarios* - members of rural communities labelled *ejidos* - were the beneficiaries of the land reform and received the constitutional right to the usufruct of a stipulated quantity of land. The government retained the ownership of the land. In the 1990's, the Mexican constitution (Article 27) was amended and the *ejidatarios* obtained the outright land-ownership title. Although the distinction therefore becomes superfluous in a strict institutional sense, it generally still connotes a marked contrast in terms of management and capitalisation. However, within the class of *ejidatarios*, differences can still be substantial, often reflecting the quality of the allocated land resource.

[14] Providing direct drill rental services in itself implies a number of trade-offs. First, it implies a substantial investment. Second, it substitutes for established services. Third, it is perceived (by tractor owners) to increase operational risk in unknown fields.

the investment in CRM technology, may well function as an active diffusion agent to recap the investment.

Institutional interrelationships
Transactions in the area have increasingly commercialised, but several interlinkages remain. For instance, some transactions are paid in kind with crop produce (*e.g.* rent for traction animals; harvest labour on occasions) and share contracts for livestock exist (also see McIntire, 1993). Interlinkage is particularly common and relevant for CRM in the land rental market. Although in most cases rents were paid in cash, the landlord generally retained the right to the residues. Conceivably, prospective tenant adopters are thereby limited to the no till option that allows for (some) extraction. Alternatively, they should refrain from interlinking or ensure the landlord limits the quantity extracted. Other interlinkages in the land rental market included share-cropping and labour services.

7.1.4 Private assessment

The present subsection assesses the private implications of CRM-based practices for the farm household, in terms of farm household preferences and decision making, valuation and private returns.

Farm household preferences and decision making
In general, the farm households participate actively in the factor and produce markets. Private returns are thereby likely to be influential in household decision making. For instance, the central location of the area implies that wage rates for agricultural labour are high for rural Mexico (*e.g.* compared to other study areas). This has induced households to substitute capital (notably mechanisation and herbicides) for labour-intensive agricultural operations, particularly in the high rainfall zone. Similarly, it has induced a fifth of the households to substitute permanent labourers for day labourers. This was further aided by the potentially higher returns to family labour outside the regional agricultural sector (including migration to the USA), which has induced the substitution of external for family labour.

Risk implications are also likely to be influential in household decision making. Risk markets tend to be imperfect - whereas the potential incidence of drought increases the agricultural production risk. Most farm households produce maize and combine this with livestock production. The prevalence of maize reflects household consumer preferences as well as a number of benefits - including household food security, crop-livestock complementarity (residues and grain) and a secure produce market. The prevalence of the livestock sector also reflects a number of benefits - including crop-livestock complementarity, portfolio diversification, finance, insurance and status (also see Bosman *et al.*, 1997).

Some of these issues imply direct trade-offs - for instance in terms of the choice of crop (sorghum is more drought tolerant than maize). These issues also have direct implications for CRM-based maize production. On the one hand, CRM fits in with current preferences and constraints. CRM's water-conserving potential reduces the crop production risks *ex ante*. CRM's cost-saving potential could enhance the economic returns to crop production.

Further, the farm household's market integration facilitates adapting the farm household's resources as needed. On the other hand, CRM (particularly the reduced till option) is constrained by the prevalence of the livestock sector and the residue extraction this implies (see Annex C for a model). Displacing livestock production is unlikely to be an acceptable proposition - in view of current preferences. The critical question therefore is if the household's marginal benefits (utility) of adopting CRM make the marginal costs (disutility) to satisfy CRM's conservation-standard worth incurring.

Valuation

The area has reasonably developed produce and *factor* markets. The average land rent in the area is taken as indicative of the opportunity cost of land. The local day labourer wage rate is assumed to be a fair approximation of the (opportunity) cost of labour. External inputs are valued at their acquisition plus transport costs. Most households do not own a tractor. Tractor use is therefore valued at the going rate for such services (which includes operator, operation and maintenance).[15] Costs of financing are highly variable - but five percent per month is assumed to be a reasonable approximation of its average/opportunity cost.

The marketed crop *produce* (84% of average farm production) is valued at the local on-farm sale price - the internal consumption at the local on-farm purchase price. The intercrop is valued at a representative lump sum. The crop residues have productive value as fodder and residue extraction is near universal (94% of households). Extraction levels are largely compatible with the no till option, and in the short term, the corresponding opportunity cost of retaining the residues is assumed to be negligible. However, the reduced till option implies foregoing extraction. For households that sell surplus residues this implies cash income foregone. For households that use the residues internally this implies fodder foregone. In this case the opportunity cost is likely to reflect the cost of substituting for the fodder foregone - as reducing internal demand is not likely to be an attractive proposition. The developed residue market conceivably allows to substitute off-farm for on-farm residues.[16] Alternatively, other fodder sources could provide a substitute. The presence of the dairy farming in the area ensures such alternatives are available - albeit on a limited scale (*e.g.* alfalfa produced locally on irrigated land or imported from other areas) and at a substantially higher cost (partly reflecting better quality). In the short term, the current sales price of crop residues is assumed to provide an adequate valuation of the opportunity cost of the mulch for the reduced till option. However, in the event CRM adoption becomes widespread, this price most likely will increase over time.

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[15] *E.g.* rates average US$ 48.5 ha^{-1} for ploughing; US$ 25 ha^{-1} for disc harrowing; US$ 38.2 ha^{-1} for use of traditional mechanised seed drill; and US$ 80.9 ha^{-1} for use of direct seed drill.

[16] The substitution of external for internal residues occasionally already happens: Two percent of the households reported simultaneously selling and buying residues. Farmers may recover the transaction costs implied by such trading through reduced extraction costs (*e.g.* when trading the residues of a distant field for those close to the homestead).

Private returns

Table 7.6 provides an overview of the short-term budget implications of current and prospective CRM-based maize production in the area, for both the high and low rainfall zones. The budgets highlight a number of issues. First, on average, current maize production technology remunerates internal production factors at less than the estimated opportunity costs - particularly in the high rainfall zone. Second, CRM has different economic implications in the two zones.

Table 7.6 Prospective short-term crop budgets in the Southern Jalisco study area

	High rainfall zone			Low rainfall zone		
	Actual	No till	Red. till	Actual	No till	Red. till
A. Gross production value (US$ ha^{-1})	541	541	541	289	396	396
a1. Maize grain	507	507	507	226	362	362
a2. Maize residue	34	34	34	34	34	34
a3. Intercrop				29		
B. Recurrent expenses (US$ ha^{-1})	391	348	391	168	232	234
b1. External physical inputs	181	194	188	79	104	98
b2. External services [a]	207	151	166	80	119	93
b3. Residue input			34			34
b4. Internal physical inputs	3	3	3	9	9	9
C. Labour (days ha^{-1}) [a]	7.7	8.3	7.8	12.6	14.8	16.8
D. Capital and financing (US$ ha^{-1})						
d1. Financing costs	52	46	47	22	31	26
d2. Average working capital	347	304	313	150	208	176
E. *Procampo* (US$ ha^{-1}) [b]	103	103	103	103	103	103
F. Value added (US$ ha^{-1})	150	193	150	121	164	162
G. Household income (US$ ha^{-1})	184	232	189	175	204	203
H. Return to own land (US$ ha^{-1})	92	143	102	87	96	89
I. Return to own capital (% $month^{-1}$)	3.5%	9.0%	4.4%	2.8%	4.9%	3.6%
J. Return to own labour (US$ day^{-1})	4.6	13.5	6.3	6.3	7.3	6.7

[a] Labour provided by operator of tractor/bullocks included in service charge. [b] Area-based government support payment that compensates farmers for the liberalisation of basic commodity prices, including maize and beans. *Formula*: A = a1+a2+a3; B = b1+b2+b3+b4; F = A - B; G = [A + E - B - (external labour)*(wage) - d1]; H = [G - (opp. cost own labour) - (opp. cost own capital)]; I = [G - (opp. cost own labour) - (opp. cost land)]/(own capital); J = [G - (opp. cost land) - (opp. cost own capital)]/(internal labour). *Assumptions*: Factor opportunity costs - capital 5% $month^{-1}$; labour US$ 7.35 day^{-1} (wage rate); land US$ 107 ha^{-1} high rainfall zone; US$ 97 ha^{-1} low rainfall zone. Factor ownership assumptions - all tractor services contracted; working capital: 50% own + 50% borrowed; land: own; labour: 71% own + 29% hired (derived from survey data).

In the high rainfall zone, CRM is not expected to affect gross production value (average yields remain unaffected). CRM's potential therefore revolves primarily around its cost-saving nature. Both CRM-options reduce costs - but this is only substantial in the case of the no till option. This option reduces the recurrent expenses (particularly tractor services) with 11%, with only a minor increase in labour. On aggregate, this represents a US$ 43 ha^{-1} increase in value added and a US$ 48 ha^{-1} increase in household income. Consequently, internal production factors are now remunerated at more than the estimated opportunity costs. The cost-saving potential of the reduced till system appears to be rather ambiguous in the current setting. It generates only a minor cost saving and with a corresponding slight increase in the return to the household's production factors.

In the low rainfall zone, CRM provides a substantial boost to the gross production value. However, to achieve this, both options imply a substantial increase in production costs. In the end, the cost increase largely offsets the value of the yield gain. Therefore, although value added and household income increase substantially, the returns to the various production factors are only slightly affected.

The CRM-induced changes in private returns are possibly less than expected. In the high rainfall zone, it remains to be seen whether the prospective adopter actually finds the cost savings to be a sufficient compensation - in view of the complexity of the change and the perceived probability of actually achieving a saving.[17] In the low rainfall zone, the consideration of the average returns alone makes autonomous adoption unlikely.

Three factors curtail the private potential of CRM in the area. First, the sheer number of necessary and complementary changes in crop management. Neither option is a simple add-on component. Second, the opportunity cost of the residues in the reduced till option. Although not prohibitive, the cost is definitely not negligible. Third, the high rental cost of direct seed drills in the no till option. Each of these factors ensures that the potential gains are partially/largely forfeited.

Three last issues warrant highlighting in terms of the private returns. First, these reflect short-term considerations - *i.e.* the immediate implications of the adoption decision. They thereby implicitly reflect a high time preference and a planning horizon of one year. They also reflect current prices. However, if CRM practices were to become more common in the area, the price of the direct seed drill is likely to decline, whereas the opportunity cost of the residues is likely to increase. Both would tend to make the no till option more attractive relative to the reduced till.

Second, the budgets reflect average situations with a number of underlying assumptions (*e.g.* contracting all tractor services). The actual returns to adoption for a given household - or household type - are bound to be household-specific, being dependent on the household's actual productivity and opportunity costs, and thereby are affected by such factors as tractor ownership and whether it is a mixed/dairy farm. A production function approach and/or farm household modelling could conceivably incorporate such differences and thereby strengthen the analysis (Heerink & Ruben, 1996). These considerations also reiterate the site-specificity of adoption decisions.

[17] For most "traditional" adoption decisions, farmers generally weight the increased benefits against the increased costs to assess if these are worthwhile (*e.g.* in terms of their marginal rate of return - CIMMYT, 1988). With cost-savings, this is somewhat more problematic. However, it is unlikely that farmers consider minor cost savings of complex packages worthwhile.

Third, the returns are based on averages and thereby do not adequately reflect risk considerations. A comprehensive valuation of the risk trade-offs requires data that currently are not available. For instance, to assess CRM's potential reduction of crop yield variability, a more elaborate time series is needed. Further, to assess risk trade-offs at the farm level also requires quantifying the risk implications of livestock activities (*e.g.* in terms of portfolio risk, financial risk, insurance). Follow-up research in the area is to more adequately address such risk considerations.

In sum, CRM is not a very attractive proposition from the private viewpoint in the current setting. Crop management would require a number of changes to become compatible with CRM. In the high rainfall zone these changes still generate potential cost savings - particularly in the no till option though subject to the availability of a direct seed drill. In the low rainfall zone, cost increases largely offset CRM's water conservation potential. The limited short-term gains reduce the likelihood that the technology will diffuse autonomously in the area.

7.1.5 Social assessment

'Traditional' (clean-till) maize production practices in the area imply a substantial soil erosion hazard in agricultural fields at the onset of the summer season. CRM-based maize production could help off-set erosion-induced externalities. In addition to making agricultural production more sustainable (soil conservation), CRM-based practices also could make production less risky (water conservation) and more competitive (cost-savings). These effects could generate spill-over effects for the regional economy (*e.g.* by enabling productivity investments) and ease rural-urban migration. The cost-saving element is of particular interest: in 1994, Mexico joined the North-American Free Trade Agreement (NAFTA). Import parity pricing thereby replaced the elaborate output subsidies for basic commodities (including maize).

The available data do not allow for an elaborate social assessment, let alone assess whether the divergence between private and social interests actually warranted policy intervention. Assuming CRM-based maize production is socially attractive and policy intervention warranted, policy intervention could help create an enabling environment for CRM. For instance, policy could address missing and imperfect markets - *e.g.* by helping set up private rental services for sowing equipment. Policy could also help address information problems. Local farmers frequently equated the technology with reduced tillage and not burning residues. However, both are necessary but not sufficient conditions for CRM. Indeed, farmer's perceived use of the technology (9% of survey households) contrasts sharply with the actual use of CRM (about 1%). This indicates a terminology problem and the need to clarify the role of the mulch component. Policy could also look into the development of alternative fodder sources and promote not burning crop residues.

The general trend in Mexican agricultural policy in the 1990's is to scale down and/or privatise government support services - including agricultural research and extension. Policy intervention therefore requires a successful alliance between the major stakeholders in the area. In this regard, several organisations initiated a collaborative effort to promote CRM and provide for further fine-tuning and participative adaptation of the technology to local needs (Scopel, 1997). Farmer participation is of particular relevance here. Even within an enabling environment, CRM is unlikely to be a utility-enhancing proposition for all farm households (*e.g.* mixed/dairy farms). Farmers adopt CRM components as they see fit - and not necessarily as a package. The data indeed confirm the already existent disarticulation between the adoption of herbicides and no burning (*e.g.* Figure 7.3:161). In the end, the population is therefore likely to divide between non, partial and complete adopters of CRM-based maize production. Farmer participation could help identify further constraints for CRM and promising complementary and/or substitute practices in the local context.

7.2 The potential of CRM-based maize production in Southern Veracruz, Mexico[18]

The Southern Veracruz study area is located on the Gulf of Mexico (Figure 7.1:155). The area encompasses some of the remote and steep slopes of the Sierra de Santa Marta volcano. Its undeveloped rural economy is based on agriculture and forest exploitation. The population is mainly indigenous and is only partially integrated in markets. The area is tropical lowland (mainly 300-900 m) with abundant annual rainfall (1,300-3,000 mm).[19] Agriculture is rainfed with two distinct cropping seasons: a major summer season and a minor winter season. There is a short pronounced dry season in spring. Flat to rolling arable land is scarce, and agricultural production is mainly located on sloping land.

Crop production is still in transition from an itinerant (slash-and-burn) to a sedentary system. Fallow periods have been drastically reduced over time, replacing full-grown forest fallows with grassy variants.[20] The adaptations in crop management are generally insufficient to compensate for the incomplete regeneration (*i.e.* in terms of increasing the regeneration rate or decreasing the degradation rate - see annex A). Consequently, the sustainability of the system is undermined - highlighted by a downward spiral of shortening fallows, decreasing yields, and increasing weed and fertility stress. In the mid-1990s, CRM adoption levels in the study area were negligible during the major season - although a CRM-like technology occurs by default during the minor season.

The selection of the study area reflects the presence of the Proyecto Sierra de Santa Marta (PSSM) - a non-governmental organisation (NGO) engaged in the sustainable development of the Sierra, with an on-going partnership with CIMMYT and other stakeholders in the area (PSSM, 1994a; 1994b; Rice *et al.*, 1998). The study area encompasses a watershed of approximately 6,000 ha. The data presented in this case study were primarily collected through a formal single visit survey of 33 farmers at the onset of the 1995 summer cropping season. The study used a random sample, stratified by community and land tenure with a sampling fraction of 18%. Overall, data collection

[18] This case study draws on Rice, Erenstein, and Godinez (1998) and Buckles and Erenstein (1996). The present case study delimits itself to the Texizapan watershed. Credit is due for the co-authors of the original studies and the collaboration received from PSSM (Proyecto Sierra de Santa Marta, Mexico).

[19] The range reflects the effects of altitude, prevailing winds and location (*e.g.* rain shadows).

[20] The fallow:use area ratio tends to hover around unity (Stuart, 1978; Perales, 1992; Rice *et al.*, 1998) - *i.e.* a R-value of 50% (Makeham and Malcolm, 1986).

required an estimated one man month. The following subsections assess the potential of CRM-based maize production following the steps specified in the TA framework.

7.2.1 Crop system implications

Maize is the main annual crop in the local farming system and is cultivated in both seasons. Summer maize is generally intercropped to different degrees with beans and other crops. The present subsection assesses how CRM would affect maize production in physical terms in both seasons - thereby emphasising crop management implications and the corresponding changes in input-output levels.

Necessary practices for CRM

Necessary conditions for CRM-based maize production include compatible weathering and production levels. In the warm and humid tropical lowlands, the rate of residue weathering between cycles can be substantial (Wilson and Akapa, 1983; Lal, 1989:99). In the local context, the weathering losses in the run-up to the summer season are limited and compatible with CRM due to two factors. First, the residues are typically kept as standing stubble (in part due to piece-meal harvesting) - thereby limiting their exposure to weathering agents. Second, there is a pronounced dry spell in spring - thereby reducing the inter-season rate of weathering.

Maize grain yields are low in the local context - reflecting both low input use and a marginal environment for maize growth. At the same time they reflect an overall low crop biomass production, particularly in the single cropped fields (*i.e.* only summer season). Notwithstanding low levels of crop residue production, these are still potentially compatible with CRM. Further, the residue balance focuses on crop residues and thereby ignores the contribution of weeds. Under the prevalent circumstances, the production of weed residues tends to be substantial in view of (i) incomplete weed control; (ii) a self-reinforcing feedback between maize and weed growth; and (iii) winter season weed growth. The area combines the characteristically vigorous weed growth of the lowland tropics with the typically limited labour and capital resources of resource poor farmers. The combination tends to ensure *incomplete weed control* and a substantial weed biomass build-up during the crop cycle. This is also aided by the traditional wide spacing between maize hills and the resulting low plant densities.[21] Vigorous weed growth adversely affects maize growth and yield. In turn, a poorly developing maize crop is a poor competitor for weeds - creating a *self-reinforcing feedback*. Further, the area's ecology allows for plant (and thus weed) growth during the *winter season* - even in single cropped fields. Whenever a farmer decides not to grow a winter maize crop, weed growth continues unabated.

Consequently, both residue production and weathering levels are potentially compatible in the local context. There is a need though to distinguish between the single and double cropped maize fields. The current residue balance for a 'typical' single and double cropped maize field is estimated based on the prevalent practices (Table 7.7) and a number of

[21] Wide spacing facilitates inter and/or relay cropping; facilitates manual weeding; and reduces labour needs for maize planting.

assumptions.[22] The 'current'-columns in Figure 7.4 depict the results. The current residue balance highlights that the quantity of residues remaining as mulch at the onset of the summer season is minimal - irrespective of being a single or double cropped field. Typically, most residues are burned prior to planting the summer crop.[23]

Table 7.7 Overview of current and CRM-based crop residue management practices in the Southern Veracruz study area

Practice	Current residue management	CRM-based residue management
Pre-plant burning	Yes in summer; no in winter	No in both seasons
Tillage	None	None
Residue extraction	Negligible	None to limited
Mulch	No in summer; 'standing' in winter	Yes in both seasons

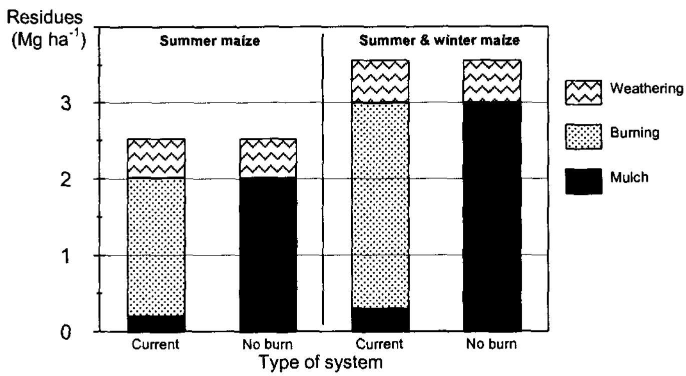

Figure 7.4 Current and prospective CRM-based residue balances in the Southern Veracruz study area

Pre-plant burning for summer maize is incompatible with CRM and would need to be abandoned. The other residue management practices are already compatible with CRM (Table 7.7). Incorporation levels are negligible as farmers already use a manual no till system: physical soil tillage is totally absent and field-based operations are manual.[24]

[22] Assuming an average yield of 840 kg ha^{-1}; a harvest index of 25%; and a weathering index of 20% for summer maize. For winter maize the respective estimates are 260 kg ha^{-1}; 20% and 5%. The burning index is assumed to be 90%.

[23] Figure 7.4 does not include the potential contribution of weed residues. However, in the current case these would also be largely burned: *i.e.* even the combined crop and weed mulch would still be marginal.

[24] With such tools as a machete/cutlass, dibble stick and backpack sprayer. Equines are occasionally used to transport goods to and from the field. With slopes of maize fields averaging

Residue extraction levels are also negligible. Therefore, in this instance, no burning is a necessary and sufficient condition for adoption. Especially in double cropped fields, no burning implies the two Mg mulch threshold is surpassed with ease (see Figure 7.4).

Winter maize is already planted without pre-plant burning. The winter crop is relay planted into the summer crop - the presence of the un-harvested summer crop thereby preventing the use of fire. The presence of the 'doubled' summer maize[25] and prevalent weed control practices - with machete and/or herbicides - generally ensure sufficient soil cover to make the winter crop a CRM-based system by default.

Complementary cultural practices for CRM

CRM-based maize production would also have a number of implications for complementary practices. Pre-plant burning eliminates most organic debris and thereby facilitates *crop establishment*. This was a necessity in the original slash-and-burn systems from which the current system has evolved. The amount of organic debris in the current systems is substantially less and not prohibitive for crop establishment. However, retaining it as mulch would slow down the manual sowing operation (with dibble stick, Table 7.8).

Table 7.8 Overview of current and CRM-based crop management practices in the Southern Veracruz study area

Practice	Current crop management [a]	CRM-based crop management
Sowing	Manual (100%) [a]	Manual, but time increase
Weed management		
- prior crop emergence	Physical (slash-and-burn, 100%)	Slash and herbicides
- after crop emergence	Mixed, including herbicides (76%)	Mixed
Intercropping	Yes (100%)	Yes, but restrictions on herbicide use
Pest/disease management	Burning (100%) and biocides (48%)	Biocides
Nutrient management	Fallowing and chemical fertiliser (52% use, average 37 kg N ha^{-1})	Chemical fertiliser (>80 kg N ha^{-1})

[a] Percentage refers to survey population currently implementing practice. Source: derived from survey data - Rice *et al.*, 1998.

Pre-plant burning eliminates the weeds present in the field (*i.e.* above ground) at the time. However, the overall weed-control effect is typically limited, whereas burning actually stimulates the germination and/or regeneration of certain weed species.

50% (*i.e.* 27°), mechanisation was unlikely anyway in most fields. The likelihood of mechanisation is further reduced by the remoteness, overall poverty and limited agricultural potential of the area.

[25] Farmers typically 'double' their summer maize below the maize ear once it reaches physiological maturity. This practice is widespread in Meso America, enhances drying, and reduces grain losses.

Nonetheless, not burning implies the need for alternative *weed control* prior to maize emergence - *e.g.* through an additional herbicide application (Table 7.8). The choice of herbicide (*e.g.* atrazine) may impose limitations on intercropping (or *vice versa*). Here one additional application with a non-residual herbicide (*e.g.* paraquat) is assumed necessary. The post-emergence weeding practices already rely on a combination of herbicide use and manual control with machete - CRM compatible and thus implying few adaptations. The weed growth inhibiting effect of the mulch is probably marginal in view of the limited residue quantities and rapid intra-season weathering.

The implications for *pest and disease management* are still unclear. Farmers tend to link the presence of the mulch to an increased incidence of rodents, snakes and diseases (*e.g.* tar spot - *Phyllachara maydis*). Here the net productive effect is assumed to be minor.

Not burning also affects *nutrient management*. The ashes from burning organic debris are perceived by farmers to enrich and soften the soil. However, the burning-induced boost of soil fertility may be limited in view of moderate debris levels (compared to fallow vegetation), whereas it does lead to the permanent loss of soil N and organic matter. On the other hand, the retention of the mulch is likely to exacerbate the immobilisation (temporary loss) of N. Only half the households reported using chemical fertilisers, whereas application levels for those that do are low (average $N:P_2O_5:K_2O$ dose of 37:20:10, Table 7.8). In order to maintain yield levels in the short term, CRM implies the need to increase N-application rates.

Input-output implications

Current maize production is land and capital extensive, hence labour intensive, requiring on average 70 labour days ha^{-1}. Not burning and its complementary practices for CRM-based maize production alter the input into the crop system, particularly in terms of labour, capital and crop residues for the summer crop (Table 7.9). On aggregate, adoption of CRM-based maize production practices would increase the use of the various inputs (labour, external inputs and crop residues).

The labour implications reflects two issues. First, CRM implies few labour savings: with the exception of pre-plant burning, residue management practices are already CRM compatible. Second, CRM does imply labour increases - *e.g.* it needs to substitute for the foregone initial weed control effect of burning and increases the time needed for sowing and fertilisation. Weeding is the most labour demanding activity for maize cultivation (amounting to 40% of labour needs) and generates a substantial labour peak in the agricultural calendar (in the first two-months after planting).[26] Although CRM does not directly alter post-emergence weeding itself, some of the implied labour increases fall in the run-up to this peak.

CRM also implies learning costs in terms of (i) no burning and (ii) external input use. CRM clashes with the long established practice of pre-plant burning. Indigenous technical knowledge reflects the farmers' understanding and interpretation of complex processes, and explains the benefits of burning in terms of 'hot' and 'cold' (Buckles and Perales, 1995;

[26] Substantial labour-savings could be made by increasing the substitution of herbicides for labour. However, complete substitution is not a necessary condition for CRM adoption.

Chevalier and Buckles, 1995:211).[27] In this regard, pre-plant burning for the summer season is 'hot' (dry) and is done to avoid excessive 'coldness' ('wetness'). In contrast, farmers consider mulching as beneficial in the winter cycle as it increases 'coldness' during the overly 'hot' winter season. This categorisation correlates closely with the expected water conservation effect of mulching on the maize crop.

CRM also implies learning costs in terms of external input use. Although most households had used herbicides and fertilisers (respectively 79% and 64%), adoption of both inputs was recent (each four years on average, and positively correlated). Farmers' understanding of the basic properties and application requirements of herbicides is typically limited in the area (Tasistro, 1994). Most farmers have picked up herbicide use through learning-by-doing - with implications for input use efficiency and human health. Farmers use different herbicides but mainly rely on toxic paraquat. Its frequent use and generally lax precautionary measures imply health risks/costs for the user. Indeed, one-third of the farmers who used herbicides reported having felt poorly after using them.

Current maize yields (farmer reported) in the main summer season averaged 840 kg ha^{-1} in the survey year. The intercrop yields also appear to be low (*e.g.* < 50 kg beans ha^{-1}). The winter season is risky for maize, as drought-stress and occasional strong winds are common, particularly at altitudes >500 m. The study area is located in a transition zone between single and double cropping, and reported winter maize yields averaged 170 kg ha^{-1} in the survey year.[28]

There are no experimental results available from within the area to corroborate the expected influence of CRM on maize yield. Inferences are thereby based on relevant secondary data.[29] These suggest that CRM's water conservation effect is unlikely to affect *summer season* yield levels in the short-term. First, water shortage is generally not a limiting factor. Second, eventual water excess is mitigated by the well-drained nature of most soils. CRM is likely to exacerbate fertility stress in the short-term due to temporary N-immobilisation by the residues. However, after adapting nutrient management the net effect of CRM on summer yield is negligible. CRM is likely to alleviate the occasional intra-season drought in summer, and may thereby enhance summer season yield stability.

CRM is very likely to boost *winter season* yield levels in the short-term at the lower elevations (albeit from a very low base), and to enhance overall yield stability. Drought stress is a major limiting factor in this season whereas CRM is inherently water conserving. Although the farmers already use a CRM-like practice for the winter season, CRM is still

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[27] The dichotomy of hot *versus* cold is not particular for the study area (*e.g.* also see Dove, 1992).

[28] In the lower part of the study area this average was 260 kg ha^{-1}. This compares to winter maize yields of around 400 kg ha^{-1} (Perales, 1992; Buckles and Perales, 1995) and 800 kg ha^{-1} (Chevalier and Buckles, 1995) in nearby communities. In other areas of Veracruz, winter maize yields are substantially higher (partly reflecting higher input use) - *e.g.* 1.7 Mg ha^{-1} in Los Tuxtlas (Zambada, 1996); 3-4 Mg ha^{-1} around Poza Rica (Violic *et al.*, 1989a).

[29] For instance, results from other areas under similar circumstances (*e.g.* in terms of slope: Lopez, 1993; in terms of humidity: Violic *et al.*, 1989a) and from nearby communities with cover crops (*e.g.* Buckles and Perales, 1995).

likely to substantially improve water conservation over the two seasons and thereby enhance winter yields.[30]

The maize fields are subject to a high soil erosion hazard at the onset of the summer season, when they combine high erodibility (no cover; steep slopes) with high erosivity (tropical rainstorms). CRM's soil conserving effect would reduce the hazard and ensure yield levels will be more adequately maintained over time. CRM's soil ecology effects are likely to ameliorate the low inherent soil fertility over time.

Table 7.9 Output-input levels in current and prospective CRM-based maize production in the Southern Veracruz study area

	Summer maize production		Winter maize production	
	Current[a]	CRM-based[b]	Current	CRM
Output (kg ha^{-1})				
- Maize yield	840	ditto	260	400
- Maize residues (estimate) [c]	2,520	ditto	1,040	1,600
- Intercrop yield (bean eq.)	46	ditto	0	ditto
Recurrent input (units ha^{-1})				
- Crop residues (kg at sowing time, estimate) [d]	200-300	2,000-3,000 (mulch)	2,500 (standing)	ditto
- Seed (kg)	13	ditto	13	ditto
- Herbicide (l)	3.6	7.6	0	ditto
- Fertiliser ($N:P_2O_5:K_2O$; kg)	17:7:3	80:7:3	0	ditto
- Insecticide (l)	0.3	ditto	0	ditto
- Transport animals (day)	2.3	ditto	0.7	1.1
Labour input (days ha^{-1})				
- Clearing (incl. eventual burning)	13.5	15	6	ditto
- Sowing	5.1	6.1	4	ditto
- Weeding	27.9	ditto	8	ditto
- Fertilisation	2.9	8	0	ditto
- Insecticide application	1.0	ditto	0	ditto
- Doubling maize	3.9	ditto	0	ditto
- Harvesting & shelling	15.4	ditto	4.8	7.3

[a] Based on survey averages (Rice *et al.*, 1998) and Buckles and Erenstein (1996). [b] Inferred, where ditto: same as actual. [c] Based on harvest index - 25% summer crop, 20% winter crop. [d] Estimate from residue balance. For summer maize, low figure refers to single cropped field; high figure to double cropped field. For winter maize all residues are still in the field as doubled summer crop.

