

**Quantified and integrated crop and livestock
production analysis at the farm level**

Exploring options for land use of mixed farms on heavy limestone soils
south of Malang, East Java, Indonesia

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Stellingen

- 1 Huidig lage-externe input gerichte landbouw in het kalksteengebied van Oost Java, waarin inputs van buiten het bedrijf worden geminimaliseerd, is biofysisch niet duurzaam.
Dit proefschrift

- 2 Meer bomen, de introductie van opbrengstgerichte landbouwsystemen en meer vee ten opzichte van het huidig landgebruik bevorderen de biofysische duurzaamheid van Oost Java, in termen van het behoud van, voldoende plantaardige bodembedekking om de erosie op een laag niveau te houden, voldoende hoog organisch stofgehalte van de bodem en een gesloten balans voor de meest beperkende nutriënten.
Dit proefschrift

- 3 Meerlagige gemengde gewassystemen zijn ecologisch en sociaal-economisch beter dan éénjarige gewassystemen in de hoger gelegen gebieden van Java.
Palte, J.G.L., 1989. Upland farming on Java, Indonesia. A socio-economic study of upland agriculture and subsistence under population pressure. Nederlandse geografische studies 97. Amsterdam/Utrecht.

- 4 Het bewust overmatig voeren van vee in het kalksteengebied van Oost Java, om productie van compost te verkrijgen, is een strategie voor biofysisch duurzame landbouw.
Tanner, J.C., Holden, S.J., Winugroho, M., Owen, E. & M. Gill, 1993. Feeding livestock for compost production: A strategy for sustainable upland agriculture on Java. In: Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. J.M. Powell, S. Fernández-Rivera, T.O. Williams & C. Renard (eds.). Volume II: technical papers. ILCA. Addis Ababa, Ethiopia, p. 115-128.

- 5 De efficiëntie van nutriëntenstromen in lage-externe input gerichte landbouw kan worden verbeterd door de afstemming van het vrijkomen van nutriënten, met de vraag van nutriënten door planten in de tijd.
Swift, M.J., Frost, P.G.H., Campbell, B.M., Hatton, J.C. & K. Wilson, 1989. Nutrient cycling in farming systems derived from savanna: Perspectives and challenges. In: Ecology of arid lands. M. Clarholm & M. Berstrom (eds.). Kluwer, Dordrecht, Netherlands, p. 63-76.
Dit proefschrift

- 6 Het in- en uitlenen van grond en vee is een uitstekende lokale aanpassing op Oost Java aan de verschillen in beschikbare arbeidskracht tussen boeregezinnen.
Dit proefschrift
- 7 De bijdrage van vee aan de biofysische duurzaamheid van gemengde bedrijven op Oost Java is bij een lage veedichtheid minimaal. De rol van vee is meer die van spaarpot.
Dit proefschrift
- 8 De nutriëntenbalans van bodem-gewassystemen in het kalksteengebied van Oost Java kan niet in evenwicht worden gebracht met alleen mest; het aankopen van kunstmest is hier noodzakelijk.
Dit proefschrift
- 9 "Waar een wil is, is een weg" geldt vaak niet voor een interdisciplinair onderzoeksteam waarin onderzoekers, van zowel verschillende als dezelfde disciplines, een verschillende opvatting zijn toegedaan.
- 10 Het naast elkaar bestaan van vele modellen, die hetzelfde proces beschrijven, getuigt niet van bewondering voor elkaars werk noch van behoefte en drang tot samenwerking.
- 11 Veel teksten van door volwassenen verzonden kinderliedjes doen vermoeden dat wijsheid niet met de jaren komt.
- 12 Als duurzaamheid betekent het balanceren van "in's" en "out's" dan hebben wij voor een duurzame mentale balans naast kritiek evenveel complimentjes nodig.
- 13 De tijd die je in een eetgelegenheid moet wachten op je eten is evenredig met de prijs die je ervoor betaalt.

Stellingen behorend bij het proefschrift "Quantified and integrated crop and livestock production analysis at the farm level. Exploring options for land use of mixed farms on heavy limestone soils south of Malang, East Java, Indonesia".

S.L. Efdé, Wageningen, 26 april 1996.

Abstract

Quantified and integrated crop and livestock production analysis at the farm level.
Exploring options for land use of mixed farms on heavy limestone soils south of Malang, East Java, Indonesia - Efdé, S.L., 1996.

To develop adequate and sustainable land use plans, a clear assessment of the potential of the land and of the existing farming systems, as well as an identification of ways to attain these potentials is required. The agricultural system in the limestone area south of Malang is classified into different land units, land uses and livestock units. Land uses include a further distinction into agro-forestry system and annual crop. Simulation models are used as a tool to explore the production potential of crops and livestock. Existing crop simulation models are used and adjusted to the situation at hand. A new livestock simulation model is developed that includes major farm household influences, particularly the influence of land and land use on the feed resource and on livestock production. The model considers also the seasonality of feed availability; feed is quantified on a monthly basis. Two production orientations, with their specific technologies, were distinguished; low external-input agriculture (relying on manure only) and yield-oriented agriculture (relying on inorganic fertilizers only). The present crop and livestock productions are far below the potentials, as were explored with the simulation models. Constraints to agricultural production in the research area are high erosion, a low soil organic matter and a declining natural soil fertility. Hence options for land use are explored which focus on biophysical sustainability. The latter is defined here as avoiding excessive erosion, at least maintaining the present soil organic matter content of 2% and maintenance of a closed balance of the most limiting resource.

Systems with cattle, more perennials and yield-oriented agricultural systems leave more biomass than current cropping thus creating more cover, litter and mulch. An increase in the use of inorganic fertilizers seems the only viable direction towards more biomass production. Increased fertilizer use will improve the quantity and quality of crop yields as well as of crop residues for animal husbandry. Since 100% of crop residues never will be used in animal husbandry, effort should be made to return the left-overs to the soil in order to maintain or increase the soil organic matter content, i.e. better residue management. The extra manure both in terms of quantity and quality will also contribute to the latter goal. Finally, the higher soil organic matter content will improve the physical state of the heavy clay soils thus improving their water holding capacity, it will lower the soil's erodibility and improve nutrient use efficiency. So, use of inorganic fertilizers will trigger a cascade of effects that all point in the direction of a more sustainable use of the natural resources.

additional key words: crop production, livestock production, modelling, sustainability, erosion, soil organic matter, nutrient balance, Indonesia

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Chapter 1

General introduction

Over the past 20 years Indonesia's efforts in agriculture have been aimed predominantly at increasing the productivity of sawah land. The green revolution, the improvements of infrastructure, and the construction and rehabilitation of irrigation systems have all resulted in a spectacular increase in the production of rice in the lowlands. Uplands were given much less attention until recently. Uplands often have a lower agricultural production than the rice producing lowlands. The main reason for this low productivity of the non-volcanic uplands is believed to be the low soil fertility (Palte, 1989). Recently uplands and rainfed crops have received more attention since it was recognized that the vast majority of the upland area used for agriculture, and the vast majority of the upland farmers have been bypassed by previous 'green revolutions'. The Government of Indonesia would like to see agricultural development in the uplands similar to that in the lowlands. The question is whether such development is feasible since natural resources, infrastructure and socio-economic conditions vary greatly between lowlands and uplands. Therefore an interdisciplinary research project was started in one of the poorest uplands on the densely populated island of Java, the limestone area south of Malang.

Research was conducted from 1990-1992 in the limestone area south of Malang, at latitude 7°57'S and longitude 112°37'E. The research area is hilly to mountainous. It consists largely of volcanic deposits of early-miocene age over limestone bedrock. The slopes vary from relatively flat to very steep, and soil loss has occurred for a long time particularly where the land has been cultivated. Erosion is most intense on steep slopes where the soils are very shallow. Land use is characterized by the growing of annual crops in association with perennial crops either on valley bottoms or on hillsides. The land use systems differ from each other in spatial arrangements of the trees and in type of annual crops grown. Poor and degraded uplands in Java often have high migration rates, with people moving away temporarily or permanently to find work elsewhere. Many farm households in the southern limestone hills of Malang have members who earn their income outside the farm.

The research was conducted in two particular villages, Putukrejo and Kedungsalam, which are situated in the uplands of Malang district. The research concentrated on semi-subsistence farms that were small (< 1 ha), and that produced the major staple crops in the area, maize and cassava, and kept livestock. The climatic pattern is largely determined by the tropical monsoon cycle that divides a year into two main seasons, dry and rainy, with two short transitional periods in between. The mean annual rainfall for Malang was 1900 mm falling

on average in 100 rainy days.

The aim of this thesis is to determine whether and how, for heavy textured limestone soils on Java, it is possible to increase production and welfare on the one hand and to improve the sustainable use of the resource base on the other hand. Two hypotheses are underlying this study. The first one is that the soil base in this limestone area causes certain constraints to agricultural development that are difficult to overcome by presently known affordable technology. Hence, for this erosion-sensitive area a compromise must be found between an increase in production and farm income, and measures and rules that enhance the long-term sustainable use of the soil base. The second hypothesis is that the present practice of mixed farming offers the best opportunity for such a balance between development and sustainability.

The soil is one of the most important factors in maintaining the balance in the biosphere and therefore to sustainable development. Life and livelihood depend strictly on the capacity of the soil to produce, whether by agricultural or other practices. The soil is a natural resource, non-renewable in the short term or very difficult to renew, and expensive either to reclaim or to improve following erosion or physical and chemical depletion. Since the soil is a natural resource it is of utmost importance to maintain it for the future, as well as to obtain the best benefit from its use today. Therefore, research should be directed to the physical, chemical and biological aspects, as well as to those environmental and technical aspects that affect soil use (Stoops & Cheverry, 1992). Livestock is an integral part of the local farming system and performs a variety of roles, like providing meat, offspring, draft power and manure. The often complex but vital role played by livestock in regulating fluxes in the nutrient cycles is often ignored in experimentation and crop modelling exercises (Romney et al., 1994). The role of manure, an animal-related factor which can influence the dynamics of nutrient cycling in mixed farming systems, is of particular importance. Development programmes for farming systems with a livestock component need to reconsider their priorities and options in the light of the accelerating environmental degradation and increasing population pressure (Kaasschieter et al., 1992). For the study described in this thesis, crop and livestock production were examined together in order to explore options for land use which focus on biophysical sustainability.

It is evident that soil research must consider the capacity of the local system to solve problems. Soil heterogeneity in the research area justifies the need for research at farm level. In many areas land degradation is rapidly reaching an irreversible state and therefore action is required as soon as possible. In this context it is important to realize that efficient and sustainable soil use depends on the level of inputs brought to that soil and on the technology used in managing it.

Most soils in the research area have a heavy clay texture (50-85% clay) and an organic matter content that is too low compared to their clay content (< 2% organic matter). Hence, soil structure is poor (the soil structure is angular blocky with sharply-edged structure elements); soil tillage operations are difficult; root growth is hampered; water infiltration rates are low. Aeration in these soils seems insufficient to allow for high annual crop production

(Janssen, personal communication). The heavy clay texture of the soils is considered as the main technical obstacle to the improvement of agricultural production in the research area. An increase of soil organic matter in heavy textured soils affects the following:

- chemical soil fertility: Soil organic matter (SOM) has a critical role in buffering the effects of carbon and nutrients as a sink and source. SOM has the capacity to retain cations (K) and therefore the cation exchange capacity is increased, and hence leaching of cations is decreased.
- physical soil fertility: An increase in the water holding capacity and an improvement of the stability of soil structure decreases sensitivity to erosion. As a result of the improved aggregation of the soil particles, soil aeration also improves and plants can take up ions more easily.

In the research area the main effect of soil organic matter on soil structure is probably the improvement of soil aeration. Increasing the soil organic matter by adding large quantities of organic materials requires, annually, too much to be feasible. Therefore the farmers in the research area developed very labour-intensive cultural practices like the building of beds in order to avoid water logging and to improve soil rootability. Similar agricultural practices are also recommended by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) for Vertisol watersheds with average annual rainfall of 2000 mm. Guidelines were developed by ICRISAT for soil-, water-, and crop-management systems comprising planting, tilling, harrowing and fertilizing practices (Krantz et al., 1978; Chowdhury & Bhatia, 1971).

In the research area the soil physical problems, as previously mentioned, may also prevent possible yield increases upon fertilizer application. Soil constraints of heavy texture and low organic matter content, and climatic constraints, such as long-lasting dry periods and high-intensity rains, result in cracks, and waterlogging and erosion respectively. The steep slopes further aggravate the situation.

The question arises as to what scientists can do, and what they can do better than the farmers. More specifically, which recommendations can be offered to the farmers and how can such recommendations be derived. Solutions are sought for a change in the distribution of the restricted sources, a change in land use, or a change in inputs.

Outline of the thesis

It is argued in Chapter 2 that the only appropriate scale for this study is the farm scale, given the size of holdings and the complexity of the mixed farming systems with on-farm as well as off-farm activities. In the same chapter the new method that was developed for a more quantified analysis of farming systems, by the team of researchers of the project, is described. This methodology is only partly used in this thesis, since this thesis examines the biophysical production only, which includes the crop and livestock production in relation to the soil base.

The methodologies developed for data gathering, and a description of the general farm conditions in the two villages where field studies were undertaken, are presented in Chapters 3 and 4 respectively. Present crop and livestock production systems, yields and constraints are described in Chapter 5. Special attention is given to the synergetic opportunities of combining crop growth with livestock rearing. Chapter 6 touches upon the constraints and opportunities with respect to the soil base in this limestone area. Chapter 7 provides a quantified analysis of possibilities for enhancing crop production. Not only is the present situation analysed but various options for different technology and different production levels are explored. Chapter 8 does the same for livestock and includes the synergetic effects of mixed farming. Chapter 9 deals with the role of manure in regulating fluxes in the nutrient cycling in mixed farming systems. Finally, Chapter 10 quantifies a balance between an increase in production and welfare, and the improvement of the sustainable use of the resource base.

This thesis touches upon various disciplines like agronomy, soil science, animal husbandry and focuses in particular on their integration. Inevitably in this process subject matter is occasionally given that comes close to common knowledge in one discipline but is necessary to explain for other disciplines.

Chapter 2

Land use planning at the farm level

In developed countries, there is generally an excess of food made available by efficient agricultural production systems and policies (for example subsidies, tariffs and quotas). However, residues of fertilizers and biocides contaminate soil and water resources. Consequently, environmental issues are prominent in land use planning. In low-income regions, food security is the main reason for land use planning. Low food production in low-income regions is often caused, besides unfavourable climatic conditions, by the low productivity of traditional agricultural production systems developed by gradual evolution. Farmers in the research area practice a form of agriculture primarily based on the use of local resources with modest use of external inputs. Local resources include soil, water and vegetation, as well as local knowledge, labour and agricultural practices. External resources are technological inputs such as inorganic fertilizers, pesticides, hybrid seeds, tractors, irrigation systems, and information obtained from outside the area. Many low-income regions are over-exploited leading to degradation of the local resources (Stroosnijder et al., 1994).

Planning land use in low-income regions is done at several levels, from the national level, via the regional and the village, down to the farm level. The latter is important since it directly concerns the ultimate decision-maker, the farmer. A major reason for planning at the farm level is that the agrarian sector is endangered if production systems decline as a result of inappropriate technology. Production is increased by increasing the area cultivated or by increasing the yield per hectare. The first option has limited scope in the uplands of Indonesia. The latter is associated with increased inputs of capital and technology. Changes in production technologies are necessary; development policies must give incentives to producers to mobilize all resources, and create technical progress. This will eventually reduce the gap between yield levels obtained under traditional forms of production and the biophysical yield potential.

Planning at a specific level introduces space scale problems. An analysis at the farm level takes into account constraints that exist at the farm level, and not constraints that exist at higher levels. This may hinder identification of realistic development goals. However, it is possible to aggregate detailed, low level information, to a higher level. The reverse, describing individual farmers by disaggregating information from a higher level, is not possible. There are also time scale problems. Traditional technology may be used that was introduced long ago. This is established by studying secondary data sources. Present technologies are studied via detailed field surveys. A dynamic simulation of the farming situation can reveal whether

technical changes to the system hold promise (Stroosnijder & van Rheenen, 1993). Finally there is the problem of the data gathering. The lower the planning scale, the more detailed data are needed, and the higher the costs.

In this thesis land use planning at farm level examines the crop and livestock production systems in relation to their productivity and demand on natural resources. An increase in the production is necessary to ensure food security considering local and environmental constraints, and in order to avoid over exploitation and degradation of the natural resources.

Land Evaluation and Farming System Analysis

The term 'land use planning' is used here to indicate methods aimed at changing current land use in order to better meet set objectives. To enable weighing of objectives, science must provide quantitative information on the costs and effects of different alternatives. Two categories of studies focusing on the possibilities of future land use are distinguished: predictive studies and explorative studies. Predictive studies aim mostly at forecasting developments in land use on the short term, and descriptions of production technologies are based predominantly on present farming practices (Erenstein & Schipper, 1993; Sharifi, 1992; SOW, 1981). In explorative studies, the limits of the possibilities for sustainable land use in the long term are explored. Since the limits of the socio-economic factors change constantly, these studies focus on more or less stable limits, that is the bio-physical limits (WRR, 1992; Veeneklaas et al., 1991; Stroosnijder et al., 1994). As a result, descriptions of production technologies are based on experimental data or on estimates of the most efficient ways of production. Both types of studies can be complementary, but differ essentially in approach and objectives (Hengsdijk & Kruseman, 1993). Both are needed to set up a thorough land use plan.

Agricultural research institutions, particularly those in developing countries, increasingly recognize research of system approaches as a crucial and integral part of their research programmes. Farming systems research and development (FSR&D) is commonly referred to as "farmers oriented" or "bottom-up". Shaner et al. (1982) define FSR&D as "an approach to agricultural research and development that (1) views the whole farm as a system, and (2) focuses on the interdependencies among components under the control of members of the farm household and how these components interact with the physical, biological, and socio-economic factors." FSA is a crucial part of FSR&D. FSA studies structures and functions in farming systems, analyses the constraints on agricultural production at farm level, and translates its findings into adaptive research programmes (Fresco, 1988). The analysis of farming systems usually comprises a study of background information, an informal survey (rapid rural appraisal/sondeo) and a formal survey. FSA sets the research agenda and research priorities. Methodologies used in FSA are documented a.o. in Byerlee & Collinson (1980), Conway (1985) and Collinson (1987).

A land evaluation study as developed by the FAO (1976), also called a land suitability analysis, combines a study of land (properties) with a study of land use (requirements) and determines whether the compounded requirements of the defined land use are adequately met by the compounded properties of the land. The use of land is typified by a Land Utilization Type (LUT) which is characterized by its 'key attributes', i.e. by those biological, socio-economic and technical aspects of land use that are relevant to the functioning of the LUT. In practice, LUT's are described by (1) the crop selection, and (2) a set of non-physical attributes of land use describing the management/technology available to the producer and defining the limits within which management measures are taken. A Land Unit (LU) is described by its major 'Land Characteristics'. Such Land Characteristics are singular or compound. Singular Land Characteristics are straight forward properties of the land expressed in an explicit term or in a number. Examples include: the annual rainfall sum, the slope of the land, and the soil depth. Compound Land Characteristics are composed of associated singular characteristics, e.g. the soil moisture holding capacity. Those Land Characteristics, which together cover a basic requirement of land use, are aggregated and called Land Qualities. The expression of each Land Quality is determined by a set of interacting singular or compound characteristics with different weights in different environments depending on the values of all characters in the set.

Land evaluation studies and farming systems analysis are two methods often used to provide a land use planning study, predictive as well as explorative, with data. However these methods suffer from a number of inherent deficiencies that limit their usefulness as a tool for land use planning. Their weaknesses for land use planning are:

1. Comparability

The inability to compare quantitatively alternative land utilization types. In the FAO method, comparisons are only made within land utilization types. It is even disputable whether the suitability ranking of different land-mapping units for a given land utilization type is theoretically possible, because a land utilization type is defined by the required properties of the land. If the land differs, land utilization type, land use requirements and land characteristics must differ too (Johnson et al., 1994).

2. Quantitative

The failure to predict crop yield and develop objective relationships between biophysical criteria, crop productivity and management costs are serious limitations. What is needed instead are explicit quantitative methods, i.e. methods in which numerical parameters are used in calculation procedures to produce numerical results (van Diepen et al., 1991). One of the missing links for such a quantitative integration is a quantitative description of management practices. Almost without exception these are presently treated in a qualitative way. Quantitative information is needed on monetary, environmental as well as social costs (Johnson et al., 1994).