7.2.2 Resource implications for the farm household

The typical components of the local farm household system include maize production, coffee production, other productive and household activities. Maize is the main food crop

[30] *E.g.* on-farm trials with cover crops and fertilisers in the area highlight a 54% increase in average winter maize yields (from a 374 kg base), mainly due to water conservation (Buckles and Perales, 1995).

and is grown predominantly to meet consumption needs. It is grown by all households in the summer season (on average 2.2 ha, sd [standard deviation] 1.0), and by three-quarters in the winter season (1.1 ha; sd 0.9). Coffee is the main cash crop (0.9 ha household^{-1}; sd 1.0), but is limited by agro-ecological factors to altitudes >500 m where it generally is grown under shade. Other activities are varied and include small scale livestock production (*e.g.* a fifth of the households reported having cattle), off-farm work (reported by 33%) and extractive activities from forests (*e.g.* construction wood and fuel). The household encompasses an average of 6 people, living in rudimentary housing. Two-thirds of households possessed equines, used primarily for transport purposes. The present subsection briefly reviews the main resource related implications of CRM for the other farm household activities.

Factor related implications

CRM-based maize production clearly has implications for the *land* resource: it will more adequately retain the soil's productive capacity over time, as the carry-over effects in terms of soil ecology and soil conservation accumulate. This reduces the need for periodic fallowing, which frees land that otherwise would have been fallowed for alternative use.

CRM-based maize production is likely to be *labour*-using on aggregate. This implies it would draw labour from alternative use (productive or leisure).

CRM-based maize production has two main *capital*-related implications. First, it imposes limited additional equipment needs as 76% of farm households already owned a backpack sprayer. Second, it increases the recurrent outlays for external inputs. This demand is likely to compete with the demands of other activities (*e.g.* working capital; daily consumption) for typically scarce cash and other liquid assets.

Crop produce related implications

Maize is the major food crop and maize grain is predominantly consumed internally by the farm household. In terms of the annual pool of maize grain available for consumption, CRM is likely to: (i) increase it for those farm households with double-cropped fields; (ii) stabilise it for all households. Maize residues are generally not used internally for any productive or consumptive purpose. CRM therefore does not conflict with internal residue use.

7.2.3 Institutional setting

The local institutional setting is characterised by incomplete and imperfect markets for produce and production factors. In part, this reflects the area's remoteness and limited accessibility. Only the occasional dry-weather feeder road provides a lifeline that opens the remote communities to the municipal towns of Soteapan and Mecayapan, and beyond. The present subsection briefly assesses the relevant institutional issues.

Crop produce rights & markets

There are no established *crop residue* rights or markets in the area. However, this is not an issue for CRM. First, residues are typically not extracted. Second, the interval during which residues are an open access resource is typically limited in view of the piecemeal harvesting of the maize grain.

The low land use intensity ensures that most maize fields adjoin forests and fallow vegetation. This affects *burning arrangements* with two implications for CRM. First, although pre-pant burning is the rule in the area, farmers that want to burn are required to take precautionary measures to prevent their fires from going wild. Second, non-cropped areas provide buffer zones for prospective adopters of no burning, thereby reducing the risk of accidental burning.[31]

Agricultural produce markets are rudimentary. Unit transport costs are high in view of the remoteness and limited transportation possibilities (*e.g.* only dry-weather roads; virtually absent motorised transportation facilities). High transport costs are a main transaction cost, which in turn result in substantial differences between sales and purchase price of food produce. The quantities of maize marketed locally are minor as most farm households produce maize - the main staple - for internal consumption. Maize trades at a premium above official producer prices - thereby reflecting the food deficit nature of the area. Indeed, half of the sample households reported being net buyers of maize in the survey year. The remaining half of the sample was divided between households that apparently were self-sufficient (either they could not or did not need to buy maize) and those that marketed a surplus. The need to buy beans – the main protein source – was even more widespread. Market imperfections also affect cash crops. Coffee marketing seems to suffer from information problems and a lack of competition between marketing channels. The introduction of oranges as alternative cash crop failed because of the lack of an adequate outlet for produce.

Factor rights & markets

In terms of *land* rights, there is a need to distinguish between those with and those without constitutional land use rights. The first are *ejidatarios*: the direct beneficiaries of land reform (see footnote 13), with secure tenure. The second are un-entitled residents ("avecindados"), mostly relatives of *ejidatarios* living within the same community (*ejido*). The land rights give rise to a marked difference between farm households in terms of access to land. The *ejidatarios* are land-holding households and make up about half the population and own 20.4 ha per household on average. The un-entitled residents are tenant households that do not own any land, but may be granted temporary access to a limited area (on average 2.25 ha). The land market is rudimentary and tenant access is typically free of charge, mainly reflecting mutual help. This suggests that the inter-temporal implications of CRM (in terms of subsequent productive capacity on CRM land and land use options on fallow land) accrue mostly to the land holding households.

[31] The implications for CRM are particularly apparent upon comparison with neighbouring communities at lower elevation. These characteristically have less buffer vegetation. In addition, ranching is more common - which uses burning to regenerate pastures. Wild fires are more common in these communities and may travel large distances, especially towards the end of the dry season.

Farm households mainly rely on family *labour* but also participate in the local rudimentary labour market. This relies more on labour exchange between households[32] than actual market transactions. For instance, of maize labour needs, labour exchange provides an average of 15% and day labourers 6% - the household the rest. The local wage rate for agricultural day labour in the maize crop was US$ 3.8 day^{-1} for the 1994 season, irrespective of activity. An increasing market integration of the agricultural economy may contribute to the demise of the labour exchange institution. This is particularly likely with the advent of herbicides, which reduce the need for such mutual help during weeding.

Capital markets in the area tend to be undeveloped and imperfect. Agricultural support services are few in the region, and if existent at all, are typically based in the municipal towns or further afield.[33] Coverage of government services (credit and extension) is extremely limited, and tends to be biased towards coffee and land holding households. Some households had access to subsidised official credit (0% nominal interest), other households relied on informal credit (*e.g.* 5-10% $month^{-1}$). The relative institutional vacuum has prompted non-governmental initiatives such as the Sierra de Santa Marta Project (PSSM, 1994b), and inter-institutional follow-up (SARH *et al*, 1994). The latter initiative resulted in the setting up of a network of farmer para-technicians to provide farmer-to-farmer extension (Buckles and Erenstein, 1996).

CRM-based maize production practices increase the use of fertiliser and herbicides. It thereby depends on the input market for a timely access to these inputs. The remoteness also implies that transaction costs substantially increase the on-farm cost of external inputs. Farm households may also need credit - in kind or cash - to bridge the gap between the time of outlays for external input acquisition and household cash receipts.

Institutional interrelationships

The undeveloped institutional setting implies that a number of intricate relationships exist between institutions. The existence of reciprocal exchange relationships (*e.g.* labour; equines) reflects an overall shortage of cash and the lack of short-term credit facilities (Upton, 1996). To acquire external inputs, the farm household needs to transact some other internal resource in exchange - possibly labour and/or agricultural produce. These transactions are occasionally interlinked, or alternatively imply two monetized transactions in two different markets.[34] There is no inter-linkage though between land and residue transactions - an important consideration for CRM in view of widespread tenancy.

7.2.4 Private assessment

The farm households typify peasant households in the sense implied by Ellis (1988:12): livelihoods based on access to land, utilising mainly family labour and only partially engaged in imperfect markets. The present subsection assesses the private implications of

[32] Reflecting mutual help, a common institution in indigenous communities in Meso America.

[33] This also creates information problems - *e.g.* one community appeared to be unaware of the existence of a government handout (*Procampo*).

[34] Either arrangement tends to increase the acquisition cost, notably as market imperfections typically imply unfavourable terms of trade for resource poor farm households.

CRM-based practices for the farm household, in terms of farm household preferences and decision making, valuation and private returns.

Farm household preferences and decision making

The farm households have a marked preference to produce their own food, as reflected by (i) the choice of all households to produce maize; (ii) the choice of a narrow maize area range; (iii) the preference to grow local maize varieties of different grain colours (such as black and yellow, although white materials predominate - reflecting dietary preferences); and (iv) the limited marketing of maize produce. In turn, the preference is explained by such factors as high transaction costs, overall limited market participation and limited opportunities to substitute other income generating activities for maize production.

Farm households could more adequately meet internal food demands by increasing external input or labour use. For instance, labour needs for weeding typically constrain the maize area that can be handled. As a result, weeding is the activity that shows the highest internal labour participation rates (*i.e.* farm households tend to supplement their usual adult male labour with female and child labour), and non-family labour participation rates. In addition, farmers have increasingly taken up the use of herbicides.

Enhancing food production through external inputs and labour implies a trade-off with increased market exposure. Most farm households tend to be risk-averse and typically prefer to limit their exposure to market risks. Further, external input use in maize presents another dilemma - as most of the produce is consumed internally. This implies that most farm households depend on another source of (cash) income to acquire these inputs for maize. External input use in maize (fertiliser, and particularly herbicide) is indeed substantially more common amongst the households cultivating coffee - the main local cash crop (see Table 7.10). Within coffee cultivating households, external input use is more common in maize than coffee - reiterating the use of the coffee crop as 'cash cow' (also see Reardon and Vosti, 1995). In fact, farmers may purposefully divert inputs from coffee to maize, as in the case of using compound coffee fertiliser (18:12:6) on maize. In other words, coffee producers rely on their cash crop so as to obtain external inputs for their food crop.

Coffee also creates a marked differentiation in terms of labour market monetisation (Table 7.10). First, much like external input use, the use of day labourers for maize is more common amongst coffee cultivating households - in part a reflection of the household's cash availability. Second, maize cultivation tends to draw on labour exchange for supplementary non-family labour, coffee on paid day labourers - directly paralleling the crop's market orientation.

Farm households without coffee need to rely on an alternative source of (cash) income. For instance, about two-thirds of tenant households without coffee had members working as migrant labourers within the larger region. Land holding households without coffee mainly rely on other productive activities within the farm (*e.g.*, maize, livestock, and orange production).

CRM's maize yield stabilising potential (both seasons) and yield increasing potential in the winter season are largely compatible with household preferences. However, CRM implies an increase in external input use and therefore in the households' market exposure.

It remains to be seen whether the household's marginal benefits (utility) of adopting CRM make the marginal costs (disutility) to satisfy CRM's conservation standard worth incurring.

Table 7.10 Indicators of external input and labour use in the Southern Veracruz study area

	Farms without coffee	Farms with coffee	
	In maize production	In maize production	In coffee production
Percent of households that:			
- Had used herbicide prior to survey	47	94	17
- Had used fertiliser prior to survey	40	55	39
- Used day labourers in 1994	20	39	71
- Used labour exchange in 1994	73	78	41

Source: derived from survey data - Rice *et al.*, 1998

Valuation

The valuation of the CRM-induced changes is compounded by market imperfections and the farm household's partial engagement in markets. For simplicity focus here is on *average* values - though actual values are likely to be household specific.

The opportunity cost of *land* is assumed to be negligible - both for land holding and tenant households. Land holding households typically have surplus land: they only use a fraction of their land actively; and also provide land free of charge to tenants. Tenant household are *de jure* land constrained: they only have usufructuary rights over the allocated land. However, *de facto* they can obtain other land if so needed. The local day labour wage rate is assumed to be a fair approximation of the (opportunity) cost of *labour*. External inputs are valued at their acquisition plus transport costs. Costs of financing are highly variable - depending on such factors as credit source and household liquidity (*e.g.* coffee producing households are likely to have more liquid assets, *ceteris paribus*). Five percent per month is assumed to be a reasonable approximation of its average/opportunity cost.

The *crop produce* is valued at the local on-farm purchase price. As the area is remote and presents a maize deficit this value is substantially higher than the market price in more commercial areas. The productive value of *crop residues* as fodder is low - reflecting (i) low fodder demand (overall livestock numbers are low); (ii) the availability of abundant alternative fodder sources; and (iii) the problematic nature of residue extraction. Maize fields are generally far afield and harvested piecemeal, making them less suitable for stubble grazing. Less than half of the maize fields are fenced - but fencing seems to be more a matter of safeguarding the crop against stray animals than to enable stubble grazing. The productive value of residues as construction material and/or the consumptive value as household fuel are also minimal. Wood generally provides a better and still abundant alternative (although forest cover has declined over time). The area is indeed characterised by an absence of residue extraction. Consequently, the opportunity cost of retaining the crop residues as mulch is negligible.

Private returns

Table 7.11 provides an overview of the short-term budget implications of current and prospective CRM-based maize production in the area, for both single and double cropped maize. The budgets highlight a number of issues. First, current maize production remunerates internal production factors at less than the estimated opportunity costs. Value added and household income are typically positive in single cropped fields - but returns to internal production factors unfavourable. Returns are even less favourable for the double cropped fields.

Table 7.11 Prospective short-term crop budgets in the Southern Veracruz study area

	Summer crop only		Summer & winter crop	
	Current	CRM-based	Current	CRM-based
A. Gross production value (US$ ha^{-1})	252	252	317	353
a1. Maize grain	210	210	275	311
a2. Maize residue	0	0	0	0
a3. Intercrop	42	42	42	42
B. Recurrent expenses (US$ ha^{-1})	62	129	71	140
b1. External physical inputs	46	113	46	113
b2. External services	0	0	0	0
b3. Residue input	0	0	0	0
b4. Internal physical inputs	16	16	25	27
C. Labour (days ha^{-1})	69.7	77.3	92.5	102.7
D. Capital and financing (US$ ha^{-1})				
d1. Financing costs	11	21	11	21
d2. Average working capital	46	113	46	113
d3. Average value capital goods	15	15	15	15
d4. Depreciation capital goods	4	4	4	4
E. *Procampo* (US$ ha^{-1}) [a]	65	65	65	65
F. Value added (US$ ha^{-1})	190	123	246	213
G. Household income (US$ ha^{-1})	228	149	279	233
H. Return to own land (US$ ha^{-1})	(38)	(154)	(69)	(161)
I. Return to own capital (% $month^{-1}$)	-9.9%	-30.0%	-23.4%	-31.5%
J. Return to own labour (US$ day^{-1})	3.2	1.7	3.0	2.2

[a] Government compensation for liberalisation of basic commodity prices, received by 63% of households. *Formula*: A = a1+a2+a3; B = b1+b2+b3+b4; F = A - B; G = [A + E - B - (external labour)*(wage) - d1]; H = [G - (opp. cost own labour) - (opp. cost own capital) - d4]; I = [G - (opp. cost own labour) - (opp. cost land)]/(own capital); J = [G - (opp. cost land) - (opp. cost own capital) - d4]/(internal labour). *Assumptions*: Factor opportunity costs - capital 5% $month^{-1}$; labour US$ 3.82 day^{-1} (wage rate); land US$ 0 ha^{-1}. Factor ownership assumptions - capital: 50% own + 50% borrowed; land: own; labour: 94% own + 6% hired (survey data).

Second, CRM-based maize production further lowers the returns to the internal production factors. The decrease is particularly acute in single cropped land - where CRM does not alter output levels, yet increases the capital and labour input. In double cropped fields CRM does ameliorate winter season output. However, the corresponding value is still less than the value of the implied capital and labour increase. Therefore, CRM is not a privately viable proposition in the current setting.

The budgets also highlight that CRM-based maize production more than doubles the cost of external inputs and finance. In part, this reflects the low base (in terms of current external input use). In addition, it reflects the costly nature of external input use (particularly in terms of procurement and financing). These high costs, in conjunction with the local opportunity cost of labour, eliminate the cost-reducing potential of herbicides in the area. Indeed, despite their substantial labour-saving potential, the direct cost of herbicides (procurement plus financing) equate the labour cost saved (Table 7.12). However, weeding presents a major labour peak. Therefore, although relative prices forfeit their cost-reducing potential on a ha basis, herbicides can still have additional benefits. First, they could enhance flexibility by reducing the dependence on non-family labour. Second, they could enable a more timely weeding - and thereby limit the weeds-induced yield loss. Third, they could enable the household to expand the annual cropping area. These factors help explain the advent of herbicides in the area. However, these considerations are not specific for CRM as current post-emergence weeding practices are already CRM-compatible.

CRM-based maize production increases the outlays for variable inputs, but does not imply major investments. In fact, CRM is quite scale neutral in the current setting. Further, although CRM conceivably frees land for alternative use - the value of this is negligible for most farm households, the more so as CRM does not alleviate the other more binding resource constraints.

In sum, CRM-based maize production is not a privately attractive proposition in the current setting. Although the crop management practices are already largely compatible with CRM (*e.g.* no incorporation; no extraction), the necessary and complementary changes for adoption are costly. Farmers are therefore unlikely to adopt the entire technology voluntarily.

Table 7.12 Indicative cost comparison for alternative post-emergence weeding technology in the Southern Veracruz study area

	Purely manual		Herbicide based
	2 weedings	3 weedings	3 weedings
Labour (days ha^{-1})	32.1	46.1	16.8
Herbicide (l ha^{-1})	0	0	12
Cost (US$ ha^{-1})[a]	123	176	188

[a] Labour valued at wage rate (US$ 3.82 day^{-1}); herbicide at on-farm cost (US$ 7.94 l^{-1}) plus interest (5% $month^{-1}$; 6 months). Source: derived from survey data - Rice *et al.*, 1998.

7.2.5 Social assessment

From the social viewpoint, CRM-based maize production in the area is likely to be perceived more favourably. The current slash-and-burn practices impose various negative externalities. First, the study area comprises a watershed that is dammed further downstream and is the major source of potable water for nearby urban centres. Widespread adoption of CRM-practices would reduce the soil erosion externality.[35] Second, the area is located on the Sierra de Santa Marta volcano - declared a Special Bio-sphere Reserve during the 1980's (PSSM, 1994a; Chevalier and Buckles, 1995:347; PSSM *et al.*, 1997). CRM reduces pressure on the forest reserve by making agriculture more sedentary and reducing the probability of wild fires. Furthermore, the area has a poor and mainly indigenous population. CRM reduces the degradation of the land resource that is the basis of their livelihood and may more adequately secure local food supply.

The available data do not allow for an elaborate social assessment. Whether policy intervention is actually attractive is likely to be determined by effectiveness and efficiency considerations. However, several policy options are conceivable. First, policy could try to raise the *utility of CRM*-based maize production through targeted interventions (incentives; regulation). Such a scheme could rely on transfers from the downstream municipal water users. However, implementation will be subject to the general limitations that affect the use of economic incentives and legal sanctions in general. Implementation is further compounded by the remote nature of the area and the typically partial market engagement of most households.

Second, policy could try to raise the *utility of farming* in general through broad interventions. Agricultural development in the region is constrained in many ways, and policy could tackle these constraints. For instance, improving infrastructure would ostensibly integrate the region more fully into the national markets, and conceivably improve the functioning of local markets. Government could also provide an enabling role through the establishment of various support services. However, this policy option needs to acknowledge the potential conflict between conservation and development of the Sierra. This option may alleviate some of the overarching constraints for CRM and would thereby require a reassessment of CRM from the private and social viewpoint.

Third, policy could try to integrate CRM into a more *comprehensive package*, including for instance no burning, fertiliser, improved seed and crop spacing. This would imply a much larger overhaul of the current crop management practices, but the other components should provide a productivity boost to ensure that the package is economically attractive. However, technological packages are subject to disarticulation as farmers tend to adopt only those components that are most attractive.

Fourth, policy could look into *conservation alternatives* to CRM. Other conservation technologies may indeed have a comparative advantage over CRM. For instance, cover crop mulching relies mainly on internal resources (land, labour) and could alleviate soil fertility

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[35] But could exacerbate another negative externality if it increases surface water contamination with agro-chemicals - *e.g.* due to run-off of applied inputs or when farmers clean backpack sprayers in streams. However, the predominant herbicides are tightly adsorbed to the soil (*e.g.* paraquat and glyphosate).

constraints. In this regard, *Mucuna spp.* has received some attention in the Sierra - from both farmers and researchers. About half of the farmers in the watershed reported they were experimenting with it - albeit on a limited area. Although not without its problems, farmers in nearby communities rated the soil fertility enhancing and weed control potential as the biggest benefits of mucuna (Buckles and Perales, 1995; Soule, 1997). Some agencies also consider contour hedgerow farming (with *Gliricidia sepium*) as an alternative in the wider region.[36] However, this technology implies a substantial investment and delayed benefits, and is not widely known or used in the watershed. In fact, adoption seems to hinge on the attached incentives (Zambada, 1996).

Last, the above options are not exclusive and could be combined in various ways. For instance, Buckles and Erenstein (1996) have analysed the implications of a technological package that included CRM, other conservation alternatives (cover crop mulching and contour hedgerows) and productivity enhancing elements (chemical fertiliser and crop spacing) in the wider Sierra. However, although productivity would be substantially improved over time, returns would remain low. Even more problematic is the timing aspect of the private returns: the 'package' would require a probably prohibitive investment period of about five years, and only afterwards becomes self-supporting. It seems unlikely that the farm households are willing to undertake such a venture under the prevalent conditions. Even a combined approach may therefore still need to tackle some of the broader and overarching development constraints.

7.3 Concluding summary

The present chapter applied the technology assessment framework (Chapter 6) to two contrasting *ex ante* case studies in Mexico. The first case in Southern Jalisco provides an instance of market-based production with a significant crop-livestock interaction. CRM-based maize production has cost-saving and water-saving potential. However, this is partially or fully offset by the number of required changes, the opportunity cost of the residues and the high rental cost of direct seed drills. Viability therefore remains marginal to doubtful in the short-term and rapid autonomous diffusion unlikely. Policy could intervene so as to create a more enabling environment for CRM and thereby accelerate its diffusion.

The second case in Southern Veracruz provides an instance of maize production for home consumption with partial market integration. The system is already largely compatible with CRM and changes are few - but nonetheless costly. CRM proper is not viable under the current setting - particularly in view of overarching constraints. Without policy intervention, autonomous adoption of CRM is highly unlikely. Conservation alternatives may provide more viable options.

The application of the framework in an *ex ante* setting allows the necessary conclusions to be drawn in terms of (i) the technology, and (ii) the framework itself. In terms of the *technology*, a number of issues stand out. First, CRM implies numerous adaptations in the

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[36] Zuñiga *et al.*, 1993; Cano *et al.*, 1994; Buckles and Erenstein, 1996. Also see Carter, 1996.

production technology and the farm system. Second, the CRM-induced productivity effects are inherently site-specific - dependent on local ecological and technological factors. Third, adoption implies a number of trade-offs. The opportunity costs of the required changes may well be high, and this may offset productivity gains (if any) partially or fully. In the end, the short-term viability for prospective adopters may be questionable. Fourth, CRM is subject to disarticulation. The adoption levels of CRM in both cases were insignificant. However, in both cases, farmers had already adopted some of CRM's essential components - in different degrees and sometimes by default.

The implications of CRM adoption also transcend the farm boundary. This was to be expected in view of the underlying soil conservation externality. However, the socio-economic setting of the farm household may inherently constrain or enable CRM adoption. In turn, CRM-adoption may directly affect the socio-economic setting. For instance, CRM may fit in with - and contribute to - the trends towards commercialisation of agricultural economies in the developing world.

With respect to the *framework,* a number of methodological issues stand out. The framework provides a comprehensive grouping of the various factors potentially affecting the farm household adoption decision. Application of the framework provides for an assessment of the economic implications of adoption, the likelihood of adoption and the corresponding policy implications. The data needs for an in-depth *ex ante* assessment of these implications are substantial. The individual case studies draw on a comprehensive farm household survey and local on-farm trials, and still allow for only a tentative assessment. However, even such an assessment provides valuable feedback about the potential of the technology. If warranted, further subsequent quantification is always possible (*e.g.* of the temporal and risk implications).

Upon applying the framework, there is a clear trade-off in terms of the width and depth of analysis (*e.g.* space *versus* time). A wider analysis allows for more general inferences, particularly apt in view of the variability over space. An in-depth analysis allows for more specific inferences, particularly apt in view of the complexity of the technology and farm systems. Such trade-offs directly affect the type and level of analysis - *e.g.* in terms of inter- *versus* intra-area comparisons. The present chapter included two cases and thereby allows for both.

Intra-area comparisons can be clarified by stylised farm household typologies. However, with CRM the number of potentially relevant variables is substantial, implying a trade-off between homogeneity and number of farm household types. The present chapter chose to apply the framework to only a limited number of farm types in each area (*e.g.* based on rainfall in Southern Jalisco; length cropping cycle in Southern Veracruz) thereby forfeiting some further specific insights (*e.g.* in terms of farm household dynamics). Such analytical trade-offs are important considerations for the objectives of study and delimitation of a study area.

A last particular trade-off is between the private and social analytical viewpoints. The applications of the *ex ante* framework clearly emphasise the private viewpoint, as this is the more relevant for predicting the immediate adoption decision. Further, a good understanding of the farm household implications and decision making is a crucial first step for deriving the corresponding social implications and eventual policy interventions.

CHAPTER 8

EX POST APPLICATION OF THE TECHNOLOGY ASSESSMENT FRAMEWORK

Chapter 6 developed a technology assessment (TA) framework to evaluate the socio-economics of crop residue mulching (CRM). The present chapter will apply the TA framework in an *ex post* fashion: *i.e.* assess the actual adoption of the technology in specific empirical settings. It will do so for two additional case studies in Mexico - again depicting contrasting situations in terms of biophysical and socio-economic conditions. The first case - Chiapas Highlands (Figure 7.1:155) - analyses the use of CRM-based maize-beans production in a semi-market oriented system. The area is of high altitude with a humid climate. The agricultural landscape is mountainous and steeply dissected; the rural economy is developing. The second case - Central Chiapas (Figure 7.1) - analyses the use of CRM-based maize production in a mixed setting. Production is both on a commercial and semi-commercial basis, and located both in arable valley plains and on rugged hillsides. The area is of low to medium altitude with a subhumid climate, and has a developing rural economy. Both cases coincide in an active government involvement in promoting the technology.

The contribution of each *ex post* case study is two-fold. First, it provides retrospective insight into the functioning and aptness of CRM in specific empirical settings. Second, it provides insight into the *ex post* applicability of the framework. Each case study draws on chronological (before-after) and contemporary (adoption strata) comparisons. However, these comparisons are inherently constrained by the reliance on *ex post* surveys. For instance, the before-scenario can tentatively be sketched in qualitative terms - but quantification remains ambiguous in view of missing base line data. Each case study therefore emphasises contemporary adoption-strata comparisons - although even these are imperfect due to the existence of 'noise' and the lack of reliable baseline and control data (see 6.6). The first section presents the Chiapas Highlands case study, the second Central Chiapas. The last section draws conclusions with respect to the technology and the TA framework.

8.1 The adoption of CRM-based maize-beans production in the Chiapas Highlands, Mexico[1]

The case study assesses the adoption of CRM-based maize-beans production in the Chiapas Highlands. This study area is located on the South-Eastern fringe of Mexico and encompasses some of the remote and steep slopes of the Sierra Madre of Chiapas State (Figure 7.1:155). Its rural economy is characterised by low incomes and an orientation of agricultural production for home consumption with a small marketed surplus. The area is

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[1] Data for this case study are mainly derived from Erenstein and Cadena (1997). Preliminary results from this case were documented in Cadena (1995). Credit is due for the valuable contribution of Pedro Cadena Iñiguez (INIFAP).

tropical highland (around 2,000 m) with abundant rainfall (1,500-3,000 mm yr^{-1}). Agriculture is rainfed, with a prolonged single cropping season in the summer. Flat to rolling arable land is scarce, and agricultural production is mainly located on steep slopes.

The study area encompasses what was a pilot area for a subsequent state wide extension campaign of CRM related practices. The area was selected purposively with the expectation to find substantial adoption levels. The data presented in this case study were primarily collected through a formal single visit survey of 82 farmers and their fields (for the verification of residue quantities) at the onset of the 1994 summer cropping season. The study used a random sample, stratified by community (*ejido*) with an average sampling fraction of 18.5%. Overall, data collection required an estimated 2.5 man months. The following subsections assess the adoption of CRM-based maize-beans production following the steps specified in the TA framework.

8.1.1 Crop system implications

Maize is the main annual crop in the local farming system, generally intercropped with beans. The present subsection reflects on CRM-based maize-beans production practices, thereby emphasising crop management practices and physical input and output levels. It will briefly reflect on the chronological setting, thereby distinguishing between past, current and CRM-based systems (where 'past' refers to the traditional practices prior to the introduction of CRM practices). Emphasis will be on the contemporary setting and a CRM-based adoption typology is developed for this purpose.

Necessary practices for CRM

Both residue production and weathering levels have traditionally been potentially compatible for CRM-based maize-beans inter-cropping. The same applies to tillage practices: the extremely steep fields (slopes average 71%, *i.e.* 35°) ensure that farmers use no mechanisation whatsoever in field based operations. Manual tillage with the hoe was typically limited to creating a miniature bowl shaped terrace as planting slot - leaving most of the field surface undisturbed.[2]

Traditionally the stubble was grazed communally by sheep and equines and the remaining residues were burned prior to planting the subsequent maize crop. Consequently, the quantities of residues left as mulch were minimal. At the outset, the necessary changes for CRM in the local context therefore related to abandoning pre-plant burning, and (possibly) limiting residue extraction. At the time of the survey, all sample farmers had abandoned pre-plant burning, but communal grazing was still widespread. Quantities of mulch were more substantial - although for 62% of sample farmers this was still insufficient to qualify as CRM. This highlights two issues. First, it reiterates that no burning was a necessary but not sufficient condition for CRM. Second, it suggests that limiting residue extraction remains a necessary change for CRM for most farmers (given adoption of no burning, Table 8.1).

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[2] Other traditional but less common tillage practices included scraping the soil surface and soil inversion - both with hoe.

A contemporary comparison between adopters and non-adopters of the mulch component underlines that the quantity extracted through grazing is the decisive difference.[3] Although quantity extracted was not measured directly, a number of related indicators show significant differences between adopters and non-adopters (Table 8.2). Stubble grazing was reportedly more common in the fields where the mulch component was not adopted.[4] Three further indicators support such a lesser exposure to residue extraction: (i) enclosure; (ii) slope; and (iii) residue treatment. Adequate enclosure with a barbed-wire fence protects the residue stubble from communal grazing. Steeper slopes are less easily accessible to livestock, which therefore tend to disproportionately graze the less inclined fields.[5] Post-harvest chopping of residues with a machete - instead of leaving residues standing upright or doubled - could reduce the attractiveness of residues as forage - *e.g.* through a loss of palatability by trampling. Purposive adoption of CRM requires that the residues are protected against excessive extraction. Given communal grazing, enclosure appears the most secure option for retaining sufficient residues as mulch. Indeed, over four-fifths of the adequately fenced fields retained more than 4 Mg residues ha^{-1} as mulch.

Table 8.1 Overview of past, current and CRM-based residue management practices in the Chiapas Highlands study area

	Crop residue management		
Practice	Past	Current [a]	CRM-based
Pre-plant burning	Yes	No (100%) [a]	No
Tillage	Reduced	Reduced (100%)	Reduced
Residue extraction	Yes (communal grazing)	Yes (communal grazing, 91%)	Restricted
Mulch	No	Insufficient (<2 Mg residues ha^{-1}, 62%)	Yes

[a] Percentage refers to survey population currently implementing prevalent practice. Source: derived from Erenstein and Cadena (1997)

Table 8.2 Comparison of selected indicators over mulch adoption strata in the Chiapas Highlands study area

	Adoption of mulch component		
Indicator	No	Yes	Prob.
Percent of sample fields reportedly stubble grazed	76	32	.00
Percent of sample fields that were fenced	2	19	.03
Average estimated %-slope of sample field	63	84	.00
Percent of sample fields where residues were chopped	2	52	.00

Source: derived from Erenstein and Cadena (1997)

[3] On average though, estimated current extraction levels are largely compatible with CRM. The issue is therefore that residue extraction is not equally spread.