3. Livestock and land use relationships

Land evaluation studies are focused on crops through the definition of land utilization types in combination with land units. No link with livestock is made although livestock

often plays an integrated role with crops (Norman, 1978). FSA also puts too much emphasis on the technological crop possibilities in the planning area. This pertains to what is perhaps the major problem in farming systems analysis: the quantitative integration of crop and livestock information. Livestock research with a farming systems perspective is usually restricted to collecting masses of baseline data, in the mistaken belief that data-gathering is always useful (Morris, 1991), or to on-farm testing of new technologies without proper evaluation of existing technologies.

4. Bio-physical and socio-economic management practices

The FAO defines management practices as all human interventions into the bio-physical system related to agricultural and forestry production. In the FAO publications (1976, 1983, 1984) management practices are mixed with typical socio-economic aspects like availability of labour and capital, education, and prices in the land utilization type. In this way the reasons underlying the farmers choice for a particular set of cropping practices are disguised rather than elucidated. The bio-physical aspects of management practices and the criteria governing their selection by land users should be defined explicitly, but independently, as they are part of different sub-systems of the land use system (Fresco et al., 1989; Stomph et al., 1994).

5. Integration of bio-technical and socio-economic analysis

To facilitate the decision-making process, data for different land uses must be presented in a form which allows for the comparison between uses, based on some common measure of performance. This requires systems that include socio-economic variables in addition to biophysical elements. Such information provides the technical base which is required for the making of land use decisions by planners of the community (Fresco et al., 1989; Stomph et al., 1994). Although at the bio-physical side the mainly qualitative assessments are gradually being replaced by quantitative methods (van Diepen et al., 1991), and attempts are made to formulate procedures for a more balanced approach to both the bio-physical and the socio-economic aspects of land use systems (Fresco et al., 1989), the problem of quantitative integration remains as yet unsolved. The hierarchical approach in systems analysis in agriculture suggested previously (e.g. Fresco, 1986; Conway, 1987) has one major drawback: at the lower level mainly bio-physical criteria were used (e.g. cell-plant-crop) and at the higher levels mainly socio-economic or administrative criteria (e.g. village-district-country). The point in these hierarchies at which the criteria change from mainly bio-physical to mainly socio-economic and administrative is the only level at which relations between the bio-physical and socio-economic aspects of land use systems are explicitly treated (generally the farming system). In reality, however, socio-economic and bio-physical factors interact at various systems levels (Stomph et al., 1994).

6. Explorative analysis

Land evaluation studies lack the flexibility to reflect a changing technological and economic environment.

Although the weaknesses of both methods are elaborated extensively in literature no one has been able to overcome all points of criticism raised. For example, Johnson et al. (1994), presented a framework whereby both biophysical and economic factors affecting land use were included in the one assessment. They stated that a comparison of bio-technical and socio-economic analysis were most easily made when elements were expressed in dollar terms. Essentially the methodology was described as an economic approach to land evaluation. Although economic efficiency is widely promoted as the principal criterion for assessing options in resource use, the method presented by Johnson et al. (1994) excludes the evaluation of resource developments and policies with respect to multiple and often conflicting goals and objectives. In addition to direct economic comparisons, a number of other considerations play an important role in the planning process. These include existing land use and land tenure patterns, supply and demand relationships for outputs produced, land availability, regional economic indicators, potential environmental impacts, and community goals and expectations.

Stomph et al. (1994) presented a new concept for the description of management practices (called land use practices). Management practices were separated into their bio-physical aspects and their socio-economic aspects and only a format for the quantitative description of the first was given. Management practices were characterized by the crop(s) or livestock species to which they referred and the quantitative description of their constituent operations. Operations were defined by their mode of action on the bio-physical sub-system, generally identified by their name (e.g. soil tillage, herbicide spraying, fertilizer application), and five attributes: timing, applied material inputs (types and quantities), source of traction power (type and quantity), implements used (types) and types of output exported from the system (not the quantities). No answer is given by Stomph et al. (1994) to quantified relations between management and crop productivity. Hence, there is still an urgent need for a method for land use planning studies which overcomes the problems encountered above. Therefore a new method, QFSA, was developed by researchers of the project (Stroosnijder et al., 1994). New developments in research techniques permit the improvement of methodologies used so far. QFSA is a combination of Land Use Systems Analysis (LUSA) (Driessen & Konijn, 1992; van Diepen et al., 1989; van Lanen, 1991) and FSA. In the next section only that part of the QFSA approach is described which was used in this thesis for the quantified and integrated crop and livestock production analysis.

Bio-physical system analysis

The approach used, in this thesis, to optimize cropping and livestock systems, used the definitions of activities as their building stones. The approach did not consider socio-economic constraints, like ownership of the means of production, distribution of income and uncertain economic behaviour. A technology is a well defined production activity, whereby inputs are

converted into products. There are many technologies available, but not all are feasible in the physical environment of a given region. Technologies were selected that correspond with the prevailing physical environment and best promoted the development goals of the region and of other legitimate stakeholders. Activities represent production technologies that convert resources (inputs) into products or services (outputs). The resources included natural physical and biological resources that existed in the region and also inputs that were obtained from outside the region. Each activity is a set of coefficients (a vector) that relates all the relevant inputs of a specific production process to its outputs. The activity vector describes the input/output relations per unit of a relevant production factor. Thus, cropping activities were described in relation to the unit of land: livestock activities to the appropriate animal unit. The description of production processes via input-output coefficients enables integration of the crop and livestock activities.

A bio-physical system analysis examines the relation between inputs of production means and corresponding outputs of certain activities. The following information on a combined crop and livestock production system was required:

- actual and potential production levels for: (a) single cropping, e.g. cassava, maize on well defined land units, (b) intercropping, e.g. combinations of annuals with perennials on well defined land units and (c) animal species, in particular cattle, sheep and goats;
- the technologies applied for actual and potential production (agronomic methods, with specified fertilizer use, animal feeding tables);
- analysis of the reasons for the yield gap between potential production and actual production for relevant crop and livestock systems;
- specific measures to sustain crop and animal production potential (i.e. to avoid soil erosion and degradation, and to maintain the structure of soils).

The analysis started with the investigation of physical production potentials resulting in quantitative estimates of the potential production of defined activities. Such quantitative estimates were generated using crop growth simulation models (Spitters et al., 1989) and a livestock simulation model. Thereafter the required inputs of various means of production were defined for different production techniques. The cropping and livestock components of a farming system affected each other, both on the output as well as the input side. Crop and livestock activities were quantified independently, and during analysis interaction was guaranteed since inputs and outputs of both drew on the same bio-physical limits. The bio-physical output provided an estimate of total dry matter production and its distribution over different plant parts, as well as weight gain and milk production of animals. Also provided was an estimate of other outputs from the system, such as soil lost through erosion, nutrients leached, and an estimate of changes in the state of system components, e.g. changes in physical or chemical soil properties. The analysis ended with finding optimal land use considering the objectives of increase in soil organic matter, decrease of soil erosion, maintenance of soil fertility and food security.

Technical coefficients quantify the inputs needed and their corresponding outputs for each

activity. These were obtained through farming systems analysis, for production activities which were currently practised. For activities which were not yet practised in the region, the coefficients were generated and quantified by crop growth simulation models and an animal production model, or from available information from other sources. Although simulation models were useful tools during the analysis of the bio-physical sub-system, none were available as yet that dealt with the effects of pests, weeds and diseases and different management operations concurrently. The development of more comprehensive models combining specified operation sequences with crop growth modelling remains therefore a research priority. The resources of the region and the constraints varied with the properties of the various land units, and were defined. Other resources, e.g. the population of the region and its demographic composition, crop rotation constraints, and animal breeds and herd sizes in the region, were sampled by farming systems analysis and rural surveys.

The approach incorporated a large amount of general and local knowledge on actual and potential production techniques, regional physical resources and constraints. This made it possible to conduct an analysis of a dynamic planning process that explicitly took into account a large number of technical possibilities and regional interests. The analysis avoids the very complex problems associated with these aspects of development and allows for full, untrammelled analysis of a wide range of technically feasible development pathways including innovative, unexpected ones. As a consequence, the results may raise too optimistic expectations for development in a region. For instance, a desirable development may require common use of scarce resources, which is only possible through policy measures aimed at promoting or even forcing cooperation, and legislation is required to regulate such cooperation. Here the political dimension comes into play and the analysis can help to define the technical based benefits and costs that could motivate desirable change (de Wit et al., 1988).

Chapter 3

Research methodology

Field research for this study took place from 1989-1992 in Malang, East Java, Indonesia in the framework of an interdisciplinary PhD-training project (INRES). Integrated field research resulted in a common data base to be used for several special studies on: household decision making, quantified land evaluation, development scenario's (van Rheenen, 1995), perennials, animal husbandry systems (Ifar, 1996) and, for this study, the prospects of mixed farming for food security on the one hand and sustainable land use on the other hand. Results of the field research are presented throughout the following chapters.

Farm household surveys

Farm household surveys were conducted to collect information on farm resources, the activities performed by the members of farm households, and the inputs and outputs connected with these activities. A multi-visit Farm Household Survey (FHS) was conducted from October 1990 until February 1992 and included 35 households in the villages of Putukrejo and Kedungsalam, located in different agro-ecological regions in the limestone area south of Malang (Figure 3.1). These two villages were selected on the basis of landform and soil base. Putukrejo is situated on the most elevated part of the limestone range at an altitude of 500 meter above sea level where soils are relatively deep. Kedungsalam is situated in the lower part of the limestone range where altitudes range from 0 to 400 meter above sea level and soils have shallow to medium-depths. Soil characteristics are more variable in Kedungsalam than in Putukrejo.

The FHS concentrated on homogeneous groups of households, in line with current FSR&D philosophy, in our case on semi-subsistence farms that were small (< 1 ha), and that produced the major staple crops in the area, maize and cassava, and kept livestock. Farms with irrigated rice and sugarcane were excluded, because these crops were considered of minor importance. Every six days, the 35 FHS households were visited by enumerators who recorded all activities of household members and their inputs and outputs. Six day intervals were chosen to avoid bias from constantly interviewing households on the same day of either the week or the (Javanese) market cycle of five days (pasar). The survey disclosed:

- farm household information, in particular their use of resources for their various activities
- information on inputs and outputs of annual crop production on individual plots

- information on inputs and outputs of perennial crop production on individual plots
- data on labour use for on-farm and off-farm feed collection
- information on the use of draught power

Livestock composition, livestock dynamics, and volume and composition of feeds were monitored in separate surveys. Other separate studies concerned, for example, inventories of tree and perennial crops on all parcels, inventories of selected home gardens, soil surveys, inventory of farm household resources, rainfall readings and crop experiments. As the FHS progressed it became clear that many farm holdings were larger than initially thought because respondents cultivated more parcels than reported initially. It also appeared that some farmers did grow irrigated rice and sugarcane after all. Nonetheless 66% of the FHS households were categorized as small (operating less than 1 ha) and 17% as medium farmers (operating 1 to 1.5 ha). The gradual discovery of additional parcels among the sample farm households may serve as an example of the necessity of multi-visit surveys for achieving greater accuracy. Some of these additional plots, however, were cultivated for the first time. The "increase" in farm sizes was partly offset by the fact that farmers appeared to have overestimated the sizes of parcels during the preliminary survey. Farmers' estimates were on the average 159 percent of the parcel sizes measured.

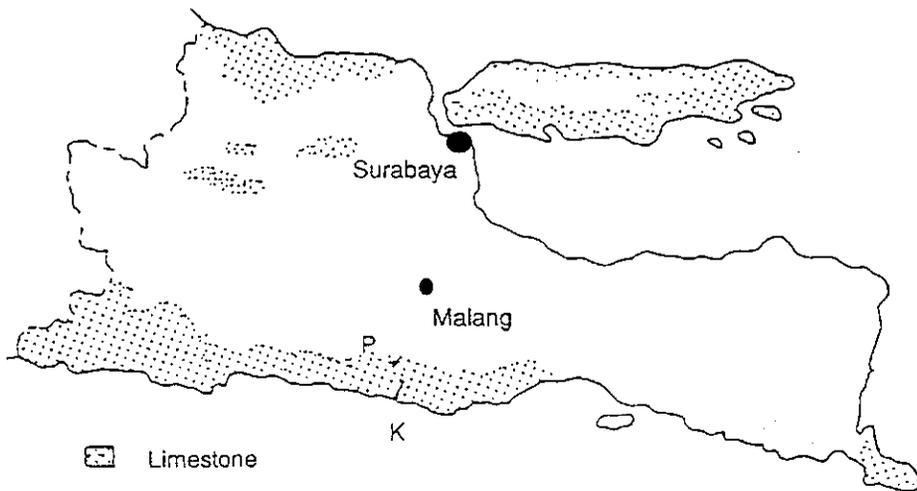


Figure 3.1 Location of the research villages Putukrejo (P) and Kedungsalam (K) in East Java, Indonesia.

Later on the absence of certain groups of farm households was deemed unacceptable, regarding the possible extrapolation of research findings to village and regional level. To make up for this, a single-round survey (SRS) was conducted in the course of 1992 and included 556 households. Out of these 556 households, 150 households were randomly chosen for an Expanded Farm Household Survey (EFHS). These 150 households were visited twice and questioned about inputs and outputs per activity over the same period in which the FHS took place. An inventory of the land resources was made during a separate field survey.

Field measurements

Weather data

Field experiments were conducted from 1990-1992 in the limestone area south of Malang, at latitude 7°57'S and longitude 112°37'E. Daylength at this latitude varied from 11h 55min to 12h 45min over the year. Daily weather data recorded in 1991 in Kedungsalam included hourly temperature (°C), maximum daily temperature (°C), minimum daily temperature (°C), precipitation (mm), relative humidity of atmosphere (-), sunshine hours (h) and calculated potential rate of evapotranspiration (cm d⁻¹). The meteorological station nearest to the research area was Karangates, at 285 m altitude, in the north of the limestone area. It provided data on daily mean air temperature (°C), daily maximum and minimum air temperatures (°C), air humidity (-), day length (h), baro-metric air pressure (mbar), wind speed (m s⁻¹), precipitation (mm) and open pan evaporation (cm d⁻¹).

Farmers fields

All fields operated by the farmers were studied in order to quantify the potential and the constraints for agricultural purposes from December 1990 to May 1991. A field was divided in plots if it was considered not uniform in land quality, or if more than one land utilization type (Chapter 2) could be distinguished. Field visits were carried out in cooperation with the farmers. Fields were mapped to state the shape, size and orientation of the fields as well as special features. On the basis of landform units recognized from secondary information, all identified plots were classified and the soil type determined in about two hundreds sites (augerholes observation). Information collected during this survey work included site information, e.g. location, landforms, slope, land cover, parent material, presence of stones, evidence of erosion, and the description of individual layers or horizons such as thickness of layer, colour, field texture, consistence. Classification of plots led to 12 selected sites for opening soil pits which were then described according to standard soil description (FAO, 1976).

Agronomy trials

Yields of maize and cassava were studied by monitoring on-farm yields and through two field

experiments. Crop yields of maize and cassava were measured in fields grown under local management practices. In the crop growing season 1990-1991 only cassava was sampled. In Putukrejo a total of 51 plots and in Kedungsalam 32 farm plots were sampled. In the crop growing season 1991-1992, 18 plots of cassava in Putukrejo, 14 plots of cassava in Kedungsalam, 24 plots of maize in Putukrejo and 32 plots of maize in Kedungsalam were monitored. At each plot 10 plants were harvested and the average planting density was measured. The fresh weight of the different plant organs was measured with a weighing scale, whereafter their dry weights were determined in the laboratory. These values were considered, together with soil survey information, to give average estimates of the yields per village and per land unit class.

In the first field experiment in 1990 crop growing performance and nutrient uptake was studied on plots with no fertilizer application, and those with a supply of nitrogen, phosphorus and potassium. The effect of fertilizer application on the yield of maize and cassava was compared for monoculture and intercropped maize and cassava. For maize, a hybrid variety was used and for cassava, a local variety. The experimental field used in Kedungsalam was situated at an altitude of 200 meter and located in a valley bottom, sloping to the south and terraced. The soils were deep, heavily textured throughout the profile and very slightly gravelly. Composite soil samples were taken at each plot before planting at 0-30 cm and 30-60 cm depth. These samples were analysed at the soil laboratory on mechanical composition (clay, silt and sand contents), organic matter content, pH, P-Olsen and exchangeable cations (Ca, Mg and K). Analysis of the soil samples were performed at the Department of Soil Science, of the University of Brawijaya in Malang.

Faroka is the most common cassava cultivar in the research area. It takes about 6 months from planting to maturity but the crop can be harvested till the age of 2 years. Arjuna, an improved selection of a traditional cultivar, is a yellow flint maize with a growing period of about 96 days. The planting date for both maize and cassava was 17 November 1990. The planting density for cassava was 1 plant per m² and for maize, 4 plants per m². At the day of planting, fertilizer was applied via broadcasting of 45 kg nitrogen per ha in the form of urea, of 30 kg phosphorus per ha in the form of triple superphosphate, and of 50 kg potassium in the form of potassium chloride. Another dose of 45 kg N was supplied 30 days after sowing and another dose of 45 kg N at 100 days after sowing, just after the maize was harvested. The experiments were laid out as a randomized complete block design, with no replicates. Maize plants were harvested 94 days after sowing and cassava plants 264 days after sowing whereafter the dry weight of the plant organs was determined (drying to a constant weight in a forced ventilated oven at 85°C). Results of this field experiment are presented in Chapter 5.

Field experiment 2 in 1991 in Putukrejo was used to study the effect of farmyard manure on the soil physical properties, soil fertility, and the growth and yield of maize and cassava intercropped. The experimental site had soil derived from volcanic material. The plot was located on top of a hill with a slope of 5 to 8 percent. The soil was deep, light clay textured. For maize the Arjuna cultivar was used, and for cassava the cultivar Faroka. Maize was

planted at a planting density of 4 plants per m² and cassava at a planting density of 1 plant per m². There were six treatment combinations:

1. no manure and no inorganic fertilizer
2. 10 t manure per ha and no inorganic fertilizer
3. no manure and inorganic fertilizer
4. 5 t manure per ha and inorganic fertilizer
5. 10 t manure per ha and inorganic fertilizer
6. 15 t manure per ha and inorganic fertilizer.

The manure applied was air dried but still contained about 15-20% moisture. The amount of inorganic fertilizers applied per ha were 135 kg N (urea), 20 kg P (triple super phosphate) and 50 kg K (potassium chloride). The manure was broadcasted and then incorporated in the top soil during the second time of ploughing. The first time of ploughing was performed by the farmer in August followed by the second time of ploughing in October. Urea was split into three applications of 100 kg each: 10 days, 40 days and 100 days after planting of maize and cassava, banded between cassava and maize rows. Triple super phosphate and potassium chloride were broadcast just before planting. The experimental design was a modified randomized block design. There were replications, subsampling within a plot was used as the replication in the statistical analysis. The planting date for both crops was 13 November 1991; maize was harvested 90 days after planting, and cassava, 10 months after planting. Chapter 5 gives the results.

Inventory of perennials

Perennials were defined as plants with a lifecycle of more than 2 growing seasons. They included trees, shrubs, bamboos and bananas. An inventory was made in which all individual perennials per plot, per parcel and per farm were recorded. Recorded data were: species, location, total height and diameter at breast height (dbh). The species were determined by local enumerators. Location of the perennial was recorded with the following possibilities: located on the edge of the terrace, located on the border of the parcel, located on the field, located and arranged in a fence. The total tree height was measured with a 5 meter long aluminium stick. Heights above 5 meter were measured with a clinometer. Tree girth was measured at 1.30 meter with a girth tape. Girths were divided by pi (3.14), in order to obtain the diameter at breast height. All stems which originated below 50 cm above the ground from one stem were measured. Then the mean dbh was calculated by taking the square root of the sum of the squared diameters: $dbh = (\text{dbh}_1^2 + \text{dbh}_2^2 + \dots + \text{dbh}_n^2)^{0.5}$. Although Robinson and Thompson (1988) did not recommend the transformation of multiple stems in one for research on stem, branch, foliar and total biomass, as it disregards the stem multiplicity, no better alternative was available. For non-woody perennials (bananas and papaya) the diameter was not measured. The results are given in Chapter 5.