[4] However, this indicator is of indicative value only - given the prevalence of communal grazing which makes it possible that the fields were grazed without the knowledge of the farmer.

[5] There is a significant negative relationship between slope and reported stubble grazing (slope averages 64% for reportedly grazed fields; 82% for non-grazed; probability .00). This relation persists when correcting for enclosure.

Complementary cultural practices for CRM

The adoption of CRM seems to have imposed few other - qualitative or quantitative - changes for crop management (Table 8.3). A comparison of such practices between adopters and non-adopters of the mulch component indeed shows no significant differences. Traditionally the manual *sowing* operation with hoe was combined with the preparation of the planting slots - a practice compatible with CRM. Further, CRM did not require substantial alterations in terms of *nutrient management*. Fertiliser use is currently near universal (98% use) and long established (on average 11-12 years at the time of the survey). The average current $N:P_2O_5:K_2O$ dose is 79:4:3 kg ha^{-1} - thereby reducing the risk of N immobilisation.[6] Farmers' practices of splitting N applications (61%) and less commonly, of fertiliser incorporation (38%) may positively affect N-use efficiency under CRM. CRM also did not require substantial alterations in terms of *pest and disease management*.

Table 8.3 Overview of past, current and CRM-based crop management practices in the Chiapas Highlands study area

	Crop management		
Practice	Past	Current [a]	CRM-based
Sowing	Manual with hoe	Manual with hoe (100%)	Manual with hoe
Weed management	Manual with hoe	Herbicides only (66%)	Herbicides only
Pest/disease management	Limited	Limited	Limited
Nutrient management	Fallow and compost	Chemical fertiliser (98%)	Chemical fertiliser

[a] Percentage refers to survey population currently implementing practice. Source: derived from Erenstein and Cadena (1997)

Strictly speaking, CRM-based crop production did not require substantial alterations in terms of *weed management* either. Except for not burning, it did not inherently alter local land preparation practices and initial weed competition for that matter.[7] However, compared to physical weed control with the hoe, chemical weed control is bound to strengthen the soil conservation aspect of the mulch (by maintaining its effectiveness instead of destroying it). Two thirds of sample farmers now rely completely on herbicides for their weed control - *i.e.* they had substituted herbicides completely for hoe weeding. As tillage during land preparation is already limited to preparing a planting slot, complete substitution thus implies the adoption of a complete zero till system (from harvest to harvest). Retaining the practice of inter-cropping could limit the choice of herbicides - but this did not appear problematic in the local context due to farmers' near sole reliance on paraquat, a non-residual herbicide.

[6] Application levels were in fact close to the crossover point (see Figure 5.5).

[7] Weeds present in the planting slot are eliminated by hoe at establishment.

A CRM-based adoption typology

A narrow CRM-based adoption typology would encompass only the necessary changes for CRM in the local context - *i.e.* in terms of pre-plant burning and residue extraction. A wider typology could also take into account that a complete reliance on herbicides for post-emergence weeding enhances CRM's conservation effectiveness - hereafter referred to as the herbicide component. If each practice is independent and is categorised dichotomously, the wide typology gives rise to eight conceivably combinations (*i.e.* adoption strata). However, the current sample population had completely abandoned pre-plant burning. Consequently, the number of adoption strata in the sample population collapses to four. Table 8.4 categorises the sample population in terms of these - given adoption of no burning. It thereby provides the adoption pattern for the survey year. It suggests that sole reliance on herbicide was a more attractive option than CRM proper. Only 29% of the survey farmers adopted both the mulch and herbicide components simultaneously.

Table 8.4 Adoption matrix of selected soil conservation practices in the Chiapas Highlands study area (%)

		Adoption of herbicide component [a]		
		No	Yes	Σ
Adoption of mulch component	No	26	37	62
	Yes	9	29	38
	Σ	34	66	100

Source: Erenstein and Cadena (1997). Figures represent percentage of total survey population. Summation discrepancies due to rounding. Classification based on situation in largest maize field at survey time. Mulch component verified in field; herbicide component farmer reported. [a] Sole reliance on herbicides for weeding.

A confounding factor of the 2x2 adoption classification is the existence of partial adoption in terms of residue retention and herbicide use. For instance, the non-adopters of CRM still abandoned pre-plant burning and this represents an improvement in terms of soil conservation compared to the traditional practice. Figure 8.1 depicts the confounding effect of partial adoption of the mulch component, presenting three typical adoption cases (X, Y, and Z). Z reflects the typical local CRM adopter with a little over 3 Mg maize residues ha^{-1} as mulch corresponding with a 50% soil cover. X reflects the typical non-adopter in the past (burning residue surplus; retaining only 200 kg of residue). Y reflects the partial adoption of CRM: abandonment of burning but not retaining sufficient residues (1 Mg) to qualify as CRM. Given the 30% soil cover threshold, neither X or Y adopted CRM. However, the fact that Y retained more residues still lowers the level of erosion (relative to X). The confounding effect is exacerbated by the non-linear response of relative erosion to soil cover. Therefore, the difference in the relative levels of erosion is much less between the fields of Z and Y (about 30% in the stylised figure) than between those of Z and X (about 75%). The existence of this partial adoption thereby masks the full impact of CRM.

In much the same way, 24% of the farmers combine herbicide and hoe weeding - thereby confounding the effect of herbicide use. This reiterates two issues. First, the ambiguity of a dichotomous adoption threshold - especially when the response is continuous and subject to diminishing returns. Second, the need of a control group for impact assessment. The absence of such implies care is needed in terms of interpreting the imperfect adoption strata comparisons presented hereafter.

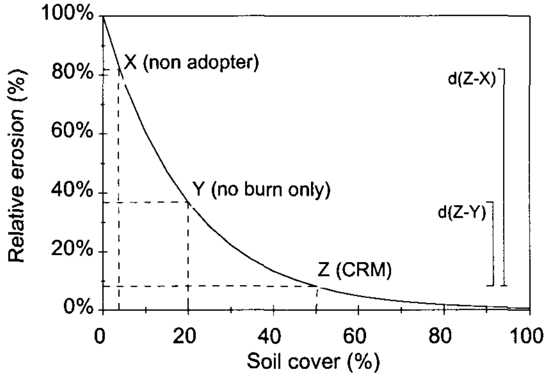

Figure 8.1 The confounding effect of partial adoption of mulch on erosion control

Input-output implications

The lack of baseline data makes a chronological input-output comparison highly speculative. The present discussion therefore emphasises contemporary comparisons over adoption strata - which are summarised in Table 8.5.

Maize-beans production has traditionally been - and still is - a very labour intensive enterprise in the area. The difficult terrain conditions prohibit mechanisation of field operations and make the manual operations themselves very laborious. The necessary changes for CRM and the sole reliance on herbicides alter the input into the crop system, particularly in terms of labour, capital and crop residues. The input implications of the mulch component revolve primarily around fencing (*i.e.* assuming purposive adoption) so as to retain sufficient residues. The herbicide component implies the complete substitution of herbicide for hoe weed control and is thereby inherently labour saving. The partial adoption of herbicide confounds the labour saving potential of herbicides in Table 8.5. Weeding required an average of 44 days ha^{-1} when relying solely on the hoe, 20 days ha^{-1} when relying solely on herbicides.

The mulch component did/does not impose major learning costs, in contrast to the herbicide component. Most farmers have picked up herbicide use through learning by doing. Potential health risks are thereby an issue - particularly in view of the reliance on toxic paraquat, difficult application conditions and limited precautionary measures.

Herbicide use is currently near universal (91% of sample farmers use), whereas all sample farmers had used herbicides before (see Figure 8.2).

Table 8.5 Comparison of output-input indicators over adoption strata in the Chiapas Highlands study area

	Components adopted [a]				
	Neither	Only mulch	Only herbicide	Both	Prob.
Output (kg ha^{-1})					
- Maize grain [b]	2,230 a	2,440 ab	2,200 a	2,690 b	.00
- Beans grain [b]	214 a	164 a	220 a	259 b	.03
- Maize residues (estimate) [c]	4,100	4,500	4,100	5,000	
Recurrent input (units ha^{-1})					
- Crop residues (kg at sowing)[d]	1,000	2,800	900	3,200	
- Seed (kg maize:beans)	16:9	ditto	ditto	ditto	NS [e]
- Herbicide (l)	1.97 a	2.46 a	5.78 b	5.64 b	.00
- Fertiliser (kg $N:P_2O_5:K_2O$)	79:4:3	ditto	ditto	ditto	NS
Labour input (days ha^{-1})					
- Land preparation and sowing	23.7	ditto	ditto	ditto	NS [e]
- Weeding	34.1 a	34.2 a	18.5 b	20.4 b	.00
- Fertilisation	14.7	ditto	ditto	ditto	NS
- Harvesting & shelling	20.8	ditto	ditto	ditto	NS
Sum	93.3	93.4	77.7	79.6	

Source: Erenstein and Cadena, 1997. Data followed by different letters differ significantly - Duncan (.10), within row comparison. [a] Given adoption of no burning. [b] Weighted average of farmer reported yields in survey, good, regular and bad years. Weight for regular year .4, for other years .2. [c] Based on 35% harvest index. [d] Estimate from photo comparison in field. [e] NS: differences between adoption strata statistically not significant - thereby assumes survey average for all strata.

Farmers were generally positive about the implications of the mulch and herbicide components - in terms of soil and water conservation, fertility enhancement and labour savings.[8] However, the two components typically had independent adoption patterns - for instance Figure 8.2 highlights the disarticulated nature of the diffusion of herbicides and no burning, necessary conditions for the herbicide and mulch component respectively.

A composite index of farmer reported current yields averaged 2.37 Mg maize ha^{-1} and 225 kg beans. In terms of crop management, current crop yields reflect both current practices and cumulative carry-over effects - if any - from previous seasons. It is unlikely that CRM drastically altered/alters yield levels in the short term. For instance, water is typically not a limiting factor whereas yield loss through temporary N-immobilisation by the residues is unlikely. Similarly, the yield stabilising effect will be limited. With traditional clean till practices (no cover), the exceptionally steep fields were subject to a high soil

[8] The components were generally not perceived to increase soil compaction or weed problems. Opinion was more divided in terms of the effects upon weed control costs; soil pests incidence; lodging and crop yield.

erosion hazard at the onset of the cropping season. CRM's soil conserving effect reduces such hazard and ensures yield levels are more adequately maintained over time. CRM's soil ecology effects are likely to ameliorate the soil fertility over time.

A yield comparison shows that the farmers that adopted both the mulch and herbicide components obtained significantly higher maize-beans yields than the other strata.[9] This suggests that the mulch and herbicide components are complementary. However, maize yield tends to be related to the mulch component. For instance, there is a marked positive interaction between maize yield and mulch levels (correlation coefficient 0.5; prob.:.00) - especially above the two Mg mulch threshold. Care is needed in interpreting this linkage as there is a reverse causality: higher grain yields imply a higher crop residue production (assuming a similar harvest index) and thereby increase the likelihood of CRM adoption, *ceteris paribus*. Unfortunately, the single-visit survey data do not allow to test for Granger causality. The yield stability implications of the mulch and herbicide components also remain ambivalent. There is a non-significant tendency for the mulch component to reduce yield variability. The herbicide component however tends to increase the risk of maize lodging - a widespread problem in the area.

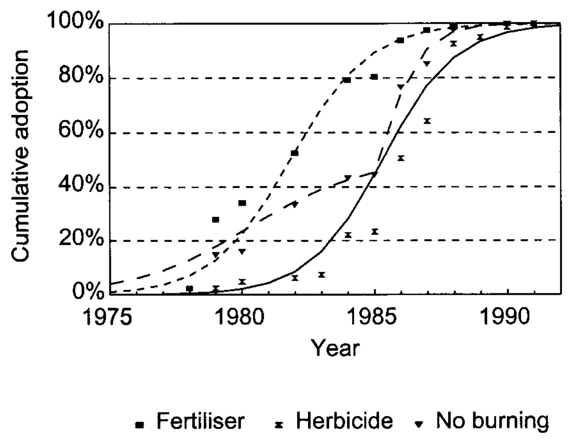

Figure 8.2 Diffusion of some management practices in the Chiapas Highlands study area (actual points refer to survey data; logistic curves estimated thereupon. Abrupt nature no burning curve due to change in institutional setting. See text for details).

8.1.2 Resource implications for the farm household

The typical activities of the local farm household system include crop production, livestock production, other productive and household activities. Crop production is characterised by the prevalence of maize (generally inter-cropped with beans). In the 1993 cropping season its cultivation was universal and occupied 77% of the average farm area (2.76 ha). Other crops - including beans as sole crop, vegetables and fruits - occupied 2% of the average

[9] Reported yields reflect a composite index - but the individual years showed a similar tendency.

farm. The remaining area (21%) was fallow and mainly used as pasture. Most households have at least one head of livestock - most commonly equines for transportation purposes. In terms of numbers, the average herd shows a bias towards sheep. Other types of livestock (*e.g.* goats, pigs and cattle) are uncommon. On-farm agricultural income is frequently supplemented by other activities, especially temporary emigration of family members within the region or further afield (79% of sample households). Emigration is closely associated with the household's labour availability and gender composition. Male household heads tend to migrate within the region (*e.g.* to pick coffee) once they are freed from the chores of maize-beans production. Other household members tend to travel further afield. The household encompasses an average of 6 people. The present section briefly reviews the main resource related implications of CRM for the other farm household activities.

Factor related implications

The dominance of maize-beans production in terms of *land* use, implies land-resource effects remain internal to the CRM-based production system. CRM therefore had no major land-related effect on other crops. However, it did curtail the use of the CRM-land as pasture in the off-season - an issue elaborated below. CRM could reduce the need for periodic fallowing - thereby freeing land for alternative use. Retrospective data indeed suggest fallowing is less common now.

The mulch component did not drastically alter *labour* use in CRM-based crop production. However, restricted access to residues is likely to have increased the labour needs of herding. The herbicide component is inherently labour saving - particularly for weeding, a major labour peak. Adoption of the herbicide component thereby freed labour for alternative use (productive or leisure).

The mulch and herbicide components also influence *capital* use. The purposive adoption of the mulch component implies the need to invest in fencing. The herbicide component requires access to a backpack sprayer and imposes recurrent outlays for external inputs. Additional demands for short and long term finances are likely to compete with the other productive and consumptive demands for typically scarce cash and other liquid assets.

A comparison of farm household indicators (activities and resources) can underwrite or contradict the stylised implications - with the caveat that uncontrolled variables may confound effects. For instance, the practice of fallowing does not differ over adoption strata (Table 8.6). In part this may reflect partial adoption. In addition, CRM substitutes for the fertility recovery function of fallowing. However, other substitutes now co-exist - chemical fertiliser being a widely used example. Further, fertility recovery is not the sole reason for fallowing. Fallow fields double as pasture and fallowing may also be imposed by farm household resource constraints.

The portfolio of farm household activities showed no significant difference over adoption strata, but the farm household resources did - particularly in terms of land. Adopters of the herbicide component had larger farms and cultivated larger areas (Table 8.6). Given similar labour endowments at the household level, adopters of the herbicide component were therefore more likely to be labour constrained. Adoption strata comparisons support this proposition: households that adopted the herbicide component had a lower farm labour availability per unit of cultivated land (Table 8.7). The influential role of the labour constraint is particularly likely given the labour intensive nature of the crop production system in general and the labour peak arising from weeding in particular. Weeding is typically done during the first two months of the crop cycle and was the most labour demanding activity for maize cultivation prior to the use of herbicides. For non-adopters of the herbicide component, weeding remains the single most labour demanding activity (amounting to 35-40% of estimated labour needs). Retrospective data suggest cultivated area per farm household increased as a result of herbicide use in general (*i.e.* partial or complete adoption of herbicide component). Farm size however typically also correlates with the farm household's overall resource availability - which may inherently have facilitated adoption of the herbicide component.

Table 8.6 Comparison of land-related indicators over adoption strata in the Chiapas Highlands study area

	Components adopted				
	Neither	Only mulch	Only herbicide	Both	Prob.
Maize area (ha)	1.6 a	1.8 ab	2.0 b	2.8 c	.00
Other crop area (ha)	0.1	0.0	0.1	0.0	NS
Fallow area (ha)	0.4	0.5	0.8	0.5	NS
Sum (*i.e.* farm size, ha)	2.1 a	2.3 ab	2.9 bc	3.3 c	.01

Source: Erenstein and Cadena (1997). Data followed by different letters differ significantly - Duncan (.10), within row comparison.

Table 8.7 Comparison of labour-related indicators over adoption strata in the Chiapas Highlands study area

	Components adopted				
	Neither	Only mulch	Only herbicide	Both	Prob.
Farm labour availability per household [a]	3.1	3.2	3.3	3.8	NS
Farm labour availability per cultivated ha [b]	2.2 a	2.0 ab	1.8 ab	1.5 b	.09

Source: Erenstein and Cadena (1997). Data followed by different letters differ significantly - Duncan (.10), within row comparison. [a] Household labour potentially available for agricultural work - equivalents of adult persons working full-time. [b] Preceding household labour indicator divided by cultivated area.

Crop produce related implications

Maize and beans are both staple crops and are primarily produced for internal consumption. CRM-based crop production with its higher and more stable yields is likely to more adequately secure farm household staple needs over time, thereby freeing resources previously destined to that purpose. Crop residues are used internally by the farm household as fodder source - but farmers generally do *not* consider these as an important source.

Although such internal use is common, intensity of use is low: the internal livestock component is small and fodder demand correspondingly curtailed. On average, internal livestock pressure amounted to 1.3 animal units per ha of maize - extracting an estimated 1.5 Mg residue ha^{-1}. Such levels of extraction are largely compatible with CRM.

A comparison of the household's own livestock herd and corresponding internal livestock pressure showed no significant difference over adoption strata - *i.e.* adoption of the mulch component is independent from the farm household's own livestock enterprise. This finding is in line with the communal/open access nature of crop residues - an issue elaborated below. Notwithstanding, none of the adopters of the mulch component considered the residues as an important fodder source (*versus* 48% of the non-adopters; prob.:.00). Further, overall livestock numbers per household reportedly declined over the decade preceding the survey, whereas reported fluctuations by adoption stratum were consistent with expectations (*e.g.* an increase for the non-adopters of the mulch component).

8.1.3 Institutional setting

The mountainous topography makes the entire area remote, and farm households are partially - but increasingly - integrated in produce and factor markets. In part, this is related to the proximity of the municipal town of Motozintla - a major stopover on the road that connects the coastal plain and the inland central plain of Chiapas State. The study area is perched on steep mountains high above Motozintla. The communities tend to be accessible by motorised transport, though travel times are substantial (typically one hour, for a geographic distance of some 5-7 km). The present subsection briefly assesses the relevant institutional issues.

Crop produce rights & markets

Traditionally, *pre-plant burning* of crop residues was the rule. However, as from the second half of the 1980s local regulations prohibited unregularised pre-plant burning. *De jure*, this implied that the practice was only permitted when respecting a number of strict regulations, including the need to obtain permission from the relevant authorities. In the study area, such permission was generally only granted to burn fallow vegetation (Cadena, 1995). Neglecting the regulations had potentially dire consequences in terms of a substantial fine when caught.[10] *De facto*, this implied that pre-plant burning was practically prohibited. In the study area discouragement was so effective (see Figure 8.2), that a similar state law passed at the end of 1992 had little additional effect. The drive for imposing local regulations originated in the local government's agricultural extension service in Motozintla. Enforcement was facilitated by the *ejido* institution[11] and proximity to Motozintla. Comparisons over adoption strata yield no further insight given the complete eradication of the practice in the sample population.

Communal *crop residue rights* were prevalent in the area - but the advent of CRM-practices has put considerable stress on this institution. Nearly all (95%) farmers currently

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[10] The equivalent of 50 days minimum wage or the same time served in jail (Cadena, 1995).

[11] *Ejidatarios* from the same *ejido* are organised, have a management structure, and live in one community. Meetings can easily be called for and members potentially disciplined.

dislike the practice of stubble grazing, as they believed it encouraged soil erosion by leaving the soil exposed and trampled. At the time of the survey the area was grappling with institutional change. Fencing is a locally accepted means of claiming private residue rights - a tenth of the farm households had already done so, and a similar number was contemplating doing so. However, official regulations prohibit the cutting of trees, thereby constraining the availability of fence posts. One *ejido* tried to impose a local law in 1993 that required everyone to take care of its own animals and prevent them from grazing freely. However, the law was not successfully enforced and several members with livestock violated it. Being increasingly subject to restrictive and preventive measures, the demise of communal grazing seems likely - a residue market being the logical substitute. A comparison of the communal livestock pressure over adoption strata highlights that this tended to be lower for the adopters of the mulch component - though only significantly so for the adopters of both components (Table 8.8).

Surplus produce is sold in the local *crop produce market* or in Motozintla. On average, about a third of the crop produce (for maize 36%; for beans 31%) is marketed immediately after the harvest - the remainder largely used internally. A comparison of marketing rates showed significant differences over adoption strata (Table 8.8). Average staple consumption levels are similar for the different adoption strata, so that the differences in marketing rates are largely a function of the crop area and productivity differentials discussed earlier.

Factor rights & markets

Most farm households are *ejidatarios* - they thereby own their *land* and have secure tenure. The farm household provides most of the agricultural *labour* - *e.g.* it supplies 85% of maize labour needs. Family labour is typically supplemented with paid day labourers, which have largely displaced the previously common labour exchange between households. The increasing monetisation of the local labour market was likely facilitated by the advent of herbicide use and monetary influx from emigration. The typical local wage rate for agricultural day labour was US$ 3.23 day^{-1}, irrespective of activity. Seasonal emigration links the local labour market with those elsewhere (*e.g.* coffee growing regions).

Motozintla is the base for *capital* markets and services, including providers of inputs, equipment, official credit and extension. The mulch and herbicide component variously depend on these - *e.g.* for the timely acquisition of herbicides; barbed wire; finance; and information. During the 1980s and early 1990s, CRM practices - particularly abandoning pre-plant burning and using herbicides - were intensively promoted in the area by various governmental agencies (both Federal and State level - Cadena, 1995:3-7).

A comparison of the household's participation in factor markets showed some significant differences over adoption strata - particularly in the local labour market. Adopters of the herbicide component contracted significantly more labour (Table 8.8), which is a reflection of the farm household labour constraint discussed earlier. In addition, it implies that these households are relatively less cash constrained. This contrasts with the non-adopters, that are characterised by having smaller farms and where hiring *out* of farm labour within the zone is more common. Overall, the more commercial farmers tended to adopt the promoted components - particularly the herbicide component.

Institutional interrelationships

The acquisition of external inputs like herbicides requires some form of parallel trade by the farm household. In the local context, crop produce and labour are the most likely candidates. A comparison over adoption strata indeed supports such a linkage for crop produce (Table 8.8). In the case of (temporary) emigration no significant linkage is apparent, in part a reflection of the widespread use of both herbicides and (temporary) emigration. Herbicides appear to have enabled temporary emigration, whereas the proceeds from the latter enable herbicide use.[12] The cash proceeds are also likely to make up for financial market failures.

The extension campaign promoting CRM practices was also characterised by institutional interlinkages. In addition to the usual supply of information, the campaign provided a number of conditional incentives such as free back pack sprayers and inputs, and subsidised credit. The campaign also was linked with the regularisation of pre-plant burning. A comparison of incentives received over adoption strata shows that the receipt of credit correlated positively with the adoption of the mulch component - probably reflecting its conditional nature.

Table 8.8 Comparison of institutional indicators over adoption strata in the Chiapas Highlands study area

	Components adopted				
	Neither	Only mulch	Only herbicide	Both	Prob.
Communal livestock pressure (AU ha^{-1}, estimate) [a]	1.3 a	1.2 a	1.3 a	0.9 b	.00
Maize market integration [b]	15% a	35% bc	38% b	53% c	.00
Labour market reliance [c]	6% a	7% ab	18% b	21% b	.05

Source: Erenstein and Cadena (1997). Data followed by different letters differ significantly - Duncan (.10), within row comparison. [a] Animal units in community divided by cultivated area in community, correcting for enclosure. [b] Maize sold immediately after harvest divided by total farm production. Beans show a similar tendency. [c] Hired labour divided by total labour use in maize cultivation.

8.1.4 Multivariate adoption analysis

Several of the above farm household factors affecting adoption can be grouped in one single multivariate logistic regression model. Table 8.9 presents such a model which predicts the probability that a farmer will adopt the mulch, the herbicide or both components, based on a series of farm household characteristics (CIMMYT, 1993; Nagy and Ahmad, 1993; Sain *et al.*, 1996).[13]

[12] The study area indeed typifies the triangular herbicide relation depicted in Figure 6.6.

[13] A description of a logistic regression model should preferably outline the rationale for the selected variables prior to presenting the results. However, to economise space, here only the

The model highlights that the adoption of the mulch component is largely explained by two variables that relate to the intensity of stubble grazing: (i) the slope of the field (% slope); and (ii) communal livestock pressure on field (animal units per planted ha within community, corrected for fencing). The steeper the *slope* of the field, the less accessible it is for grazing livestock - thereby enhancing the likelihood of mulch adoption. Similarly, a higher *communal livestock pressure* reduces the likelihood of mulch adoption (for adopters of both components).

Table 8.9 Factors affecting adoption in the Chiapas-Highlands study area (multivariate logistic model, normalised on non-adoption)

	Components adopted		
Variable	Only mulch	Only herbicide	Mulch and herbicide
Slope of field (% slope)	0.0793 (.0276) ***	0.0108 (0.0183)	0.0687 (0.0232) ***
Communal livestock pressure on field (AU ha^{-1})	- 0.773 (1.67)	- 0.997 (0.961)	3.62 (1.23) ***
Farm size (ha)	0.627 (0.548)	0.995 (0.388)**	1.48 (0.448) ***
Household labour (adult male equivalents)	0.546 (0.530)	0.344 (0.374)	0.885 (0.432) **
Sole cropping of maize in field (dummy)	1.53 (1.12)	0.0614 (0.812)	1.48 (0.958)
Household involved in non-agricultural business (dummy)	- 0.183 (1.55)	2.17 (0.889) **	1.11 (1.17)
Constant	- 9.56	- 3.11	- 8.27

Source: Erenstein and Cadena (1997). Sample size 82; χ^2 for importance of equation: 63.5; degrees freedom: 15; prob.:.000; Cases predicted correctly: 62%. Values in parenthesis indicate asymptotic standard errors; ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

The other significant variables in the model help explain the adoption of the herbicide component. *Farm size* (ha per household) is particularly influential - the larger the farm size, the higher the likelihood of adopting the herbicide component. This links back to the amount of work required on the farm and overall resource availability. The two other significant variables affect only one stratum and include (i) availability of household labour (adult male equivalents available full-time per household); and (ii) involvement in a non-agricultural business (dummy). The more *family labour* the household has, the higher the likelihood of adopting the herbicide component. This seems to link back to family labour enabling emigration, and emigration in turn enabling herbicide use. A *non-agricultural business* increases the likelihood of adopting the herbicide component, probably in relation to an increased cash availability and higher opportunity cost of family labour. The non-significant variable included in the specified model is sole cropping of maize in the field (dummy).

significant variables are described and explained. For a detailed and more conventional description of the model see Erenstein and Cadena (1997).

According to the model, the 'typical'[14] farmer has a 61% probability of adopting only the herbicide component (which is also the most common group of adopters in the sample). A steeper than average field (90% slope) increases the likelihood that the typical farmer adopts both components (71% prob.). Similarly, if the farmer encloses his field he will probably adopt both components (98% prob.). Farm size strongly influences the adoption of the herbicide component. A typical farmer with only one hectare of land will probably adopt neither, but a farmer with five ha is most likely to adopt the herbicide component (either alone or in combination with mulch, 94-95% prob.). The results for family labour are similar. Having a side business makes it more likely (93% prob.) that the farmer will adopt only the herbicide component.

8.1.5 Private assessment

The present subsection reviews the private implications of CRM-based practices for the farm household, in terms of farm household preferences and decision making, valuation and private returns.

Farm household preferences and decision making

All farm households present a marked emphasis on maize-beans production. These staples are primarily produced for internal consumption - reflecting two underlying issues. First, that farm households strive to produce enough food to meet consumption needs. Second, that the area is characterised by a marked competitive disadvantage for agricultural production - biophysically by its extreme slopes, socio-economically by its remoteness. Consequently, farm households typically rely on seasonal emigration to supplement on-farm income.

By maintaining productive capacity, CRM would more adequately secure long term household food security. However, resource poor farm households typically have a pronounced time preference. This adversely affects the investment nature of fencing needed to safeguard the residues. Farm households also typically are risk averse, making compliance with the no burning regulation likely as long as it is genuinely enforced.

The herbicide component frees labour for alternative use. This is of particular interest to the farm household as off-farm wages are high relative to the prospects for farm income. The function of the farm may thereby change from income generation and/or food production towards the provision of a rent free place to live and communal pastures on which to keep livestock in which remittances are invested - similar to what is reported in Southern Africa (Abel *et al.*, 1987 in Stocking and Abel, 1992). Simultaneously, off-farm employment and permanent emigration may increase the potential of perennial based systems which have lower labour requirements and are less prone to soil erosion - as was the case in Indonesia (Barbier, 1990).

Overall, the various components seem to fit relatively easily in the farm system. Many established crop management practices are compatible with CRM-based crop production. Crop residue use as mulch also does not conflict with alternative internal use - whereas it does offer the potential for increasing yields and reducing production risks. The critical

[14] Based on average or most common values for respective variables.

question is if the household's marginal benefits (utility) of adopting the mulch and herbicide components make the corresponding marginal costs (disutility) worth incurring.

Valuation

Not all produce and factor markets are equally developed. The *land* rental market is particularly thin. Notwithstanding, the average land rent in the area was similar and is taken as indicative of the opportunity cost of land. The local day labourer wage rate is assumed to be a fair approximation of the opportunity cost of *labour*. In terms of *capital*, external inputs are valued at their acquisition plus transport costs. Costs of financing are highly variable - but five percent per month is assumed to be a reasonable approximation of its average opportunity cost.

The marketed *crop produce* is valued at the local on-farm sale price - the internal consumption at the local on-farm purchase price. The *crop residues* have both production value as fodder and soil conservation value as mulch. However, crop residues traditionally could be considered a quasi private product: a non-exclusive yet divisible product (Turner *et al.*, 1993:77). The opportunity cost of the crop residues therefore revolves around the costs of asserting exclusive ownership - here approximated by the investment in fencing. Once private ownership is asserted, the opportunity cost of fodder forgone is typically negligible for most households (internal demand is compatible with mulching).

Private returns

The lack of baseline data makes a chronological crop budget comparison highly speculative. The present discussion therefore emphasises contemporary comparisons over adoption strata - which are summarised in Table 8.10. However, it is clear that the regulation regarding pre-plant burning substantially increased the cost of adhering to this practice - particularly as the practice was *de facto* forbidden and probability of apprehension high. The cost increase was sufficient to induce all sample farmers to forgo pre-plant burning in the study area.

The budgets highlight a number of issues. First, on average, maize-beans production remunerates internal production factors at around the estimated opportunity costs only. Second, the returns vary over adoption strata. These differences are assumed to be mainly a function of technology, and not of uncontrolled variables.

The *purposive* adoption of only the mulch component is not privately attractive. Although gross production value and value added show a slight increase over non-adoption, household income and the returns to internal production factors actually decline. This is largely a result of the need to invest in fencing. Assuming *accidental* adoption without an investment in fencing, returns improve substantially.[15] Interestingly, none of the farmers that only adopted the mulch component had invested in fencing.

[15] Accidental as the farmer would have no means of ensuring sufficient residues are actually retained. The corresponding indicators: household income US$ 389 ha^{-1}; return to land US$ 106 ha^{-1}; return to capital 12.9% $month^{-1}$; and return to labour US$ 3.6 day^{-1} (same calculations as Table 8.10).

The adoption of only the herbicide component substitutes capital for labour without significantly altering gross production value. Per ha value added and household income thereby decline somewhat - but the substitution implies a cost-saving that raises the remuneration of the internal production factors above the estimated opportunity costs.

The purposive adoption of both the mulch and herbicide components (i) raises gross production value (by 21% based on non-adoption), (ii) substitutes herbicides for labour, and (iii) implies a capital investment in fencing. These changes favourably affect both value added and household income. However, the needed investment in fencing largely offsets the production value increase. The remaining favourable effect on the remuneration of the internal production factors is thereby similar to that achieved by adopting only the herbicide component. Assuming accidental adoption without investment in fencing, returns again improve substantially.[16]

Table 8.10 Crop budgets over adoption strata in the Chiapas Highlands study area

	Components adopted			
	Neither	Only mulch	Only herbicide	Both
A. Gross production value (US\$ ha^{-1})	544	558	541	656
a1. Maize grain	432	472	426	521
a2. Maize residue	0	0	0	0
a3. Intercrop	112	86	115	135
B. Recurrent expenses (US\$ ha^{-1})	101	104	126	125
b1. External physical inputs	87	90	112	111
b2. External services	0	0	0	0
b3. Residue input	0	0 [a]	0	0 [a]
b4. Other internal inputs	14	14	14	14
C. Labour (days ha^{-1})	93.3	93.4	77.7	79.6
D. Capital and financing (US\$ ha^{-1})				
d1. Financing costs	20	61	24	65
d2. Average working capital	87	90	112	111
d3. Average value capital goods	22	159	22	159
d4. Depreciation capital goods	6	33	6	33
F. Value added (US\$ ha^{-1})	443	454	415	531
G. Household income (US\$ ha^{-1})	378	348	353	427
H. Return to own land (US\$ ha^{-1})	96	(3)	111	112
I. Return to own capital (% $month^{-1}$)	10.4%	0.9%	12.7%	10.0%
J. Return to own labour (US\$ day^{-1})	3.4	2.2	3.7	3.7

[a] Cost of fencing to safeguard residues included as capital good. *Formula*: A = a1+a2+a3; B = b1+b2+b3+b4; F = A - B; G = [A - B - (external labour)*(wage) - d1]; H = [G - (opp. cost own labour) - (opp. cost own capital) - d4]; I = [G - (opp. cost own labour) - (opp. cost land)]/(own capital); J = [G - (opp. cost land) - (opp. cost own capital) - d4]/(internal labour). *Assumptions*: Factor opportunity costs - capital 5% $month^{-1}$; labour US\$ 3.23 day^{-1} (wage rate); land US\$ 80.6 ha^{-1}. Factor ownership assumptions - capital: 50% own + 50% borrowed; land: own; labour: 85% own + 15% hired (survey average).

[16] *E.g.* household income becomes US\$ 469 ha^{-1}; return to land US\$ 222 ha^{-1}; return to capital 36.6% $month^{-1}$; and return to labour US\$ 5.3 day^{-1}.

The returns to adopting each component in the current setting are possibly more ambiguous than expected. There are a number of underlying reasons. First, the mulch component does favourably affect crop yields - but the cost of purposively securing sufficient residues as mulch is high. Second, the herbicide component is constrained by the relative prices of herbicides and labour. Based on the survey results and average opportunity costs, partial adoption of the herbicide component on a given area represents a benefit/cost ratio of 1.41, full adoption a ratio of 1.55 (*i.e.* a marginal rate of return of 41 and 55% respectively). This compares with a ratio of 1.5 to 2.0 generally considered as the minimum payoff required by farmers (CIMMYT, 1988). The borderline average returns, in conjunction with variations in preferences and opportunity costs over households, largely explains the partial adoption of this component. Third, there is also the confounding effect of partial adoption. The non-adopters are an imperfect control group as it includes partial adopters of both the mulch and herbicide components.

To facilitate comparisons over adoption strata the budgets are on a ha basis and apply average local values. This is not an issue as long as households are equally productive and face similar opportunity costs. However, adoption strata differ in farm size and labour constraints (see 8.1.2). Production functions may thereby also vary over adoption strata (Ruben *et al.*, 1996; 1997). However, estimates of aggregate and disaggregate production functions on the basis of available data do not show significant differences, and in any event are not very insightful.[17] Farm household modelling could highlight differences in opportunity costs. For instance, the substitution of herbicides for labour, conceivably allows (i) to extend the cultivated area; (ii) to reduce contracted labour use; (iii) to increase time devoted to other home(stead) activities (*e.g.* leisure); and/or (iv) to increase seasonal emigration of household members. The attractiveness of the different options is thereby household dependent. However, in view of data limitations, farm household modelling for the different adoption strata would imply numerous assumptions and is not pursued here.

In sum, farmers were complied to abandon pre-plant burning. Given no burning, the purposive adoption of mulch is unlikely to be privately efficient. The adoption of mulch seems to be primarily the coincidental combination of reduced access of livestock to steeply sloping fields and the farmers' decision to stop burning. The adoption of the herbicide component hinges on the opportunity cost of labour. This raises questions about the nature of the farmer's adoption decision (Tripp, pers. comm.). The decision to adopt CRM practices supposedly reflects a new understanding on the part of farmers and its subsequent application. However, the adoption process observed in the study area is related to changes in production practices that originated in another way - be it imposition, chance or financial gain.

8.1.6 Social assessment

Two crop production induced externalities stand out in the study area: (i) soil erosion; and (ii) forest fires. The cultivation of annual crops on steep slopes increases the erodibility of already fragile soils. The resulting soil erosion hazard is substantial at the onset of the summer season, the more when using 'traditional' clean till practices (pre-plant burning and

[17] *I.e.* limited explanatory value, probably due to data variability and uncontrolled variables.

hoe tillage). The traditional annual ritual of pre-plant burning has also been singled out as the major cause of forest fires in Chiapas State (Sandoval, 1994). CRM-based practices largely curtail these externalities.

The farm households dwelling in this remote mountainous area are also predominantly resource poor. It may be in the interest of society to reduce the likelihood of permanent emigration. CRM-based practices reduce the degradation of the livelihood basis, yet enable temporary emigration - thereby providing an adequate vent for surplus labour.

A social assessment of CRM-based practices will thereby diverge from the preceding private assessment. However, whether the divergence between social and private viewpoint was sufficient to make a case for intervention remains an open question. The fact that government intervened suggests that the divergence was at least perceived to be sufficient, or alternatively, the existence of underlying social objectives.

Policy intervention followed a two-tier approach: (i) raise utility of adoption of CRM-based components (conditional incentives, information); and (ii) raise disutility of adherence to pre-plant burning (regulatory procedures, fines upon non-compliance). The use of these measures suggests that the proposed changes were perceived not to be in the private interest. This may have been the case for the mulch component, but is more questionable for the herbicide component. This study does not allow for an elaborate assessment of these specific policy instruments. However, it does provide some indicative feedback about the effectiveness of the different measures. The survey highlights that the eradication of pre-plant burning in the study area at least,[18] was successful. In this respect, the regulation of pre-plant burning was definitely effective, chiefly because it was actually enforced at the local level. However, the effectiveness of the distributed incentives is less clear. The backpack sprayer incentive did not seem to alleviate a typically binding constraint, as herbicide use was already widespread.[19] The adoption of the herbicide component may have occurred even without an extension program, simply because farmers needed to free labour to perform more remunerative work outside of the study zone.

The study highlights a substantial adoption of CRM and related components. However, it appears to be more problematic to move on from here. Purposive adoption of the mulch component is not in the private interest. Hereto, policy intervention also has not really addressed the mulch component as such - instead emphasising pre-plant burning and herbicide use. For the forest fire externality the emphasis on pre-plant burning is logical. For the soil erosion externality, however, pre-plant burning and tillage are only partial aspects. The soil conservation aspect of the proposed practices hinges on the quantity of residues remaining as mulch. However, CRM adoption was based on the 30% soil cover threshold - whereas the response in terms of soil conservation is continuous and subject to diminishing returns. CRM adoption levels therefore underestimate the actually achieved

[18] Anecdotal evidence from nearby communities suggests that pre-plant burning was not completely eradicated from the wider region.

[19] Most farmers reportedly received their backpack sprayer in 1990. Figure 8.2 depicts the reported diffusion of herbicide use. Only 6% of the sample farmers had not received a backpack sprayer as incentive (on the condition of not burning) - none of whom had adopted the herbicide component.

impact in terms of soil conservation - especially as partial adoption of the mulch component is widespread.

Finally, policy intervention typically implies trade-offs, but some of these remain unresolved. For instance, current policy promotes mulch retention practices, yet prohibits tree felling - it thereby constrains fencing possibilities that would enable CRM. There is also an implicit trade-off between equity and sustainability when intervening in such areas.[20] Too much attention may serve as a magnet and keep population in fragile areas (Anderson and Thampapillai, 1990); too little may result in environmental havoc and exacerbate externalities.

8.2 The adoption of CRM-based maize production in Central Chiapas, Mexico[21]

The case study assesses the adoption of CRM-based maize production in Central Chiapas. The study area is located in southern Mexico, in the Fraylesca, a renowned maize-producing region of Chiapas State (Figure 7.1:155). Its rural economy is developing, with both semi-commercial and commercial agricultural production. The area is low to mid-altitude (600 - 1,500 m) with an annual rainfall of 1,200 mm. Agriculture is predominantly rainfed, so that the unimodal rainfall distribution gives rise to a single cropping season in the summer and a prolonged dry season in winter - with an occasional intra-season drought (*canicula*). Agricultural production is located both in the arable[22] valley plains and on the non-arable slopes of surrounding hills and mountain ranges.

The selection of the study area reflects its substantial history of CRM-related research and extension (*e.g.* Lopez, 1993; Lopez *et al.*, 1994; van Nieuwkoop *et al.*, 1994). The area was thereby selected purposively with the expectation to find significant adoption levels. The data presented in this case study were primarily collected through a formal single visit survey of 164 farmers at the onset of the 1995 summer cropping season. This was a follow up visit of the same farmers that were surveyed two years earlier by van Nieuwkoop *et al.* (1994). The original study used a random sample, stratified by community and technology with an overall sampling fraction of 1.3%. The data from the follow up study were weighted to account for the over sampling of adopters of CRM practices in the original study. Overall, data collection required an estimated 4 man months. The following subsections assess the adoption of CRM-based maize production following the steps specified in the TA framework.

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[20] This is a traditional policy conflict characteristic for Mexico. Equity considerations have induced land reform in the past - yet *ejidos* were frequently carved out on land best left undeveloped from a conservationist perspective. The study area is one example, the Southern Veracruz case study another.

[21] The case study data are mainly derived from Erenstein *et al.* (1998), which is a follow-up study to van Nieuwkoop *et al.* (1994). Credit is due for the (co-)authors of the original studies and the collaboration received from INIFAP.

[22] In the sense that tillage could be applied.

8.2.1 Crop system implications

Maize is the main annual crop in the local farming system. There is a marked distinction between maize production systems depending on whether the agricultural field is arable (*i.e.* whether tillage could be applied). Non-arable fields tend to be located on the hillsides and in stony areas (average slope 48%, *i.e.* 26°), and by definition, allow no mechanisation whatsoever. Intercropping with beans is common practice. Arable fields are typically located in the valley plains (average slope 5%, *i.e.* 3°), and are characterised by mechanised land preparation and sole cropping.

The present subsection reflects on CRM-based maize production practices in the two systems, thereby emphasising crop management and physical input and output levels. It will briefly reflect on the chronological setting, thereby distinguishing between past, current and CRM-based systems (where 'past' refers to the traditional practices prior to the introduction of CRM practices). Emphasis will be on the contemporary setting and a CRM-based adoption typology is developed for this purpose.

Necessary practices for CRM

Both residue production and weathering levels have traditionally been potentially compatible with CRM-based maize production - irrespective of whether the field is arable. Traditionally the stubble was grazed and the remaining residues were burned prior to planting the subsequent maize crop. In the arable fields, land preparation also implied an intensive mechanical soil tillage. In the non-arable fields no tillage whatsoever was applied.[23] Despite differences in tillage, the quantities of residues traditionally left as mulch in either arable or non-arable fields were minimal - *i.e.* the crop was established in a clean field. At the outset, the necessary changes for CRM in the local context therefore related to abandoning pre-plant burning, (possibly) limiting residue extraction, and in arable fields, reducing tillage intensity.

At the time of the survey, most sample farmers had reportedly abandoned pre-plant burning, particularly in arable fields. Residue extraction - notably stubble grazing - was still widespread, as was intensive tillage in arable fields. Residue quantities remaining as mulch typically were still insufficient to qualify as CRM. This reiterates that no burning was a necessary but not a sufficient condition. CRM adoption would require further changes in terms of reducing tillage (in arable fields) and extraction levels (in both types of field). Most fields (63%) are currently already fenced, thereby potentially enabling the regulation of extraction. Nonetheless, adoption of CRM-based maize production in the area is complex - particularly in arable fields. Indeed, extraction, burning, and incorporation are all relevant substitutes in terms of residue elimination. Adoption therefore typically required a set of changes in residue management (Table 8.11).

Adoption typology

A CRM-based adoption typology encompasses the necessary changes for CRM in the local context - *i.e.* in terms of pre-plant burning, tillage and residue extraction. Figure 8.3 uses these practices as determinants for adoption strata - whereby burning and tillage are

[23] Prior or after crop establishment - *i.e.* a complete zero till system from harvest to harvest.

considered explicitly, residue extraction implicitly in the last criterion. In arable fields four strata can be distinguished. In non-arable fields, the reduced till criterion is satisfied by default, thereby reducing the strata to three only.

Table 8.11 Overview of past, current and CRM-based residue management practices in the Central Chiapas study area

	Crop residue management					
	Arable fields			Non-arable fields		
Practice	Past	Current[a]	CRM-based	Past	Current[a]	CRM-based
Pre-plant burning	Yes	No (91%)	No	Yes	No (75%)	No
Tillage	Intensive	Intensive (70%)	Reduced	No	No (100%)	No
Residue extraction	Yes	Yes (74%)	Restricted	Yes	Yes (82%)	Restricted
Mulch	No	Insufficient (95%)	Yes	No	Insufficient (81%)	Yes

[a] Percentage refers to survey population implementing prevalent practice in largest field at survey time. Source: derived from Erenstein *et al.* (1998)

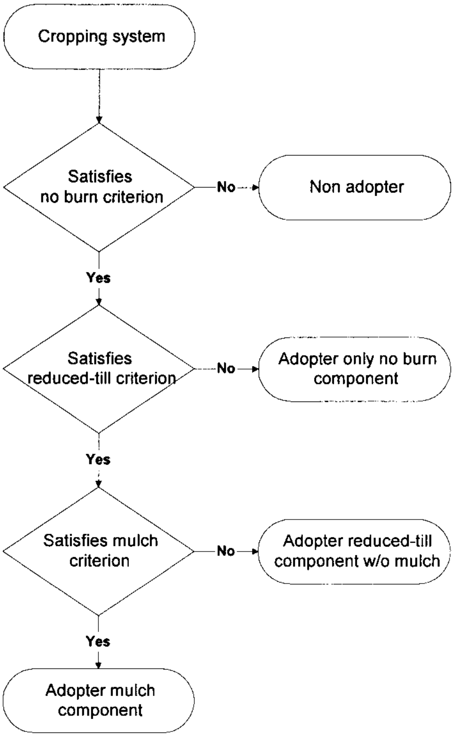

Figure 8.3 Flow chart to categorise CRM adoption

Figure 8.4 categorises the sample population in terms of these strata - both for the survey year and the preceding survey, and distinguishing between arable and non-arable fields.[24] The 1994 data highlight the extent of partial adoption of CRM practices. In arable fields the adoption of only the no-burn component prevailed; in non-arable the reduced till without residues. This contrasts with the situation two years earlier, when pre-plant burning was still common, especially in the non-arable area. Over this time period, the abandoning of pre-plant burning resulted in a concomitant increase of the next adoption category in the arable area - *i.e.* incorporation typically substituted for the burning of residues. In the arable area, the adoption of the mulch component remained very limited and apparently stagnant.[25] The abandoning of pre-plant burning had more mixed results in the non-arable area. The largest increase still was in the next adoption category, but the adoption of mulch nevertheless received a substantial boost.

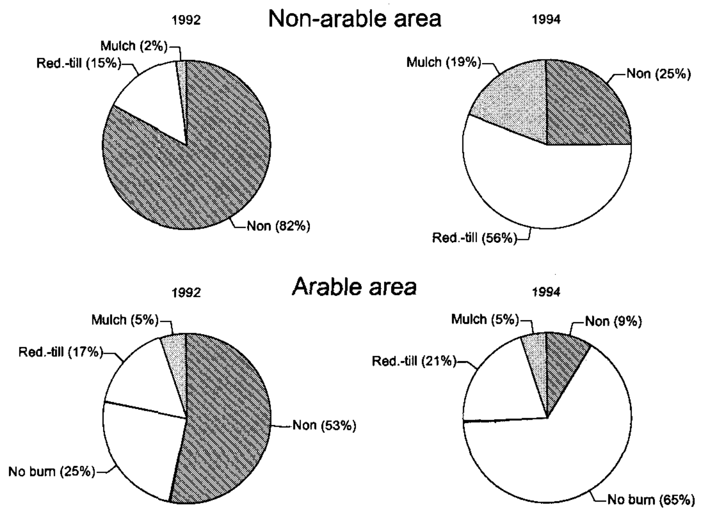

Figure 8.4 Adoption strata over time and space in the Central Chiapas study area (Erenstein *et al.*, 1998)

Based on the survey results and a number of assumptions[26], it is possible to estimate residue balances for a "typical" maize field for each adoption stratum. Figure 8.5 depicts the results, distinguishing between arable and non-arable fields. There exist marked

[24] Classification based on farmer reported practices in selected maize field at survey times. For 1994 season, farmers were also asked to indicate mulch levels on the basis of photo comparisons.

[25] The small size of this stratum also curtails the relevancy of comparisons with other strata.

[26] Maize yields, land preparation practices and residue extraction reflect average/typical levels reported for each adoption stratum. Assumes average yield for last 4 years; a harvest index of 35% in non-arable fields, 40% in arable; and a weathering index of 10%. Assumed incorporation indices: ploughing 80%; harrowing 30%; sowing 2.5%.

differences in terms of residue extraction levels between adoption strata. Extraction levels of the adopters of reduced till without residues are high and clearly incompatible with CRM: less than two Mg residues ha^{-1} remain as surplus. The residue extraction levels of non-adopters and adopters of mulch are much lower. However, whereas adopters of CRM typically leave the surplus as mulch, non-adopters prefer to burn it. Adopters of only the no-burn component have intermediate extraction levels, potentially compatible with CRM. However, these farmers typically incorporate most of the surplus residues during land preparation. In the end, non-adopters and adopters of only the no-burn component typically have eliminated most residues, leaving only marginal amounts as mulch. Adopters of the reduced till component typically leave about one Mg residues ha^{-1} - a substantial amount, although insufficient for an effective mulch. Adopters of the mulch component typically leave about two to three Mg residues ha^{-1} as mulch. The existence of partial adoption of the mulch component masks the full impact of CRM introduction.

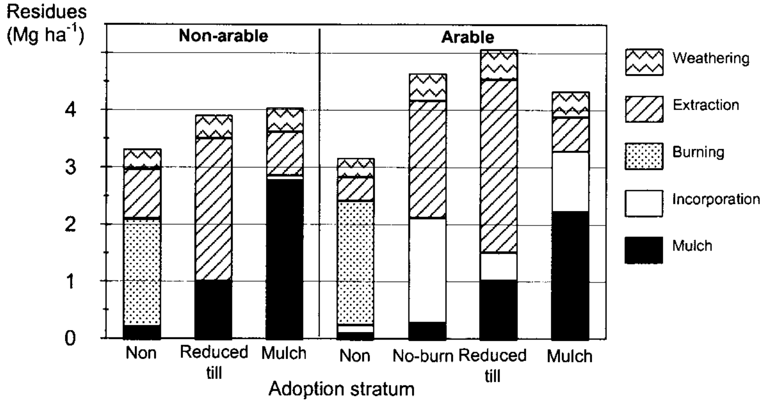

Figure 8.5 Residue balances over adoption strata in the Central Chiapas study area

The case suggests the existence of stepwise adoption much like reported for technological packages (Byerlee and Hesse de Polanco, 1986) - *i.e.* farmers seem to adopt CRM components one at a time. For instance, in the arable area, there is a positive relation between the number of CRM components adopted and the years of not burning. The situation is more complicated in non-arable area due to two countervailing forces. On the one hand, CRM adoption seems to be relatively easier in non-arable fields. Already being zero till systems, these systems require fewer adaptations for adoption of CRM. Adoption is indeed more widespread in this area (1994 data in Figure 8.4). On the other, farmers are relatively more reluctant to abandon pre-plant burning in non-arable fields. Farmers have less alternative means of residue disposal to substitute for burning. Indeed, given a low level of residue extraction, pre-plant burning is the only viable option for residue elimination. In such an instance, forfeiting burning, automatically results in a substantial mulch. Alternatively, given a high level of residue extraction, the effect of not burning is less substantial - potentially facilitating abandoning the practice. The survey data support this proposition: in non-arable areas, farmers using reduced till without residues were the first to abandon burning. This may also partially explain why non-adoption is concentrated in this area (1994 data in Figure 8.4).[27]

Complementary cultural practices for CRM

The adoption of CRM seems to have imposed few other changes for crop management (Table 8.12). Traditionally the *sowing* operation of maize has been manual with dibble stick - irrespective of whether the field was arable or not. The prevalence of manual sowing in arable fields circumvents the dependence on direct drills, which frequently constrains adoption of CRM practices in mechanised agriculture (*e.g.* see Southern Jalisco case study - 7.1). Manual sowing is compatible with CRM, with the caveat that it may become more cumbersome and time consuming. However, a comparison of labour use for sowing shows no significant differences over adoption strata. A comparison of seed rate over adoption strata did show a positive relation with the number of CRM components adopted, which is a rational adaptation under CRM systems.

Table 8.12 Overview of past, current and CRM-based crop management practices in the Central Chiapas study area

	Crop management		
Practice	Past	Current [a]	CRM-based
Sowing	Manual	Manual (arable 92%, non-arable 100%) [a]	Manual
Weed management	Mixed (physical & chemical)	Herbicides only (81%)	Herbicides only
Pest/disease management	Mixed (burning & biocide)	Biocide (89%)	Biocide
Nutrient management	Chemical fertiliser	Chemical fertiliser (100%)	Chemical fertiliser

[a] Percentage refers to survey population currently implementing practice. Source: derived from Erenstein *et al.* (1998)

Weed management typically relies on herbicides: their use in the sample was near universal (99% use) and long established (on average 16 years at the time of the survey). Herbicides have increasingly substituted for 'traditional' forms of manual weeding - *e.g.* with machete, hoe, and/or animal drawn implements. In fact, four-fifths of the survey farmers relied completely on herbicides for weed control. The advent of herbicides conceivably facilitates substituting for the foregone weed control effect of pre-plant burning and more intensive soil tillage. A comparison of weed management practices over adoption strata showed only minor differences - the more significant differences pertained to whether the field was arable or not. However, in non-arable fields, purely manual weed control

[27] Differences in the institutional setting are another major contributor (see below).

practices showed a marked concentration amongst the non-adopters - partially related to the lack of access to water (which is necessary for herbicide use).[28]

Farmers tend to intercrop their maize, particularly in the non-arable area. Retaining this practice could limit the choice of herbicides. A comparison over adoption strata highlights that intercropping did not seem to affect the portfolio of herbicides used. For beans, the temporal separation is apparently sufficient to alleviate potential incompatibility with residual herbicides. However, for squash this temporal separation does not exist, giving rise to a conflict between the use of residual herbicides such as atrazine and intercropping.

Pest and disease incidence was reportedly common, and *pest and disease management* tended to rely on biocides (insecticides and fungicides), commonly applied to the foliage and as seed treatment. CRM practices can alter pest incidence and management. A comparison over adoption strata did show such biocide use was less common for non-adopters in non-arable areas. Further, the presence of the mulch seemed to imply an increased incidence of some insect pests (*e.g. Phyllophaga spp*, and *Pseudoplusia includens*).

Nutrient management typically relies on chemical fertilisers: their use in the sample was universal and long established (on average 24 years at the time of the survey). The average $N:P_2O_5:K_2O$ dose was 145:8:0 kg ha^{-1} - thereby reducing the risk of N immobilisation. Farmers generally split N applications - thereby increasing N use efficiency. Past and current practices are largely compatible with CRM and did not require major adaptations. A comparison over adoption strata did show that adopters of the mulch component applied more N, whereas splitting was more common - both rational adaptations under CRM systems.

Input-output implications

The lack of baseline data makes a chronological input-output comparison highly speculative. The present discussion therefore emphasises contemporary comparisons over adoption strata - which are summarised in Table 8.13.

In arable fields, (farmer reported) maize yields averaged 3.0 Mg ha^{-1} over the last four years. In non-arable fields, yields averaged 2.0 Mg maize and 450 kg beans. It is unlikely that CRM drastically altered/alters yield levels in the short term - except for those years with a severe intraseason drought. In most years though, water is not a limiting factor, so the yield stabilising effect will be limited. With traditional clean till practices (no cover), the sloping fields were subject to a high soil erosion hazard at the onset of the cropping season. Not burning and retaining sufficient residues as mulch reduces such hazard and ensures yield levels are more adequately maintained over time. CRM's soil ecology effects are likely to ameliorate the soil fertility over time.

Results from a long-term experiment in the area confirm these expectations. Lopez (1993) highlights an overall negative effect of pre-plant burning compared to mulch based practices over seven years - although on an annual basis, the negative effect is only detected in dry years. This reiterates that water conservation is CRM's major short term yield effect in the area, thereby reducing production risks.

[28] Household resource availability seems another major contributor (see below).

Table 8.13 Comparison of output-input indicators over adoption strata in the Central Chiapas study area

	Arable zone				Non-arable zone		
	No	No-burn	Red. till	Mulch	No	Red. till	Mulch
Output (kg ha^{-1})							
- Maize grain [a]	2,100a	3,090b	3,370b	2,880ab	1,780u	2,100v	2,170v
- Maize residues (estimate) [b]	3,150	4,640	5,060	4,320	3,310	3,900	4,030
- Intercrop [c]	16	2	6	13	139u	500v	653v
Recurrent input (units ha^{-1})							
- Maize residues (kg prior to tillage, estimate)[d]	200	2,100	1,500	3,300	200	1,000	2,900
- Ploughing (average operation #)	0.5	1.0	0.0	0.0			
- Discing (average operation #)	0.7	1.4	0.8	1.0			
- Seed (kg, maize)	20a	22ab	25c	26bc	16t	18u	20v
- Herbicide (l)	8.9	5.9	8.3	7.1	5.0	6.6	5.9
- Fertiliser ($N:P_2O_5$; kg)	139:0	174:15	162:9	179:5	110:10	120:0	157:10
- Insecticide (l)	1.5	1.4	1.3	0.9	0.8	1.1	1.4
Labour input (labour days ha^{-1})							
- Land preparation and sowing	9.7	4.9	7.7	3.5	13.1	9.2	9.6
- Weeding	6.9	6.9	7.0	6.7	10.7	9.9	9.5
- Fertilisation (estimate)	7.2	7.9	7.3	6.6	8.8	9.8	12.5
- Harvesting & shelling (estimate)	7.6	11.2	12.3	10.5	8.6	10.2	10.5
- Intercrop (estimate)	1.7	0.3	0.7	1.5	7.7	11.3	12.7
Sum	33.2	31.2	34.9	28.7	48.9	50.4	54.8

Source: Erenstein *et al.*, 1998. Data followed by different letters differ significantly - Duncan (.10), within row comparison. Summation discrepancies due to rounding. [a] Average yield last four cycles. [b] Based on harvest index - 40% arable, 35% non-arable zone. [c] Yield equivalent of major intercrop in 1994 - squash in arable fields; beans in non-arable. [d] Estimate from residue balance.

A yield comparison over adoption strata shows that non-adopters obtained significantly lower yields than the other strata in both arable and non-arable fields (Table 8.13). Non-adopters also have more variable yields and higher production risks. This finding is in line with the experimental data, and suggests that the CRM components have a beneficial effect on yield over time. However, care is needed in interpreting this result, as problems of multicollinearity severely entangle the effects of the different factors.[29] Higher grain yields also imply a higher crop residue production (assuming a similar harvest index).

The necessary changes for CRM alter the input into the crop system, particularly in terms of labour, capital and crop residues. A comparison over adoption strata thereby reflects some of the issues discussed earlier - *e.g.* in terms of tillage intensity; seed rates; and fertiliser rates. Other differences are more ambiguous and generally not statistically significant. These being survey data, there are also the confounding effects of partial

[29] *E.g.* farmers typically apply more inputs on arable than on non-arable fields; non-adopters typically apply less inputs than (partial or full) adopters do.

adoption and/or other uncontrolled variables. Overall, external input use is substantially higher in the arable fields.

Most farmers already had a substantial experience with herbicides (Figure 8.6). This reduces the learning costs inherent to herbicide use and implies access to herbicide application equipment is not an issue. Notwithstanding, experience does not necessarily imply a safe, effective and efficient herbicide use (*e.g.* Angehrn, 1994). Once more, farmers typically learned herbicide use by doing, and health risks are an issue as farmers tend to rely on toxic paraquat (although the use of 2,4-D, atrazine and glyfosate is also common). Such issues affect biocide use in general - *e.g.* nearly half of the farmers in the area have suffered intoxication symptoms in relation to pesticide use (van Nieuwkoop *et al.*, 1994:46).

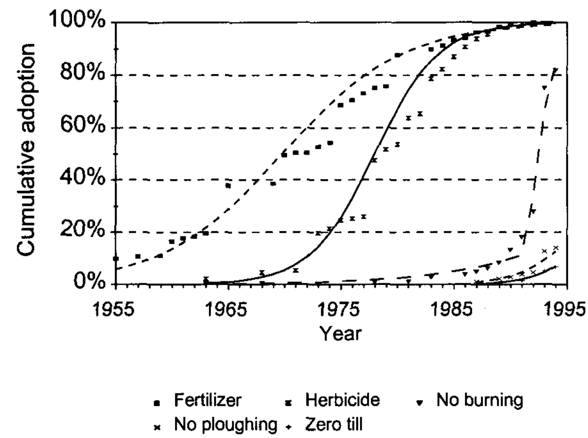

Figure 8.6 Diffusion of some management practices in the Central Chiapas study area (actual points refer to survey data; logistic curves estimated thereupon. Abrupt nature no burning curve due to change in institutional setting. See text for details).