Light measurements

Light availability for annual crops grown in combination with perennial crops, was quantified and used as input in annual crop growth models. Light measurements were only needed for those plots which were cultivated with perennials. The spatial arrangements, tree density and species composition of the perennial vegetation differed considerably, and had a different impact on the amount of intercepted radiation and transmitted radiation. The different vegetation types present on the land of the 35 respondents were classified in perennial classes based on the tree inventory data. The fields were divided in homogeneous units or land utilization types. Representative fields were selected in such a way that all perennial classes were covered. The row direction for a row of trees was taken into account. A unit differed if the row direction differed, as light interception depended on it. During the measurements, the homogeneity of the units was evaluated. If the variation in fraction light intercepted was too high, the unit was considered not homogeneous enough and was either split up or left out of the sample.

The fraction of transmitted radiation was measured under the canopies and in the open field at the same time. It was assumed that the fraction intercepted was 1 minus the fraction transmitted. Reflected values were not measured because measurements above the canopy were not possible. Measurements were performed with a Sunfleck Ceptometer and a Kipp Solari/Pyranometer. The Ceptometer (Decagon Sunfleck Ceptometer model SF-80) was used for measuring transmitted Photosynthetically Active Radiation (PAR) under the canopy or in the field under shadow influence. The Ceptometer measured only the PAR (PAR 300-700 nm) in $\mu\text{mol m}^{-2} \text{s}^{-1}$ and the values were direct readable. The Solarimeter was used to measure the reference value in the open field, as approximation of above canopy measurements. The solarimeter was connected with a datalogger (squirrel) to display the values. These were given in mv on a channel with a range of (-20) - (+20) mv and a resolution of 10 uv. Because both instruments measure different parts of the radiation waveband they were calibrated first with each other. The Solarimeter itself was calibrated first (in a meteorological institute "Badan Meteorologi dan Geofysika" in Jakarta) whereafter it was calibrated with the Ceptometer, to relate PAR measurements with the global radiation.

The fields of the farms were measured according to a grid of 5 * 5 m. The coordinates of this grid were the same as the ones used for an already existing database of the trees. Before the measurements were done small sticks were placed every 5 m. The fields were measured three times a day because the sun angle varies over a day and therefore also the amount and place of shadow on a field. The values of morning, midday and afternoon were integrated to find a value for the daily mean. The PAR readings were done by turning around in a circle and taking 20 readings which in the end were averaged (Decagon manual). Chapter 5 gives the results.

Animal feeding

The amount of feed offered to the animals was monitored in 1991 (Ifar, 1996). Once a month the amount of feed collected, per type of feed, was recorded at 7 cattle farms in Putukrejo,

6 cattle farms in Kedungsalam, 2 sheep farms and 6 goat farms. During a visit the fresh amount of feed collected was weighed for every fodder species, the source of the species was registered (either on-farm or off-farm) and the type of plant organ fed to the animal was recorded (e.g. stems or leaves). Samples were taken for analysis. The quality of the individual feeds, in terms of organic matter, crude protein and digestibility, was determined in the laboratory of the Department of Animal Husbandry, University of Brawijaya, Malang.

Chapter 4

The research villages

The villages (*desa*) Putukrejo and Kedungsalam are situated in the uplands of Malang district (*kabupaten*) about 50-60 km south of the city of Malang (Figure 3.1). Putukrejo is part of sub-district (*kecamatan*) Kalipare, and Kedungsalam is part of sub-district Donomulyo, the most south-western *kecamatan* of the *kabupaten*. Kedungsalam is made up of four sub-villages (*dusuns*): Krajan, Summersih, Sumbermanjing and Ngliyep. Demographic data for Putukrejo and Kedungsalam are listed in Table 4.1. Putukrejo counted 3740 inhabitants in 1980, which suggests that the population of Putukrejo had grown at a net rate of 0.48 percent per year over 10 years. Kedungsalam counted 9305 inhabitants in 1980. The population of Kedungsalam had thus grown at a net rate of 0.81 percent per year over 10 years. Both villages were less densely populated than the overall for eastern Java which was 992 people per arable square km. Poor and degraded uplands in Java often have high migration rates, with people moving away temporarily or permanently to find work elsewhere. Transmigration, the resettlement of people from Java to the other less densely populated Indonesian islands, was until recently greatly encouraged by the central government, particularly in poor upland areas to relieve these areas from their state of overpopulation. The populations of Putukrejo and Kedungsalam are ethnically almost entirely Javanese with only a small group of Madurese families. Almost all are Muslim, except for a small group of Roman-Catholics that have their own church in Ngliyep, close to the coast.

Table 4.1 Demographic data of Putukrejo and Kedungsalam (Census Penduduk, 1990).

Characteristic	Putukrejo	Kedungsalam
number of households	953	2366
number of males	1917	5119
number of females	2005	4972
total number of people	3922	10091
area size (km ²)	8.18	33.56
Average family size	4.12	4.27
population density (km ⁻²)	479	301
growth rate (% y ⁻¹)('80-'90)	0.48	0.81

The research area is connected with the central basin of Malang district, and with Malang town to the north east, and with Blitar to the east, by two asphalt roads. Putukrejo lies off the main road. Village roads, some unpaved, some of cobblestones, connect its various hamlets with the main road. Two of the hamlets of Kedungsalam are situated along the asphalt road; its other hamlets and scattered houses are connected with village roads as well. Putukrejo lies 4 kms from the subdistrict town, Kalipare, and 50 km from Malang; Kedungsalam is situated at 7 km distance from subdistrict centre Donomulyo and 65 kms from Malang. Most of the village roads to third level villages (*dukuh*) can only be used by four-wheel drive vehicles (including small trucks). Footpaths are also open to motorcycles, although during the wet season, some of them become impossible to traverse. Public transport is provided by regular minibuses.

The subdistrict centres of Kalipare and Donomulyo have a market once every five days. Products are sold to consumers and farm produce is collected by traders. Livestock is traded as well. Kedungsalam has only a small market. In 1991, farmers were able to sell much of their agricultural produce, such as *gaplek* (dried cassava) (45%), banana (50%), coconut (50%), and kapok (75%), to small local traders (van der Molen & Schultink, 1994). The traders may come to the farmers, or the farmers may take their products to them. There is another group of traders who visit outside markets, but most traders operate on local markets only. Marketing was not studied in depth, but the impression existed that it functioned quite efficiently.

The research villages fit under the Pagak Extension Office (BPP Pagak) located in a neighbouring subdistrict. Extension work in the two villages was virtually limited to advice to farmers who grew rice (by government extension officers (PPL)), or sugarcane (by Kebon Agung sugar factory near Malang town). None of the FHS respondents was ever in personal contact with an extension officer. Most innovations already adopted in the area, such as the planting of *gliricidia* and other tree species, the use of inorganic fertilizer, and the cultivation of improved rice and maize varieties, have spread through informal contacts between neighbours, and relatives.

Many farm households in the southern limestone hills of Malang have members who earn their income outside the farm (off-farm income). 'Off-farm labour' and 'limestone burning' are area-specific activities. Off-farm labourers work on sugarcane fields of large farms in Putukrejo, whereas limestone burning requires wood and labour which are abundant in the village Kedungsalam. Limestone burning is so lucrative that at the time of this study wood was imported into the southern region. Some people hire out their kilns, which enables them to build larger kilns and to employ more people. Many, especially young people, migrate from the area to towns and cities; some leave for schooling, but most go to Jakarta, Surabaya or Malang to work as *bakso* (soup) sellers, *becak* drivers, servants or factory workers. Some even migrate to Singapore or Saudi Arabia.

Sugarcane was introduced only recently and has quickly become an important cash crop. Expansion of the sugarcane area into the limestone hills is part of a general shift of sugarcane

cultivation from the lowlands to the uplands after a law was passed by the Indonesian government stipulating that all irrigated lowlands were to be planted to rice. This measure was intended to make Indonesia self-sufficient in rice production (Edmundson & Edmundson, 1983). Better land, larger parcels and farms, a shorter distance to the sugar factory, better infrastructure and a better market structure, explain why sugarcane cultivation had been restricted to the Northern part of the research area.

Farm resources

The research area is hilly to mountainous. It consists largely of volcanic deposits of early-miocene age over limestone bedrock. The slopes vary from relatively flat to very steep, and soil loss has occurred for a long time particularly where the land has been cultivated. Erosion is most intense on steep slopes where the soils are very shallow, Lithosols over limestone bedrock. On the less-steep slopes, where erosion is less severe, most soils are still very deep. The washed away soil materials are partly deposited at the valley bottoms where they form very deep soils mostly with a heavy clay texture.

Table 4.2 gives an overview of the distribution of farm sizes by households included in the EFHS. The average farm size in Putukrejo was 0.72 ha and in Kedungsalam 0.99 ha. Holdings in the area were large by Javanese standards. The average farm size on Java was 0.63 hectare in 1983 (BPS, 1986). In Kedungsalam, farms were on average larger than in Putukrejo, possibly due to the different soil physical conditions in the two villages.

Table 4.2 Average household size, household work force and number of households per farm size class for Putukrejo and Kedungsalam.

Farm size (ha)	Household size		Household labour units		No. of households	
	Putukrejo	Kedungsalam	Putukrejo	Kedungsalam	Putukrejo	Kedungsalam
> 1.50	4.3	4.5	3.3	3.6	7	18
1.01-1.50	4.7	4.2	3.2	2.9	3	22
0.51-1.00	3.7	4.2	2.7	3.1	16	31
< 0.51	3.6	3.7	2.5	2.6	18	28
landless	4.8	4.0	3.1	2.0	5	1
Total					49	100
Average	3.8	4.1	2.7	3.0		
Average farm size (ha)					0.72	0.99

Households were defined as families who lived together and shared their resources as well as their produce. Households were defined in much the same way by the village administration. Determining those who are regarded as household members posed a problem. Definitions requiring a minimum period of residence with the household proved impractical, because of frequent departures and arrivals of people. All family members who participated in household activities and lived with 'their' household were considered household members. Their coming and going was recorded for labour availability calculations.

The average number of individuals per household during the survey year was calculated using weighing factors. Each individual was given a participation factor (between 0 to 1) in accordance with the length of his/her stay with the household during the survey year. The family size thus found was 3.8 persons for Putukrejo and 4.1 persons for Kedungsalam (Table 4.2). If the labour potential of a household is assessed, it is customary to express the labour capacity of each of its members in household labour units (HLU). One HLU is the labour equivalent of one adult worker. In this thesis adult workers were defined as persons from 15 to 60 years old. Children from 10 until 15 years and aged people of 60 years and older were assigned a value of 0.5 HLU. Children younger than 10 years were not counted as part of the household work force (FAO, 1984). The average labour potential for EFHS households was thus calculated at 2.7 HLU for Putukrejo and 3.0 HLU for Kedungsalam. Evidently, this measure gives only a rough estimate as it does not take into account differences in labour quality between individuals.

Land quality varied greatly, not only between farms, but also within farms. According to the criteria for general annual crops developed by the Soil Research Centre in Bogor (1983), larger farms appeared to include a greater share of land that was unsuitable for growing upland annual crops (Table 4.3). The following parameters were taken into account: effective soil depth, stoniness and slope gradient. Any soil with an effective depth of less than 25 cm, more than 50 percent stoniness, and a slope greater than 8 percent was classified as "not suitable". The slope criterion, however, seems unrealistic. It probably does not apply to terraced land. Holdings in Kedungsalam compared less favourably with holdings in Putukrejo, which were consistent with the general differences in physical conditions in the two areas.

Table 4.3 Proportions of land (%) in Putukrejo and Kedungsalam, unsuitable for annual upland crops, per farm size class.

Farm size (ha)	Putukrejo	Kedungsalam
> 1.50	55	70
1.01-1.50	35	68
0.51-1.00	41	46
< 0.51	16	39
Average	45	64

Weather data

The climatic pattern is largely determined by the tropical monsoon cycle that divides a year into two main seasons, dry and rainy, with two short transitional periods in between. The rainy season starts in October or November and ends somewhere between April and July. The average monthly temperature values for Karangates over the period 1981 to 1988 are listed in Table 4.4 together with the temperature values of Kedungsalam between November 1990 and October 1991. Table 4.4 shows that the mean daily temperature in Karangates varied from 24.8 to 26.5 °C and in Kedungsalam the 24 hour temperature varied from 25.2 to 29.9 °C. The temperature variation in the research area will not constrain crop growth. Table 4.4 shows that incoming solar radiation was lowest during the wet season (from December to March), and highest near the end of the dry season (August to October). The intensity of radiation fluctuated over the day and was different for different layers in the canopy.

Annual rainfall in Malang, recorded from 1973 to 1990, varied from 1130 mm to 2700 mm, with 62 to 147 rainy days. The mean annual rainfall for Malang was 1900 mm falling on average in 100 rainy days. Annual rainfall in the research area was high (1130 to 2700 mm) but the distribution of rainfall varies strongly over time. Table 4.5 shows the average monthly rainfall sums of Karangates and Malang, and monthly values recorded in the

Table 4.4 Daily average temperature data of Karangates (285 m: 1981 - 1988) (Proyek Brantas, 1989) and Kedungsalam (200 m: November 1990 - October 1991) (INRES project), and daily radiation data of Malang (500 m: 1973 - 1990).

Month	Temp. Karangates (°C)			Temp. Kedungsalam (°C)			Radiation (MJ m ⁻²) Malang
	T24H	Tmax	Tmin	T24H	Tmax	Tmin	
January	26.0	31.4	21.7	26.9	31.9	21.8	11.5
February	25.8	31.8	21.2	29.9	31.9	22.0	12.1
March	26.1	32.0	21.7	28.2	34.7	21.8	14.5
April	26.2	32.4	21.0	28.0	33.8	22.1	15.6
May	26.0	32.3	20.7	27.4	33.9	20.9	16.5
June	25.3	31.5	20.5	26.7	33.5	19.9	15.8
July	24.8	31.3	19.8	25.9	32.2	19.6	16.2
August	25.2	31.5	19.8	25.2	30.3	20.1	17.6
September	25.9	32.1	20.5	26.3	32.0	20.6	17.6
October	26.5	32.5	21.4	27.0	32.6	21.4	17.4
November	26.2	32.2	21.5	27.1	32.2	22.0	15.8
December	25.8	31.5	21.5	27.1	32.3	21.9	13.4

Tmax and Tmin are recorded; T24H = ((day1 * Tmax) + (24 - day1) * Tmin) / 24

villages Putukrejo and Kedungsalam in 1991. Especially in Kedungsalam, the total rainfall in the year 1991 was lower than average; therefore 1991 was 'a dry year'.

Land units

Farmers operated one or more different pieces of land or parcels. Homogeneity of parcel distribution in the research area is outlined in Figures 4.1 and 4.2. Figure 4.1 shows the number of parcels in each parcel size class in the research area. The number of small parcels (< 1 ha) was far greater than the number of large parcels (> 1 ha). When a homogeneous parcel distribution is identified, the result of number of parcels multiplied by the size of the parcel class (ha) should on average result in equal total parcel sizes per parcel class. However, such a relation was not identified in the research area (Figure 4.2). Most of the land in the research area was found in small parcel sizes and only a small part of the area was seen as large parcels. In the research area 56 % of the farm households operated landholdings smaller than three quarters of a hectare. The average farm size for the entire survey area was 0.84 ha.

Table 4.5 Monthly rainfall sums (mm) at Karangates (285 m; 1981 - 1988) (Proyek Brantas, 1989), Malang (1973 - 1990) and Putukrejo and Kedungsalam (1991).

Month	Karangates	Malang	Putukrejo	Kedungsalam
January	314	319	311	411
February	261	296	256	328
March	296	235	291	108
April	191	164	176	182
May	122	112	139	17
June	116	47	70	3
July	15	32	36	8
August	17	17	27	15
September	64	44	46	48
October	138	100	126	49
November	249	206	191	127
December	294	299	263	299
Total	2077	1872	1932	1595

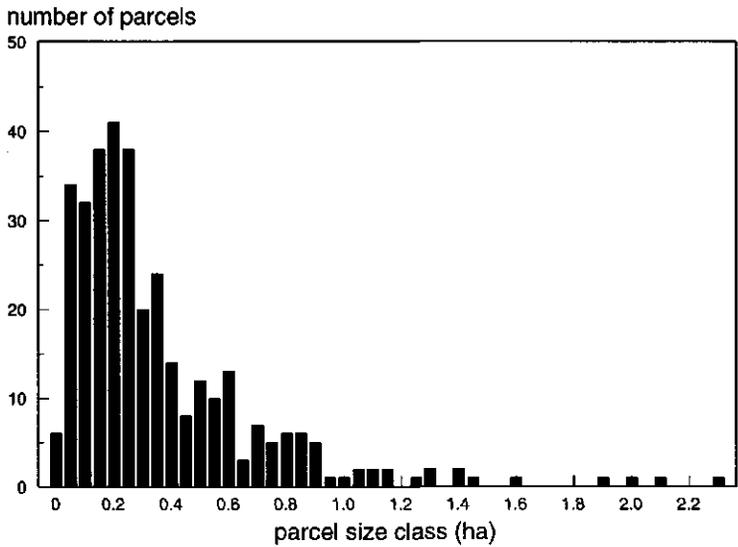


Figure 4.1 The number of parcels per parcel size class (ha) for the combined villages Putukrejo and Kedungsalam in East Java, Indonesia (EFHS).

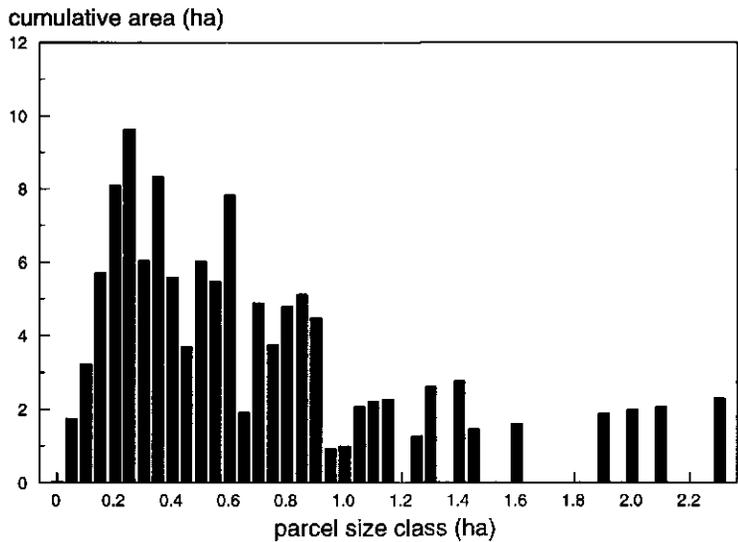


Figure 4.2 Cumulative areas of parcel size classes for the combined villages Putukrejo and Kedungsalam in East Java, Indonesia (EFHS).

As mentioned earlier a parcel was divided in subparcels if it was not uniform in land quality or if more than one land utilization type (LUT) was distinguished. In the research area, 84%

of all parcels were homogeneous, 15% of the parcels were divided in 2 subparcels and only 1% were divided into 3 or 4 subparcels. In the first instance 24 land unit classes were distinguished based on soil physical as well as soil chemical characteristics, such as: soil depth, soil texture, pH, organic C, total N, C/N and macro and micro nutrients. Since 24 land units were too detailed, and some land units contained only 1 plot, a broader classification was required. In Chapter 1 it was already mentioned that under cultivation, soil heterogeneity may decrease due to the mixing action of soil tillage operations, and increase as a result of terracing, localized fertilizer application, and differences in the rates of application of inorganic fertilizers and manure. Results of a study on spatial variability (van Dongen, 1991) showed that the net effect of farmer's activity in the research area was an increase rather than a decrease in soil heterogeneity. Chemical soil properties change, within one season, more easily than physical soil properties, and are therefore more heterogeneous. As a result the land suitability assessment for each parcel or subparcel was only judged by five soil physical land variables. Since weather conditions do not vary between LU's, the five land variables observed or measured for each subparcel were: soil depth, soil texture, degree of terracing, slope and position. Farmers landholdings were thus classified in four major types of LU's (Widianto, personal communication) (Table 4.6).

Much of the research area was qualified as land unit 2 or land unit 4, and only small parts were classified as land unit 1 or land unit 3. In limestone areas, erosion products from elevated parts accumulate on flat to gently sloping foot slopes and in valleys where very deep clay soils occur. This explains why the above land units occurred adjacent to each other in catenas. Land unit 1 was found in valleys and land unit 4 on hill crests. In such hilly to mountainous terrain, land units were small in extent. There was a strong correlation between the land variables slope, soil depth and stoniness. With increasing slopes, the soils became shallower and stony.