8.2.2 Resource implications for the farm household

The typical activities of the local farm household system include crop production, livestock production, other productive activities, reproduction and leisure. Crop production is characterised by the prevalence of maize - either as sole crop or intercropped with beans or squash. In the 1994-cropping season, its cultivation was universal and occupied 48% of average farm area (18.1 ha). Other crops - including beans as sole crop, groundnut, sorghum, coffee and fruits - occupied less than 2% of the average farm. Pastures occupied 40%, and the remaining 9% were mainly devoted to forestry. Most households have at least one head of livestock - most commonly traction/transportation animals (54% of sample households) and cattle for meat or dual purpose (41% of sample households). In terms of numbers, the average herd shows a marked bias towards cattle. On-farm agricultural household income is occasionally supplemented by other income sources, such as off-farm work in the region (23%) and non-agricultural activities (17%). The household encompasses an average of 6 people. The present section briefly reviews the main resource related implications of CRM for the other farm household activities, and reflects on a contemporary comparison of household indicators.

Factor related implications

The dominant land uses are maize and pasture, implying CRM had no major land-related effect on other crops. CRM's *land* resource implications for pasture are two-fold. First, it curtails the use of the CRM-land as stubble pasture in the off-season - an issue elaborated below. This may imply the need to extend the area under annual (permanent) pasture. Second, it influences the prospects of rotating crop and pasture land (ley farming) - farmers traditionally rely on burning and (if possible) tillage to transform pasture into crop land. CRM practices did not drastically alter *labour* and *capital* use in crop production, and thereby had limited effect on the other farm household activities. The implications of substituting herbicide for tillage in arable fields depend in part whether the farm household owns a tractor - only 6% do.

A comparison of farm household indicators over adoption strata, however, indicates some noteworthy differences, both in terms of the portfolio of farm household activities and resources. All farm households were engaged in maize production, but there is marked distinction in terms of maize production system. Adopters of no burn only stand out as they typically cultivate maize as sole-crop in arable fields (Table 8.14) - in part a direct reflection of the adoption typology. The same adopters of no burn also are characterised by a more significant livestock enterprise (number of cattle in Table 8.15) and resource availability. For instance, although farm size did not differ significantly over adoption strata, there is a tendency for these adopters to have larger farms (Table 8.14). The land resource of the adopters of no burn only also stands out in qualitative terms - typically located in arable and accessible areas (Table 8.15). Possession of tractors is also concentrated in this stratum. On the other hand, non-adopters are typically located in marginal and remote areas. In part, this explains the substantial share of their land devoted to forestry (Table 8.14). The adopters of the reduced till and mulch component take an intermediate position.

Table 8.14 Comparison of land-use indicators over adoption strata in the Central Chiapas study area

	Adoption stratum				
	No	No-burn	Red. till	Mulch	Prob.
Arable maize area (ha)	2.8 a	8.2 b	3.9 a	2.5 a	.00
Non-arable maize area (ha)	6.9 c	1.1 a	3.7 b	7.0 c	.00
Pasture area (ha)	1.2	15.1	4.8	5.2	NS
Other crop area (ha)	0.5 b	0.4 ab	0.1 a	0.2 ab	.09
Forest area (ha)	4.2 c	0.2 a	1.8 b	1.8 ab	.00
Sum (*i.e.* farm size, ha)	15.5	24.9	14.4	16.7	NS

Source: Erenstein *et al.* (1998). Data followed by different letters differ significantly - Duncan (.10), within row comparison. Summation discrepancies due to rounding.

Table 8.15 Comparison of selected farm household indicators over adoption strata in the Central Chiapas study area

	Adoption stratum				
	No	No-burn	Red. till	Mulch	Prob.
Percent of households with access to arable land	40	100	54	75	.00
Remoteness of farm (virtual km to municipality) [a]	58 c	35 a	48 b	48 b	.00
Number of cattle (heads)	1.9 a	14.4 b	8.4 a	3.1 a	.02
Internal livestock pressure on residues (AU *[maize ha^{-1}]) [b]	0.32 a	1.40 bc	1.53 c	0.63ab	.03

Source: Erenstein *et al.* (1998). Data followed by different letters differ significantly - Duncan (.10), within row comparison. [a] Equates 1 km surfaced road with 2 km unsurfaced to take into account travel time. [b] Calculated as (owned or shared) household animal units that graze residues divided by the household's maize area.

Differences in farm household resource availability help explain differential adoption patterns. However, the same also confounds assessing the effect of technology adoption. The very fact that non-adopters are resource-poor makes them an imperfect control group. With the current data it becomes impossible to disentangle the productivity effects of technology from those inherent to resource constraints. For instance, are the lower maize yields of non-adopters a result of adhering to pre-plant burning or of resource-constrained management? Resource constraints are likely to raise the opportunity cost of capital and thus explain the more limited use of herbicides. However, the same constraints also may make a timely acquisition and application of other yield enhancing inputs - say fertiliser - more problematic.

Crop produce related implications

Maize is the local staple crop and is partially produced for internal consumption. CRM-based maize production is likely to more adequately secure farm household staple needs over time, thereby freeing resources previously destined to that purpose. Crop residues are widely used as important internal fodder source during the dry season, *i.e.* cattle production is generally complementary to crop production. The compatibility of CRM with these internal demands is thereby an influential factor.

A comparison of internal livestock pressure over adoption strata indeed show some marked differences (Table 8.15), which parallel the differences in extraction levels at the field level. Adopters of the reduced till component without residues typically have a very high internal livestock pressure, explaining their substantial extraction levels. This reflects the combination of a substantial livestock activity with a limited maize area. Adopters of no burn have a high internal livestock pressure, reflecting a substantial livestock activity. In contrast, the adopters of the mulch component and particularly non-adopters typically have low internal pressures, thereby reducing the tension between residue extraction and retention. Adopters of the mulch component also typically reported having sufficient residues to meet fodder needs. The farm household's own livestock enterprise therefore plays an influential role in the adoption of CRM.

8.2.3 Institutional setting

The area is centrally located within the state and is easily accessible from the state capital. The twin municipal towns of Villaflores and Villacorzo are the major agglomerations, centrally located in the study area. Most rural communities tend to be accessible by motorised transport on unpaved roads, though travel times to the municipal towns can be substantial. The farm households tend to be integrated in produce and factor markets, which are reasonably developed. The present subsection briefly assesses the relevant institutional issues.

Crop produce rights & markets

Traditionally, *pre-plant burning* of crop residues was the rule. As from the end of 1992, the area was subject to the re-institutionalised state law regularising pre-plant burning.[30] The law stipulated a number of mandatory procedures upon adhering to pre-plant burning, and severe penalties upon non-compliance. The law was accompanied by large-scale, state wide extension campaigns. Abandoning of pre-plant burning spread slowly prior, but accelerated substantially after the imposition of the state law (Figure 8.6 above). This suggests the cost of adhering to pre-plant burning was successfully increased and served as a sufficient deterrent to discourage many farmers.[31] However, the state law did not eradicate the practice - as reflected by the existence of the stratum of non-adopters. More worryingly, this seems to relate to a slack enforcement. Indeed, the non-adopters at least had no trouble in "admitting" their use of pre-plant burning - although in a quarter of these cases the burning was reportedly "accidental". Further, adherence to pre-plant burning is positively correlated with the remoteness of the farm (Table 8.15) - which links back to the difficulty of enforcement.

In view of the slack enforcement, the future adoption levels of no-burning remain uncertain. The state law was clearly imposed upon the region by the state government. Some farmers may revert to pre-plant burning upon realising the actual probability of being apprehended. Informal observations after completion of the survey support this proposition (Cadena, pers. comm.). On the other hand, farmers may also adhere to no-burning - *e.g.* upon realising burning is not worth the trouble; or simply to comply with state regulations.[32]

Communal *crop residue rights* were widespread in the area, but have increasingly been privatised. Whereas 46% of the households reported communal grazing in the previous survey, only 11% did so in the 1994 season. This suggests a rapid development and advent of the residue market. In the current setting, 18% of the farm households reported selling,

[30] The original law dates back to 1926 but had never been actively enforced (Cadena, 1995:4).

[31] Although the survey may have overestimated the abandoning of pre-plant burning in view of the sensitive nature of the issue.

[32] Resource poor households are typically risk averse. This may imply that farmers augment the real probability of being apprehended with a subjective risk aversion factor. For law abiding, risk averse citizens this factor may be disproportionately large.

and 12% reported buying residues. Market transactions were typically as standing stubble, with an average transaction price of US$ 33 ha^{-1}. As expected, net household sales correlate negatively with on-farm fodder demands.[33] Seven percent of households reported ceding their residues.

A comparison of residue transactions over adoption strata highlights a number of issues (Table 8.16). Communal grazing was reportedly more common amongst the adopters of the mulch component. At first glance, this is surprising, as the farmer has no direct influence over the quantity extracted. On the other hand, communal rights are likely to persist in those areas where livestock pressure upon residues is low. Consistent with expectations, adopters of the mulch component did not report buying residues. Adopters of the mulch component do not significantly differ in terms of selling or ceding residues - thereby highlighting that these can (occasionally) be compatible with residue retention as mulch.

Potential adoption of CRM by the other strata - particularly adopters of reduced till - would imply the need to forego some residue extraction. Widespread use of CRM is therefore likely to increase the market price of residues. Furthermore, selling the right to partial extraction requires adapting the residue transaction and implies additional transactions costs.

Most of the *crop produce* is marketed (on average, 86% of the household's production in the survey year). A comparison of produce marketing rates over adoption strata showed these are significantly higher for adopters of no-burn-only (Table 8.17). This mainly relates to a substantially higher annual maize production than the other strata - reflecting the more favourable location of their land.

Table 8.16 Comparison of residue transactions in survey year over adoption strata in the Central Chiapas study area

	Adoption stratum			
	No	No-burn	Red. till	Mulch
Percent of households:				
- that bought residues	10	13	16	0
- that sold residues	9	23	18	19
- that ceded residues	2	10	10	2
- with communal grazing	0	8	15	27

Source: Erenstein *et al.* (1998). Data followed by different letters differ significantly - Duncan (.10), within row comparison.

Factor rights & markets

Most farm households own their *land* resource (only 6% are tenants) and are *ejidatarios* (only 9% are 'small proprietors'). Tenure is typically secure and the inter-temporal implications of CRM are unlikely to be a major issue. A comparison of land rights over adoption strata, highlights that it is more likely for adopters of no burn to be a tenant

[33] Internal livestock pressure on residues was 0.19 AU ha^{-1} maize for households that sell; 2.74 AU ha^{-1} for those that buy; and 1.13 AU ha^{-1} for those that do not sell or buy (prob.:.00).

household and/or small proprietor. This links back to the underlying qualitative difference of the land, typically located in arable and accessible areas.

Farm households mainly rely on family *labour* but frequently (79%) supplement this with day-labourers on an as-needed basis. Fifteen percent of farm households reported renting-out agricultural day-labour. A comparison of day labour transactions over adoption strata highlights that non-adopters are characterised by less renting in, and more renting out of day-labour (Table 8.17). This reiterates that these households are resource poor. The typical local wage rate for agricultural day labour was US$ 4.41 day^{-1}, irrespective of activity. The commercial nature of the local labour market probably aided the substitution of herbicides for labour.

The municipal towns serve as base for *capital* markets and services, including providers of inputs, equipment, official credit and extension. Agricultural inputs are also readily available outside these towns, and dependence upon third parties for a timely and efficient provision of external inputs does not seem to be an issue. Most farm households contract tractor input for the land preparation in their arable fields. As CRM substitutes herbicides for such tractor services, it is likely to affect the corresponding markets. Access to the financial markets - *e.g.* for bridging the gap between outlays and receipts - seems to be more problematic, particularly for resource-poor farmers.

During the late 1980s and early 1990s, various governmental agencies (both Federal and State level) took up the promotion of CRM practices in the region (van Nieuwkoop *et al.*, 1994:18-20). The promotion of CRM emphasised abandoning pre-plant burning and using herbicides, as well as reducing tillage intensity in arable areas. As in the Chiapas highlands, the extension campaign distributed a number of conditional incentives (*e.g.* handout of backpack sprayers and inputs; provision of credit).

Table 8.17 Comparison of selected institutional indicators over adoption strata in the Central Chiapas study area

	Adoption stratum				Prob.
	No	No-burn	Red. till	Mulch	
Maize market integration [a]	83% ab	91% c	86% b	79% a	.02
Percent of households that:					
- hired in day labour	49	97	85	57	.00
- hired out day labour	32	9	11	19	NR

Source: Erenstein *et al.* (1998). Data followed by different letters differ significantly - Duncan (.10), within row comparison. [a] Maize sold divided by total farm production.

8.2.4 Multivariate adoption analysis

Several of the above farm household factors affecting adoption can be grouped in one single multivariate logistic regression model. Table 8.18 presents such a model which predicts the probability that a farmer will not or only partially adopt CRM, based on a series of farm household characteristics.[34]

Table 8.18 Factors affecting adoption of CRM in the Central Chiapas study area (multivariate logistic model, normalised on complete adoption)

	Adoption stratum		
Variable	Non-adoption	No-burn only	Red. tillage only
Internal livestock pressure (AU ha^{-1} maize)	-1.01 (.55) *	0.416 (.209) *	0.461 (.178) ***
Residue transactions between household and others (dummy)	-1.80 (.86) **	0.442 (.778)	0.450 (.564)
Access to water in the field (dummy)	-1.99 (.72) ***	-0.793 (.762)	0.0423 (.564)
Household labour (adult male equivalents)	0.136 (.279)	-0.230 (.265)	-0.241 (.252)
Arability of the field (dummy)	0.315 (1.02)	15.9 (0.7) ***	0.284 (.721)
Technical assistance (dummy)	-0.969 (.729)	-1.28 (.79)	-0.955 (0.598)
Constant	2.13	-12.5	1.23

Source: Erenstein *et al.* (1998). Sample size: 154. χ^2 for importance of equation: 145. Degrees of freedom: 15; prob.:.000. Cases predicted correctly: 66%. Values in parenthesis indicate asymptotic standard errors; ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

The model highlights that crop-livestock interaction is influential in the adoption of CRM, with a significant role for both of the related variables: (i) internal livestock pressure on residues (household's animal units per ha maize); and (ii) residue transactions between household and others (dummy). Having normalised upon adoption of the mulch component, the *internal pressure* has a two-fold effect. On the one hand, it decreases the probability of the household being a non-adopter. The relative absence of extraction apparently favours the adherence to pre-plant burning amongst non-adopters. This reiterates that pre-plant burning and extraction are substitutes in terms of residue elimination. On the other hand, it increases the probability of the household being a partial adopter. This reiterates that excessive extraction harms the prospects of adoption of the mulch component. *Residue transactions* between the household and others, decreases the probability that the household is a non-adopter. Such transactions alleviate differences in livestock pressure and thus residue extraction between households. It thereby provides alternative modes of residue elimination to substitute for burning. This reiterates the need to include both internal and external residue extraction variables when assessing CRM.

Two field characteristics are also particularly influential in the adoption of CRM: (i) access to water in the field (dummy); and (ii) arability of the field (dummy). *Access to water* decreases the probability that the farm household is a non-adopter - *i.e.* not having access to water makes it more likely that the farmer adheres to pre-plant burning. This seems to relate to two issues. First, access determines the ease of using herbicides

[34] For a detailed description of the model, see Erenstein *et al.* (1998).

(herbicides as substitute for burning in terms of weed control). Second, it frequently determines the degree of stubble grazing (extraction as substitute for burning in terms of residue elimination). *Arability* greatly enhances the probability that the farm household adopts only the no-burn component - *i.e.* that residues are incorporated. This reiterates that burning and incorporation are substitutes in terms of residue elimination. The non-significant variables included in the specified model are household labour (adult male equivalents available full-time per household) and surprisingly, technical assistance (during preceding year, dummy).

The 'typical' farm household with a non-arable field has a 79% probability of adopting the reduced till component without residues (which is also the most common group of adopters in the sample). However, if only the arability of the field is changed, the model predicts the typical farm household would be an adopter of no-burn only (93% prob.). Not having access to water augments the probability that the farmer continues using pre-plant burning (from 32 to 77% prob.). The absence of an internal livestock pressure has a largely similar effect (to 60% prob.). On the other hand, a high internal livestock pressure or the existence of residue transactions reduces the probability that the farmer is a non-adopter (to some 10% prob.). At the same time, these variables consolidate the probability that the typical farmer adopts the reduced till component without residues (>85% prob.).

8.2.5 Private assessment

The present subsection reviews the private implications of CRM-based practices for the farm household, in terms of farm household preferences and decision making, valuation and private returns.

Farm household preferences and decision making

All farm households present a marked emphasis on maize production. The prevalence of maize reflects a number of benefits - including household food security, a secure produce market and multiple products (grain, forage and potential intercrop). Two-fifths of households combine maize and cattle production, whereby the livestock benefits include crop-livestock complementarity, portfolio diversification, finance, insurance and status.

Agricultural production is to a large extent market-oriented, which implies that private returns are likely to be influential in household-decision making. The southern location within Mexico implies that wage rates for agricultural day labour are much lower than in central-northern Mexico (*e.g.* the southern Jalisco study area).[35] This has induced households to substitute capital only for the most labour-intensive agricultural operations, particularly land preparation in arable fields, weeding and shelling. However, the use of other potential labour-saving mechanisation in the arable area is uncommon - particularly mechanised sowing and harvesting.

Farm households typically are risk averse, and risk markets are imperfect. Risk implications are thereby likely to be influential in household-decision making. This also would make compliance with the pre-plant burning regulation likely as long as it was

[35] The low cost of labour in combination with the pre-NAFTA (North American Free Trade Agreement) practice of pan-territorial maize pricing gave the area a competitive advantage.

genuinely enforced. However, enforcement appears to have been slack, so that it was an insufficient deterrent for some farm households.

In some ways, CRM practices fit in with current preferences and constraints. CRM would more adequately secure long-term household food security. The farm household's market integration facilitates some of the needed adaptations - *e.g.* the marketing of crop produce secures a recurrent cash source that enables herbicide use. CRM's cost saving potential could enhance the private returns to crop production - *e.g.* through tractor service-savings for land preparation in arable areas. The reduced need for tractor services also reduces dependency on service providers, particularly upon using zero till practices. CRM's water-conserving potential makes crop production less susceptible to the occasional drought.

In other ways, CRM practices do not fit in seamlessly. CRM is especially constrained by the fodder value of the residues and the residue extraction this implies. This is particularly an issue for farm households with a high internal livestock pressure on residues. Displacing livestock production is unlikely to be an acceptable proposition for these households - in view of current preferences. Conceivably, such farm households could substitute off-farm for on-farm residues - provided they are willing to pay for mulch retention. The marked contrast in terms of internal pressure between adoption strata suggests this is typically not the case. Further, residue demand and supply are not evenly distributed over space. Residue surplus tends to correlate with remoteness, thereby increasing transaction costs. The critical question therefore is if the household's marginal benefits (utility) of adopting CRM make the marginal costs (disutility) worth incurring.

Valuation

Not all factor markets are equally developed. Especially the land market is still undeveloped. Renting of land is uncommon (11% reportedly renting in some land and 8% renting out) and arrangements variable - land frequently being lend to family members. Land rents of US$ 118 ha^{-1} for arable land and US$ 88 for non-arable are taken as indicative of the opportunity cost of land. The local day labourer wage rate is assumed to be a fair approximation of the opportunity cost of *labour*. In terms of *capital*, external inputs are valued at their acquisition plus transport costs. Most households do not own a tractor. Tractor use is therefore valued at the going rate for such services (which includes operator, operation and maintenance).[36] Costs of financing are highly variable - but five percent per month is assumed to be a reasonable approximation of its average opportunity cost (*e.g.* see Angehrn, 1994).

The marketed *crop produce* is valued at the local on-farm sale price - the internal consumption at the local on-farm purchase price. The *crop residues* have both production value as fodder and soil conservation value as mulch. The current market transaction price for residues on a ha basis is assumed to provide an adequate valuation of the fodder value. This value can be converted into a fodder value per Mg of residue for arable and non-arable

[36] *E.g.* rates average US$ 35.3 ha^{-1} for ploughing; US$ 19.1 ha^{-1} for disc harrowing.

fields, by taking into account the residue yield and price differences.[37] CRM allows for limited extraction as it does not require all residues to be retained as mulch. Here the residues that need to be retained as mulch are valued at their fodder value foregone.[38]

The valuation of adherence to pre-plant burning needs to factor-in the cost of following regulatory procedures, the fines upon non-compliance and the probability of being apprehended.[39] This is a delicate matter and reliable data are limited. Here the regulation is ambiguously assumed to double the cost of pre-plant burning.

Private returns

The lack of baseline data makes a chronological crop budget comparison highly speculative. The present discussion therefore emphasises contemporary comparisons over adoption strata - which are summarised in Table 8.19.

On average, maize production remunerates internal production factors above the estimated opportunity costs - both in arable and non-arable fields. However, this favourable remuneration hinges on the government support payment (*Procampo*) and the value of by-products (notably the intercrop in the non-arable area and the crop residues, see Table 8.19). For instance, without the support payment remuneration approximates opportunity costs. In fact, yields are low compared to the levels of external input use - *i.e.* input use efficiency is low (Hibon *et al.*, 1992). There indeed appears to be considerable scope to improve private returns through a more effective and efficient use of current inputs in the area (Angehrn, 1994).

The budgets also highlight that the returns vary over adoption strata. In part, these differences are a function of the CRM technology. However, they also reflect the confounding effect of non-CRM variables - in terms of overall crop production practices (see 8.2.1), farm household resources (see 8.2.2) and institutional setting (see 8.2.3). A production function approach does not solve the issue of confounding effects, as two types of multicolinearity are present with respect to input use: (i) between arable and non-arable fields; and (ii) between non-adopters and the other adoption strata.

The non-adopters obtained the least favourable returns, both in arable and non-arable fields. The low returns are a direct reflection of low gross production values - which links back to the characteristically low yields, as non-adopters typically had the lowest recurrent costs. The adopters of the reduced till without residues typically obtain the most favourable returns. In the non-arable area, this reflects substantially lower costs than the adopters of

[37] In arable fields US$ 7.52 per Mg residue, based on US$ 33.8 ha^{-1} and an estimated 4.5 Mg residue ha^{-1}. In non-arable fields US$ 8.43 per Mg residue, based on US$ 31.2 ha^{-1} and 3.7 Mg residue ha^{-1}.

[38] In non-arable fields two Mg of residue are needed prior to land preparation; in arable fields 2.9 to allow for incorporation inherent to the prevalent reduced till practices of adopters.

[39] In formula (adapted from Sain, pers. comm.): $C_{total} = C_{field} + d*C_{procedure} + (1-d)*p*F$; where C_{total}: cost of pre-plant burning after regularisation; C_{field}: cost of actual field based activities to perform pre-plant burning (equivalent to the cost prior to regularisation); $C_{procedure}$: costs incurred upon following stipulated procedure; d: dummy whether procedures are followed (0: no; 1: yes); p: probability of being apprehended upon non-compliance; F: fine imposed upon non-compliance.

mulch component, as the latter obtain higher gross production values. In the arable area, the favourable returns of the adopters of reduced till largely reflects high gross production values. Adopters of no-burn-only had the highest capital input.

Notwithstanding the confounding effect of uncontrolled variables, the returns to adopting CRM once more appear to be rather ambiguous in the current setting. There are a number of underlying reasons. First, CRM imposes a number of changes in residue management, especially in the arable zone. Second, immediate yield gains from the mulch component are limited to the years with intra-season drought. Third, the mulch component implies an opportunity cost of fodder foregone. Finally, there is also the confounding effect of partial adoption. For instance, adopters of the reduced till component typically are partial adopters of the mulch component. Both partial and non-adopters also rely on labour-saving herbicides.

Table 8.19 Comparison of crop budget implications over adoption strata in the Central Chiapas study area

	Adoption stratum						
	Arable zone				Non-arable zone		
	No	No-burn	Red. till	Mulch	No	Red. till	Mulch
A. Gross production value (US$ ha^{-1})	441	612	669	588	410	588	649
a1. Maize grain	393	576	630	542	327	384	400
a2. Maize residue	34	34	34	34	31	31	31
a3. Intercrop [a]	14	2	5	12	52	173	219
B. Recurrent expenses (US$ ha^{-1})	254	311	269	287	181	208	264
b1. External physical inputs	190	203	205	194	150	174	210
b2. External services	53	93	49	48	18	21	22
b3. Residue input	0	0	0	22	0	0	17
b4. Other internal inputs	11	15	15	23	13	14	16
C. Labour (days ha^{-1}) [c]	33.2	31.2	34.9	28.7	48.9	50.4	54.8
D. Capital and financing (US$ ha^{-1})							
d1. Average working capital	225	270	226	218	153	177	213
d2. Financing costs	34	41	34	33	23	27	32
E. *Procampo* (US$ ha^{-1}) [b]	103	103	103	103	103	103	103
F. Value added (US$ ha^{-1})	187	301	400	301	229	379	385
G. Household income (US$ ha^{-1})	215	324	426	336	248	393	389
H. Return to own land (US$ ha^{-1})	76	185	281	212	70	206	182
I. Return to own capital (% $month^{-1}$)	-1.2%	13.3%	29.0%	19.3%	1.0%	27.2%	19.7%
J. Return to own labour (US$ day^{-1})	2.6	7.4	10.9	8.9	3.9	7.7	6.8

[a] Squash in arable, beans in non-arable zone. [b] Government compensation for liberalisation of basic commodity prices. [c] Labour provided by tractor operator included in service charge. *Formula*: A = a1+a2+a3; B = b1+b2+b3+b4; F = A - B; G = [A + E - B - (external labour)*(wage) - d1]; H = [G - (opp. cost own labour) - (opp. cost own capital)]; I = [G - (opp. cost own labour) - (opp. cost land)]/(own capital); J = [G - (opp. cost land) - (opp. cost own capital)]/(internal labour). *Assumptions*: Factor opportunity costs - capital 5% $month^{-1}$; labour US$ 4.41 day^{-1} (wage rate); land US$ 118 ha^{-1} arable zone; US$ 88 ha^{-1} non-arable zone. Factor ownership assumptions - all tractor services contracted; working capital: 50% own + 50% borrowed; land: own; labour: 72% own + 28% hired (derived from survey data).

The limited returns to the mulch component are also supported by the observed (i) disarticulation; and (ii) disadoption. The existence of various adoption strata directly reflects the degree of current *disarticulation* between CRM components. The data also highlight that 10% *disadopted* some component between 1992 and 1994 - including 3% who reverted to pre-plant burning; 5% who reverted to ploughing and 2% who did not conserve sufficient mulch. Further, only half of the 1994 adopters of the mulch component left sufficient residues in the subsequent season.

The analysis could be elaborated by farm household modelling. This would more adequately reflect varying opportunity costs over adoption strata - *e.g.* in terms of the opportunity cost of fodder foregone for residues retained as mulch. However, in view of data limitations and the numerous assumptions that would be needed, such modelling is not pursued here.

In sum, CRM-based production implied a number of changes in crop residue management. Partial adoption seems to have been preferable from the private viewpoint. The data also raise questions about the nature of the farmer's adoption decision. The widespread abandoning of pre-plant burning is a direct reflection of government regulation, rather than a purposive decision to retain residues as mulch. The results also suggest non-adopters kept to burning for not having alternative modes of residue disposal - *i.e.* in terms of extraction or incorporation. Indeed, many of those that abandoned pre-plant burning state that they now eliminate their 'trash' through incorporation or extraction. Further, the use of reduced till seems to be concentrated in non-arable areas. In addition, the adoption of the mulch component seems to be the result of a household having adopted the no-burn and reduced till components, in combination with a low livestock pressure upon residues. Indeed, of all the farmers that adopted both the no-burn and reduced till components, most do *not* leave sufficient residues as mulch. This more or less accidental adoption process differs from the adoption decision of farmers who purposely conserved their crop residues as mulch. The dynamic aspect of adoption and disadoption also reiterates the spontaneous nature of adoption for at least some households.

8.2.6 Social assessment

Similar to the Chiapas Highlands, soil erosion and forest fires stand out as the main crop production induced externalities in the study area. With 'traditional' clean till practices, the soil erosion hazard in agricultural fields is substantial at the onset of the summer season, aggravated by intensive tillage in arable fields and the prevalent slopes in non-arable fields. In addition to the on-site effects of soil erosion, several off-site effects have been reported in the area, including water treatment costs, damage to road infrastructure, and siltation of the Chicoasen hydroelectric dam (Lopez *et al.*, 1994). The traditional practice of pre-plant burning also implies a substantial wildfire hazard.[40] CRM-based practices largely curtail these negative externalities. A social assessment will incorporate these benefits and therefore diverge from the preceding private assessment. However, the available data do not

[40] As mentioned, pre-plant burning has been singled out as the major contributor to forest fires in the state (Sandoval, 1994).

allow for an elaborate social assessment, let alone assess whether the divergence between private and social interests actually warranted policy intervention.

Policy intervention followed a two-tier approach similar to the Chiapas Highlands: (i) raise utility of adoption of CRM-based components (conditional incentives, information); and (ii) raise disutility of adherence to pre-plant burning (regulatory procedures, fines upon non-compliance). With full-fledged adoption of CRM-based production not in the private interest, the approach rightly addresses the private utility issue. This study does not allow for an elaborate assessment of the specific policy instruments applied, but it does cast some doubt on whether the chosen instruments and their mode of application were the most appropriate. The intervention emphasised herbicide use and not burning. However, herbicide use was already widespread and likely to be privately attractive irrespective of the intervention. Slack enforcement ensured eradication of pre-plant burning was incomplete, and in some cases abandonment may only be temporary. Indeed, it seems the logistics of coercion were taken too lightly, with too little local involvement. Ironically enough, eradication of pre-plant burning was least successful in those areas where most of the forest resources are actually located.

Further, intervention emphasised only *some* of the necessary practices for CRM-based production, and not the mulch component as such. However, the potential soil conservation benefits of CRM hinge on the use of residues as mulch and this will need to be clarified in future extension efforts. Livestock pressure upon available residues seems to be a limiting factor for many farmers. Research and extension services could play an important enabling role by helping develop compatible residue-extraction systems.[41] The same services could also play a leading role in making the production systems more efficient by developing and disseminating productivity enhancing technology. In this regard, special attention should be given to enhancing input-use efficiency. Last but not least, such efforts should be done in a much more participative way - *i.e.* link up more effectively with the beneficiaries *during* instead of *after* the development and dissemination process.

8.3 Concluding summary

The present chapter applied the technology assessment framework (Chapter 6) to two contrasting *ex post* case studies in Mexico. The first case in the Chiapas Highlands provides an instance of semi-commercial maize production. Adoption levels of CRM and zero till practices are substantial. Adoption of zero till practices freed family labour for off-farm employment. A locally enforced prohibition of pre-plant burning made CRM adoption more probable. However, actual adoption of CRM is determined by field exposure to communal grazing, whereas the returns to purposive adoption through fencing are not privately attractive.

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[41] For instance, in terms of developing easily applicable indicators that allows farmers to extract residues and simultaneously retain sufficient residues. *E.g.* in arable fields one can graze X heads of cattle for Y months in a field of Z ha in a regular year.

The second case in Central Chiapas provides a mixed instance of both commercial and semi-commercial production, located in both arable and non-arable areas. State regulation boosted the abandoning of pre-plant burning, but in the arable area this mainly generated a substitution of incorporation for burning - and adoption of CRM remains very limited. In the non-arable area farmers were more hesitant to abandon pre-plant burning - possibly the combined result of having less substitution possibilities for residue elimination and slack enforcement. Nonetheless, adoption was easier in the non-arable area, where adoption is also concentrated. The existent crop-livestock interaction implies an opportunity cost of fodder foregone for residues retained as mulch. The returns to CRM adoption appear rather ambiguous, and partial adoption seems to have been preferable from the private viewpoint.

In both cases, externalities were the driving force for substantial government intervention. In fact, without government intervention adoption would have been less widespread, as the returns to CRM adoption were not privately attractive. Nonetheless, both cases do question the effectiveness of the followed intervention approach. Incentives reinforced paternalistic attitudes and may not always have been efficient. Their conditional nature may even have contributed to the disarticulation of the technology. Both cases also relied on regulation, but the use of coercion was not equally successful. This reiterates that regulation will succeed only if it is actually enforced, and is more effective when applied through local institutions.

The *ex post* cases reiterate some of the earlier technology issues, in relation to the complexity of adoption, site-specificity, trade-offs, disarticulation and the influential role of the institutional setting. Chapter 10 will pull together these findings across all cases - both *ex ante* and *ex post*. Suffice to say here that the *ex post* cases do question the nature of the farmer's adoption decision. Farm households seem to have adopted whatever CRM component was attractive, fitted in easily or was successfully forced upon them. Consequently, some households ended up adopting CRM by accident; others simply remained partial adopters. However, few households seem to have adopted CRM purposively.

The framework provides a comprehensive grouping of the various factors affecting the farm-household adoption decision, and data permitting, allows for a private and social assessment. Similar to the *ex ante* cases, the *ex post* application of the framework emphasised the private viewpoint, as this is the more relevant for understanding the actual adoption decision. However, for a private *ex post* assessment data needs appear a major issue - be it in a retrospective or contemporary setting. Paradoxically, there is a trade-off in terms of the clarity of the cause and effect of the adoption decision, because of the reliance on survey data. Pronounced structural differences between farm households help explain the adoption decision - but also confound impact assessment upon comparing adoption strata. This is particularly problematic when baseline and control data are missing - as was the case in both instances.

CHAPTER 9

PARTIAL APPLICATION OF THE TECHNOLOGY ASSESSMENT FRAMEWORK

Chapter 6 developed a technology assessment (TA) framework to evaluate crop residue mulching (CRM); and Chapters 7 and 8 applied the TA framework to individual cases in an *ex ante* and *ex post* fashion respectively. Each case provided insight into CRM and the framework - with as two recurrent findings the site-specificity of the technology and the considerable data needs of the TA framework. The present chapter addresses these two issues by looking into the partial application of the TA framework.

Partial application reduces data needs. The framework provides a comprehensive listing of the factors affecting the farm household adoption decision. In the standard application, information is gathered for all these factors, typically through their inclusion in a formal farm household survey to derive the corresponding data, proxies and estimates. In the partial application, the framework can be used as checklist to flag the salient issues in a particular setting. Partial application naturally comes at a trade-off, as insight gained from each particular setting is (substantially) reduced. For instance, data for a multivariate adoption analysis are typically not available. This is partly compensated by a better understanding of the technology across more varied settings, as partial application typically allows for a wider application.

Both of the standard *ex post* cases discussed in Chapter 8 came from Chiapas State (Mexico) and were characterised by substantial government involvement. Within Mexico, Chiapas State was one of the pioneers in terms of development and dissemination of CRM practices. However, adoption of CRM is not limited to this State. Other areas within Mexico have been subjected to different degrees of CRM research and promotion. Indeed, various Mexican federal government agencies (*e.g.* agricultural research - INIFAP; ministry of agriculture - SAGAR [before SARH]; agricultural trusts - FIRA and FIRCO) and individual state governments are - or have been - involved in different degrees.[1] This has resulted in various other CRM adoption spots, although blanket adoption of CRM practices remains rare. Something similar applies for Central America (*e.g.* Bolaños *et al.*, 1993; Bolaños, 1997).

This chapter will partially apply the framework to two other cases in Meso America with reported adoption of CRM practices. Compared to the *ex post* cases in Chapter 8, these cases depict particularly contrasting situations in terms of biophysical and socio-economic conditions. The first case - the Bajio in Central Mexico (Figure 7.1:155) - analyses the adoption of CRM in a high potential, commercial production system. Agriculture is irrigated and mechanised, centrally located in high altitude valley plains. The second case - Guaymango in El Salvador (Figure 7.1:155) - analyses the adoption in a semi-commercial hillside production system in the tropical lowlands.

[1] *E.g.* AMLC, 1989; Figueroa and Morales, 1992; Mendoza *et al.*, 1993; FIRA, 1996a, 1996b; Claveran and Velazquez, 1997.

9.1 The adoption of CRM-based cereal production in The Bajio-Guanajuato, Mexico[2]

The present section briefly assesses the adoption of CRM-based irrigated cereal production in the Bajio. This study area is located in Central Mexico (Figure 7.1:155) and comprises irrigated fertile highland plains (1,750 m). The main source of irrigation is surface water, sometimes supplemented with groundwater (from private and communal schemes). Agriculture is commercial with both large and small scale farms. The area contrasts markedly with the other Mexican case studies in terms of (i) factor productivity; and (ii) capital input. Access to irrigation has a pronounced positive effect on factor productivity (in comparison with rainfed systems). Irrigation allows for two cropping seasons a year, that contrasts with the typically single cropping season in rainfed areas. This enables a more even utilisation of the households' production factors over the year. Crop productivity is also typically higher and less variable with secured access to water. The production systems are capital-intensive. Field operations are typically mechanised (notably land preparation; sowing; first fertiliser application and harvesting) and the use of other external inputs widespread (notably chemical fertilisers; improved varieties; insecticides; herbicides).

The study area encompasses the irrigation districts surrounding a conservation tillage training centre (FIRA Villadiego), which actively promotes CRM practices since the end of the 1980s (Agro-sintesis, 1992; FIRA, 1996a). The area was selected purposively with the expectation to find substantial adoption levels. The data presented in this case study were primarily collected through a short, formal single-visit survey of 189 farmers at the onset of the 1995 summer cropping season. The study used a random sample, stratified by irrigation units with an average sampling fraction of 6.5%. Compared to the standard cases, data gathering was less intensive - in part dictated by the additional complexity of irrigation and preferences of the collaborating agency. Overall, data collection required an estimated two manmonths. The following subsections follow the framework, but only flag the salient issues for the adoption of CRM-based irrigated cereal production.

9.1.1 Crop system implications

Access to irrigation implies two cropping seasons in the area. Maize and sorghum are the prevalent crops in the wet summer season (predominantly rainfed with supplementary irrigation), wheat and barley in the dry winter (irrigated). CRM-based crop production requires a compatible residue balance so as to retain sufficient residues to surpass the 30%-cover threshold. The amount of cover provided by residues is a function of its geometric composition and is therefore crop dependent. The summer cereals (maize and sorghum) have coarse residues and >2 Mg residues ha^{-1} are needed to surpass the threshold. The winter cereals have fine straw and only >0.5 Mg residues ha^{-1} are needed.

In the case of irrigated cereal cropping, residue production is abundant with two cropping cycles a year, each with high residue production levels. Two cycles also imply the time between cycles is limited and weathering losses correspondingly curtailed. Consequently,

[2] The Bajio data are mainly derived from Erenstein and Valiente (1997). Credit is due for the co-author of the original study and the collaboration received from FIRA (Federal Trust Fund for Agriculture, Mexico) - especially their Villadiego centre.

both residue production and weathering levels have traditionally been potentially compatible with CRM-based cereal production.

Traditionally some residues were extracted - but with two cycles a year the time between cycles is limited, as are the potential modes of residue extraction. Whereas stubble grazing generally is the rule in rainfed areas, it is impracticable in irrigated areas. Therefore, in case of residue extraction, farmers typically opt for baling residues. Residue extraction is common after the summer cycle, but *average* residue extraction levels[3] are potentially compatible with CRM in either season.

Traditionally, the surplus residues were eliminated through pre-plant burning and intensive mechanical soil tillage. The quantities of residues traditionally left as mulch were therefore minimal - *i.e.* the crop was established in a clean field. The necessary changes for CRM in the local context therefore primarily related to abandoning pre-plant burning and reducing tillage intensity.

At the time of the survey, about half of the households still used pre-plant burning for both seasons. Slightly over a quarter did not burn in either season, whereas the remainder burned in one season only. Tillage remained typically intensive in both seasons, although reduced till practices were on the rise in the area. Nearly half of the households had adopted a reduced till system in either season, mainly over the decade preceding the study. In the end, however, only a tenth of the households had actually adopted the mulch component in either season (Table 9.1). This reiterates that abandoning pre-plant burning or reducing tillage intensity are necessary but insufficient conditions for CRM.

The study also suggests an interaction between the different CRM components. Adopters of the reduced till component without mulch seem to have substituted pre-plant burning for incorporation as preferred mode of residue elimination (Table 9.2). Non-adopters of the reduced till component use intensive tillage systems: typically a disc-ploughing and 2-3 disc-harrowings. This ensures most residues are incorporated, and "only" three-fifths of these farmers rely on pre-plant burning as (additional) mode of residue elimination. For adopters of the reduced till component, residue incorporation is by definition reduced (and marginal for those that adopted zero tillage). Adopters of the reduced till component without mulch therefore typically rely on pre-plant burning to still eliminate these residues. However, such substitution undermines the resource conserving potential of the reduced till component.

The existence of two distinct cropping seasons gives rise to differential adoption over seasons. Adoption of the mulch component was less likely in the winter cycle (4% *versus* 9% in the summer season, Table 9.1), although it was more common not to burn in this cycle (46% *versus* 37% in the summer). This suggests an interaction with other factors, including more intensive tillage and extraction prior to the winter season and the lower residue cover index of the coarse summer residues. For the winter season, these factors conceivably make it: (a) less necessary for farmers to opt for pre-plant burning (if they want to eliminate the residues); and (b) less feasible for farmers to meet the 30% cover threshold upon not burning (if they want to retain the residues as mulch). The reverse is true for the summer season.

[3] An estimated 40% and 23% of residue production in the summer and winter cycle respectively.

Table 9.1 Overview of past, current and CRM-based residue management practices in the Bajio study area

	Crop residue management					
	------------ Summer cycle --------------			----------- Winter cycle -----------		
Practice	Past	Current [a]	CRM-based	Past	Current [a]	CRM-based
Pre-plant burning	Yes	Yes (63%)	No	Yes	Yes (54%)	No
Tillage	Intensive	Intensive (62%)	Reduced	Intensive	Intensive (78%)	Reduced
Residue extraction[b]	No	No (66%)	Restricted	Yes	Yes (61%)	Restricted
Mulch	No	No (91%)	Yes	No	No (96%)	Yes

[a] Percentage refers to survey population actually implementing prevalent practice (Erenstein & Valiente, 1997). [b] Prior to cycle

Table 9.2 Tillage and pre-plant burning practices in the Bajio study area

	Tillage practice		
	Intensive	Reduced without mulch	Reduced with mulch (CRM)
Percent of sample fields that were burned			
- pre-summer season	58	91	0
- pre-winter season	51	75	0

Source: Erenstein & Valiente (1997).

Reducing tillage and retaining residues as mulch can imply changes for complementary cultural practices. Traditionally the *sowing* operation of cereals is typically mechanised using a conventional seed drill. With zero till and/or substantial mulch levels, this implement needs to be substituted by a direct seed drill. *Nutrient management* emphasises chemical fertilisers, with an average $N:P_2O_5:K_2O$ dose of 227:46:0 kg ha^{-1} in the 1994 summer season. Current N-application rates reduce the possibility of a N-immobilisation related yield loss with CRM; and fertiliser applications are commonly split. A comparison over adoption strata shows that adopters of zero till use less N fertiliser (194 *versus* 236 kg N ha^{-1}, prob.:.01) but more P fertiliser (66 *versus* 41 kg N ha^{-1}, prob.:.00) - which is largely explained by their limited use of ammonium fertiliser at sowing time. Comparisons over adoption strata of weed,[4] pest and disease management show these were relatively unaffected. With CRM-based cereal production resprouting of the previous crop is more problematic.

Actual cereal yields (farmer reported; two-year average - 1993 and 1994) average 5.7 Mg of maize or 7.3 Mg of sorghum ha^{-1}. Yields in the winter season averaged 5.4 Mg of

[4] Weed management includes an array of measures, encompassing physical and chemical control, and manual and mechanised modes.

wheat or 5.7 Mg of barley ha^{-1}. CRM could enhance crop yields as the reduced tillage component enhances timeliness and the mulch component enhances water use efficiency and soil fertility. However, a comparison over adoption strata showed no clear-cut yield effect. Given similar yield levels, this implies an increased N-use efficiency for adopters of zero till.

Most farmers acknowledge the technology's potential in terms of the enhanced timeliness of crop establishment, soil fertility enhancement and water conservation. However, farmers also highlight a couple of problems - most commonly that the mulch disturbs during sowing, the need to use a direct drill, and pest problems. Non-adopters typically felt stronger about these problems than adopters of the zero till and mulch components.

9.1.2 Resource implications for the farm household

The typical activities of the local farm household system include crop production, livestock production, other productive activities, reproduction and leisure. Crop production is characterised by access to irrigation and the prevalence of cereals in both summer (maize and sorghum) and winter (wheat and barley) seasons (Table 9.3). Other land uses - including vegetables, fodder crops and winter fallow - occupied less than 20% of the average farm per season. Most households (63% of sample households) have at least one head of livestock - most commonly cattle for meat and/or milk production. Half of the households reported supplementing their farm income through off-farm work; migration of family members to the USA; and/or various side businesses. This also relates to the size of the land holding: although average cultivated area was 16 ha, four-fifths of farm households cultivated not more than 10 ha.

Table 9.3 Irrigated land use in the Bajio study area (average area per farm household).

	Area (ha)			Area (ha)
Crop	Summer '94	Summer '95	Crop	Winter 94/95
Maize	7.6	3.4	Wheat	5.4
Sorghum	7.1	11.5	Barley	7.9
Vegetables	0.7	0.8	Vegetables	1.4
Alfalfa	0.7	0.8	Alfalfa	0.8
			Fallow	0.9
Sum	16.2	16.4	Sum	16.4

Source: Erenstein & Valiente (1997). Summation discrepancies due to rounding.

Two-thirds of the farm households were (co-)owner of a tractor, typically with a disc-plough; disc-harrow and a normal seed drill. A quarter of tractor owners reportedly already made the investment in a direct seed drill - this being especially common amongst adopters of the mulch component. Most of the typical implements could become obsolete upon complete reliance on zero till systems. This is less of an issue upon using reduced till systems (*e.g.* in case of only abandoning ploughing). Likewise, if the farmer relies on differential tillage systems over cycles and crops.

Although livestock ownership is common, internal crop-livestock interaction is typically not a major issue for CRM in the area. Various factors contribute to this, including a limited internal livestock pressure on residues (1.1 animal units per ha of seasonal cereals); two annual crop cycles; high residue production per cycle; and the availability of alternative fodder sources of better quality (notably alfalfa).

9.1.3 Institutional setting

Crop production is primarily for the market and factor and produce markets are relatively developed. In some ways though, the situation is not propitious for the development of a *residue market*. The area combines a limited local residue demand (low livestock pressure) with abundant residue production. Time between cycles is also a constraining factor. Two-fifths of the households reported grazing of stubble was free - though delimited by the establishment of the subsequent crop. At the same time, this implies that in three-fifths of the cases access was not free. This was reportedly more common amongst the adopters of the mulch - consistent with expectations. More surprisingly though, this seemed to be related to the residue market, as the adopters of the mulch component were more likely to market their residues. The explanation seems to be two-fold. First, the levels of extraction upon commercialisation are largely compatible with CRM (in view of the high production levels). Second, such mode of extraction may provide a CRM compatible way of eliminating *excess* residues. Conversely, non-adopters of the mulch-component tend to burn and/or incorporate residues to make up for the limited elimination through extraction.

Overall, a little over one-third of the households reported participating in the residue market post-summer season (25% of sample households selling; 11% buying). This was less common in the post-winter season (19% selling; 4% buying). Although most residue transactions occurred within the region, a little over one-third of the post-winter season trading was interregional - reflecting the export of surplus residues to residue deficit areas.

There is a reasonably established rental market for direct seed drill services in the area: about half of the reported direct drill users had contracted this service. This compares with the typically private machinery ownership of normal seed drill users. The rental possibility makes the technology less lumpy and facilitates adoption. The conservation tillage training centre in the area is one of the providers of such rental services. The centre also plays an enabling role in the acquisition of direct seed drills (especially in terms of providing information and facilitating funding).

The training centre also serves as catalytic agent by providing information. About half of the survey farmers knew about the existence of the centre and a quarter of the farmers had participated in at least one of their training events. Both knowledge and participation rates were significantly higher amongst adopters of the mulch component, suggesting the centre plays a propitious role for its adoption.

Last, the study area is organised in irrigation districts. These districts also play an influential role in adoption. First, this implies farmers are organised. Second, the (privatised) districts are themselves actively involved in extension. Third, the districts as such have an interest in enhancing water use efficiency, and thereby in technologies that conserve water.

9.1.4 Private and social assessment

The data do not allow for an elaborate private or social assessment, but do allow some general inferences to be drawn. The farm households are integrated in markets, and private returns to CRM-based cereal production are thereby likely to be influential for the adoption decision. With crop yields unaffected in the short term, private returns to CRM-based cereal production depend on eventual cost savings. Particularly influential are the eventual cost savings for land preparation and crop establishment. Most farmers acknowledge this cost saving potential, although the exact nature and extent of these savings are likely to be household-specific (depending amongst others on, tractor ownership; tractor implements owned; cost of acquiring direct seed drill; costs of operation and maintenance; farm household crop production activities, farm size and economies of scale; and cost and dependability of renting in direct drill services).

The opportunity cost of mulch in terms of fodder foregone appears to be negligible. Indeed, in view of residue production levels, residue extraction is largely compatible with CRM-based cereal production. In fact, residue excess seems to be more of an issue than residue scarcity. Upon adoption of reduced till practices a number of farmers therefore resort to pre-plant burning to substitute for incorporation. This again raises the possible questioning of the nature of adoption of the reduced till component. It seems more emphasis should be placed on mulch management as such - especially CRM compatible modes of residue-elimination merit attention.

The study area comprises irrigated plain fields, so that soil erosion as such is limited. Nonetheless, CRM still generates several externalities - including those relating to irrigation water use efficiency; nutrient and chemical runoff; and overall soil degradation. A divergence between private and social assessment is thereby still likely to exist. However, whether this merits government intervention remains an open question.

9.2 The adoption of CRM-based cereal production in Guaymango, El Salvador

The present section briefly assesses the adoption of CRM-based cereal production in the Metalio-Guaymango area. This area is located in western El Salvador (Figure 7.1:155) and comprises sub-humid lowland hills (<250 m, 1,900 mm unimodal precipitation). Agriculture is semi-commercial with predominantly small-scale farms. The area is included here as it is frequently mentioned as the regional showcase in terms of CRM-based cereal production. The present section draws on existing literature (particularly Calderon *et al.*, 1991; Mendoza *et al.*, 1991; Choto and Sain, 1993; Sain and Barreto, 1996) and a short visit to the area by the author. The following subsections follow the framework but only flag the salient issues for the adoption of CRM-based cereal production in the area.

9.2.1 Crop system implications

The typical cropping pattern comprises a maize - sorghum relay system. Maize is sown in May and harvested in November. Sorghum is relayed into the maize in June and harvested in December (Choto and Sain, 1993). CRM-based cereal production requires a compatible residue balance so as to retain sufficient residues to surpass the 30%-cover threshold at the time of crop emergence (*i.e.* a mulch of >2 Mg crop residue ha^{-1}). Maize-sorghum relay-cropping, implies two annual cereal crops, with a correspondingly high residue production: an estimated 9.7 Mg residues ha^{-1} yr^{-1} (Sain and Barreto, 1996). Weathering levels have traditionally been potentially CRM compatible, and the same applies to tillage practices. Farmers use zero till practices, in part conditioned by the location of the fields on hillsides with steep slopes (40-90%), thereby eliminating the possibility of mechanical tillage.

Traditionally, the stubble was grazed communally and the remaining residues were burned prior to planting the subsequent maize crop. Consequently, the quantities of residues left as mulch were minimal. The necessary changes for CRM in the local context therefore originally related to abandoning pre-plant burning, and (possibly) limiting residue extraction. Farmers have typically abandoned pre-plant burning in the 1970's, but communal grazing remained widespread. Cattle typically graze the stubble during the dry season (January-April). However, extraction levels appear compatible with CRM. For instance, Choto and Sain (1993) estimate that about 4 Mg residue ha^{-1} remain at planting time. Adoption of CRM-based cereal production is reportedly widespread in the area since the early 1980's (*ibid.*; Sain and Barreto, 1996).

The traditional manual sowing operation was compatible with CRM, but other cultural practices such as weed and nutrient management needed adapting. These complementary practices for CRM were included in an overall technological package that included herbicide, fertiliser, high yielding varieties and increased density. The overall package thereby substantially increased capital use, but also provided a substantial yield boost: average yields tripled over the decade following 1974 (*e.g.* maize from 1.0 to 3.2 Mg ha^{-1}; sorghum from 0.7 to 2.0 Mg ha^{-1} - Sain and Barreto, 1996). Farmers generally adopted the package as a whole and the data do not allow for a complete breakdown of the individual contributions. However, the short term yield boost can largely be attributed to the productivity enhancing components of the package, and not to the CRM component as such. Compared to the traditional slash and burn land preparation, the short term contribution of CRM primarily revolved around the substitution of capital for labour. The yield boost also implied a substantial increase in residue production, thereby easing an eventual conflict between residue extraction and residue retention as mulch (see Annex C for a model).

Table 9.4 Overview of past, current and CRM-based residue management practices in the Guaymango study area

	Crop residue management		
Practice	Past	Current	CRM-based
Pre-plant burning	Yes	No	No
Tillage	No	No	No
Residue extraction	Yes (communal grazing)	Yes (restricted communal grazing)	Restricted
Mulch	No	Yes	Yes

9.2.2 Resource implications for the farm household

CRM-based cereal production was largely compatible with the local farm household system. CRM did not conflict with other established farm household activities. Livestock production is a common household activity, but internal livestock pressure on crop residues tends to be compatible with CRM in view of substantial residue production. CRM also did not require major investments. The overall technological package did increase external input use, and thereby competed with other household activities for cash and other liquid assets.

9.2.3 Institutional setting

The institutional environment played a rather influential role in the adoption of CRM-based cereal production in the area. Two particular issues merit highlighting: (i) residue rights and markets; and (ii) institutional packaging.

There is a nascent residue market in the area, but communal grazing still prevails. Most fields are unfenced, and the farm household thereby has limited possibilities to regulate extraction levels. Instead, the local communal grazing rights stipulate that about 50% of crop residues must remain at the end of the grazing period. This threshold compares with 20-30% in two other areas in El Salvador. Compared to these areas, the Guaymango area indeed has substantially lower stover depletion rates (*i.e.* extraction plus weathering) over the dry season (Choto and Sain, 1993; Sain and Barreto, 1996). The local institution thereby helps ensure sufficient residues are retained as mulch and eliminated the need to actually enclose the fields.

CRM was successfully packaged in an integrated productivity/conservation recommendation. A critical issue appeared the use of conditional credit as incentive. Credit was only provided to farmer groups who as a group had adopted the technical package, including CRM practices. The coveted component generated effective peer monitoring (Stiglitz, 1993) that ensured compliance. Such institutional interlinking prevented the disarticulation of the productivity and conservation components, and thereby successfully enforced the adoption of CRM practices. It thereby induced decentralised, self-interested compliance that slashed enforcement costs. However, the provision of credit as incentive results in other, less visible costs that are nevertheless born by the government budget. Conservation contests and a multimedia extension drive provided further back up to the promotion of the technology package. About half the farmers now cite soil conservation as the reason for not burning the residues (Sain and Barreto, 1996).

9.2.4 Private and social assessment

Sain and Barreto (1996) provide partial budgets that compare farmers' practice with the technological package. The package as a whole provides immediate private returns, with an attractive benefit-cost ratio of 2.5. However, the package thereby masks the negative returns of implementing the CRM component. Indeed, without the CRM component, the returns to the package are even more attractive with a benefit-cost ratio of 2.8. It is therefore likely that, given the choice, farm households would have opted for the productivity enhancing components only. However, such disarticulation was prevented by institutional interlinking.

The traditional cereal production practices implied a substantial soil erosion hazard at the onset of the cropping season. CRM addresses this externality, but was not in the private interest - so intervention may have been warranted. The data do not allow for an elaborate social assessment, but do suggest intervention was effective and opportune. Guaymango indeed highlights a case of successful packaging of an integrated productivity/conservation recommendation. The success in terms of CRM adoption is such that Guaymango is now a national and even regional showcase (*e.g.* CENTA *et al.*, 1995). Indeed, so far it has been difficult to achieve similar adoption levels elsewhere. This suggests that the combination of circumstances that provided an enabling environment for CRM were particularly opportune. Further, it suggests that the use of peer monitoring merits more attention.

9.3 Concluding summary

The present chapter applied the technology assessment (TA) framework (Chapter 6) partially to two additional case studies in Meso America. The first case in the Mexican Bajio, provides an instance of commercial cereal production in an irrigated, highly productive setting. Residue-excess seems more of an issue than residue-scarcity. CRM-based cereal production typically required access to a direct seed drill and exposure to information, whereas the adoption decision seems to hinge on eventual cost savings for land preparation and crop establishment.

The second case in Guaymango provides an instance of widespread use of CRM practices in semi-commercial cereal production in lowland tropical hillsides. Adoption was aided by substantial residue production, compatibility with the farm household system and the successful packaging with other productivity enhancing components.

Partial application of the TA framework allows for a rapid appraisal of the technology while spending only limited resources. Compared to the standard application of the TA framework, partial application thereby enables a wider coverage of biophysical and socio-economic conditions with the same resources. Partial application also provides a more rapid feedback for on-going and/or future research, extension and policy efforts. It can thereby be used in a stepwise analysis to specify existing information gaps and focus information gathering efforts.

Partial application presents a fundamental trade-off between insight gained and resources spent. By definition, partial application implies a less substantial data collection effort - *e.g.* by relying on available secondary data as in the Guaymango case. Each individual partial assessment thereby provides only an incomplete picture. In some instances, this is sufficient to draw the necessary conclusions. Particularly in the case of assessing CRM, incomplete information can be problematic. For instance, although several CRM adoption spots have been reported in Meso America, it remains notoriously difficult to interpret the nature and extent of CRM adoption from secondary data. First, as socio-economic aspects are typically underreported. Second, because of terminology and measurability problems. The "conservation tillage"-nomenclature is marred by confusion (Chapter 5) - but reported results frequently fail to specify the used definition of conservation tillage, let alone the levels of residues retained as mulch. As long as the actual residue levels remain unclear, one can not judge whether the mulch component was actually satisfied - *i.e.* whether the system can be categorised as CRM. Part of this reflects the problematic nature of assessing residue levels empirically.

In one instance, Pereira *et al.* (1997) describe the adoption of zero and reduced tillage in the Azuero region of Panama. Adoption of such practices was linked to the potential reduction in production costs; non-adoption to the limited availability of direct seed drills. The authors equate these reduced till practices with conservation tillage. However, there is no mention whatsoever of the residue levels actually remaining as mulch in farmer's fields. What is more, they do highlight that stubble grazing is widespread; tenant's residues accrue to the landlord; and that there is a nascent residue market. These indicators suggest residue extraction can be substantial. Indeed, reduced till is frequently a necessary but not sufficient condition for CRM. Therefore, in the end even partial application of the technology assessment framework may still demand some first-hand data collection.

In conclusion, the TA framework should be retained as analytical tool. Depending on research objectives and resource availability, preference could be given to either partial or full application.

CHAPTER 10

LESSONS LEARNED

This final chapter presents and discusses the main conclusions from parts I and II of this study. It does so in three sections. The first section revisits the original objectives and provides the main conclusions with respect to methodology. The second section presents the main technological conclusions, particularly in relation to crop residue mulching (CRM). The third section derives the main policy conclusions for soil conservation intervention.

10.1 Methodology

Economics of soil conservation in developing countries

A first objective of this study is to assess the economics of soil conservation in developing countries. Conceptualising the implications of soil conservation is straightforward, but quantifying and valuing them poses considerable analytical challenges. In fact, the economic impact of soil erosion - the underlying problem - is highly controversial (Chapter 2). Soil erosion is complex with no straightforward cause-effect relationships. It has both biophysical and socio-economic aspects, both only partly understood and hardly measurable. The temporal and spatial dimensions of soil erosion imply the existence of externalities with respect to the farm household. They also make an assessment scale dependent and give rise to often arbitrary decisions regarding (temporal and spatial) boundaries and valuation. The locational aspect - the extreme site-specificity of its dimensions and valuation - further confounds soil erosion. The assessment of soil erosion thereby inherently depends on the time and place of analysis (*e.g.* in terms of the time profile of soil erosion, prevailing prices, and downstream activities).

Soil conservation itself presents additional challenges for economic analysis (Chapter 3). Soil conservation averts the damage inflicted by soil erosion, requiring investment now at a readily determined - but technology dependent - cost, whereas benefits - in terms of soil erosion averted - remain largely uncertain, far in the future and difficult to measure. Soil conservation itself also adds another layer to the site-specificity of the analysis, both in biophysical and socio-economic terms. Further, different interpretations of conservation exist - absolute, standards-based, efficient and optimal - implying different degrees of erosion control. Absolute and optimal conservation remain largely hypothetical in view of the costs and complexities involved respectively. In practice, the implementation of soil conservation tends to be standards-based in view of the prevailing uncertainty, whereas economic analysis tends to assess the efficiency implications.

The different analytical approaches to soil conservation can be broadly grouped under two main schools of economic analysis: (i) the evaluation school and (ii) the adoption school (Chapter 3). The *evaluation school* basically tries to quantify the economic impact of different soil conservation scenarios. However, such attempts are curtailed by stringent data limitations. The *adoption school* tries to explain and predict the divergences in soil conservation behaviour between economic agents. However, the extreme socio-economic site-specificity of soil conservation both justifies and complicates this line of research.

In sum, the economic analysis of soil conservation in developing countries is typically imperfect and controversial. Notwithstanding, such analysis still provides valuable feedback to focus further research, technology development and policy efforts. In this regard, economic analysis can help identify and assess promising technological options - as is done in this study for the crop residue mulching (CRM) technology.

The technology assessment (TA) framework

A second objective of this study is the development of an analytical framework to assess the socio-economics of the CRM technology in developing nations. The proposed conceptual framework (Chapter 6) contributes to the adoption school of the economic analysis of soil conservation. It provides a comprehensive grouping of the various factors affecting the adoption decision by the farm household and its effects. It thereby stipulates a stepwise expanding analysis along a three-tier hierarchy: crop production, the farm household and the institutional setting. The proposed framework tentatively assesses the overall implications from a private and social viewpoint. Tentative, because current data limitations preclude more comprehensive modelling approaches. Based on the social assessment, a number of policy implications are explored.

Assessing the TA framework

A third objective of this study is the assessment of the proposed TA framework in the *ex ante*, the *ex post* and the partial analysis of CRM in Meso America. An individual case study only provides for an imperfect validation of the framework, in view of 'noise', the absence of a control group and the absence of baseline and inter-temporal data. The validation process is, however, enhanced by applying the framework in different ways - *ex ante*, *ex post* and partially - to a number of distinctly different settings (Table 10.1). Indeed, although the cases are delimited to Meso America, they provide a wide range of biophysical and socio-economic settings. The cases rely primarily on survey data, complemented with experimental and secondary data (particularly for *ex ante* assessment, Table 10.1).