Table 4.6 Characteristics and distribution of LU's for the combined villages Putukrejo and Kedungsalam in East Java, Indonesia (data from EFHS).

	Land class			
	LU1	LU2	LU3	LU4
Soil depth (cm)	>75	>75	50-75	<25
Soil texture ¹	+++	++	+	-
Terracing ²	+++	++	+	-
Slope (%)	<3	3-50	15-50	>50
Position	valley	slope	upper slope	hill crests
Distribution (ha)	21.62	52.28	19.45	40.24

¹ Soil texture: heavy clay with no stones (+++) to clay with many stones (-)

² Terracing: fully terraced (+++) to not terraced at all (-)

Land use

Intercropping of maize (*zea mais*) and cassava (*manihot esculenta*) is the most widely applied cropping system in the uplands on Java. Reasons for intercropping include risk aversion, spreading of food supply, and adjustment of the cropping system to local soil conditions. Indeed, most of the research area was cultivated under maize and cassava (Table 4.7). The area under *sawah* (i.e. banded field in which water, through irrigation or rain, is impounded for rice cultivation) was very small. Other crops grown in the area were rainfed rice (*oryza sativa*) and sugarcane. Groundnut (*arachis hypogaea*), soybean (*glycine max*), chili (*capsicum annuum*), taro (*colocasia esculenta*), vegetable crops and cowpea (*vigna sinensis*) were found incidentally. Sugarcane was grown for commercial purposes, especially on larger farms in the *desa* Putukrejo.

Farms in Kedungsalam contained patches of sloping land that was once planted to annuals but was now left fallow (*bongkoran*), either covered with shrubs and grasses, or planted to firewood and timber trees such as gliricidia (*gliricidia maculata*) and teak (*tectonia grandis*). The productivity of such land for annual crops has declined over the years due to nutrient depletion and erosion. Producing timber and supplying firewood for the local lime burning industry has become a good alternative use. Around 35 % of the farmland included in the farm household survey in Kedungsalam was made up of such fallow land, with or without trees. This was less than one % in Putukrejo.

Table 4.7 Land use distribution (ha and %) in the research area in 1991 (EFHS, 1992).

Land use	Putukrejo	Kedungsalam	Total	%
sawah	2.7	9.2	11.9	9
maize+cassava	12.7	33.5	46.2	35
sugarcane	15.4	0.5	15.9	12
upland rice	0.7	4.2	4.9	4
total annuals	31.5	47.4	78.9	60
fruit/perennials	0.2	0.1	0.3	-
bongkor	0.1	34.8	34.9	26
forest	0	5.5	5.5	4
total perennials	0.3	40.4	40.7	30
homegarden	3.5	10.5	14.0	10
Total	35.6	98.3	133.6	100

Nearby state forest land is largely under plantation forest managed by Java's state forest corporation, Perum Perhutani. For the reforestation of forest land, Perum Perhutani devised the so-called 'tumpangsari' system, under which local people grow annual crops on plots, of on average 0.25 ha, for a period of three to four years in return for clearing the plots, planting and maintaining trees. In addition farmers are expected to share their crop produce with forestry personnel. The forest area is generally regarded and used by the population as communal land. As such, it represents an important off-farm resource. Many go there to collect fodder, firewood, teak leaves and even timber. Fishing in the nearby sea (3 km from the southernmost hamlet of Kedungsalam) is rare, perhaps because safe harbours are scarce.

Land with crops around the house lot is called homegarden or *kebun*. A house lot is called a pekarangan referring to the entire plot including the area occupied by dwellings and stalls. On average, landholdings of the FHS respondents in Putukrejo and Kedungsalam consisted of 3.8 and 3.0 parcels respectively, including the pekarangan. Parcels are sometimes situated at a great distance from the respondents house, particularly the forest plots (up to 15 km). This affects the intensity of land use and crop management.

Annual cropping practices

Figure 4.3 shows the most common cropping patterns in the research area. On "tegal" (non-irrigated agricultural land), maize is grown at the start of the rainy season, from October to December, and early in the second season from February to May. If water availability permits, maize is again planted in June. Water availability determines whether maize is planted as a monocrop or in a mixture. In circumstances where sufficient water is available throughout the growing period, maize is normally planted as a single crop, whereas maize is interplanted with cassava or grain legumes where water availability decreases. Most farmers tend to grow maize as an intercrop because water availability in the second half of the rainy season is insufficient to grow a second crop of maize. In 1980 the improved maize variety Arjuna was released (Soetarjo et al., 1986). Yields of Arjuna grown by farmers in the research area remained low and did not exceed 2.2 t ha^{-1} when grown under traditional management practices. At an experimental station, Arjuna matured in 96 days; its plant height was 130-200 cm, the yield amounted to 5-6 t ha^{-1} and the 1000 grain weight was 272 g.

Cassava is grown almost exclusively on tegal. Average yields of 9 t of fresh tubers were obtained; the yields varied from 5 to 17.5 t. Yield potentials of improved varieties reportedly reached fresh tuber yields between 19 and 25 t ha^{-1} (Soetarjo et al., 1986). Cassava fits well in most mixed cropping systems. The time of planting is often dictated by the soil-water status and by the tolerance to shading of the other crops in the mixture. Cassava grows well during periods with less rainfall when other crops perform poorly, requires little labour, and has no specific harvesting age. Cassava is often grown in combination with upland rice (dry sown rice), maize and grain legumes. Pure stands of

monthly rainfall (mm)

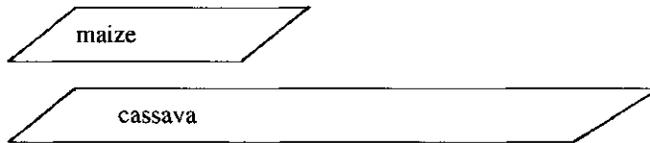
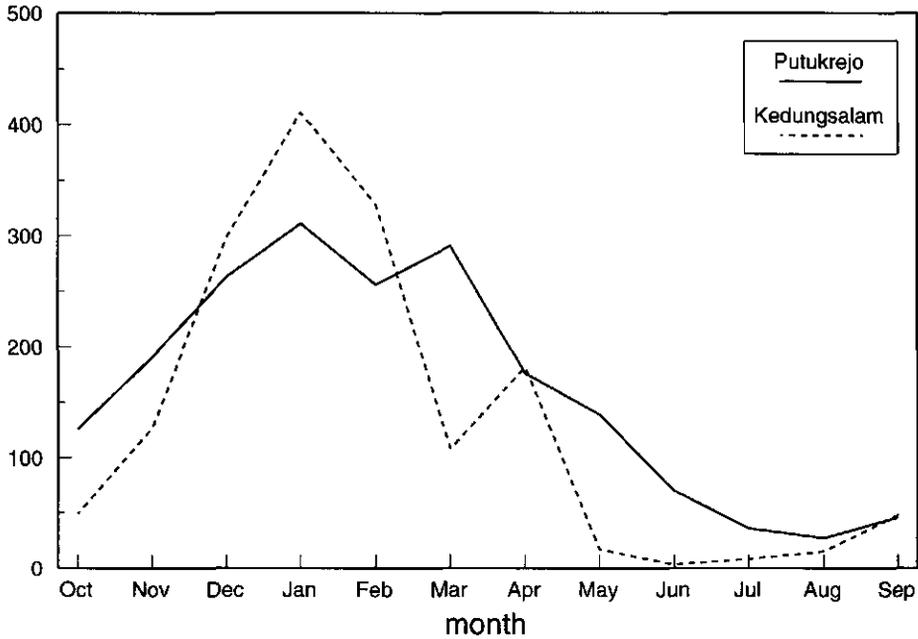


Figure 4.3 Rainfall and cropping patterns in Putukrejo and Kedungsalam, East Java, Indonesia.

cassava are usually confined to areas with poor soils and low or unreliable rainfall. Cassava is planted during the rainy season (October-January) and harvested at any time between 7 and 24 months after planting. In the research area, most cassava was harvested within one year. The need to clean and prepare the land for new crops at the onset of the rainy season dictates the harvest time.

Perennial cropping practices

The planting and management of trees, not only for fruit production but also for wood production, nowadays is an important element in farming in the research area. The number of trees has increased since the 1960's due, to the Regreening programmes, which aimed to

regreen the bare upland areas to combat erosion, but also by the demand of wood for limestone burning. They were funded by the governmental 'Inpres" (Instruksi Presiden) programme which was meant to give more opportunities for local development initiatives. Farmers who owned the land coming under the programme were simply instructed to participate, since it was regarded to be for their own benefit. The main species planted under the greening programme were: leucaena (*leucaena leucocephala*), acacia (*acacia villosa*), teak (*tectonia grandis*), mahogany (*swietenia macrophylla*) and acacia (*acacia auriculiformis*). The greening programme often showed low survival rates of planted trees due to adverse weather conditions, deficient plant material, unskilful planting, inadequate organization and the top-down nature of the entire approach. The most important, indirect contribution of the greening programmes, however, was that it enabled farmers to experience the performance and benefits of the trees, to observe its effects on annual crop cultivation, and to find out in what acceptable ways tree planting can be incorporated into the farming system. Although the planting of trees was compulsory in the beginning, it became a habit for those farmers who eventually came to acknowledge the viability and the advantages of tree growing. Furthermore, a stock of trees of preferred species had gradually built up, sufficiently large to produce seeds and seedlings for further tree propagation. The planting of fruit trees and other trees not primarily grown for their wood but for some other product had also expanded as a consequence of greater marketing opportunities, particularly *melinjo* (*gnetum gnemon*) and banana (*musa paradisiaca*). The introduction of higher yielding varieties of species already common in the area, such as kapok tree (*ceiba pentandra*) had stimulated farmers to plant more of them. Other fruit trees found in the area are coconut palm (*cocos nucifera*), jackfruit (*artocarpus integra*) and mango (*mangifera indica*).

In the research area the highest tree densities were found in the homegardens. The "pekarangan" comprised hilly terrain completely planted with wood trees, or valley bottom land cropped with staples. The pekarangan was used as a homegarden with wood and fodder trees and shrubs growing on the boundaries. The main tree species used for firewood or fodder were: turi (*sesbania grandiflora*), leucaena, leucaena (*leucaena glauca*) and gliricidia (*gliricidia maculata*). Fruit trees, wood trees and spices were grown in the gardens for household needs as well as for cash. In large homegardens moderate amounts of staple crops were found. Fruit trees were cropped close to the house to facilitate harvesting and protection from theft, and at the same time, produced shade. Many wood species were grown in the homegardens as well.

In the valley bottoms fruit trees such as coconut palm and breadfruit (*artocarpus communis*) were traditionally grown in the corners of the terraces, and bananas along the edges of the terraces. In addition to those, fruit species, such as *melinjo* trees, are now planted on valley bottoms, outside the homegardens. Rows of short rotation trees such as turi are grown across the terraces, while on the outer edges rows of timber trees have been planted. Apart from the terrace edges, however, most of the valley bottoms have remained free of trees to ensure optimum conditions for annual crop cultivation.

With the exception of bananas and papaya (*carica papaya*) very few fruit trees were grown on hillsides. Only a few were found on the lower parts of permanently cultivated slopes. Fruit trees are highly susceptible to water-stress which easily occurs on the shallow soils on the hillsides and they do not tolerate competition from fallow vegetation. The hillsides were the domain of the timber trees where about 75% of total wood volume of the standing stock was made by trees scattered over the plots and the remaining 25% by trees on plot boundaries. Trees on hillsides perform less optimally than on valley bottoms. Consequently, more trees and bigger trees were found on the edges of the valley bottoms and the lower parts of the hillsides, where the soil was thicker than upslope.

Farmers are very much aware of the competition for light, nutrients and soil moisture between trees and annual crops grown on their fields. They generally try to maintain a balance in the tree canopy, which differs from farmer to farmer and from plot to plot, depending on plot conditions and the farmers' needs and preferences. Thinning and pruning are regular operations to permit penetration of sufficient light to the annual crops and to provide farmers with firewood and fodder at the same time. Farmers often transplant seedlings, which are germinated in the middle of their fields to the boundaries, so as to keep the numbers of trees spread across the field at an acceptable level. Farmers generally considered a tree density of 200 trees per hectare acceptable in association with annual crop cultivation. In the greening programmes, however, densities of 400 trees per hectare were the aim. Firewood and fodder trees are usually cut after two years and replanted. They would otherwise cause too much shade for the crops on the valley bottoms. Trees producing construction wood such as teak and mahogany were cut after 10 sometimes 15 years. Timber trees are all constantly pruned to obtain firewood and fodder as well as to reduce shade.

Livestock

Cattle, sheep and goats are kept in the research area, often in combination. Cattle in the area are mainly local Ongole, which are kept for their meat, offspring, manure and draft power. Two types of goats occur: local goats, predominantly of Kacang origin, and Etawah-grade goats with substantial influence of Jamnapari goats from India. Both types are kept for their meat only. The most common sheep breeds are the "Javanese Thin tailed" and the "East Java Fat tailed". The preference for particular types of livestock is partly explained by socio-economic factors. Aside from their direct functions in the farming system, such as providers of manure and draft power, animals are predominantly kept to obtain funds either for planned transactions or for contingencies. Some farm households not only tend their own animals but also those of others. Stallfeeding is common practice, with most feed collected by household members. Part of the feed is produced on farm but much is obtained from outside the farm. Feeds include residues of annual crops, grasses, weeds and tree leaves, particularly gliricidia. Concentrates are not fed nor is forage cultivation practised (Efdé & van Rheenen, 1994).

Table 4.8 shows that many farmers (42%) kept only cattle, as a type of livestock, on their farm, besides their crops. Twenty seven percent (27%) of the farmers did not keep animals at all. A few farmers kept only goats (10%) or sheep (6%), or a combined herd of cattle and goats (9%) or sheep (6%). The total number of cattle was three times greater than the number of sheep and two times greater than the number of goats. On average, one cattle, half a goat and one-third sheep was available to a farm household in the area. The predominance of cattle over goats and sheep is because cattle are used as draft animals. Ifar et al. (1996) mentioned preference of cattle because of their higher cash income if sold than small ruminants. Goats are especially kept in Kedungsalam where they are mainly fed the available *gliricidia* leaves. Sheep are less popular, because farmers believe that to obtain satisfactory weight gain the sheep must be herded, and this is considered tedious. However, some farmers do not herd their sheep and accept a poorer performance. The average agricultural area per cattle-keeping household was 0.98 hectare. The ratio draught animals/cultivated area was 1.01.

The numbers of males and females in the herd are shown in Figure 4.4. Age distribution was recorded into three categories: 'young' if the animal was suckling, 'intermediate' if the animal was not suckling and did not yet produce offspring, and 'adult' if offspring was produced. For male animals the distinction into the last two categories was determined arbitrary. The results show clearly that the share of males in the herd declined with age; the opposite was found for females. This pattern was independent of the type of animal. Farmers are more keen to keep female animals and keep female animals longer than males possibly because of their ability to produce progeny. Another reason is that the market price for males

Table 4.8 Number of animals kept in several types of herd, on 555 farms in the combined villages of Putukrejo and Kedungsalam (SRS, 1992).

Type of herd	No. farms	<u>Total number of animals</u>			Average area (ha)
		Cattle	Sheep	Goats	
no animal	152	-	-	-	0.57
cattle only	232	439	-	-	0.97
sheep only	31	-	92	-	0.48
goats only	54	-	-	158	0.75
cattle + sheep	32	49	73	-	0.97
cattle + goats	48	92	-	101	0.95
sheep + goats	1	-	1	1	0.06
cattle + sheep + goats	5	10	17	16	1.85
Total	555	590	183	276	
Average	1.0	1.1	0.3	0.5	0.83

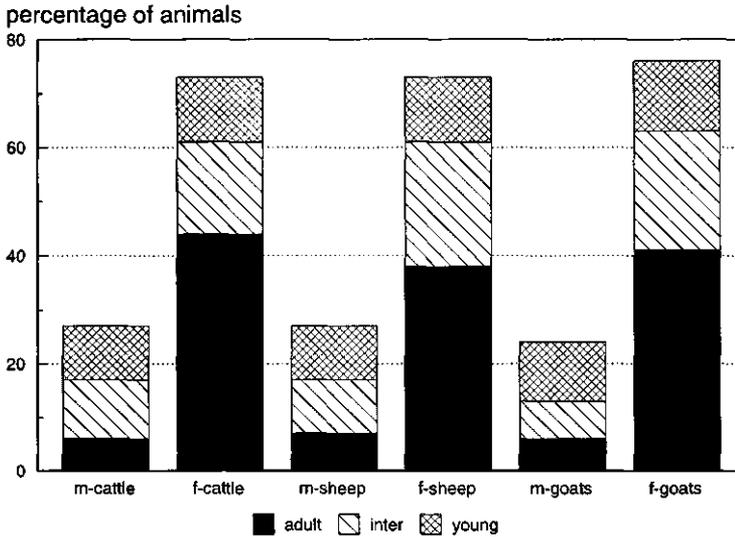


Figure 4.4 Sex and age distribution (%) of the cattle, sheep and goat populations (m=male and f=female) in Putukrejo and Kedungsalam, East Java, Indonesia (SRS, 1992).

is much higher, on the basis of their weight, than that for females and for that reason farmers are very eager to sell their males.

Both males and females provide draft power. However, most draft power was performed by females while their number was much bigger compared to the number of males (Figure 4.4). Arguments in favour of using cows for work are that fewer animals are needed, cows are easier to train, and they can also supply calves. The two major arguments against cows are that they are smaller than bullocks and, if not properly fed, their milk yield, suckled by their calf, and reproductive rate might go down. The greater number of females might be caused by the scarcity of feed. It was observed that more cows are used for draught work in areas where feed is scarce; at the same time poor quality feed implies that the cows are not fed according to requirements, hence productivity and reproductive rates may suffer, resulting in more dependence on cows for draught work. The number of potential draught cattle (bullocks, bulls, cows and heifers) in the area was 361 cows and heifers, and 99 bullocks and bulls. The percentage of the work done by cows and heifers amounted to 78%.

Ifar et al. (1996) gave the farmers' ranking of the motives for keeping livestock. Most farmers opted for the production of progeny and manure as their first objective in rearing ruminants, followed by providing draft power, and savings. Progeny provided the farm with an additional tradable asset. Manure was considered essential to maintain soil fertility in the area. Farmers referred to their ruminants as a saving that gave security. Liveweight gain was ranked lowest. Access to animals was influenced by the reproductive performance of the animals and controlled by a sharing system. In the research area farmers were able to share

animals owned by better-off relatives or friends living in the same village or elsewhere. The sharer was responsible for the daily management of animals, including feeding and breeding. The sharer could use the manure and could use the animal for draft power on his land. The benefits were either the sharing of profits or the sharing of offspring. Though there were exceptions, sharing profit normally applied to male animals, whereas sharing offspring applied to females. Sharing might provide capital-poor, labour-rich households with additional income; for capital-rich, labour-poor households sharing meant a way of investing capital. Sharing resulted in better utilization of (variable) labour, capital and feed resources.

Table 4.8 presents average areas operated per farm for several types of herd. Farmers with no animals on the farm operated less land than farmers who kept animals. Keeping cattle permits one to work more land than that tilled by farmers who kept only sheep, goats or a combination. A combined herd of cattle with either sheep or goats permits one to work more or less the same area as worked by a farmer who keeps cattle only. It is concluded that 1 hectare of land requires the keeping, on average, of one head of cattle. A combined herd of cattle, sheep and goats required the largest land size.

One cattle unit (CU) is defined as an animal with a standard weight of 250 kg. The analysis below assumes that one cattle equals 1 CU, one sheep equals 0.17 CU and one goat equals 0.21 CU. In Table 4.9, the variation in number of CU's on the 555 farms in Putukrejo and Kedungsalam was analysed by least squares methods. Note that each component of the analytical model was adjusted for any other component of the model. The analytical model included the effects of land use, land area and household labour. There was a significant difference ($p < 0.05$) in cattle units between farms with annuals other than sugarcane and farms

Table 4.9 Least squares means and regression coefficients for land use, land area and household labour with number of cattle units as dependent variable for the 555 households in Putukrejo and Kedungsalam, East Java, Indonesia (Ejfé & van Rheenen, 1994).