Application of the TA framework to these cases highlights different issues at different hierarchical levels (Table 10.2). At the crop production level, different (residue and crop) management and input-output issues are brought to light. Similarly, different farm household level and institutional issues are influential over cases.

The distinct issues generate different outcomes over cases (Table 10.3). From a private viewpoint, economic indicators vary in terms of value added, household income and return to production factors. Expected adoption levels also vary over cases, though these correlate well with the observed adoption levels. Finally, the framework tentatively highlights different social and policy issues.

In sum, the TA framework is used in different ways, in different settings and generates different outcomes. The set of these empirical applications thereby stresses the usefulness of the TA framework and its potential as analytical tool.

Table 10.1 Case study areas: characterisation, data sources and type of TA framework application

	Southern Jalisco, Mx		Southern	Chiapas	Central Chiapas, Mx		Bajio Guana-	Guaymango,
	high rainfall	low rainfall	Veracruz, Mx	highlands, Mx	arable	non-arable	juato, Mx	El Salvador
Biophysical variables								
- altitude (m)	1,000-1,500	ditto	300-900	2,000	600-1,000	600-1,500	1,750	<250
- annual rainfall (mm)	600-1,000	400-600	1,300-3,000	1,500-3,000	1,200	ditto	650-800	1,900
- topography	flat to rolling	ditto	hillside	steep mountain slopes	valley plain	hillsides; stony plains	valley plain	hillsides
- irrigation	no	no	no	no	no	no	yes	no
- crop seasons	summer	summer	summer & winter relay	summer	summer	summer	summer & winter	summer & winter relay
Socio-economic variables								
- production orientation	commercial	semi-commercial	subsistence	semi-commercial	(semi-) commercial	semi-commercial	commercial	semi-commercial
- farm activities	crop, livestock (meat, dairy, dual), off farm, non-agricultural	crop, livestock (meat), off farm, non-agricultural	crop (maize, coffee), forest extraction, off farm	crop, off farm	crop, livestock (meat, dual), off farm, non-agricultural	ditto	crop, livestock (meat, dairy), off farm, non-agricultural	crop, livestock
- main crop	maize	maize & squash intercrop	maize & maize relay	maize & beans intercrop	maize	maize & beans	maize, sorghum, wheat, barley	maize & sorghum relay
- external input use	tractor services, fertiliser, herbicide, pesticide, seed	ditto but less intensive	herbicide, limited use fertiliser and pesticide	herbicide, fertiliser	tractor services, fertiliser, herbicide, pesticide, seed	herbicide, fertiliser, pesticide, seed	herbicide, fertiliser, pesticide, seed, O&M tractor[a]	herbicide, fertiliser, seed
Main data source	survey, experiments	ditto	survey, literature	survey	survey, experiments	ditto	survey	literature
Mode of application TA framework	*ex ante*	*ex ante*	*ex ante*	*ex post*	*ex post*	*ex post*	partial	partial

Ditto: same as previous column. [a] O&M: operation and maintenance own tractor.

Table 10.2 Overview of major issues from technology assessment framework over case study areas

	Southern Jalisco, Mx		Southern	Chiapas	Central Chiapas, Mx		Bajio Guana-	Guaymango,
	high rainfall	low rainfall	Veracruz, Mx	highlands, Mx	arable	non-arable	juato, Mx	El Salvador
Necessary residue management issues	burning, tillage; extraction [a]	burning, extraction [a]	burning	burning [c], extraction	burning [c], tillage, extraction	burning[c], extraction	burning, tillage, extraction	burning[c], extraction
Complementary crop management issues	sowing (direct seed drill)[b]	sowing (direct seed drill)[b], weed control, intercropping	fertilisation, weed control	weed control	minor	minor	sowing (direct seed drill)	fertilisation[c], weed control[c]
Crop system input issues	substitution among capital input, crop residues [a]	increase in labour and capital inputs, crop residues [a]	external input & labour increase	herbicide-labour substitution; protection crop residues (fencing)	labour/capital ambiguous, more seed & fertiliser (N), crop residues	ditto	substitution among capital input, excess crop residues	increase in labour and capital inputs[c]
Crop system output issues	reduced yield variability	yield boost, reduced yield variability, intercrop foregone	minor season yield boost & reduced yield variability	minor short term effect, positive cumulative effect	reduced yield variability, minor short term effect, positive cumulative effect,	ditto	reduced yield variability	as a package, yield boost; alone minor short term effect
Farm household issues	crop-livestock interaction (for mixed farms) [a], working capital, investment capital (for tractor owners)	ditto	working capital (for farms without coffee), land saving[d], enhanced food security	crop-livestock interaction (for mixed farms), land saving[d], working capital, investment capital (fencing), enhanced food security	crop-livestock interaction (for mixed farms)	ditto	investment capital (for tractor owners)	crop-livestock interaction (for mixed farms)
Institutional issues	residue market, residue rights (for tenants), direct drill rental services [b]	ditto	rudimentary factor and produce markets, transaction costs	communal grazing, local no-burn bylaw, tree felling prohibited (fencing)	burning prohibited by state law, residue rights and markets	ditto	residue market, direct drill rental services, training centre	communal grazing, peer pressure to ensure no burning

[a] For reduced till option. [b] For no till option. [c] Only an issue at time of CRM introduction, not currently. [d] Reduces need to fallow and thereby land input crop production.

Table 10.3 Private and social assessment issues from technology assessment framework over case study areas

	Southern Jalisco, Mx		Southern	Chiapas	Central Chiapas, Mx		Bajio Guana-	Guaymango,
	high rainfall	low rainfall	Veracruz, Mx	highlands, Mx	arable	non-arable	juato, Mx	El Salvador
Value added [a]	+0 [b] - 29% [c]	+34-36%	-13-35%	positive (+2- 20%)[d]	ambiguous, but partial adoption positive [e]	ditto	potential increase	as a package positive, alone negative
Household income [a]	+3 [b] - 26% [c]	+16-17%	-16-35%	variable (-8 to +13%) [d]	"	ditto	"	"
Private return to production factors	minor [b] to substantial [c] increase	minor increase	substantial decrease	variable [d]	"	ditto	"	"
Expected CRM adoption	no till option potentially substantial but subject to availability direct drill	negligible	none	occasionally, but not purposively	partial adoption likely, full adoption unlikely	partial adoption likely, full adoption occasionally	hinges on cost savings	hinged on packaging
Actual CRM adoption	negligible	negligible	none	substantial (38%)	very limited (5%)	quite substantial (19%)	limited (<10% each season)	reportedly widespread
Social issues	soil erosion, production risk, competitiveness	ditto	soil erosion, biodiversity, equity	soil erosion, forest fires	ditto as Chiapas highlands	ditto	soil degradation, irrigation water use, pollution	soil erosion
Policy issues	whether to create an enabling environment for CRM	ditto	raise utility of CRM and/or farming, develop comprehensive package and/or conservation alternatives	promote CRM-based practices by raising utility of CRM-components, raising disutility of adhering to burning	ditto as Chiapas highlands	ditto	whether and how to intervene	successful packaging of conservation with productivity components

[a] Based on actual, ha basis. Financial prices. [b] For reduced till option. [c] For no till option - subject to availability of direct seed drill. [d] Indicators tend to be negative for CRM only, positive for CRM in combination with herbicides. Percentages of indicative value only - based on imperfect adoption strata comparison with confounding effect of uncontrolled variables. Assumes need for fencing - *i.e.* purposive adoption. Without fencing CRM privately more attractive. [e] Substantial increases compared to non-adopters - but these are imperfect control group in view of confounding variables.

Strengths of the TA framework

The TA framework provides an analytical structure for raising and understanding the pertinent socio-economic issues. It can also be variously used. In terms of setting, it can be used both *ex ante* (Chapter 7) and *ex post* (Chapter 8) - its application being prospective in the former and retrospective in the latter. In terms of mode, application can be chronological, contemporary and mixed. The TA framework can also be used partially (Chapter 9), allowing for a rapid appraisal of the technology while spending only limited resources.

The TA framework is comprehensive and can be used in a stepwise analysis to specify existing information gaps and focus on information gathering efforts (*e.g.* for more formal household modelling). Indeed, none of the framework variables can be discarded *a priori*, and their relevancy needs to be assessed in each setting. The framework also incorporates both biophysical and socio-economic aspects. It thereby provides a platform to link different disciplines. The framework itself is straightforward, flexible and applicable to a variety of settings. Further, although developed specifically for the CRM technology, the TA framework can conceivably be adapted to assess other agricultural production technologies.

Limitations of the TA framework

Applying the TA framework does not give answers to all questions. It typically provides only a tentative assessment, whereas the data needs for an in-depth assessment are substantial. In this respect the framework is characterised by 'optimal ignorance': *i.e.* not investigating irrelevant aspects or being concerned with unnecessary detail (Conway and Barbier, 1990).

Resource conservation typically has inter-temporal aspects. Yet, the current applications of the framework emphasise the locational rather than the temporal aspect of CRM-based crop production. This is partly a direct consequence of the need to understand the implications of the technology, before one can fully decide what to ignore and what to focus on. In addition, it reflects the inadequacy of the used case study data to fully assess the temporal aspect - which typically requires more elaborate time series and baseline data. Alternatively, it reflects the need for technology to be privately attractive - which for most farm households in developing countries implies the need for an immediate payback.

Similarly, resource conservation typically has spatial aspects (externalities). Yet, the current applications emphasise a private rather than a social viewpoint, as this is the more relevant for predicting and/or understanding the adoption decision. Further, a good understanding of the farm household implications and decision making is a crucial first step for deriving the corresponding social implications and eventual policy interventions.

Although the framework emphasises private assessment, this still remains imperfect. The private analysis is only partial, emphasising the crop system level within the context of the farm household and its institutional setting. The current applications of the framework are confounded by numerous uncontrolled variables - both biophysical and socio-economic. In part, this is a direct result of relying on survey data. The assessment can thereby be enhanced by incorporating more survey variables (*e.g.* soil indicators), of better quality (*e.g.* actual soil sampling) and from a larger sample. Similarly, more use could be made of experimental data (on farm and/or on station).

The confounding effects are also inherent to the aggregation level used. Using aggregate data risks losing some of the distinguishing features between farm households (*e.g.* crop-livestock interaction; tractor ownership) and within farm households (*e.g.* intensity of adoption). Disaggregating into more homogeneous farm household typologies thereby can clarify the analysis. However, with CRM the number of potentially relevant variables is substantial, implying a trade-off between homogeneity and number of farm household types. The applications chose to apply the framework to only a limited number of farm types (*ex ante*) or adoption strata (*ex post*) in each area, thereby forfeiting some further specific insights (*e.g.* in terms of farm household dynamics and opportunity costs). Such analytical trade-offs are important considerations for the objectives of study and delimitation of a study area.

The current limitations of the TA framework are acknowledged. However, they also depict some of the methodological challenges in the economic analysis of soil conservation. Indeed, the TA framework as analytical tool should be viewed as a stepping stone towards further analysis - *e.g.* in terms of incorporating temporal aspects and formal household modelling. The specific contribution of the TA framework is that it provides a comprehensive analytical platform that includes the relevant factors and linkages between these. It thereby helps ensure the empirical relevancy of the economic analysis of soil conservation.

10.2 Technology

Soil conservation technology can be categorised as barrier (linear) or cover (spatial)-type. Soil conservation research and implementation has traditionally emphasised barrier-type physical structures. However, such measures are characterised by poor private returns. They typically require substantial investment and maintenance, and entail lower land productivity in the short term. Only in the event of severe quantitative or qualitative land constraints are such measures likely to be compatible with the farm households' utility maximisation and have they led to autonomous conservation adoption. Cover-type conservation is more of a management practice and is increasingly recognised for its dual conservation - productivity potential.

The present study assesses the socio-economics of one such cover-type technology: *crop residue mulching* (CRM). CRM is defined as a technology whereby at the time of crop emergence at least 30% of the soil surface is covered by organic residue of the previous crop. The present study proposes CRM as the most adequate term for the technology in view of the substantial controversy and confusion surrounding existing terms, particularly conservation tillage (Chapter 5).

CRM is a standards-based conservation technology. However, the 30%-soil cover standard is ambiguous in view of the continuous - though diminishing - reduction of soil erosion to increasing soil cover. Empirical CRM studies are further confounded by terminology, measurability and causality issues.

CRM is a dual-purpose technology that combines conservation and productivity effects. Its conservation potential hinges on the presence of the crop residues as mulch. Mulch provides a protective layer to the soil surface that is extremely effective in halting soil erosion. The mulch also amends the soil ecology, and this tends to stabilise, and occasionally even enhance, crop yield. CRM also implies factor substitution and input use efficiency alterations. Whether the factor productivity effects are actually economically attractive is site-specific, being dependent on technology, preferences, resources and institutions. The present study takes CRM's conservation potential for granted and instead focuses on the potential and actual implications of the adoption decision for the farm household (*i.e.* upon satisfying the conservation standard).

Complexity and trade-offs

CRM implies a 'basket' of management practices whose implications permeate throughout the farm system (Chapter 6). CRM typically implies a major overhaul of the crop system, affecting both input and output levels. The input implications are conditioned by the necessary and complementary practices. Necessary practices ensure sufficient residues are retained to surpass the 30%-cover threshold. Complementary practices may be needed in order to be able to still grow a crop and/or maintain yield levels. Compared to non-arable systems, adoption is more complex in arable systems, as it generally requires additional adaptations in terms of tillage intensity and sowing. The output implications are conditioned by CRM's effect on crop produce (yield level and stability) and seasonal carry-over (soil conservation and ecology). These biophysical implications are far from straightforward and inherently site-specific, varying both over space and time. The input and output implications are indeed interdependent and dynamic.

The biophysical changes in the crop system alter the internal flow of resources within the farm household. Some of the CRM-induced changes are likely to enhance the farm household's productive and/or consumptive possibilities, others to compete with existing activities. These implications are again inherently site-specific being dependent on the nature of the other farm household activities.

The implications of CRM also transcend the farm household. The institutional setting of the farm household may inherently constrain or enable CRM adoption. In turn, CRM-adoption may directly affect the institutional setting.

CRM also embodies some new market imperfections that undermine its potential as dual-purpose technology. First, as CRM gives rise to new externalities - both positive and negative - that makes its net environmental impact fuzzy and controversial. Second, as CRM exacerbates imperfect information - particularly in relation to the health costs associated with its reliance on herbicides. The herbicide-related environmental and health costs are particularly worthy of attention. Indeed, farm households increasingly adopt herbicides in view of the labour saving potential - regardless of CRM or the hazards associated with their use.

CRM adoption

CRM adoption implies a number of trade-offs. The adoption decision of the farm household thereby hinges on whether CRM enhances the household's (expected) utility. This is more likely when adoption implies substantial private returns, a function of the magnitude and value of the underlying biophysical changes. However, the opportunity costs of the required changes can be high, and this can offset productivity gains (if any) partially or fully. Consequently, private returns to adopting CRM are household-specific, and for a number of households at least, the short-term viability of adoption is questionable.

With CRM being a basket of management practices, the net return to adopting CRM will depend on the individual contribution of each practice and their eventual interaction. However, given the opportunity, the individual household opts for only those practices that are most propitious in view of their objectives. This substantially undermines the prospects of self-interested adoption of soil conservation as it typically leads to the disarticulation of the conservation and productivity aspects. The conservation and crop yield effects are largely embodied in the same mulch component, but the labour and capital productivity effects are not. Farmers may therefore adopt the more attractive factor saving changes, without actually ensuring that sufficient residues are retained as mulch.

Numerous factors thereby influence the CRM adoption decision of the farm household, including resources, preferences, production technology, and institutions. The TA framework provides a comprehensive grouping of these and thereby explains observed differences in adoption. These factors typically include those frequently reported in the adoption literature (*e.g.* farm size; risk and uncertainty; human capital; factor proportions; credit; tenure; supply constraints - Feder *et al.* 1985; Pomp, 1994) - though the relevancy of each is inherently site-specific. Further, the empirical evidence is not always clear-cut, or alternatively, the causal interpretation problematic due to omitted variable bias.

This study does, however, question the nature of the CRM adoption decision. In most of the empirical settings analysed, farm households seem to have adopted whatever CRM component was attractive, fitted in relatively easily or was successfully forced upon them - but few households seem to have adopted CRM purposively. Stepwise adoption of CRM-components is the rule, rather than the exception. Indeed, whereas partial adoption of various CRM components is spreading, adoption of CRM as such lags behind. Estimates of CRM adoption based on single CRM components (*e.g.* no-burn or reduced till) will thereby grossly overestimate actual adoption; whereas estimates will vary over space and in time. Widespread adoption of CRM is limited to a number of adoption spots only. Within a given location, households adopt CRM differentially - as is the case for most technologies. Moreover, CRM is also subject to disadoption (rejection after initial adoption).

Reassessing the potential of CRM

CRM is a promising addition to the portfolio of soil conservation measures in developing countries. However, farm households and CRM advocates tend to view both 'means' and 'ends' of this technology differently. In terms of means, CRM advocates see crop residues as a cheap renewable source of mulch, but for farm households crop residues frequently have production and/or consumption value. In addition, farmers tend to view surplus residues as a nuisance, that need to be eliminated through pre-plant burning or incorporation (Erenstein and Harrington, 1997). In terms of ends, CRM advocates tend to emphasise the conservation aspect, farm households the productivity aspect. Such perceptual differences contribute to the disarticulation of the technology, as the productivity and conservation aspects are separable.

This study shows that the technology is less attractive than is typically put forward by CRM advocates. The private returns to adopting CRM were limited in the cases reviewed - the result of relatively modest benefits and high costs. Although some of the benefits in terms of water and cost savings are indeed short term, tangible and relevant, their actual magnitude - estimated on the basis of partial analysis - raises questions if they are actually worth the candle. Similarly, CRM is divisible, flexible and draws on renewable resources (residues), but simultaneously is not simple, also depends on external inputs, and may not be compatible with the farm household system and institutional setting. Therefore, it is not always efficient to satisfy this conservation standard - at least not from a private viewpoint. Whether it may be socially efficient to do so remains an open question. In conclusion, though promising, CRM clearly is no panacea for soil conservation in developing countries.

10.3 Policy

The complexity of soil conservation seems to both warrant and entangle public intervention (Chapter 4). Soil erosion is characterised by market failure - a necessary, but insufficient, condition for intervention. Intervention is only justified if the expected benefits of intervention to society are larger than the related costs. However, the problematic quantification and valuation of the on-site and off-site dimensions of soil erosion tend to make intervention decisions controversial. This is compounded by potential government failure - in itself likely in view of imperfect information.

The traditional approach to conservation intervention has been remarkably ineffective and inefficient in developing countries. It was based on the premise that conservation technology worked - it was just a matter of getting farmers to adopt. In this regard, intervention typically relied heavily on economic incentives and legal sanctions. However, both are fraught with difficulties in developing countries and have typically not been very successful. The traditional emphasis on barrier-type physical structures also has contributed to the lack-lustre success of conservation intervention.

Traditional conservation approaches emphasised resource conservation and thereby tended to ignore the farm household and institutional setting of the problem. Yet farm households have the final say in adoption and their participation is indispensable. For conservation intervention to become effective and efficient there is a need to harmonise the views of conservationists with those of farm households. The recent shift in soil conservation towards maintaining and enhancing soil productivity, instead of conserving the soil resource *per se*, is a necessary step in the right direction. In addition, understanding and addressing the farm households' preferences and constraints is critical. A multidisciplinary, participatory and flexible approach with the necessary feedback loops is helpful in this regard.

The challenge is to make conservation compatible with the farm households' utility maximisation. One promising approach is to ensure an enabling environment for farm households that favours conservation behaviour. Indeed, there are only a few islands of conservation success - in part because a favourable institutional environment is missing elsewhere (Pretty and Shah, 1997). A complementary approach is to incorporate farm household and institutional considerations in conservation technology development. A number of economic considerations are of relevance in this regard. These considerations are rather stringent as they imply the need for limited costs and yet immediate benefits - as well as ensuring conservation effectiveness. Ideally, this results in utility enhancing technologies, with soil conservation as added benefit. However, there are also trade-offs between conservation and productivity, thereby posing a considerable challenge to the development of acceptable dual-purpose technologies.

Policy and CRM

CRM is a promising dual-purpose technology, but no panacea for soil conservation. CRM thereby has at least five implications for policy. First, it implies the need for further conservation *technology development*, both in terms of (i) generating alternative options; and (ii) adapting options - including CRM - to local conditions. Alternative options should preferably be dual-purpose technologies that inseparably embody conservation and productivity aspects.

Second, it implies the need for CRM *targeting*. CRM presents a number of trade-offs, and the challenge is to target its development and promotion towards those instances where it is most likely to achieve its potential from a private and social viewpoint. *A priori*, and at a high aggregation level, the delineation of potential target areas remains ambiguous in view of the numerous influential factors. For instance, the water conserving effect of CRM can potentially boost and stabilise yields in semi-arid areas; however, it typically also would entail a high opportunity cost in terms of alternative residue use foregone. There is a need to target those areas where potential pay-offs - private and social - are high: *i.e.* high benefits in relation to (opportunity) costs. To assess such potential pay-offs the TA framework can be used as a comprehensive checklist (Chapter 6; also see Table 10.2 and Table 10.3).

Third, there is a need for CRM *packaging*. The conservation and productivity aspects of CRM are not inseparably linked. Instead, disarticulation between the two aspects is widespread, thereby indicating the need for novel approaches to intricately link the two. The successful use of peer monitoring for institutional interlinking in Guaymango (El Salvador, Chapter 9) is noteworthy in this regard. Further, a regulatory approach can be useful when actually enforced locally. Although both Chiapas cases (Chapter 8) relied on regulation, the use of coercion was not equally successful. The cases reiterate that regulation will succeed only if it can be actually enforced, and is more effective when applied through local institutions.

Fourth, there is a need for *information*. CRM is complex and knowledge intensive. Both farmers and other stakeholders need to develop the necessary human capital (*e.g.* in relation to necessary and complementary practices for CRM; environmental and health issues).

Fifth, there is a need for an overall *enabling environment* for agriculture in general, and CRM in particular. CRM is more likely to have a positive (private) pay-off when the institutional setting is developed and farm households are above certain poverty thresholds.

General policy lessons

The present study questions traditional research and extension approaches. Instead of top-down uniform approaches, an iterative, participatory and flexible approach is needed. This study indeed emphasises variability over uniformity. Instead of disseminating ready-made solutions, there is a need to provide options that are assessed locally through participatory adaptive research. The challenge thereby is to identify relevant utility enhancing options, which given an enabling environment, are likely to spread autonomously farmer-to-farmer.

Policy intervention also needs to emphasise critical issues, both from a private and social viewpoint. Understanding and addressing private priorities and possibilities is pivotal for lasting intervention success, and assessing the private implications of proposed interventions through the TA framework is likely to contribute to that end. Simultaneously, efforts need to be concentrated on those instances where the intervention is likely to be socially efficient. This implies focusing on those instances where intervention would generate substantial social benefits without entailing excessive social costs. Depending on the situation, this may imply creating an enabling environment for the technology in question, raising its private utility and/or addressing new market imperfections.

Incorporating the above considerations into policy will enhance the effectiveness and efficiency of soil conservation efforts in developing countries. The enhanced effectiveness will ensure a more adequate maintenance of the productive potential of the vital soil resource; the enhanced efficiency less waste of scarce resources. In the end, both will contribute to sustainable development.

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Annex A Conceptualising soil conservation options with shifting cultivation

A closer look at rudimentary agricultural systems is helpful in conceptualising the bio-physical implications of soil degradation and options to mitigate it. This annex first presents a conceptual model of shifting cultivation, and subsequently applies it to soil conservation in a more contemporary setting.

A conceptual model of shifting cultivation

Shifting cultivation is one of the oldest agricultural systems (Ruthenberg, 1976).[1] It is still practised today in the more remote regions of the tropics. It is characterised by a short period of agricultural use followed by a long period of fallow. During the use period the farmer rapidly mines the available soil productive capacity using limited - if any - external inputs. During the fallow period the productive capacity is slowly restored by natural processes. As such shifting cultivation is a prime example of purposeful soil degradation. Conway and Barbier (1990:149) even label it as one of the most environmentally destructive forms of agriculture in the world. Notwithstanding, the very absence of external inputs - especially fertiliser - implies that the rate of degradation is such that it is also easily perceptible. Shifting cultivation systems therefore provide a neat learning ground for both perceiving degradation and identifying conservation options.

Panel A of Figure A.1 conceptualises a sustainable shifting cultivation system - albeit not to scale and using only linear approximations.[2] Potential productivity of the undegraded soil is P_0. At time t_i the farmer takes the land in production by slashing and burning the vegetation. In the subsequent seasons the potential productivity of the system declines rapidly due to fertility depletion and build-up of weeds. After *n* years the system productivity drops to P_n. At this level of productivity the returns from the existing land under cultivation fall below those from clearing a new piece of land (Burgess, 1990 in Barbier and Bishop, 1995). The farmer abandons the existing field and moves to a new piece of land. Over the subsequent *m* years the fallow vegetation develops and gradually restores potential productivity to its original level of P_0. Once productivity is restored to P_0 additional years of fallow will have little to no added productive benefit. The farmer conceivably returns to the same piece of land and the cycle repeats itself.

This system is stable and sustainable as long as the fallow period remains long enough to offset the degradation, *i.e.* the productivity is restored to P_0. Indeed, shifting cultivation practices can continue for centuries without causing any long-term decline in yields (Clarke 1976, in Southgate *et al.*, 1984). Trouble starts when forces such as population pressure put strains on the system.[3] The effect of population pressure is generally two-fold (Greenland,

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[1] Alternatively labelled slash-&-burn or swidden agriculture (Thurston, 1992).

[2] A stable system might for example have 3 use-years followed by 20-25 fallow years. In addition, both degradation and regeneration are likely to be non-linear. For instance, regeneration to P_0 will in most cases be asymptotic.

[3] Additional strains can be generated by market integration and/or the institutional framework (Southgate *et al.*, 1984; Southgate, 1990; Larson, 1991).

1975). First, it tends to shorten the fallow period.[4] When the regeneration period falls short of the required *m* years, potential productivity is no longer fully restored to P_0 (Panel B of Figure A.1). Second, it tends to lengthen the use period. This implies more severe degradation and tends to undermine the regeneration capacity (*i.e.* rate) of the system. In either case, the productivity of each subsequent cycle drops and the time required for full restoration increases concomitantly.

Is there a way to get the system back on a stable and sustainable path? Basically we can alter the rate or the length of either the degradation and regeneration phases. Figure A.2 conceptualises the four potential options:

i. *Increase time of regeneration:* Increasing the length of the fallow period so that productivity is adequately restored. This option is not very attractive, as it conflicts directly with the decreasing regeneration time - one of the major reasons for the original breakdown.

ii. *Increase regeneration rate:* Speeding up the regeneration rate, shortens the time needed for adequate restoration of productivity. This is the basic idea behind improved fallows, using green manures to rapidly rebuild natural fertility.

iii. *Reduce time of degradation:* Reducing the length of the use period reduces the extent of degradation, and therefore also the subsequent regeneration needed. Conceivably this could lead to shorter fallows. Yet again this option (like i above) is not very attractive, as it directly conflicts with the increasing land pressure that lead to the original breakdown.

iv. *Reduce degradation rate:* Slowing the degradation rate implies degradation is less over the same use period thus requiring less regeneration. Alternatively, that the use period can be lengthened. A number of agronomic management measures fall in this category, such as the use of mulching and chemical fertilisers.

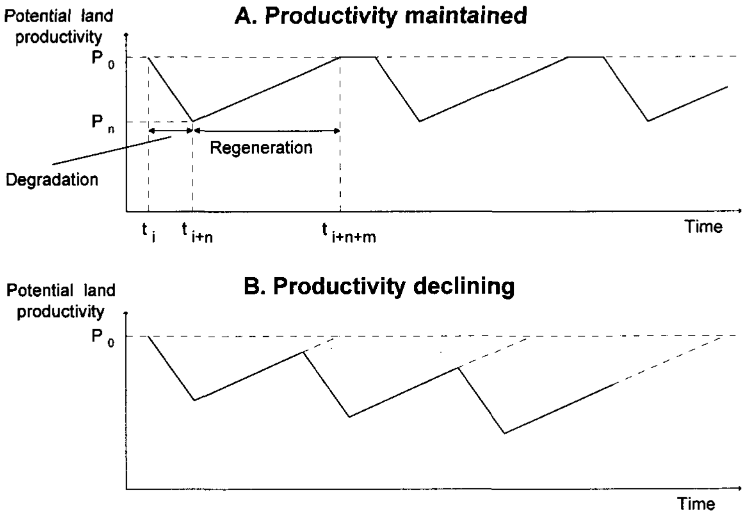

Figure A.1 Conceptualisation of soil degradation and regeneration in a shifting cultivation system (adapted from Shaxson, 1993)

[4] This may not (yet) be problematic if there is sufficient slack in the system (fallow > *m* years).

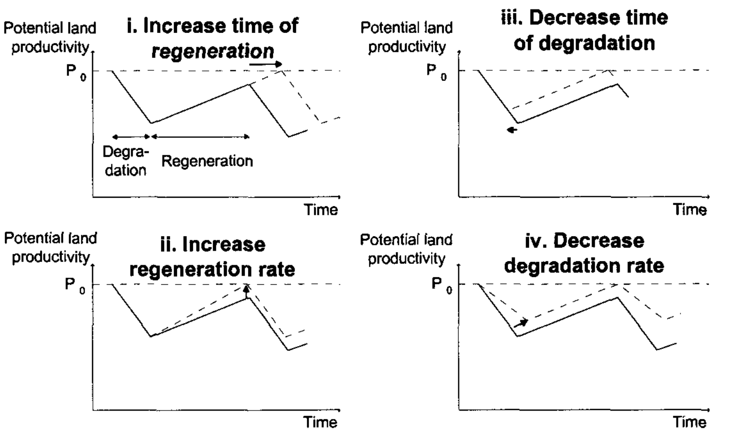

Figure A.2 Conceptualisation of soil conservation options (adapted from Shaxson, 1993)

An application to soil conservation in contemporary systems

Although the above conceptual model was applied to shifting cultivation systems,[5] the same can also be applied to more contemporary agricultural systems. First we need to make a shift of mind in terms of the timeline being considered. In the shifting cultivation case the degradation period refers to the time-of-use measured in years. In the contemporary case it refers to a single agricultural season measured in months. In the same way the fallow period would correspond with the period between seasons, varying from turn-around time through an off-season to genuine fallowing. Reducing degradation (time or rate) basically corresponds with conservation; increasing regeneration (time or rate) with rehabilitation.

The above conceptual model also highlights the sensitivity and resilience of a system.[6] The sensitivity is "the degree to which a given land system undergoes changes due to natural forces following human interference" (Blaikie and Brookfield, 1987:10).[7] This corresponds with the slope of productivity loss during the use period/cropping season. The resilience is "the ability of land to reproduce its capability after interference" (*ibid.*:10).[8]

[5] In fact, the soil degradation characterising shifting cultivation is more of a soil-mining nature than soil erosion as such. Greenland (1975) even expects soil erosion to be limited in shifting-cultivation systems because the plots are small and the soil is generally covered. The latter is the effect of mixed cropping practices, debris left over from the clearing and vigorous weed growth. Notwithstanding, localised soil erosion can still be substantial at the onset of the cropping season - with prevailing rains tending to be very erosive and the soils exposed due to the traditional practice of pre-plant burning during land preparation.

[6] Different interpretations of these concepts abound. For instance, Conway and Barbier (1990:37) do not distinguish between the two but refer to them jointly as sustainability: "the ability to maintain productivity ... in the face of stress or shock".