	I.s. mean	s.e. ¹	regression	s.e.
Overall average (CU)	0.786	0.126		
Land use*				
- annual(s)	1.278 ^a	0.047		
- sugarcane	0.509 ^b	0.283		
- perennials	0.665 ^{a,b}	0.372		
- no land	0.692 ^b	0.176		
Land area (ha)			0.210*	0.054
Household labour (HLU)			0.206*	0.032
R ² full model ² : 16%				

¹ Standard error; ² Coefficient of determination; ^{a,b} I.s. mean values with different superscripts are significantly different ($p < 0.05$); * $p < 0.001$

with sugarcane, and also between farms with annual crops and landless farms. The regression coefficients indicated to which extent specific variables increased or decreased the number of cattle units. The greatest source of variation in the number of cattle units was household labour ($p < 0.001$). The corrected mean number of cattle units was 0.786 CU. An increase in household labour by one HLU was estimated to increase the number of cattle units by 0.206 CU. Land area had a significant ($p < 0.001$) and positive effect on the number of cattle units kept. The coefficient of determination for the model used was only 16%, which indicates that many other factors are related to the number of animals kept.

Summary

Agriculture has been practiced in the research area for approximately a century and has shown a great deal of dynamics (van Rheenen, 1995). Older farmers in the research area still recall the time when all the land was under forest (Solichin, personal communication). Around 35 percent of the farmland in Kedungsalam contains nowadays patches of sloping land that was once planted to annuals but is now left fallow. The productivity of such land for annual crops has declined over the years due to nutrient depletion and erosion. Land quality varies greatly, not only between farms, but also within farms. Larger farms appear to include a greater share of land that is unsuitable for growing upland annual crops. There is a strong correlation between the land variables slope, soil depth and stoniness. With increasing slopes, the soils become shallower and stony. High migration rates occur, with people moving away temporarily or permanently to find work elsewhere. Many farm households have members who earn their income outside the farm.

In a region where a declining productivity of the soil base is observed, the exploration of options for agricultural production is highly relevant. Knowledge of the bio-physical aspects is essential, as it may help to understand the boundaries of possible cropping and livestock activities. Information derived from farm household surveys makes it possible to quantify system constraints and compare possibilities with present situations.

Chapter 5

Crop and livestock production

This chapter quantifies the actual crop and livestock production at farm level. The data are derived from the field research, as was described in Chapter 3. Further, the results of the field experiments with maize and cassava are presented, followed by their interpretation. The standing biomass of trees is calculated and compared for different land uses. Livestock production in relation to the feed resource is elaborated.

Cropping systems

Annual and perennial crops are cropped in combination and were classified into five crop cultivation types (CCT). The classification of the CCT's is mainly based on perennials. The CCT's differ from each other in tree density, species composition and vertical structure. Five CCT's were defined as follows (Sunaryo, personal communication):

CCT1 : land with sparse to no trees

CCT2 : tegal (non-irrigated agricultural land) with trees on the border of the field, at the edges of terraces or randomly distributed

CCT3 : multi-storey systems (including homegardens and pekarangans)

CCT4 : woodlands

CCT5 : "bongkor", land not used for annual or perennial cultivation

Within CCT1 and CCT2, a further distinction is made regarding the type of annual crop grown (AC), maize, cassava, upland rice or sugarcane. The differences between and within the CCT's result in different competition between trees, and between trees and AC's, in terms of light, water and nutrients.

Table 5.1 lists the distribution of the 5 CCT's over the four major LU's distinguished in the research area. Note that CCT1 occurred almost exclusively on LU1 and LU2, CCT2 was typical of LU2 and CCT3 was found on all four LU's. CCT4 and CCT5 were exclusive to LU4. Table 5.2 shows the distribution of the main annual crops over the four land units.

Table 5.1 The distribution (ha) of Crop Cultivation Types (CCT) on the four Land Units (LU) of the research area. The data pertain to a total of 624 subparcels operated by 143 households (EFHS).

CCT	LU1	LU2	LU3	LU4	Total
CCT1	10.7	11.5	1.1	0.1	23.4
CCT2	8.9	34.4	10.4	3.2	56.9
CCT3	1.7	4.7	4.6	2.5	13.5
CCT4	-	0.4	0.3	4.7	5.4
CCT5	0.3	1.5	2.9	29.7	34.4
Total	21.6	52.5	19.3	40.2	133.6

Table 5.2 The distribution (ha) of crops on the four Land Units (LU) in the research area. The data pertain to a total of 624 subparcels operated by 143 households (EFHS).

Crop(s)	LU1	LU2	LU3	LU4	Total
maize + cassava	6.4	26.9	9.8	3.1	46.2
sugarcane	3.5	12.4	-	-	15.9
upland rice	2.5	1.8	0.6	-	4.9
irrigated rice	7.0	3.9	1.1	-	12.0
other	2.2	7.5	7.8	37.1	54.6
Total	21.6	52.5	19.3	40.2	133.6

Yields of maize and cassava

Maize and cassava are the common crops in the research area and therefore field experimental research focused on these crops. Average yields of maize grain and cassava tubers in Indonesia accounted for yields of 2.37 t ha⁻¹ of maize grain and 5.99 t ha⁻¹ of cassava tubers in 1992 (Table 5.3). Maize and cassava yields, as monitored in the field of the farmers in the research area, were low in 1991 compared to average yields for 1992 (agronomy survey). It was observed that 1991 was a severe drought year compared to other years causing the low yields. Yields in the research area in 1992 were higher than the national average. Maize and cassava nearly always received some inorganic fertilizer and farmyard manure (Table 5.3). Fertilizer application rates for maize and cassava in the research area were lower than the national averages. The recommended applications per hectare were around 25 to 300 kg urea

Table 5.3 Average maize grain yields and cassava tuber yields (t DM ha⁻¹) monitored in the fields of farmers in Putukrejo and Kedungsalam in 1991 and 1992 with average fertilizer use (kg ha⁻¹) compared to average values for Indonesia (Biro Pusat Statistik, 1992).

Crop	Indonesia		Research area		Indonesia		Research area	
	1992	1991	1992	N	P	N	P	
maize	2.37	1.16	2.80	44	3	29	<1	
cassava	5.99	3.27	8.59	15	1	12	<1	

(11-135 kg N), 100 to 150 kg triple superphosphate (TSP) (20-30 kg P) and 50 kg KCl (25 kg K) (DIPERTA, 1990, Effendi, 1980). KCl was not commonly applied to cassava and maize, but was applied to sugarcane where it was included in the subsidized package of seeds and fertilizers.

The field experiment in 1990 in Kedungsalam (Chapter 3) faced waterlogging and gully erosion which made trial results erratic, and caused yields far below the levels expected (Table 5.4). Two types of relations were studied: (1) the relation between amount of nutrients applied and the amount of nutrients taken up by the crop (recovery) and (2) the relation between amount of nutrients taken up and the yield of the crop. The research on the fate of nutrients applied with fertilizer was difficult because it was not possible to distinguish between nutrients from the soil and nutrients from the fertilizer. Since the treatment in the field experiment was comprised of plots receiving no fertilizers and plots receiving N, P and K altogether, it is impossible to distinguish the recovery of each individual nutrient.

From research that has been carried out so far, it has appeared that close relationships exist between yields and amounts of nutrient taken up, as long as that particular nutrient is the growth limiting factor. It was found by van Keulen & van Heemst (1982) that almost all cereals then produced the same quantity of grains per kg of nitrogen. In this case as a result nutrient concentration was at a minimum value and nutrient efficiency (quantity of grains per kg nutrient) was therefore at a maximum value. Similar relations applied for phosphorus but less clear relationships were obtained for K. The difference is related to the fact that 60-80% of N and P arrive in the grain, and for K this is only 25% or less. For tuber crops also a clear relationship was found between yield and the quantity taken up of the most limiting nutrient. These data refer to situations in which there is one limiting nutrient only. Such situations appear rather seldom in practice. Often the amounts of two or more nutrients are rather small, and as a result none of the nutrients in the plant is diluted at maximum. Table 5.4 shows the results of the ratio of content of a nutrient and yield for the field trial as well as maximum efficiency (van Keulen & van Heemst, 1982) and minimum efficiency (Janssen et al., 1990).

Plants need a minimum nutrient concentration for optimal photosynthesis. The amount of grain dry matter produced per kg nutrient uptake was calculated for the nutrient concentrations, of the storage organs and the crop residues at maturity, as measured in the

Table 5.4 Crop yield of the grains and tubers, harvest index and nitrogen, phosphorus and potassium nutrient use efficiencies in a field experiment with fertilizer rates of 0, 90 and 135 N, 0 and 20 P, 0 and 50 K (field experiment 1990-1991). All data are in kg per ha.

Crop	Treatment	Yield	HI	Grain yield per kg nutrient uptake		
				N	P	K
maize	N ₀ P ₀ K ₀	553	0.28	50	291	38
monocropped	N ₉₀ P ₂₀ K ₅₀	1043	0.32	51	243	26
maize	N ₀ P ₀ K ₀	588	0.33	62	235	28
intercropped	N ₉₀ P ₂₀ K ₅₀	847	0.31	60	565	27
maximum efficiency ¹				70	600	120
minimum efficiency ¹				30	200	30
cassava	N ₀ P ₀ K ₀	8620	0.78	46	395	54
monocropped	N ₁₃₅ P ₂₀ K ₅₀	10650	0.67	48	467	68
cassava	N ₀ P ₀ K ₀	4590	0.69	54	429	71
intercropped	N ₁₃₅ P ₂₀ K ₅₀	10300	0.69	43	398	68
maximum efficiency ¹				90	600	70
minimum efficiency ²				30	200	30

¹ van Keulen & van Heemst, 1982; ² Janssen et al., 1990

laboratory. Higher than or values close to the maximum efficiencies mentioned by van Keulen & van Heemst (1982) can indicate that these concentrations were measured in situations deficient in that nutrient. However, Table 5.4 shows that this was not the case for each of the three nutrients for maize. Cassava only reached maximum efficiency for K, indicating K as a growth limiting nutrient. What is striking are the below minimum nutrient use efficiencies of K in maize compared to the high values for cassava. Water shortage, particularly during the reproductive stage of maize might have caused accelerated senescence of the leaf blades, hence, reduced rates of photosynthesis. Interruption of the flow of carbohydrates to the filling grain due to reduced assimilation might have caused the low harvest index in maize. In addition, under water shortage, the translocation of nutrients from vegetative material to the grains is hampered, so that vegetative material dies with a high nutrient content. Such situations result in a low content to yield ratio. This might have been the case for K in maize. If one of the other nutrients is available in limited supply, this may result in increased uptake

of the nutrient considered, resulting in a lower value of the content to yield ratio.

The relation K-content to yield varies more than for the other two nutrients, for two reasons. Firstly, at maturity the larger part of the potassium is in straw and consequently, variations in HI occur. Generally, a higher dry matter harvest index will imply a higher content to yield ratio. Therefore the very low K efficiency might be a result of a low harvest index for maize (0.28-0.33). The soil of the field experiment was very heavy and difficult to penetrate by roots; moreover waterlogging and erosion had occurred. The poor rootability was probably the cause of a low harvest index. This observation is supported by Smaling (1993) who found that on heavy soils the harvest index of maize was between 0.28 and 0.36, while on other soils it was between 0.4 and 0.5. The lower harvest index of the latter was caused by a low 1000-grain weight. Secondly, potassium has a double function in the plant: it is needed for certain physiological functions (osmotic and ionic regulation, and co-factor and activator for many enzymes of carbohydrate and protein metabolism), but also serves as a positive charge, accompanying organic and inorganic anions during transport through the plant. For the uptake of K additional soil characteristics have strong effects, i.e. the content of Ca and Mg, due to the substitution possibilities among these three nutrients in plant physiological processes. It seems that the uptake of K is not correlated to the uptake of N and P. This suggests that during grain filling K is not the only active carrier for N and P. It is likely that other cations, such as Ca and Mg may, to a varying degree, perform that function. This means that relation K-content to yield is difficult to interpret.

Another possible cause for a low nutrient use efficiency is a lower than 1 ratio of nutrient content at maturity to maximum nutrient content. Possible causes for K-losses are (i) leaf fall, (ii) translocation to roots and stubble, and (iii) leaching by rain. Unfortunately this could not be calculated for the field experiment since no additional observation on nutrient content between flowering and maturity was available.

Farmers mentioned a better yield performance when inorganic fertilizers were applied in combination with manure compared to the application of inorganic fertilizers only. Generally, the use of organic fertilizers aims at two main targets: (1) supply of nutrient and (2) increase in the content of soil organic matter. The importance of an organic manure as a supplier of nutrients is determined by the contents of nutrients and by the rate of release of the nutrients. The increase in the organic matter content depends on the decomposability of the organic manure. The more easily the organic manure is decomposed, the less remains. In other words: the two main aims that one wants to achieve with organic manure, are not achieved at the same time.

Micro-organisms prefer inorganic nitrogen to organic nitrogen. The immobilization of inorganic nitrogen by micro-organisms occurs at the cost of the uptake of nitrogen by the plant. In the tropics, organic matter, including micro-organisms, is decomposed rapidly, so that immobilized nitrogen is released again soon. Table 5.5 shows the results of a field experiment where intercropped maize and cassava had applications of several levels of inorganic fertilizers combined with several application rates of manure. The results showed an increased yield when manure was applied in combination with inorganic fertilizer

Table 5.5 Yields of maize and cassava intercropped in response to different levels of inorganic fertilizer and manure. The field experiment was conducted in the village Putukrejo, East Java, Indonesia, in 1992.

N - P - K kg ha ⁻¹	manure t ha ⁻¹	Grains t ha ⁻¹	Tubers t ha ⁻¹
0- 0 -0	0	1.83	6.97
0- 0 -0	10	2.22	7.01
135-20-50	0	2.36	10.34
135-20-50	5	3.40	11.28
135-20-50	10	3.54	12.77
135-20-50	15	4.08	14.57

compared to the crop yield with only inorganic fertilizer applied. Yields increased with increased inorganic fertilizer application as well as with increased manure application.

The main reasons why the effect of inorganic fertilizers increases in combination with manure are: (1) manure, applied in the plant hole, improves the circumstances for root growth and hence for nutrient uptake; moreover the better growing plants require more nutrients and will thus make a better use of applied fertilizers and (2) it seems that many farmers apply only urea as fertilizer thus unbalancing plant nutrition; the application of organic manures restores this balance at least partly.

Standing biomass of tree vegetations

From the inventory of perennials (Chapter 3) the wood volume of the stem of each tree was calculated using the formula:

$$V = f * \text{PI}/4 * \text{dbh}^2 * h$$

where V is wood stem volume (m³), f is form factor, dbh is diameter at breast height (m) and h is height of the tree. A form factor of 0.7 was used to account for the effect that a stem is not identical to a cylinder. This formula was also used in firewood production and consumption studies in central Java, conducted by Kuyper & Mellink (1983), Verweij (1987) and Nibbering (1991). The height was defined as height to the first branch. The dry weight density of the wood of each species was not measured in the research area. Whitmoore (1984) measured an average wood density of 0.65 g cm⁻³ in tropical rainforests, although variation between species was large. However in a species rich community, variation from the average

is mostly neglected. Since many different tree species were identified in the research area (see Chapter 4) an average dry weight density of the wood of 0.65 g cm^{-3} was assumed. Since in CCT1 no trees were grown the tree biomass production was only calculated for CCT 2, 3, 4 and 5. Tree cropping practices differ mostly between valley bottoms and hillsides and therefore a distinction was made between these two only. It was assumed that LU 1 coincided with valley bottoms and that hillsides were the average of LU 2, 3 and 4. Table 5.6 shows the results of the stem biomass calculations for 4 different crop cultivation types on valley bottoms and hillsides.

The above calculations gave a total above ground tree stem biomass of 11-68 t ha^{-1} . For trees with a diameter of less than 5 cm as well as for trees with a diameter of 5 cm or more, the number of trees on hillsides was always greater compared to the number of trees on valley bottoms. The multi-storey systems showed the highest tree number followed by woodlands. Least tree densities were found for tegal, especially on valley bottoms. The number of trees greatly corresponded with the calculated stem biomass. Multi-storey systems had the highest amount of tree stem biomass. It is noteworthy that only 3 species constituted more than 75% of the total plant biomass in the multi-storey systems. The coconut palms (*cocos nucifera*) alone accounted for more than a third. Clove (*eugenia aromatica*) and langsep (*lansium domestica*) were the other two major contributors with 22% and 19% respectively.

The proportions of biomass allocated to stem, branch, root and leaves vary with age of the tree, the stem normally increasing its part with age. Since no tree age data was available and no dry matter distribution data for different species, this is a bias in the tree biomass calculations. According to the literature, the biomass fraction of leaves ranges between 1-15%. Usually the absolute amount of leaves does not change much with stand age, but the percentage will decrease as the wood biomass increases. Values of 1-5% dry leaf weight in the total dry biomass are reported for mature forests. Toky et al. (1989) reported quite high proportions of leaves from three different agro-forestry systems in west Himalaya (8-12%), but they did not estimate root biomass and therefore the share of the leaves was higher.

The above ground dry matter biomass distribution fractions used in this study for crop cultivation type 2 and 3 were derived from a study carried out by Jensen (1990) who analysed a homegarden in the village Legokole, south of Bandung. He found the average dry matter distribution factors of 70% stems, 18% branches, 10% leaves and 2% fruits in the above ground biomass. For crop cultivation type 4 and 5, dry matter distribution factors of Bruijnzeel (1983) were used. Bruijnzeel analysed an *agathis dammara* plantation and found averages of, 81% stem, 9% branches and 10% leaves in the total above ground dry matter. Table 5.7 shows the results of the above ground dry matter biomass for the different tree organs for different crop cultivation types on valley bottoms and hillsides. Nye & Greenland (1960) reported figures of total plant biomass in an 18-year-old secondary forest in Congo of 146 t ha^{-1} , and of 123 t ha^{-1} in a 20-year-old secondary forest in Ghana. Bruijnzeel (1983) gave figures for above ground biomass of *Agathis dammara* plantations in central Java of 58 t ha^{-1} for a 14-year-old stand, and 202 t ha^{-1} for a 25-year-old stand. A 15-year-old *Pinus*

Table 5.6 Standing stem biomass for different crop cultivation types (CCT) grown on either valley bottoms or hillsides in the combined villages Putukrejo and Kedungsalam, East Java, Indonesia.

Crop cultivation type	Number of trees		Volume (m ³) of stem	Stem(t ha ⁻¹) biomass
	dbh<5cm	dbh≥5cm		
CCT2 - valley	31	100	16.29	10.59
CCT2 - hillside	309	206	19.00	12.35
CCT3 - valley	53	550	98.26	63.87
CCT3 - hillside	139	938	104.52	67.94
CCT4 - valley	71	305	59.14	38.44
CCT4 - hillside	372	227	35.99	23.39
CCT5 - hillside	150	182	30.78	20.01

CCT2 = tegal, CCT3 = multi-storey system, CCT4 = woodlands, CCT5 = fallow

Table 5.7 Distribution of above ground biomass in various crop cultivation types at valley bottoms and hillsides in the combined villages Putukrejo and Kedungsalam, East Java, Indonesia.

Crop cultivation type	Stem (t ha ⁻¹)	Branch (t ha ⁻¹)	Leaves (t ha ⁻¹)	Fruits (t ha ⁻¹)	Total (t ha ⁻¹)
CCT2 - valley	10.59	2.72	1.51	0.30	15.12
CCT2 - hillside	12.35	3.18	1.76	0.35	17.64
CCT3 - valley	63.87	16.42	9.12	1.82	91.23
CCT3 - hillside	67.94	17.47	9.71	1.94	97.06
CCT4 - valley	38.44	4.27	4.75	-	47.46
CCT4 - hillside	23.39	2.60	2.89	-	28.88
CCT5 - hillside	20.01	2.22	2.47	-	24.70

CCT2 = tegal, CCT3 = multi-storey system, CCT4 = woodlands, CCT5 = fallow

patula plantation was estimated by Bruijnzeel at 173 t ha⁻¹ and a 28-year-old teak (*tectonia grandis*) stand at 98.6 t ha⁻¹. Woodlands in the research area (CCT4) accounted for total above ground biomass of 47 t ha⁻¹ on valley bottoms and 29 t ha⁻¹ on hillsides. These values were far below those reported in literature mainly because soils in the research area were shallow, and poor in nutrient availability, factors which limit the number of trees grown and thus the biomass production. In their study in the western Himalaya, Toky et al., (1989) found values of above ground biomass from 37.4 to 55.4 t ha⁻¹ in 3 different agro-forestry systems (agrisilviculture, agrihorticulture and agrihortisilviculture). The values of Toky et al. are just between the calculated biomass productions for tegal and for multi-storey systems in the

research area. In this study, on tegal the main crops cultivated were the annual crops and therefore only a low value for tree biomass was found. The multi-storey systems were classified as agrihortisilviculture agro-forestry system, however the accent was put on trees. Therefore much higher biomass values were found compared with the values of Toky. Jensen (1990) found a total above ground biomass of 87.2 in his homegarden in Legokole. This value comes close to those of the multi-storey systems in the research area.