[7] Other authors use different terms. Lal (1993) refers to stability (susceptibility to change). Goodland (1989) refers to resistance (ability to cope with change).

[8] *I.e.* the ability to return to an initial state (Goodland, 1989); the ability to restore life-support processes after being stressed (Lal, 1993).

This corresponds with the slope of productivity regeneration during the fallow period/off-season. Soils vary greatly in terms of their sensitivity and resilience to stress and shock, reiterating the bio-physic site specificity.

Soil erosion is one form of stress. Most soil conservation practices reduce the incidence of this stress, *i.e.* they reduce the degradation rate. However, reducing the degradation rate is not the only conceivable effect of soil conservation measures. Several management practices indeed can reduce the duration of severe degradation. The on-set of the cropping season is particularly erosive as the soil is directly exposed to the elements up to the time when the canopy of the crop starts to close. Whenever a management practice helps ensure a more timely closure it thereby reduces the time of particularly severe degradation. Several practices conceivably fall under this category, including seed rate, crop spacing (*e.g.* row *v.* broadcast) and fertilisation. In much the same way, reduced tillage techniques decrease the time needed for land preparation. In the extreme, direct drilling of one crop into the previous stand could ensure a continuous cover.

Several management practices also affect the regeneration rate. For instance, improved fallows with green manures/cover crops help rebuild soil fertility. In areas using summer fallow for water conservation purposes, crop residue mulching can help rebuild and conserve soil water reserves (*e.g.* Saskatchewan in Canada - van Kooten *et al.*, 1989a; Palouse in USA - Carlson and Dillman, 1986).

Certain management measures are hybrids of some of the above options. For instance, chemical fertilisers increase the regeneration rate (by replenishing soil fertility reserves) as well as reduce the degradation rate (by reducing soil mining). In much the same way, the distinction between degradation and regeneration rates becomes increasingly vague whenever the conservation measure is applied during the degradation period (*e.g.* green manures/cover crops as intercrop).

Discussion

The present annex focused mainly on conceptualising the bio-physical implications of degradation and its mitigation. Notwithstanding, shifting cultivation also aptly highlights stringent socio-economic constraints, shifting cultivators being prime examples of resource poor farmers. Indeed, as suggested by Greenland (1975:842-3): for shifting cultivators to invest in technology of whose effectiveness they are uncertain, but of whose costs they are immediately aware, may well seem ridiculous. The technological requirement of capital should be nil, or nearly so. Land abundant settings in developing countries indeed are characterised by low external input use. Labour thereby forms the main input, and given capital scarcity, labour productivity considerations are crucial. Shifting cultivation thereby provides useful lessons when developing technology in general, and soil conservation technology in particular, for farm households in developing countries.

Annex B Yield trend scenarios

Yield trend scenarios for the with and without-case can have a major impact on the economics of conservation. This annex briefly conceptualises this issue.

Figure B.1 highlights some hypothetical yield trends upon adoption of soil conservation measures, *ceteris paribus*. It is assumed that the yield of the without-case falls linearly over time.[9] For the with-case four alternative scenarios are highlighted. In case A yield drops from its original level (Y_0) to a lower level upon implementing conservation reflecting permanent productivity loss (*e.g.* reduction of productive area to locate conservation structure). However, at some point in time, the declining productivity level of the without-case would fall below the constant productivity of the A with-case ($t^A{}_*$). Case C reflects a short-lived loss of productivity relative to the without-case. With time, temporary losses disappear and/or permanent losses are more than compensated, for instance due to improved water and fertility conservation. Again, at a certain point in time ($t^C{}_*$) the productivity in the C with-case will surpass the without-case.Both case A and C reflect the typically lower productivity in the with-case in the short term - *i.e.* net productivity costs up to point t_* - generally a number of years down the line. These costs are in addition to the substantial investment and recurrent maintenance costs. It will be unlikely that such conservation measures will be privately attractive, especially when costs and benefits are discounted.

Case B reflects the frequently held assumption that yield in the with-case is held constant (for a discussion see de Graaff, 1996:100-1). Case D reflects an immediate productivity increase from conservation. Both these cases seem to ignore any short-term productivity loss, or alternatively, assume the short-run benefits - water and fertility conservation - to be sufficient to off-set (case B) or more than compensate (case D) these. Notwithstanding, such scenarios are likely to overestimate the benefits of conservation. Indeed, with t_* equal to t_0 both incur only productivity benefits to compensate investment and maintenance. It is noteworthy that studies where soil conservation structures were reportedly privately attractive tend to assume the case D scenario (Wiggins, 1981; McIntire, 1994). However, these cases do not present any empirical data to justify such an optimistic assumption.

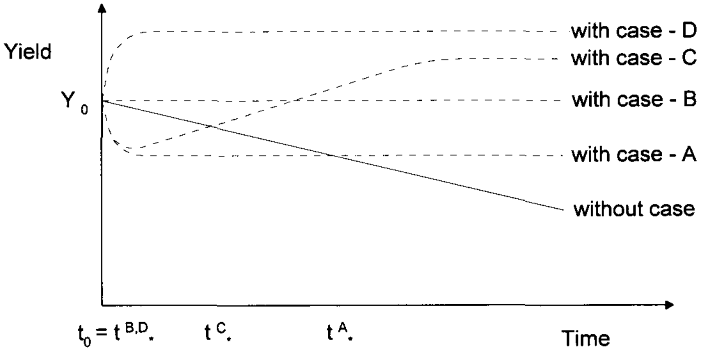

Figure B.1 Hypothetical yield trends with and without conservation

[9] For the sake of simplicity. See Chapter 2 for a discussion of erosion-induced productivity loss.

Annex C A simple crop-livestock interaction model

Crop-livestock interaction is a major factor affecting the potential of CRM. This annex presents a simple model to highlight the implications.

Let us assume a farm household has limited resources and can only produce one crop and/or one type of livestock - say maize and/or beef cattle. Quadrant I of Figure C.1 depicts the resulting production possibility curve P if we assume the two activities to be independent (and thus substitutes in terms of income generation, and not complements).

However, maize produces crop residues as by-product and these can be used as fodder for cattle. Let us assume cattle live on a residue diet. Quadrant II depicts the corresponding residue needs for livestock production - function O with the slope reflecting the residue use efficiency. Quadrant IV depicts the internal residue production as by-product of crop production - function S with the slope being a function of the harvest index. Quadrant III mirrors the production possibility curve in terms of the corresponding residue needs and internal residue production - function T. The diagonal C_1 in Quadrant III (*i.e.* $R_n = R_p$), depicts the internal residue supply constraint. To the right of C_1, internal residue production exceeds internal residue needs. To the left of C_1, internal residue demand exceeds internal supply. If we assume the existence of a crop-residue market, the shortfall could conceivably be bought there. However, in the absence of a residue market, the feasible area is constrained to the right of C_1. In turn, we can mirror the internal residue supply constraint into Quadrant I. The feasible area would now be to the right of constraint C_1 in Quadrant I.

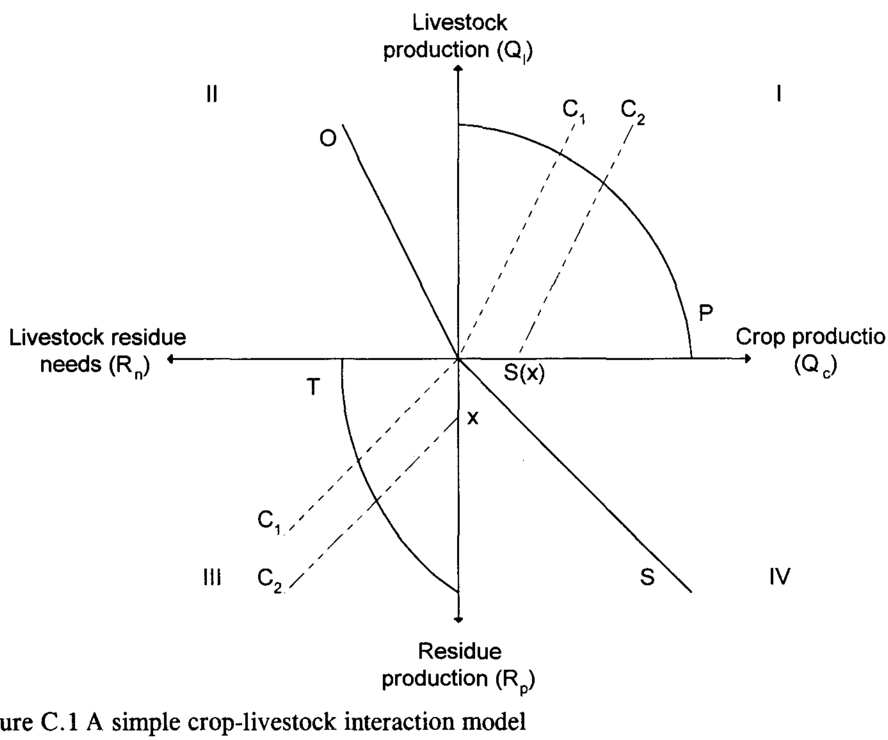

Figure C.1 A simple crop-livestock interaction model

Let us assume the farm household uses a manual zero till system without pre-plant burning for its maize production - *i.e.* no residues are eliminated through incorporation and burning. Let us also assume X tons of maize residues are needed for an effective mulch after allowing for weathering. We can now depict a CRM constraint in Quadrant III: namely by lowering C_1 with X, resulting in C_2 (*i.e.* $R_n = R_p - X$). Any point to the right of C_2 in Quadrant III would conserve sufficient residues as mulch to be compatible with CRM. Like with constraint C_1 we can mirror the constraint C_2 into Quadrant I. The feasible area for CRM would now be to the right of constraint C_2 in Quadrant I.

Figure C.2 highlights the present crop-livestock production possibility curve P, including the two residue constraints (C_1 for internal production and C_2 for CRM). In addition, the figure depicts the iso-revenue line R ($R = p_l*q_l + p_c*q_c$). The most profitable combination for the farm household to produce would be q_l' units of cattle and q_c' units of maize. This combination of maize and cattle implies internal residue supply exceeds internal residue demand. However, the surplus residues are not sufficient to form an adequate mulch. *I.e.*, under the hypothesised situation, a profit maximising farm household would not adopt CRM.

Now assume new technology gives crop productivity a boost, shifting the production possibility curve to the right to P", but that the iso-revenue curve remains unaffected. The now most profitable combination for the farm household to produce would be q_l'' units of cattle and q_c'' units of maize. The surplus residues are now sufficient to form an adequate mulch. *I.e.*, under the hypothesised situation, a profit maximising farm household would adopt CRM.

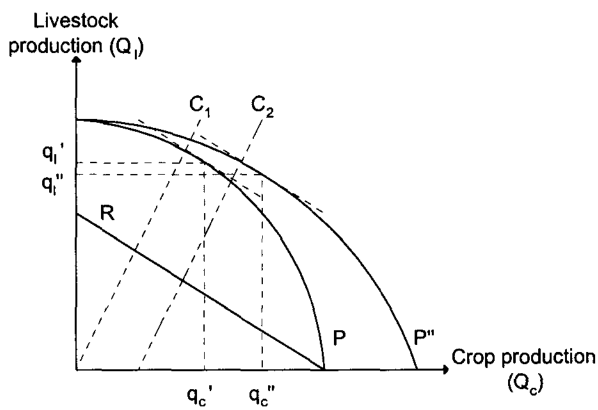

Figure C.2 The crop-livestock production possibility curve revisited

Acronyms

AU	animal unit (equivalent of one adult cow)
CBA	cost-benefit analysis
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo, Texcoco (Mexico) [International Maize and Wheat Improvement Center]
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Montpellier (France)
CRM	crop residue mulching
CTIC	Conservation Technology Information Centre, Lafayette (USA)
DITSL	German Institute for Tropical and Subtropical Agriculture
FAO	Food and Agriculture Organisation of the United Nations, Rome
FIRA	Fideicomiso Instituido en Relación con la Agricultura [Federal Trust Fund for Agriculture, Mexico]
FIRCO	Fideicomiso de Riesgo Compartido [Federal Shared Risk Trust, Mexico]
GLASOD	Global Assessment of Soil Degradation
HI	harvest index
IBSRAM	International Board for Soil Research and Management, Bangkok
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, Hyderabad (India)
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico [National Institute of Forestry, Agriculture, and Livestock Research]
IITA	International Institute for Tropical Agriculture, Ibadan (Nigeria)
IPM	Integrated pest management
LEISA	low external input and sustainable agriculture
MCA	multi-criteria analysis
NAFTA	North-American Free Trade Agreement
NGO	non-governmental organisation
NRG	Natural Resources Group, CIMMYT
OECD	Organisation for Economic Co-operation and Development
p (or prob.)	probability
PSSM	Proyecto Sierra de Santa Marta, A.C. (NGO, Mexico)
SAGAR	Secretaría de Agricultura, Ganadería y Desarrollo Rural [Federal Ministry of Agriculture, Livestock, and Rural Development, Mexico]
SARH	Secretaría de Agricultura y Recursos Hidráulicos [Federal Ministry of Agriculture and Water Resources, Mexico; now SAGAR]
SCSA	Soil Conservation Society of America
sd	standard deviation
SWCS	Soil and Water Conservation Society
SRAPTF	Socio-Economic Research Agenda Project Task Force
TA (framework)	technology assessment (framework)
USLE	Universal Soil Loss Equation
W(A)U	Wageningen (Agricultural) University (the Netherlands)
WRI	World Resources Institute, Washington

Summary

The study contributes to the search for a methodology to assess soil conservation, particularly in developing countries. The study consists of two parts. The first part focuses on soil conservation in general - with special emphasis on the relationships between technology, economic analysis and policy. The second part deals with the analysis of one particular soil conservation technology, crop residue mulching, in different settings in Mexico and Central America.

Part I: Soil erosion and conservation: Economic analysis and policy implications
Conceptualising the implications of soil erosion and conservation is straightforward, but quantifying and valuing them poses considerable analytical challenges. In fact, the economic impact of soil erosion is highly controversial (Chapter 2). The problem is complex with no straightforward cause-effect relationship. Soil erosion is most directly associated with physical soil loss, a subtle and difficult to estimate entity. However, soil loss itself still says little about the economic costs of soil erosion - either on-site or off-site. The main on-site cost is the erosion-induced productivity loss - an entity that is even more imperceptible than soil loss - which has both ephemeral and cumulative elements, is highly site-specific and is easily masked by technical change. The main off-site costs are the generally adverse effects imposed by the reappearance elsewhere of the eroded soil and chemical pollutants. These costs again present various measurability problems and tend to be highly site-specific. The temporal and spatial dimensions of soil erosion make the assessment scale dependent; the locational aspect make it extremely site-specific. Adding to the controversy is the ambivalence about whether the erosion-induced damage is irreversible.

Soil conservation itself presents additional challenges for economic analysis (Chapter 3). The cost of soil conservation represents an investment which is technology and site-specific. The benefits - in terms of soil erosion averted - remain largely uncertain, far in the future and difficult to measure. Further, different interpretations of conservation exist - absolute, standards-based, efficient and optimal - implying different degrees of erosion control with significant implications for the analysis. The economic assessment of soil conservation has been tackled in varying ways, which can be broadly classified as the evaluation and adoption schools. The *evaluation school* basically tries to quantify the economic impact of different soil conservation scenarios. However, such attempts are curtailed by the quality and quantity of available data and are influenced by the mode of costing erosion (*e.g.* dose-response, replacement cost and demand curve approaches) and the mode of analysis (*e.g.* cost-benefit analysis and optimisation models). The *adoption school* tries to explain and predict the divergences in soil conservation behaviour between economic agents. However, the extreme socio-economic site-specificity of soil conservation both justifies and complicates this line of research. The farm household's adoption decision is potentially influenced by a number of farm level, technological and institutional factors. In the end, it is the combination of these factors that influences the returns to, and capacity of, farm households to invest in soil conservation.

The problematic assessment of soil erosion and conservation tends to make government intervention controversial, and the situation is further complicated by potential government

failure in implementation (Chapter 4). Government intervention so far has typically been unsuccessful. In part this reflects the traditional intervention approach with its emphasis on economic incentives and legal sanctions. In addition, it reflects traditional conservation technology with its typically poor private returns. Intervention is likely to be more successful when it incorporates farm household and institutional considerations in technology development and implementation. Technology development faces the challenge of combining limited costs with immediate benefits and conservation effectiveness, and implementation requires a multidisciplinary, participatory and flexible approach. Ground cover is increasingly recognised for its potential in this regard: it largely prevents soil erosion, and presents productive opportunities in terms of water and fertility conservation. Crop residue and cover crop mulching are two particularly promising options.

Part II: The case of crop residue mulching

Crop residue mulching (CRM) can be defined as a technology whereby at the time of crop emergence at least 30% of the soil surface is covered by organic residue of the previous crop (Chapter 5). CRM is a dual-purpose technology that combines conservation and productivity effects: it halts soil erosion, it amends the soil ecology, it stabilises crop yields, it implies factor substitution and alters input use efficiency. CRM typically implies necessary practices (to retain sufficient residues as mulch) and complementary practices (to still grow a crop and/or maintain yield levels). CRM therefore resembles a basket of management practices and complete application will not always be privately efficient. This also opens the prospect of disarticulation - as farmers may adopt the more attractive changes, without actually ensuring retention of sufficient residues as mulch. In fact, the technology is inherently complex - both in terms of actually adopting it and subsequently measuring adoption. In addition, CRM also embodies new externalities and exacerbates imperfect information.

The study develops an analytical framework to assess the socio-economics of the CRM-technology in developing nations (Chapter 6). It thereby takes CRM's conservation potential for granted and focuses on the implications for the farm household to satisfy the conservation standard. The technology assessment framework follows a stepwise expanding analysis along a three-tier hierarchy: crop production, the farm household and the institutional setting. This subsequently allows for a private and a social assessment of the technology, and for the formulation of policy implications. The study subsequently applies the framework in the *ex ante*, the *ex post* and the partial analysis of CRM using primarily farm survey data from different case study areas in Mexico and Central America.

The prospective, *ex ante* use of the framework assesses how the CRM technology would potentially fit in the farming systems of two distinct cases in Mexico (Chapter 7). In the first case (Southern Jalisco), CRM has bio-physical potential, but the changes needed are many and costly, particularly in view of the opportunity cost of residues and equipment. In the second case (Southern Veracruz), crop production is already largely compatible with CRM and changes are few - but nonetheless costly, particularly in view of the partial market integration. Without policy intervention, rapid adoption is unlikely in either case.

The retrospective, *ex post* use of the framework assesses how the CRM technology actually fitted in the farming systems of two other sites in Mexico (Chapter 8). The first case (Chiapas Highlands) has substantial CRM adoption levels, linked primarily to the local enforcement of a pre-plant burning prohibition, to the field exposure to communal grazing and to the labour-saving potential of herbicides. The second case (Central Chiapas) provides less substantial CRM adoption levels, with adoption linked to whether fields are arable, livestock pressure on residues and the regulation of pre-plant burning. Both cases were subject to substantial government intervention.

A partial application of the framework provides a rapid, superficial assessment of the technology in two other sites, at limited cost (Chapter 9). The first case (the irrigated Bajio, Mexico) has limited CRM adoption levels, with as influential factors the excessive residues and the availability of equipment and information. The second case (Guaymango, El Salvador) has widespread use of CRM practices, aided by substantial residue production, compatibility with the farm household system and the successful packaging with other productivity enhancing components.

The empirical cases reiterate that CRM is a complex technology, which imposes site-specific trade-offs and is subject to disarticulation. The private returns to adopting CRM were typically limited - the result of relatively modest benefits and high costs. The cases also highlight the influential role of the institutional setting and question the nature of the adoption decision - as many households seem to have adopted CRM because of specific circumstances. Therefore, though promising, CRM is no panacea for soil conservation in developing countries. The cases also highlight a number of policy implications, in terms of the need for further technology development, technology targeting and packaging, provision of information, creating an enabling environment and a participatory and flexible approach to implementation.

The application of the technology assessment framework in different ways and to different empirical settings, allows for an - albeit imperfect - assessment of this framework. The varied applications do generate different outcomes that correlate with observed adoption levels, and highlight the usefulness of the framework and its potential as analytical tool. The technology assessment framework provides a comprehensive analytical structure for raising and understanding the pertinent socio-economic issues affecting the CRM adoption decision. Nonetheless, the application of the technology assessment framework does not give all answers. Indeed, the economic analysis of soil conservation in general, and CRM in particular, is typically imperfect and controversial in developing countries. Notwithstanding, such analysis still provides valuable feedback to focus further research, technology development and policy efforts in the quest for sustainable development.

Samenvatting

Deze studie draagt bij tot het ontwikkelen van een methodologie voor het beoordelen van bodemconservering, met name gericht op ontwikkelingslanden. De studie bestaat uit twee delen. Het eerste deel richt zich op bodemconservering in het algemeen - met speciale aandacht voor de relaties tussen technologie, economische analyse en beleid. Het tweede deel richt zich op de analyse van één bepaalde bodemconserveringstechnologie, het mulchen met gewasresten, met toepassingen in Mexico en Midden America.

Deel I: Bodemerosie en -conservering: Economische analyse en gevolgen voor beleid
Het inzichtelijk maken van de gevolgen van bodemerosie en -conservering is betrekkelijk eenvoudig. Het daadwerkelijk meten en waarderen van deze gevolgen houdt echter aanzienlijke analytische uitdagingen in. De economische gevolgen zijn zeer controversieel (Hoofdstuk 2). Het probleem is complex en er bestaan geen duidelijke verbanden tussen oorzaak en gevolg. Bodemerosie wordt meestal geassocieerd met het fysieke verlies van bodemdeeltjes, een subtiel en moeilijk te meten proces. Maar dit verlies zegt nog weinig over de economische kosten daarvan - zowel op de locatie zelf als daarbuiten. De voornaamste kostenpost op locatie is het veroorzaakte produktiviteitsverlies - een proces dat nog moeilijker waarneembaar is dan het verlies van bodemdeeltjes. Dit proces heeft tijdelijke en cumulatieve elementen, is zeer plaatsgebonden en wordt gemakkelijk verbloemd door technische vooruitgang in de landbouw. De voornaamste kostenposten buiten de locatie betreffen de gevolgen van de verplaatste bodemdeeltjes en de chemische verontreinigingen benedenstrooms. Deze kosten zijn moeilijk meetbaar en zeer plaatsgebonden. De tijd en ruimte dimensie van bodemerosie maken de beoordeling schaalgevoelig. De ambivalentie over de onomkeerbaarheid van de door bodemerosie veroorzaakte schade draagt verder bij tot de controverse.

Bodemconservering zelf geeft verdere uitdagingen voor een economische analyse (Hoofdstuk 3). De kosten voor bodemconservering bestaan uit een investering waarvan de hoogte afhangt van technologie en plaats. De baten – de gevolgen van vermeden bodemerosie - blijven onzeker, ver in de toekomst en moeilijk te meten. Daarnaast zijn er verschillende interpretaties van conservering - absoluut, op standaarden gebaseerd, efficiënt en optimaal - die naar verschillende graden van erosiecontrole refereren en die verstrekkende gevolgen hebben voor de analyse. De economische beoordeling van bodemconservering wordt op verschillende manieren benaderd, grofweg ondergebracht bij de evaluatie- en de adoptieschool. De *evaluatie school* probeert de economische gevolgen van verschillende bodemconserveringsscenario's te kwantificeren. Zulke pogingen worden echter beperkt door de kwaliteit en kwantiteit van de beschikbare gegevens en worden beïnvloed door de manier waarop de kosten van bodemerosie worden bepaald (bijvoorbeeld dosis-respons, vervangingswaarde en vraagcurve benaderingen) en de manier waarop de analyse wordt uitgevoerd (bijvoorbeeld kosten-baten analyse en optimalisatie modellen). De *adoptie school* probeert verschillen in bodemconserveringsgedrag tussen individuen uit te leggen en te voorspellen. De extreme plaatsgebondenheid van de sociaal-economische aspecten van bodemconservering rechtvaardigen, en compliceren, deze vorm van analyse. De adoptiebeslissing van het boerenhuishouden wordt potentieel beïnvloed door

bedrijfsmatige, technologische en institutionele factoren. Uiteindelijk is het de combinatie van deze factoren die de beloning voor, en mogelijkheden tot, het investeren in bodemconservering van het boerenhuishouden bepalen.

De problematische beoordeling van bodemerosie en -conservering maken het besluit tot overheidsingrijpen controversieel. De situatie wordt verder bemoeilijkt door mogelijk overheidsfalen bij de uitvoering van maatregelen (Hoofdstuk 4). Tot dusver is het overheidsingrijpen doorgaans niet succesvol geweest. Dit is een gevolg van o.a. de traditionele aanpak met nadruk op economische prikkels en rechtelijke sancties en de toepassing van bodemconserveringstechnologïen die doorgaans weinig opbrachten. Ingrijpen heeft meer kans van slagen als overwegingen van boerenhuishoudens en de institutionele omgeving worden geïncorporeerd in de technologie-ontwikkeling en -uitvoering. De technologie-ontwikkeling staat daarbij voor de uitdaging om beperkte kosten te combineren met onmiddelijke baten en effectieve bodemconservering; terwijl de uitvoering een multidisciplinaire, participatieve en flexibele aanpak vereist. In dit opzicht wordt het bodemconserveringspotentieel van bodembedekking in toenemende mate erkend: het voorkomt grotendeels bodemerosie en levert mogelijkheden tot opbrengstverhoging door conservering van water en bodemvruchtbaarheid. Het mulchen met gewasresten en het verbouwen van bodembedekkers zijn hiervan twee veelbelovende opties.

Deel II: Het geval van mulchen met gewasresten

Het mulchen met gewasresten (CRM) kan worden gedefinieerd als een technologie waarbij ten tijde van de ontkieming van het gewas tenminste 30% van het bodemoppervlak bedekt is met organische resten van het vorige gewas (Hoofdstuk 5). CRM is een technologie die conserverings- en produktiviteitsdoelstellingen combineert: het stopt bodemerosie, het verandert de bodemecologie, het stabiliseert gewasopbrengsten, het brengt factor-substitutie met zich mee en verandert de efficiëntie van inputs. Doorgaans impliceert CRM noodzakelijke handelingen (om voldoende gewasresten als mulch te behouden) en complementaire handelingen (om nog steeds een gewas te kunnen verbouwen en/of opbrengstniveaus te handhaven). CRM is daarom een uitgebreide set van handelingen en volledige toepassing zal vanuit privaat standpunt niet altijd efficiënt zijn. Er bestaat dan ook de mogelijkheid van gedeeltelijke adoptie: boeren nemen de aantrekkelijke veranderingen over, maar geven geen prioriteit aan het achterblijven van voldoende gewasresten als bodembedekking. In feite is de technologie complex - zowel in termen van de daadwerkelijke adoptie als de meting ervan. Daarnaast brengt CRM nieuwe externe effecten en informatie problemen met zich mee.

De studie ontwikkelt een analytisch kader om de sociaal-economische gevolgen van de CRM-technologie te beoordelen in ontwikkelingslanden (Hoofdstuk 6). De studie gaat daarbij uit van CRM's bodemconserveringspotentieel en concentreert zich op de gevolgen van adoptie voor het boerenhuishouden. Het analytisch kader volgt een stapsgewijze expanderende analyse met drie niveaus: de gewasproduktie, het boerenhuishouden en de institutionele omgeving. Deze analyse leidt tot een beoordeling van de technologie vanuit zowel privaat als maatschappelijk standpunt, met gevolgtrekkingen voor beleid. De studie past het beoordelingskader vervolgens toe in de *ex ante*, de *ex post* en de partiële analyse van CRM - daarbij gebruik makend van gegevens verzameld in het kader van studies uitgevoerd in Mexico en Midden America.

In de *ex ante* toepassing van het kader wordt beoordeeld hoe CRM mogelijkerwijs zou passen in de boerenbedrijfsystemen op twee verschillende locaties in Mexico (Hoofdstuk 7). In de eerste toepassing (Zuid Jalisco), heeft CRM bio-fysisch potentieel, maar zijn de benodigde veranderingen talrijk en duur, voornamelijk gezien de locale waarde van de gewasresten en de noodzakelijke werktuigen. In de tweede toepassing (Zuid Veracruz), is de bestaande gewasproduktie grotendeels in overeenstemming met CRM en zijn de benodigde wijzigingen beperkt maar duur vanwege de gedeeltelijke markt-integratie. Zonder overheidsingrijpen is snelle adoptie niet waarschijnlijk in geen van beide gevallen.

De *ex post* toepassing van het kader beoordeelt de feitelijke toepassing van CRM binnen de boerenbedrijfsystemen op twee andere locaties in Mexico (Hoofdstuk 8). In de eerste toepassing (hooglanden van Chiapas) is er wijdverbreide adoptie van CRM, voornamelijk gerelateerd aan de lokale handhaving van een verbod op het verbranden van gewasresten, de mate van blootstelling van het veld aan communaal grazend vee en het arbeidsbesparend potentieel van herbiciden. In het tweede geval (centraal Chiapas) is er enige adoptie van CRM, voornamelijk gerelateerd aan de ploegbaarheid van velden, de mate van gebruik van de gewasresten door het vee en een verbod op het verbranden van gewasresten. Beide gevallen werden gekenmerkt door substantieel overheidsingrijpen.

Een partiële toepassing van het kader geeft een snelle maar ook beperkte beoordeling van de technologie op weer twee andere locaties (Hoofdstuk 9). De eerste toepassing (de geïrrigeerde Bajio, Mexico) laat een beperkte CRM adoptie zien, met als bepalende factoren de excessieve hoeveelheid aanwezige gewasresten en de beschikbaarheid van werktuigen en informatie. De tweede toepassing (Guaymango, El Salvador) kent een wijdverspreid gebruik van CRM praktijken, voortkomend uit een substantiële produktie van gewasresten, verenigbaarheid met het bedrijfssysteem, en de succesvolle combinatie met andere produktiviteitsverhogende technologiën.

De detail studies onderstrepen de complexiteit van de CRM technologie, de plaatsgebonden *trade-offs*, en de mogelijkheden tot gedeeltelijke adoptie. De private opbrengsten van CRM adoptie waren in het algemeen beperkt - het resultaat van relatief matige baten en hoge kosten. De studies laten ook de invloedrijke rol van de institutionele omgeving zien en plaatsen vraagtekens bij de feitelijke beslissing tot adoptie - vele huishoudens lijken de technologie te hebben geadopteerd door specifieke omstandigheden. CRM is daarom een veelbelovende technologie, maar zeker geen panacee voor de bodemconservering in ontwikkelingslanden. De studies leiden ook tot een aantal gevolgtrekkingen voor het beleid, met name de noodzaak voor verdere technologie-ontwikkeling, het toespitsen en combineren van overheidsingrijpen, het verschaffen van informatie, een institutionele omgeving die adoptie mogelijk maakt en een participatieve en flexibele uitvoering.

De toepassing van het analytisch kader op verschillende manieren en in verschillende situaties laat een beoordeling toe. De verscheidene toepassingen genereren verschillende uitkomsten die correleren met waargenomen adoptie niveaus. Ze belichten daarbij het nut van de stapsgewijze expanderende analyse van de vele, samenhangende sociaal-economische factoren die de CRM-adoptie bepalen. Het analytisch kader leidt echter niet tot definitieve uitspraken betreffende de mogelijkheden en beperkingen van de CRM technologie. Wel geeft de analyse waardevolle inzichten ten behoeve van onderzoek, technologie-ontwikkeling en beleid in de zoektocht naar duurzame ontwikkeling.

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