Light transmission

Light transmission through tree foliage was measured for several tegal fields (CCT2 plots) in the area. The fraction of the total incoming light that falls through the canopies of trees was expressed by 'transmission coefficient', and was determined by measuring simultaneously the 'Photosynthetically Active Radiation' under and above the tree canopy (Table 5.8). Only this transmitted light was available to the annual intercrop.

Table 5.6 already showed a lower number of trees on valley bottoms compared to the number of trees on hillsides. The results of Table 5.8 for the light transmission coefficients corresponded with these findings. Light transmission on hillsides (land unit 2, 3 and 4) was lower than the light transmission coefficient for valley bottoms. Light transmission was greatest for areas with terrace planting followed by boundary planting and cropland planting. Boundary planting combined with cropland planting showed the lowest light transmission, and annual crop growth within this crop cultivation type was accordingly low. Nibbering (1991) measured the effect of moderately dense teak foliage on light intensity at ground level on a

Table 5.8 Light transmission coefficients (T.C.) (%) measured for tegal fields (CCT2 plots) with different tree configurations in the combined villages Putukrejo and Kedungsalam, East Java, Indonesia.

Tree distribution	measured area (ha)	valley T.C. (%)	measured area (ha)	hillside T.C (%)
boundary planting	0.86	0.76	1.49	0.67
cropland planting	-	-	1.07	0.63
terrace planting	0.36	0.72	1.92	0.76
boundary+cropland planting	-	-	2.36	0.49
boundary+terrace planting	-	-	0.33	0.56
Avg.*		0.75		0.62

* = weighted for size of the measured area of either valley bottom or hillside (ha)

cultivated hillside. Total illumination was only 40% of that recorded on the adjacent treeless valley bottom.

Livestock systems

In the research area feed availability was divided into two components: (1) on-farm crop residues which were determined by land size, crops cultivated and their yields, and (2) fodder collected off-farm by the household members. The amount of household labour utilized for this purpose depended on the season, the number, type and production level of animals in the herd, and the land size managed by the farmer. Figure 5.1 shows, for the years 1990 and 1991, the amount of on-farm and off-farm feed collected as a percentage of the total weight of feed fed to cattle, sheep and goats. For the three different types of animals, by far the biggest proportion of feed fed was derived off-farm. Monthly variation in the proportion of feed collected on- and off-farm might have been due to climatic conditions. The rainy season usually starts in October or November and ends somewhere between April and July.

The proportion of feed which was collected off-farm for sheep and goats increased at the end of the rainy season to a maximum of 100% in the dry months October and November. This pattern was not found for cattle because the on-farm crop-residues of cassava and sugarcane became available from July onwards. The time spent on fodder collection, in h kg^{-1} of fresh fodder collected, over the year showed high values in the dry season and low values in the rainy season (Figure 5.2 and 5.3). The reason is again that in the dry season most of the feed was collected off-farm and thus further away and therefore more time was needed.

Figure 5.4 shows the monthly weight of feed collected, in fresh material, for cattle, sheep and goats in the combined villages. Much higher weights of feed were collected for cattle compared to sheep and goats, corresponding with the higher number of cattle. As was already illustrated in Chapter 4, most animals kept were cattle followed by the number of goats and least are the sheep.

The weight of feed offered to a standard animal was calculated for each individual farm first, whereafter the overall average was calculated. For cattle, sheep and goats, standard animal weights of 250 kg, 25 kg and 30 kg respectively, were used based on average adult weights of animals in the research area (recorded by weighing animals in the field (Ifar, 1996). It was assumed that only 70% of each animal's individual feed consisted of edible parts, usable for consumption. Data were averaged over the farms for each month, resulting in monthly feed data for a standard cow, sheep or goat (Appendix 1). Calculations were performed by weighing each farm equally. For sheep and goats no distinction between villages was made since only a few farms were monitored. The quality of the eight types of fodder was determined. No feed quality distinction was made between the two villages and

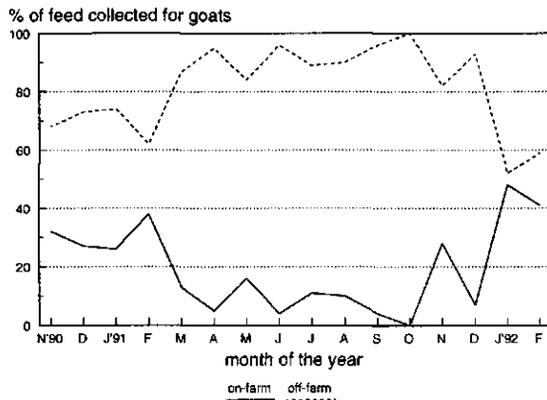
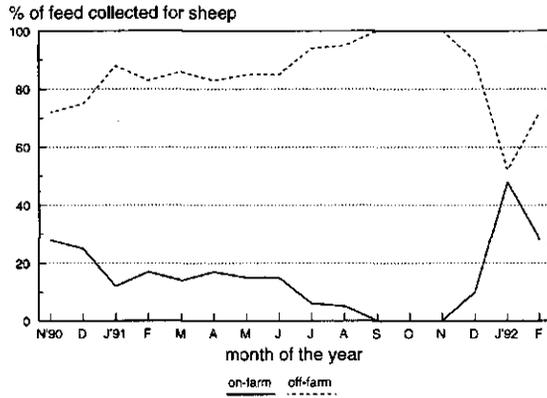
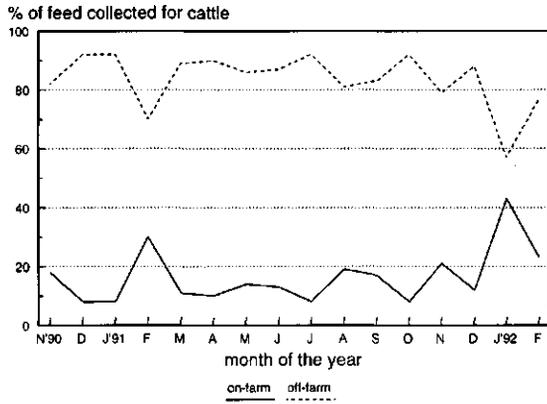


Figure 5.1 The amount of on- and off-farm collected fodder as a percentage of the total weight of fodder collected for cattle, sheep and goats. Source: FHS, 1990-1992.

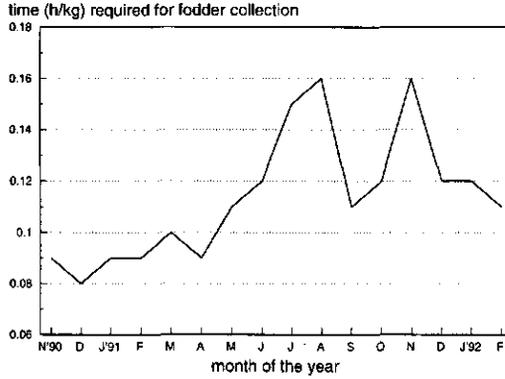


Figure 5.2 The monthly distribution of hours spent for 1 kg of fresh fodder collection for the total herd in the combined villages of Putukrejo and Kedungsalam (FHS, 1990-1992).

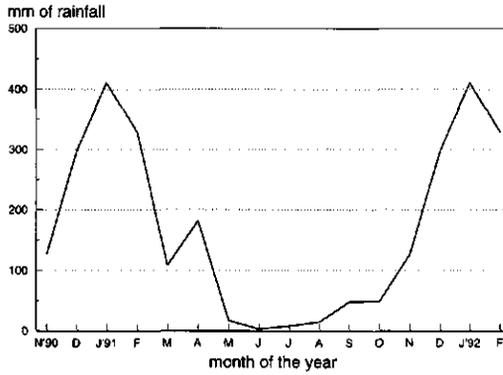


Figure 5.3 The monthly rainfall distribution in Kedungsalam, East Java, Indonesia.

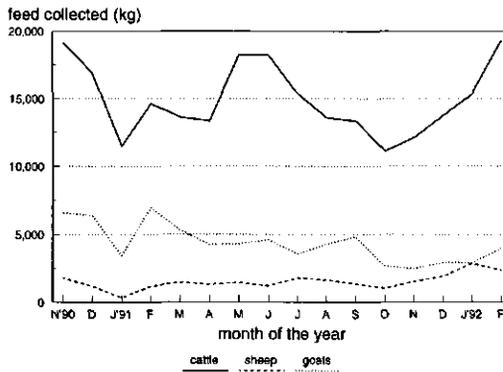


Figure 5.4 The monthly weight of fodder collected (fresh material) for the total cattle, sheep and goat population in the combined villages of Putukrejo and Kedungsalam (FHS data).

Table 5.9 Feed quality data for the feeds offered in the limestone area, south of Malang, Indonesia.

type of feed	DM %	OM % in dm	CP % in dm	ME MJ in dm	DMD %	OMD %
leguminous tree leaves	31	91	18	986	64	69
non-leguminous tree leaves	37	89	11	636	47	45
native grasses	30	78	8	672	54	55
elephant grass	28	82	10	681	48	53
sugarcane leaves	30	87	6	893	65	65
cassava leaves	31	89	21	1115	59	80
maize straw	18	88	9	740	54	54
rice straw	25	76	5	610	36	51

DM = dry matter; OM = organic matter; CP = crude protein; ME = metabolizable energy; DMD = dry matter digestibility; OMD = organic matter digestibility

Table 5.10 Least square means (lsm) and standard errors (se) of liveweight gain ($g\ d^{-1}$) of non-reproducing cattle in different seasons in the limestone area south of Malang (Ifar, 1996).

Source of variation	lsm	\pm se ($g\ d^{-1}$)
dry season 1990	208 ^a	52
wet season 1991	16 ^b	53
dry season 1991	47 ^b	52
Overall	90	33

a,b = different superscripts are significantly different ($p < 0.05$)

no distinction in feed quality over the year. Results are shown in Table 5.9.

Ifar (1996) measured the daily liveweight gain of cattle in Putukrejo and Kedungsalam on 18 farms. The study was performed in the dry season 1990 (May to October), the wet season of 1991 (November 1990 to April 1991) and the dry season of 1991 (May to October 1991). Daily liveweight gain of the cattle was calculated as the liveweight at the end of one season, minus the liveweight in the beginning of the season, divided by the number of days of the season (Table 5.10). Ifar found that only the season significantly ($P < 0.05$) affected the daily liveweight gain of the cattle. The liveweight gain in the wet and dry season of 1991 was significantly lower than in the dry season of 1990. The liveweight gains found in this survey were far below the liveweight gains of the same type of cattle ($750\ g\ d^{-1}$) fed with concentrates on-station (Tillman, 1981).

Conclusions

In Indonesia the population growth rates are high and are expected to remain so in the near future. This inevitably leads to an increase in the demand for food. Especially, where the present production levels have not been able to keep up with demand, the agricultural production will have to increase. This increase will particularly have to come from higher yield per hectare, but also through improving the efficiency levels at farm level.

Considering the limited extent to which new technologies have been incorporated into the present farming system, it seems that there is still a potential to improve traditional upland cropping systems. The overall productivity can be improved through a combination of interventions, such as: improved timing, improved field spacing designed to reduce plant competition, increased and more balanced application of fertilizers and pesticides, and the use of mulches to retard weed growth and to conserve soil moisture. However, much research is yet to be done on upland cropping in general and in particular on upland cropping in a limestone environment. Provided that suitable, high yielding cultivars and improved cultivation techniques will be developed for the uplands, it still remains to be seen whether farmers will be able to adopt them, considering the cash constraints which they face, marketing problems, and the large bio-climatological disturbances to which crop cultivation in the area is exposed (Nibbering, 1991).

The productivity of all classes of village livestock is mostly affected by the low feed quality and to a lesser extent by the seasonal feed shortage. The solution to feed problems seems difficult if one aims at non-cash inputs, unless one can make use of high yielding and locally produced feedstuffs as a supplemental feed at the period of scarcity. The basic strategy is to ensure a feed supply that can be sustained on a year round basis. The combinations of crop residues, fodder trees, forage grass and legumes, tethering and grazing, seems a viable approach to increase livestock productivity (Nitis et al., 1990).

Chapter 6

Soil fertility of limestone uplands

Crops respond differently to nitrogen, phosphorus, potassium and manure at different locations. This indicates that crops do not respond to a fertilizer application per se, but rather to the soil's response to that application. The soil's response to a fertilizer application is co-determined by the native fertility of the soil. Chemical soil fertility is defined as the capacity of a soil to supply the crop with the major nutrients N, P and K. In this chapter, the native fertility of soils in the research area and the nutrient decline in relation to land use is quantified. In natural ecosystems, loss of nutrients (outputs) is generally compensated for by nutrient gains (inputs). However, as soon as land is transferred to agricultural use under low input conditions, soil fertility tends to decline at a rate that is largely governed by the type of land use systems introduced and their management. Different land uses and their effect on soil fertility via nutrient balances were studied.

Soils and land use

The soils formed on limestone consist of a dark brownish-red topsoil which at a depth of 10 cm rapidly merges into a brownish-red subsoil resting directly on the hard limestone (Dames, 1955). Iron concretions occur throughout the soil profile. The soils are strongly subject to leaching and oxidation. They are high in clay and iron oxides, the latter lending the soil its red colour. The soils are slightly plastic and sticky. On drying, the soils tend to crack moderately into medium-sized blocks that are at first rather hard but crumble after prolonged drying. The soils are very shallow, particularly on the steep slopes, but reach depths of several meters at the bottom of the valleys. Limestone fragments usually occur throughout the shallow soils on the hillsides. The analysis of particle size indicated that the soils contained 3-22% sand, 12-28% silt and 50-85% clay. Bulk density of these soils is only 1 g cm^{-3} , because the soils are mixed with volcanic material.

Soil fertility differed for the four land units distinguished (Chapter 4) and is determined by land use as well. In the research area chemical soil characteristics were only determined in relation with land, excluding land use. Therefore it is not surprising that analysis of variance showed no major significant differences in chemical characteristics between land units (Appendix 2). To quantify the relation between soil properties and land use, data were used of Nibbering (1991). Nibbering studied in detail soil resources of the Gunungkidul

District, which belongs to the same limestone range as the research area, and which shows similar geo-morphological conditions. Chemical soil properties and research findings of the Gunungkidul District are summarized below and are considered valid for the limestone range, south of Malang, as well.

Chemical soil properties varied with intensity of land use and topography (Table 6.1). All hillside soils were weakly alkaline, while those in the valleys were weakly acid. There was a strong tendency for the concentration of exchangeable cations to decrease from forest and land under fallow to permanently cultivated hillsides. There was also a clear decrease in organic matter content from soils under forest, through soils under fallow, soils under cultivation on hillsides to valley bottom soils. The cation exchange capacity in soils on valley bottoms, however, was about the same level as in soils on permanently cultivated hillsides. In the valleys, despite the low organic matter content, the higher clay concentrations apparently made a larger contribution to CEC than on the hillsides.

Clearly, the topsoil found at the forest site in the Gunungkidul District is by far the richest in the area. Where land is fallowed it seems that a process of enrichment takes place, leading to high organic matter content and high concentrations of extracted cations released from plant litter. Hillside soils may have become more prone to alkalinity over time, as they became increasingly exposed to the limestone outcrops due to erosion. The slightly lower pH in forest soil compared to the other hillside soils supports this idea. When hillside land is put into cultivation, organic matter content declines as a result of decomposition, involving processes of oxidation and mineralization; the availability of extractable cations decreases due to uptake by crops, leaching and erosion. This decrease in organic matter content causes the CEC to fall as well. Permanently cultivated hillsides have much lower inputs of organic material (tree leaves) than intermittently cultivated hillsides. Consequently, the availability of exchangeable cations also drops.

Valley bottoms in the Gunungkidul District had the lowest organic matter content, as they received little input from crop residues or vegetation. Table 5.6 already showed a lower number of trees on valley bottoms compared to hillsides. Terracing prevents larger organic

Table 6.1 Average values of soil parameters for topsoils (20 cm) per land use in the limestone area near Yogyakarta, Indonesia (Nibbering, 1991).

Land use	pH	CEC me 100g ⁻¹	OM %	org.C g kg ⁻¹	P-Olsen mg kg ⁻¹	exch.K mmol kg ⁻¹
forest	7.0	39	9.3	47	10.0	10.2
valley	6.6	20	2.2	11	4.2	3.3
permanent c. hillside	7.3	22	3.1	16	6.3	1.4
intermittently c. hillside	7.3	32	3.6	18	4.0	3.0
fallow hillside	7.2	40	5.6	28	3.7	2.9

material from washing down, though some of the finer material may accumulate in valley bottoms. However, it was apparently not enough to bridge the difference in organic material between valley bottoms and hillsides. Some of the organic material was probably lost as a consequence of oxidation and leaching. In valley bottoms the low organic matter content, the absence of limestone rock or stones, in combination with constant leaching of the bases and crop uptake led to a slightly lower pH.

Native soil fertility

The native supply of nutrients from soils to the plant, needs to be quantified in order to distinguish the nutrient supply through fertilizer application. Since fertilizer trials are costly, a cheap alternative is the use of computer models that translate measurable or already known climatic, soil and plant parameters into an output variable such as crop yield. Most models describing relations between nutrient supply, uptake and crop yield address a single nutrient. In agricultural practice however, at least the three macronutrients should be taken into account. This principle is the cornerstone of the model QUEFTS, QUantitative Evaluation of the Fertility of Tropical Soils (Janssen et al., 1990). The model takes N, P and K into consideration, as well as the interactions between them. QUEFTS has both empirical (describing a relation between a model output variable and its original determinants, without referring to the underlying processes (Burrough, 1989)) and theoretical components. QUEFTS describes relations between (i) chemical soil tests, (ii) potential NPK supply from soils and fertilizers, (iii) actual NPK uptake and (iv) maize grain yield.

The model assumes that the production of maize is limited by N, P and K. It further assumed that water supply during the growing season, and other extraneous factors such as waterlogging, deficiencies of other nutrients or weed infestation, should not adversely affect crop development. These optimal physical conditions are, however, often not the case in the limestone uplands. The model has been extensively validated between the following limits: well-drained and deeply rootable soils (0-20 cm), with a pH(H₂O) of 4.5-7.0, organic C < 70 g kg⁻¹, organic N < 7 g kg⁻¹, total P < 2000 mg kg⁻¹, P-Olsen < 30 mg kg⁻¹ and exchangeable K < 30 mmol kg⁻¹. The chemical soil properties for different land uses of the Gunungkidul District, as is shown in Table 6.1, are all within the boundaries for QUEFTS. Therefore it was concluded that the model could be used to quantify the natural supply of N, P and K, from the soils in the research area. The calculation procedure in QUEFTS consists of four successive steps.

STEP I

The potential supply of soil nitrogen, phosphorus and potassium (SN, SP, SK), i.e. the maximum quantity of those nutrients that are taken up by maize if no other nutrients or other growth factors are limiting, is derived from empirical equations with soil chemical properties of the 0-20 cm soil layer as independent determinants.

STEP II

If the supply of one nutrient is enhanced, it can positively influence the uptake of other nutrients. These interactions are dealt with in the way actual uptake of each nutrient (UN, UP, UK) is calculated, namely as a function of the potential supply of that nutrient, taking into account the potential supply of the two other nutrients. This results in two estimates of the actual uptake for each of the three nutrients. The lower of the two estimates is considered the more realistic, in conformity with the law of the minimum.

STEP III

When the potential supply of a nutrient is low compared to the two other nutrients, the particular nutrient is growth limiting, and its internal concentration in the plant is low, eventually reaching a stage of maximum dilution. When the supply of a nutrient is large and growth is not limited by the uptake of that nutrient, the crop takes up more than required until maximum accumulation is reached. Yield ranges are calculated, represented by maximum dilution (D) and accumulation (A) for N, P and K: YND-YNA, YPD-YPA, and YKD-YKA.

STEP IV

The final yield estimate (YE) is found by comparing the three ranges. The yield range that follows from N uptake is narrowed to the overlap with the range YPD-YPA, leading to a combined estimate YNP, and to the overlap with the range YKD-YKA, with a combined estimate YNK. The same procedure is followed for P and K, and provides six estimates: YNP, YNK, YPN, YPK, YKN, YKP. The final yield estimate is the average value of these six combined estimates, and lies in the common overlap of the three yield ranges.

The results of the calculations with QUEFTS are shown in Table 6.2. The calculated nutrient supplies were rather well balanced (N:P:K = 10:1:10) for permanently cultivated valley soils. For all the soils, phosphorus was relatively least and nitrogen relatively most available in absolute terms. It is seen that for the soil under forest, potassium was the growth limiting nutrient followed by phosphorus and nitrogen. The same results were found for permanently cultivated land and fallow land on hillsides. The soils of the valley bottom as well as the intermittently cultivated hillsides showed a shortage of phosphorus compared to nitrogen and potassium. After phosphorus it was potassium which was the growth limiting nutrient. For all the five soils nitrogen was the least limiting growth factor.

Nutrient fluxes

In this study sustainability of an (agro)ecosystem implied that for each separate nutrient the input was (at least) as large as the output. This is a simplification since interactions between, for example, fertilizer nutrients and soil properties, are left out, and they are the interactions which determine nutrient availability. It only makes sense when a balanced nutrient availability exists. If the input is larger than the output, the quantity of nutrients in the

ecosystem is increasing; if the input is less than the output, the quantity of nutrients in the ecosystem decreases, and the ecosystem is not sustainable. An ecosystem was considered as a piece of land on which a certain crop or a certain natural vegetation was grown. In horizontal direction, the limits of an ecosystem were formed by discontinuities in topography, soil, vegetation or hydrology. In vertical direction the upper limit was the top of the vegetation and the lower limit was the bottom of the rooted soil. The soil under the rooted layer was not included in the ecosystem.

Nutrients may be supplied to the ecosystem from the atmosphere, the hydrosphere, adjacent ecosystems or (by human input) from far-away sources; in short: from above, from below or from beside. Three types of input from the atmosphere are: (1) wet deposition, the nutrients dissolved in the rainwater, (2) dry deposition, nutrients found in solid particles like volcanic ash and dust and in aerosols and (3) microbiological nitrogen fixation. From below, nutrients are supplied by a capillary rise of groundwater or seepage. Input from adjacent ecosystems is caused by flooding, colluvial movements or deposition of soil material eroded from elsewhere, runoff and, for example dung from cattle. Human input from far-away sources, refers to fertilizers. Nutrients may leave the ecosystem and move to the atmosphere, the hydrosphere, adjacent ecosystems or to far away destinations. Output to the atmosphere is usually in gaseous forms; this possibility only exists for nitrogen. In humid climates leaching is an important source of nutrient output to the hydrosphere. Erosion and runoff are also important processes, where the nutrients move mostly to adjacent ecosystems. In

Table 6.2 Potential supply and actual uptake of nitrogen, phosphorus and potassium (kg ha⁻¹), and ultimate yield estimate (YE in kg ha⁻¹) for unfertilized maize on different soils in the combined villages of Putukrejo and Kedungsalam, East Java, Indonesia.

	forest	valley	hillside cultivated		
			permanent	intermittent	fallow
Potential supply of nutrients:					
SN	319.6	67.3	117.0	131.6	199.9
SP	13.2	5.3	4.0	3.0	4.6
SK	34.5	52.7	10.2	19.8	13.9
Actual uptake of nutrients:					
UN	135.0	60.0	17.0	52.0	53.0
UP	11.5	<u>5.3</u>	3.4	<u>2.9</u>	4.1
UK	<u>34.4</u>	47.7	<u>10.2</u>	18.9	<u>13.8</u>
Ultimate yield estimate:					
YE	3598	2304	668	1300	1298

agriculture, harvested products form the most important output.

Integrated nutrient management is the judicious manipulation of all input and output processes that govern the nutrient balance in agricultural land use systems (Smaling, 1993). For this study the five quantified input processes were: application of inorganic fertilizer (IN 1) and organic manure (IN 2), atmospheric deposition (IN 3), biological nitrogen fixation (IN 4) and sedimentation from natural flooding, irrigation water, runoff and sediment deposition (IN 5). The five output processes were: removal of harvested product (OUT 1) and crop residues (OUT 2) from the arable field, leaching (OUT 3), gaseous losses (OUT 4) and erosion (OUT 5). The nutrient balance in this chapter is illustrated for the annual crops, maize and cassava, grown on either valley bottoms or on hillsides. At this stage, trees, including leguminous trees like *Gliricidia*, were not yet included. The contribution of trees from a nutrient point of view is extensively dealt with in Chapter 9. Therefore biological nitrogen fixation (IN 4), which is the process in which molecular nitrogen (N_2) gas is reduced to ammonia (NH_3) and converted into organic nitrogen by nitrogen fixing bacteria, was not incorporated in the calculations below. Sedimentation via irrigation water was not relevant in the research area where farmers practice rainfed agriculture.

Nutrients in inorganic fertilizers and animal manure

Data of the research area for inorganic fertilizer application rates, as are shown in Table 5.3, were used. No farmer applied potassium fertilizer. The farmyard manure was stored near the house and was often only applied to those plots which were located close to the house. The nutrient contents in the manure were assumed 1.69 (nitrogen), 0.36 (phosphorus) and 1.61 (potassium) as percentages of dry weight. The inputs of the organic and inorganic fertilizer applied to maize and cassava are shown in Table 6.3.

Nutrients in wet and dry deposition

Wet and dry deposition from the atmosphere is an important source of plant nutrients. It was assumed that dry deposition (dust as well as ash of volcanoes) varied greatly due to location, time and composition, and that the quantity was too low (except after a volcano outburst), to take into account as a separate input. Since local data on wet deposition were not available a comparison was made of some literature data (Table 6.4). Bruijnzeel (1983) measured the

Table 6.3 Farmers practiced NPK input ($kg\ ha^{-1}$) by manure (N 0.0169 $kg\ kg^{-1}$; P 0.0036 $kg\ kg^{-1}$ and K 0.0161 $kg\ kg^{-1}$) and inorganic fertilizers, for maize and cassava (EFHS).

Crop	DM	Manure			Inorganic fertilizer		
		N	P	K	N	P	K
maize	1028	17	4	17	29	1	-
cassava	377	6	1	6	12	1	-

Table 6.4 Amount of nutrients (kg ha⁻¹) in 2076 mm rainfall (average of 50 years in Karangates) for different nutrient concentrations given by three different references.

Nutrient	Nitrogen	Phosphorus	Potassium
Bruijnzeel (1983)	10.03	1.25	4.15
van Duivenbooden (1992)	13.49	1.45	10.38
Stoorvogel & Smaling (1990)	6.38	1.05	4.19

nitrogen, phosphorus and potassium content of the rainwater in Central Java as 0.48, 0.06 and 0.20 mg l⁻¹. Stoorvogel & Smaling (1990) developed a regression equation which linked nutrient input (kg ha⁻¹ y⁻¹) to the square root of average rainfall (mm y⁻¹). The regression coefficients were 0.14, 0.023 and 0.092 for N, P and K respectively. The amount of nitrogen for the West African situation was estimated by van Duivenbooden (1992) at 0.0065 kg ha⁻¹ mm⁻¹, and that of phosphorus and potassium at 0.0007 and 0.005 kg ha⁻¹ mm⁻¹ respectively. Since the data of Bruijnzeel were measured in Indonesia it seems justified to use these data for the research area.

Nutrients in harvested products and crop residues

Removing harvested product from the land entails loss of N, P and K, the quantity determined by the yield and nutrient concentration of the product. The maize grain and cassava tubers were all removed from the land, for either home consumption or sale. The crop residues were almost completely removed from the land and used for livestock feed, fuel or building material. To calculate the amount of nutrients taken up by maize and cassava, the yields of 1991 and 1992 (Table 5.3), were taken. Nutrient concentrations of the harvested products and

Table 6.5 Uptake of macro-nutrients by the harvested product (grains) and crop residues (straw) of maize and cassava grown in 1991 and 1992. Yields are the average for the villages Putukrejo and Kedungsalam, East Java, Indonesia.

Crop	N-uptake		P-uptake		K-uptake	
	Grain	Straw	Grain	Straw	Grain	Straw
maize ¹ 1991	14	6	1.5	0.8	4.2	11.6
maize ¹ 1992	34	15	3.6	2.0	10.1	28.0
cassava ² 1991	18	28	2.0	3.5	19.6	11.9
cassava ² 1992	46	74	5.2	9.2	51.5	31.3

¹ maize grain 1.2% N, 0.13% P and 0.36% K in DM; maize straw 0.52% N, 0.07% P and 1.0% K in DM

² cassava tubers 0.54% N, 0.06% P and 0.60% K in DM; cassava straw 2.0% N, 0.25% P and 0.85% K in DM

crop residues were derived from Table 7.5. For maize an average harvest index of 0.3 was used, and for cassava an average harvest index of 0.7. The uptake of N, P and K by maize and cassava is shown in Table 6.5.

Nutrients lost through denitrification

Nitrogen is present in soils in more or less complex organic compounds, as inorganic solutes, and in gaseous forms. This large reservoir of organic complexes in the soil is decomposed at widely varying rates by microbes and converted into ammonium (NH_3), which is the main substrate for soil biota. This nitrogen mineralization is counteracted by nitrogen immobilization, which leads to the biosynthesis of complex molecules of microbial protoplasm from ammonium and nitrate (NO_3^-). Both processes take place simultaneously and continuously. The net result of these two processes is commonly referred to as net nitrogen mineralization. The ammonium released by mineralization may be oxidized into nitrate, with nitrite (NO_2^-) as the intermediate form. This nitrification is generally defined as the ultimate oxidation of reduced forms of nitrogen into nitrate. Nitrate, the most oxidized form of nitrogen, is only very weakly bound to soil surfaces and is, thus, readily leachable. Nitrate leaching and the emission of gaseous forms of nitrogen are considered to be the main pathways for nitrogen loss from the ecosystem. Denitrification is the reduction of nitrogen oxides, usually nitrite or nitrate, to gaseous products such as nitrous oxide (N_2O) and molecular nitrogen (N_2). Denitrification is known to occur under upland conditions when oxygen diffusion is impaired by water layers around structure elements and plant roots, i.e. under waterlogging conditions. Nitrous oxide, however, is also a direct by-product of nitrification, which would therefore also be a process contributing to gaseous nitrogen losses.

The carbon and nitrogen cycles in ecosystems are closely linked. The decomposition of organic compounds by heterotrophic microorganisms not only yields energy and carbon for microbial assimilation, it also transforms nitrogen bound in organic compounds into available inorganic nitrogen. As a result, factors regulating decomposition are important regulators of nitrogen cycling as well. Li et al. (1992) developed a model that couples decomposition and denitrification processes, as influenced by the soil environment, to predict emissions from agricultural soils. The DNDC (denitrification-decomposition) model simulates the production of N_2O in soils using information on soil properties, agricultural practices and weather variables as input. As an example the DNDC model is run for maize grown in 1991 in the research area. The results are shown in Table 6.6.

Smaling (1993) quantified percentage of denitrification as a function of clay content (%) and average annual rainfall (P, mm y^{-1}) ($\text{DN} (\%) = -9.4 + 0.13 * \text{clay content} + 0.01 * \text{P}$). The amount of denitrified soil nitrogen and fertilizer N was then calculated from mineral soil nitrogen (N_{min}) and fertilizer nitrogen (IN₁ + IN₂) respectively. The clay content of the soils in the research area ranged between 50 and 85 percent and an average clay content of 68 was assumed. The yearly rainfall was taken at 2076 mm, the average of the last 30 years measured at Karangates. This resulted in a calculated denitrified nitrogen percentage of 20.2%. Table 6.6 shows the calculated denitrified nitrogen (N_2 and N_2O) amounts for maize and cassava

Table 6.6 Predicted amount of gaseous nitrogen ($\text{kg ha}^{-1} \text{y}^{-1}$) for different land units and crops on limestone clay soils, south of Malang, Indonesia.

Denitrified N	site	NO	N ₂ O	N ₂	Total
maize					
Li et al. (1992)	LU1	3.9	0.9	25.9	30.7
	LU2	4.4	0.8	24.7	29.9
	LU3	3.5	0.8	25.0	29.3
	LU4	3.4	0.9	26.2	30.5
Smaling (1993)	valley	-	-	-	33.3
	hillside	-	-	-	41.0
cassava					
Smaling (1993)	valley	-	-	-	28.2
	hillside	-	-	-	35.9

cultivated on a valley bottom or a hillside.

The difference of the calculations done with the DNDC model compared to the method of Smaling is that the latter did not include nitrified N₂O. Furthermore, the DNDC model uses a timestep of one day and this is of particular importance since the aerobic or anaerobic situation determines the fractions of N₂ and N₂O, while Smaling's calculations are done with a timestep of 1 year. The results of the DNDC model show hardly any difference between the different land units while the calculations done following the equation of Smaling, a big difference is found between valley bottoms and hillsides. Since it is believed that the DNDC computations are more reliable and more accurately these results will be used in this chapter.

Nutrients lost through leaching

Although comprehensive simulation models exist on solute leaching in soils, they were not used in this thesis since their data demands are high and such data were not measured. Smaling (1993) estimated leaching by means of transfer functions, using generally accepted determinants such as rainfall, texture, soil N and K content and fertilizer input. Phosphorus is not leached at all. Similar to the calculations of Smaling (1993), leaching of surface applied nitrogen (LN_{fert}) and leaching of soil derived nitrogen (LN_{soil}) were calculated as percentages of native soil and fertilizer N and K. In the research area the clay content was more than 55% and the average annual rainfall was above 2050 mm. Water percolation and run off were explicitly dealt with since the transfer functions were based on actual data of leaching. The percentage of nitrogen leaching was 20% of the total mineral soil nitrogen and also 20% of the total nitrogen fertilizer input. The percentage of potassium leaching was 0.70% of the exchangeable potassium and also 0.70% of the total potassium fertilizer input.

The mineralization rate constants for individual constituents in fresh plant litter vary from

Table 6.7 Predicted amount of nitrogen and potassium leached (kg ha⁻¹), surface applied and soil derived, for maize and cassava grown at different sites, in the limestone area of East Java.

Nutrient leached	Crop	Valley	Hillside
Nitrogen	maize	32.9	40.6
Nitrogen	cassava	27.9	35.6
Potassium	maize	1.91	0.91
Potassium	cassava	1.84	0.84

4.6 y⁻¹ for sugar (99% of all sugars decomposed in 1 year) to 0.1 y⁻¹ for phenols. For humus, decomposition rate constants are much lower than for most fresh plant material, and vary from 0.1 to 0.001 y⁻¹. Parton et al. (1992) divide soil organic carbon up into three major components which include active (microbe), slow (lignin derived material) and passive (stabilized SOM) soil carbon. The turnover time of these pools varies with the soil abiotic decomposition parameter (function of monthly precipitation and temperature). Typical turnover times for a grassland site are 2, 40 and 2000 years; respectively for the active, slow and passive pools.

Total mineral soil nitrogen (N_{min}; kg ha⁻¹) was calculated from total soil nitrogen, assuming a fixed annual nitrogen mineralization rate M, set at 0.035 y⁻¹ (N_{min} = 20 (cm) * N_{tot} (g kg⁻¹) * M * 100). A bulk density of 1 g cm⁻³ was used. LN_{soil} was then calculated as 20% of N (LN_{soil} = % * N_{min}). For lack of alternatives, and to be in line with literature data, LN_{fert} was also derived as 20% of total fertilizer input (IN 1 + IN 2). Potassium leaching was expressed as a function of rainfall, clay content and exchangeable K (LK_{soil} = % * K_{exch} (kg ha⁻¹)). LK_{fert} is 0.7% of IN 1 + IN 2. Leaching of phosphorus was assumed negligible as most soils tend to strongly retain phosphorus. Table 6.7 shows the calculated leaching results of nitrogen and potassium for four different land use types.

Nutrients lost through erosion

Only one actual measurement of erosion was carried out in the village of Putukrejo. Crops cultivated were maize and cassava intercropped, grown in the 1991-1992 growing season on land with a slope of 6%. The amount of soil loss measured yielded 22.65 t ha⁻¹ y⁻¹. The annual soil loss for valley bottoms and hillsides was assumed to be 2 and 8 t ha⁻¹ respectively when cultivated with cassava, and 10 and 20 t ha⁻¹ when cultivated with maize. Inherent soil fertility was used to translate soil loss by erosion data into nitrogen, phosphorus and potassium losses, which were then multiplied by an 'enrichment' factor of 1.5. As fine particles are dislodged first in the process of erosion, eroded soil is richer in nutrients than

Table 6.8 The nutrient contents in the soil and amount of nutrients lost via erosion for different land use types, in East Java, Indonesia.

Nutrient	Nutrient content (g kg ⁻¹)	Nutrient loss (kg ha ⁻¹)	
		Maize	Cassava
Valley			
N	1.75	22.63	5.25
P	0.28	2.53	0.63
K	0.40	2.25	0.90
Hillside			
N	2.30	94.50	27.60
P	0.39	10.12	3.51
K	0.40	9.00	3.60

soil *in situ*. Erosion implies loss of surface soil. Meanwhile, at the root base, soil formation takes place. To take that into account, it was assumed in calculating OUT 5 that the net loss of P and K was only 0.75 times the calculated loss at the surface. The data and the calculated nutrient losses are shown in Table 6.8.

The nutrient balance

Nutrient balances were calculated for maize and cassava cropping for 1991 and 1992. Differences were due to low rainfall in 1991 compared to 1992 (see Table 4.6 and 5.3). The amount of fertilizers applied to the soils was crop specific. The nutrients removed from the soil via leaching, denitrification and erosion were site specific. The results of the nutrient balance are shown in Table 6.9 to 6.11. For nitrogen, phosphorus and potassium a negative balance was found in all cases, with higher negative values for cassava and maize for 1992 compared to 1991. The negative values were higher for hillsides compared to valley bottoms. The only exception was the balance of phosphorus and potassium which was positive for maize grown in 1991 at valley bottoms and hillsides.

The amount of nutrients applied to the soil, in the form of organic and inorganic fertilizer, as well as the amount of nutrients removed from the soil, through harvesting of the grains or tubers and the crop residues, is controlled by human management. In most situations the amount of nutrients removed by crop harvesting (OUT1 + OUT2) was higher than the amount of nutrients applied to the soil (IN1 + IN2). Maize grown in 1991 was an exception with positive values mainly caused by the very low maize crop yield in that particularly year. The only other factor which added nutrients to the soil was rainfall which only added 10 kg

Table 6.9 Nitrogen balance for maize and cassava cultivated in 1991 and 1992 at valleys and hillsides in the combined villages of Putukrejo and Kedungsalam, East Java, Indonesia.

crop	year	site	Amount of nitrogen (kg ha ⁻¹ y ⁻¹)								
			in1	in2	in3	out1	out2	out3	out4	out5	TOT
maize	1991	valley	29	17	10	14	6	30	33	24	-51
maize	1992	valley	29	17	10	34	15	30	33	24	-80
cassava	1991	valley	12	6	10	18	28	25	28	5	-76
cassava	1992	valley	12	6	10	46	74	25	28	5	-150
maize	1991	hillside	29	17	10	14	6	30	41	95	-130
maize	1992	hillside	29	17	10	34	15	30	41	95	-159
cassava	1991	hillside	12	6	10	18	28	25	36	28	-107
cassava	1992	hillside	12	6	10	46	74	25	36	28	-181

Table 6.10 Phosphorus balance for maize and cassava cultivated in 1991 and 1992 at valleys and hillsides in the combined villages of Putukrejo and Kedungsalam, East Java, Indonesia.

crop	year	site	Amount of phosphorus (kg ha ⁻¹ y ⁻¹)								
			in1	in2	in3	out1	out2	out3	out4	out5	TOT
maize	1991	valley	1	4	1.3	1.5	0.8	-	-	2.5	1.5
maize	1992	valley	1	4	1.3	3.6	2.0	-	-	2.5	-1.8
cassava	1991	valley	1	1	1.3	2.0	3.5	-	-	0.6	-2.8
cassava	1992	valley	1	1	1.3	5.2	9.2	-	-	0.6	-11.7
maize	1991	hillside	1	4	1.3	1.5	0.8	-	-	10.1	-6.1
maize	1992	hillside	1	4	1.3	3.6	2.0	-	-	10.1	-9.4
cassava	1991	hillside	1	1	1.3	2.0	3.5	-	-	3.5	-5.7
cassava	1992	hillside	1	1	1.3	5.2	9.2	-	-	3.5	-14.6

of N, 1.3 kg of P and 4.15 kg of K (Table 6.4). This means that the nutrient balance can only be restored by the application of inorganic and organic fertilizer. And reducing losses (OUT3, OUT4, OUT5) is not enough to make the total balance positive. Apart from the negative nutrient balance, the soils in the research area are also too low in organic matter. Therefore the best solution for the heavy clay textured soils in the research area is to combine the application of organic manure with inorganic fertilizers. If the crop residues were not removed (i.e. used for cattle, sheep or goats) the situation would be less dramatic. However, manure production and application (IN2) would also be less and per saldo the conclusion that can be drawn from the above balances will not change.

Table 6.11 Potassium balance for maize and cassava cultivated in 1991 and 1992 at valleys and hillsides in the combined villages of Putukrejo and Kedungsalam, East Java, Indonesia.

crop	year	site	Amount of potassium (kg ha ⁻¹ y ⁻¹)								
			in1	in2	in3	out1	out2	out3	out4	out5	TOT
maize	1991	valley	-	17	4.2	4.2	11.6	1.9	-	2.3	1
maize	1992	valley	-	17	4.2	10.1	28.0	1.9	-	2.3	-21
cassava	1991	valley	-	6	4.2	19.6	11.9	1.8	-	0.9	-24
cassava	1992	valley	-	6	4.2	51.5	31.3	1.8	-	0.9	-75
maize	1991	hillside	-	17	4.2	4.2	11.6	0.9	-	9.0	-5
maize	1992	hillside	-	17	4.2	10.1	28.0	0.9	-	9.0	-27
cassava	1991	hillside	-	6	4.2	19.6	11.9	0.8	-	3.6	-26
cassava	1992	hillside	-	6	4.2	51.5	31.3	0.8	-	3.6	-77

Conclusions

At the present yield levels, more nutrients are withdrawn from the soil than added. The deficit is made up by the mineral and organic nutrient reserves in the soil, and if not replenished adequately, these pools gradually shrink. In other words, soil mining is practiced. As a consequence, crop production will gradually decline as soils are becoming poorer. To stop nutrient depletion and get the balance right, it does not suffice to just increase the use of inorganic fertilizers. There is a need for integrated soil fertility management where all inputs and outputs are manipulated in a judicious way. A future scenario is the conservation of soil fertility, increasing inputs and reducing losses simultaneously. This may be achieved by:

- applying modest amounts of inorganic fertilizer, complying with specific recommendations for combinations of crops and land, i.e. precision farming. This will improve both the nutrient use efficiency and the fertilizer recovery by crops.
- efficient use and storage of animal manure, to reduce processes as volatilization and leaching. Thus more nutrients are released from manure and additional benefits are provided, such as increased water storage and nutrient retention.
- introducing more nitrogen fixing species in cropping systems like green manures, grain legumes and woody species.
- properly timed and split application of inorganic fertilizers
- appropriate tillage and soil conservation measures; terracing can stop erosion, but strip cropping, mulching, alley cropping and multi storey cropping are simpler and often effective techniques, fitting in existing farming systems.
- In densely populated areas where land is scarce, zero grazing is the only solution. Contour

planted roughage is fed to stalled livestock.

With a combination of the above mentioned measures inputs are increased and losses may be reduced considerably. More labour may be required for sustainable nutrient management and farming systems research should elucidate what changes are desirable and feasible.

The above mentioned characteristics of the natural resource indicate that soil quality is declining, agricultural production is decreasing and therefore more and more people have to look for employment opportunities outside the agricultural sector. It will be studied in this thesis how the natural resource can be improved and which options of land uses give the best opportunity considering food security and the natural resource improvement.

Chapter 7

Crop yields and resource use

Introduction

A crop production model can provide quantitative estimates of different yield levels, and of the inputs that are needed for their realization. Possibilities and constraints for improving crop yields in the limestone area were investigated using the technique of crop growth modelling. Firstly a justification for the chosen yield levels is presented followed by a brief explanation of the models used. Then methods are discussed, used to obtain the inputs of the main resources water and nutrients. Hereafter yield estimates are presented for a variety of environmental and technical conditions, followed by the water and nutrient requirements needed to obtain these yields. The gap that exists between the actual farmers yields and the calculated improved yield is analysed and the final discussion refers to possibilities and constraints to narrow the observed yield gap.

These quantitative estimates should not be seen as final answers but rather as indications of possibilities and constraints that are based on factual knowledge. Simulation results are used to derive target yields for the crop activities. Crop activities are based on land unit and crop species. Each activity is described by a set of relevant inputs of a specific production process, related to its outputs. Cropping activities are normalized to the unit of land. The value of the input/output factors depends on the production situation and orientation. The production situation, that is the bio-physical situation in which the production takes place, determines the efficiency of, for example, fertilizer. The production situation is described by the land use, the land unit and by the crop production level. The production orientation refers to the production objectives, which in turn are defined by agricultural production technologies applied in the research area. The production objectives determine the yield level. The amount of technical input/output factors indicate the extent to which certain activities draw on the available resources and enables comparison of different land use systems. Input factors considered are water use and nutrient input (N, P and K); the output factor considered is crop yield. In Chapter 10 these data are used to find more productive land use technologies which are sustainable in the long term in the way that they do not degrade the soils further.

The concept

Land use systems in the research area were characterized by the growing of annual crops in association with perennial crops, either on valley bottoms or on hillsides. Simulation models were only available for a limited number of annual crops. They hardly existed for annual and tree crop combinations where the production of an annual crop is co-determined by interactions and competition with the tree crop. Neither were simulation models available which quantified the production of tree crops or tree production systems. Therefore in this thesis the biomass production for tree production systems was calculated empirically with available field data (Chapter 5). Annual crop production was calculated with crop growth simulation models for 4 annual crops: maize, cassava, upland rice and sugarcane. Production of intercropped maize and cassava was not modelled. Competition for light in a mixed stand had to be described by quantifying the light absorbed by each crop as a function of the properties and spatial positions of all leaves. These kind of relations required calibration with field data which were unfortunately not available for the research area. Therefore yield of intercropped maize and cassava was derived from on-farm field experiments and experimental stations.

Two light transmission coefficients (TC) were considered (Chapter 5) within CCT2. It was assumed that CCT2 on valley bottoms (LU1) faced a TC of 0.75, and CCT2 on hillsides (LU2, 3 and 4) a TC of 0.62. Three annual crop production levels (CPL) were considered, potential, water-limited, and water- and nutrient-limited. Two agricultural technology orientations were distinguished: 'Yield-Oriented Agriculture' (YOA) which attempts the highest yield possible under the prevailing conditions, and 'Low External-Input Agriculture' (LEIA) which seeks to restrict the use of inputs from outside the farm. Both technologies are hypothetical, and chosen as each others opposites in order to obtain the highest contrast possible. Differences between land units concerned mainly soil properties. It was assumed that the potential and water-limited production levels referred to yield-oriented techniques, and

Table 7.1 The 68 crop production situations analysed.

Crop production situations	Land units	Crop cultivation types	Annual crops	Crop production level	Agricultural production technology ¹
1- 4	0	1	4	potential	yoa
5-20	1-4	1	4	water limited	yoa
21-36	1-4	2	4	water limited	yoa
37-52	1-4	1	4	water&nutrient limited	leia
53-68	1-4	2	4	water&nutrient limited	leia

¹ yoa = yield-oriented agriculture, leia = low external-input agriculture

therefore to systems without application of organic fertilizer. They were based on high input levels of inorganic fertilizers and included innovative practices. The water- and nutrient-limited production level refers to a low external-input agriculture technique applying only organic fertilizer. A total of 68 crop production situations were analysed, distinguished by different land unit, land utilization types, crop production level and levels of agricultural production technology (Table 7.1).

Methodology

Crop production levels

An existing crop growth simulation model was adapted for the present study. The model was used for different production situations, shown in Table 7.1. The growth of crops was quantified on the basis of physiological, biological and chemical processes, both in the crop and in the production environment. State variables characterized the state of the crop and the land unit at any moment. State variables that typify the crop were, among others, the amount of above- and below-ground plant organs, the surface area of the leaves and the rooting depth. The model updated the state variable values for each time step of one day. The yield potential varied with the absorption of light, the fraction of the net assimilate production that was earmarked for growth of harvested plant parts, the losses incurred in maintenance respiration, and the efficiency with which the remaining assimilates were converted to structural plant matter (de Wit & van Keulen, 1987).

Crop production situations 1 till 4 calculated the potential production of a crop, i.e. the constraint-free dry matter accumulation under the prevailing weather conditions. The model simulated dry matter accumulation of a crop, as a function of radiation, temperature and crop characteristics. In crop production situations 5 till 36, the production potentials were determined by uptake of water and transpiration in the course of the season. Water may be a limiting factor but it was still assumed that the crop was free of pests, diseases and weeds and optimally supplied with nutrients. Almost all agriculture in the limestone area was rainfed. This means that the water holding capacity of the rootzone is important to the success of cropping. For simulating the water-limited production potential, information was needed on the physical properties of the soil. A water balance tracks the amount of water in the soil. This permits a correction of the crop production potential for situations in which soil moisture becomes a limiting factor for production.

Production situation 37 till 68 represented a land use system whose production potential was conditioned by radiation, temperature and both water and nutrient availability. This production situation was difficult to model because many relations that influenced system behaviour had not yet been quantified or even identified. The complexity and dynamics of nutrient supply to crops precludes the calculation of yield potentials as dependent variables.

Table 7.2 Maize grain yields ($t\ ha^{-1}$) for the water-limited (WLP), the nutrient-limited (NLP) and the water- and nutrient-limited (WNLP) production.

site	WLP	NLP	WNLP
valley	2.4	2.3	1.4
hillside	0.3-1.8	0.7-1.3	0.2-1.1

It is possible however to calculate the approximate input of fertilizer(s) needed to meet a set production target. This target cannot exceed the water-limited production potential. For this research the water- and nutrient-limited target yields were set to 60% of the water-limited yield. This value is justified when the water-limited and the water- and nutrient limited yields of maize are compared with nutrient-limited yields (Table 7.2). These nutrient-limited yields were calculated with QUEFTS (Chapter 6), where water supply is assumed not to affect the crop development of maize.

The water- and nutrient-limited yields are below the water-limited and the nutrient-limited yields. It is believed that when both water and nutrients are growth limiting factors, the crop growth is reduced more than when only one factor is growth limiting. This is due to a reduced nutrient uptake when water is limiting. The value of 60% cannot be taken lower since then, water- and nutrient-limited yields will be below the actual yields as were monitored in the fields of farmers (Chapter 5). The actual yields should be equal or below the water- and nutrient-limited yields because they are influenced by pests, diseases and all kind of environmental factors as well. It is assumed that maize can serve as an example for cassava, upland rice and sugarcane, and therefore for these crops also the value of 60% is used.

Potential, water-limited and water- and nutrient-limited yields were calculated for monocrops of maize, cassava, upland rice and sugarcane. Crop yields for yield-oriented agriculture and low external-input agriculture were derived from these simulated reference yields. A brief explanation of the model was given above. Input data (weather, crop, soil and management data) are discussed hereafter.

Weather data

The crop growth simulation model uses daily weather data collected in 1991 in Kedungsalam. The weather data set included the 24 hour temperature ($^{\circ}C$), maximum daily temperature ($^{\circ}C$), minimum daily temperature ($^{\circ}C$), precipitation (mm), relative humidity of the atmosphere (-), potential rate of evapotranspiration ($cm\ d^{-1}$), sunshine hours ($h\ d^{-1}$) and potential rate of evapotranspiration ($cm\ d^{-1}$).

Crop data

Appendix 3 gives for maize, cassava, upland rice and sugarcane common parameters and the allocation fractions of the daily produced assimilates to the leaves, stems, roots and storage

organs (kg dry matter organ kg⁻¹ dry matter crop). The allocation fractions were defined as a function of the relative development stage of the crop. The development stage of a plant reflects its physiological age; stages in plant development are characterized by the formation and appearance of specific organs. The data was partly derived from literature and partly from experimental data, (maize and cassava). It was assumed that all crop parameter values remained the same for all three crop production levels (PP, WLP, WNLP) and for all crop cultivation types.

Soil data

The soil data needed for water balance calculations were collected in field observations, laboratory analyses and literature. Soil physical data for the four land units distinguished in the research area are given in Appendix 3 as well.

Crop management

The only management data that were considered in the crop simulations were planting density and planting date. For maize, a plant density of 6.7 plants per m² was chosen, corresponding with 40 cm between plants, 75 cm between rows and 2 maize plants per seed hill. With a grain weight of 272 gram per 1000 grains, the seed rate of maize was about 36 kg per ha. For cassava, a planting density of 1 plant per m² was used based on 80 cm between plants, 120 cm between rows and 1 stem cutting per hole. The dry weight of a stem cutting was assumed to be 8 grams which brought the planting rate to about 80 kg per ha. Rice was sown 15 cm apart resulting in a planting density of 45 plants per m². The 1000 grain weight was some 33 grams which brought the seed rate of sown rice to 15 kg per ha. For sugarcane a planting rate of 110 kg per ha was assumed.

Crop growth simulations were executed with 50 days between planting dates. The planting date that gave the highest yield of storage organs was considered to be the best and assumed to be the highest yield potential. The results are shown in Appendix 4 (potential crop production and water-limited production). Planting dates used for the water-limited crop production were also used for water- and nutrient-limited crop production.

Water

Crop water use was calculated for the potential production and the water-limited production. The crop water use of water- and nutrient-limited productions was derived from that of WLP. In this study, crop water use was defined as the amount of water transpired by a crop, without any interference by pests, weeds and diseases. The maximum rate of crop transpiration was calculated as

$$\begin{aligned} \text{TRM} &= \text{TR0} * \text{CFleaf} * \text{TC} \\ \text{TC} &= 1 + (\text{TCM} - 1) * \text{CFleaf} \\ \text{CFleaf} &= 1 - \text{EXP}(-\text{LAI} * \text{ke}) \\ \text{TR0} &= \text{E0} - 0.05 * \text{E0} \end{aligned}$$

TRM is the maximum rate of transpiration (cm d^{-1}); TR0 is the potential rate of transpiration (cm d^{-1}); CFleaf is the relative exposure of leaves to the atmosphere in laminar flow; TC is momentary turbulence coefficient; TCM is maximum turbulence coefficient (Appendix 3); LAI is the leaf area index; ke is extinction coefficient for visible light (Appendix 3); E0 is potential rate of evaporation (cm d^{-1}); and, E0 is potential rate of evapotranspiration (cm d^{-1}).

The difference in crop water use between the potential and water-limited production situations, is the amount of water that a crop had to take up from sources other than rain, to attain its yield potential.

Nutrients

The relation between crop nutrient uptake at maturity and crop yield, reflects the efficiency of nutrient utilization for biomass production. The relation is linear at low uptake levels, reflecting that under conditions of limited supply the crop makes maximum use of the nutrient that is taken up (minimum concentration). The slope of this linear part of the line represents the maximum nutrient use efficiency ($\text{kg grain per kg nutrient}$). At higher nutrient uptake levels the line deviates from linearity, reflecting higher concentrations of the element in plant tissues at maturity. Finally, it levels off, indicating that the element under consideration is no longer a constraint for unrestricted growth. If higher uptake does not lead to increased yield, the additional uptake can be considered as 'luxury consumption' (van Keulen & van Heemst, 1982). The level of the plateau is determined by the growth factor in short supply and is, in the potential growth situation a function of temperature and available solar energy during the crop's growth period (van Keulen & Wolf, 1986).

Due to a lack of knowledge of the interaction of different production factors, and the effect of heterogeneity in soils and climate on efficiencies, different approaches may be followed for describing nutrient use efficiency at different production levels (Bessembinder, 1995). Generally it is assumed that efficiencies will diminish with increasing production levels. It was argued by de Wit (1992) that: "with some reservations regarding the control of pests, diseases and weeds, it may be concluded that no production resource is used any less efficiently and most production resources are used more efficiently, with increasing yield level due to the further optimizing of growing conditions." This approach supposes that most production factors can be used most efficiently at the same time, i.e. all production factors are available in a 'balanced' mixture. The level of efficiency depends only on the physical circumstances prevailing in the field, i.e. the production situation. Based on this theory the

WRR (1992) described the most efficient ways of production as "best technical means" (BTM). The definition for BTM is: Available knowledge and available means of production are optimally applied, which precludes any waste or inefficient use of resources.

It is discussed below, which efficiencies of the yield related production factors (water and nutrients) were used. Comparison of two different explorative land use studies, one in Mali, West Africa (van Duivenbooden, 1992) and one in Europe (WRR, 1992) illustrates this.

Nutrient concentrations

Nutrient concentrations in maize were compared by van Duivenbooden (1992) from his research area, Mali, with regions of comparable soils and climate. The review showed that crop nutrient concentrations in systems with high production levels (intensive system) were about 1.4 times higher for grain and 1.7 times higher for straw than the minimum concentrations found in the same study. For systems with relatively low production levels (semi-intensive and extensive systems) these factors were 1.2 for grain and 1.3 for straw. In the explorative study of Mali these factors were used to estimate the crop nitrogen, phosphorus and potassium concentrations. Thus, lower nutrient use efficiencies were used at the highest yield level. The researchers considered it unlikely that minimum nutrient concentrations would be reached, because an optimum balance between all production factors at every moment will practically never be obtained due to heterogeneity in the field and unpredictability of the weather.

In the explorative land use study of the WRR (1992) only nitrogen was taken into account and average crop nitrogen concentrations were taken for all production levels. The average concentration was based on literature from all over the world. The concentrations in the marketable product and the residues of the plant, were assumed to be crop-specific constants, high enough to allow non-constrained production (de Koning et al., 1992). The approach used in the study of the WRR, with constant nutrient use efficiencies, was based on the theory of de Wit (1992). To reach these constant nutrient use efficiencies in the plant, a balance between all production factors is required. However, it seems difficult to reach such an optimum balance. In all experiments, including the ones shown by de Wit (1992), nutrient concentrations increased as production reached the potential level.

The approaches of WRR and of Mali are compared to determine which nutrient concentrations should be used in this research. Simulated maize yields for the research area are summarized in Table 7.3. The amount of grain dry matter produced per kg nutrient uptake was calculated and compared with the minimum and maximum nutrient use efficiencies from van Keulen & van Heemst (1982). The latter were obtained after an extensive analysis of yield uptake curves of small grains. Table 7.4 shows that when using the average concentrations of the WRR and the potential yields of the research area, the nutrient use efficiency was, for the water-limited potential, higher than the maximum efficiencies mentioned by van Keulen & van Heemst (1982). This could indicate a situation deficient in nitrogen. However, the water-limited potential assumed a production situation where nutrients

Table 7.3 Simulated yield of maize (kg DM ha⁻¹) for different production levels and land units.

	Potential	Water-limited potential			
		LU1	LU2	LU3	LU4
Grains	6733	2363	1844	1097	271
Crop residues	9228	4554	2491	1840	882

Table 7.4 Nutrient use efficiencies (grain yield per kg nutrient uptake) for two approaches for maize yields as calculated in Table 7.3.

Production situation	WRR ¹	Mali-intensive ²			Mali-semi-intensive ³		
	N	N	P	K	N	P	K
PP	35	-	-	-	-	-	-
WLP-LU1	73	35	363	34	41	473	46
WLP-LU2	72	42	399	47	51	536	65
WLP-LU3	81	39	399	40	47	501	57
WLP-LU4	26	39	434	23	174	∞	40
maximum efficiency ⁴		70	600	120			
minimum efficiency ⁴		30	200	30			

¹ WRR N (kg kg⁻¹); grain 0.015 and crop residues 0.01

² Mali intensive crop production assumes yields are 80% of the water-limited potential and N, P and K concentrations (kg kg⁻¹) are; grains 0.0154, 0.0022, 0.0035 and crop residues 0.0077, 0.00034, 0.0136

³ Mali semi-intensive crop production assumes yields are 40% of the intensive system and N, P and K concentrations (kg kg⁻¹) are; grains 0.0132, 0.0019, 0.0030 and crop residues 0.0059, 0.0003, 0.0104

⁴ van Keulen and van Heemst, 1982

were not limiting and therefore average nitrogen concentrations used for all crop production levels, assumed a nutrient use efficiency which was unrealistic for the research area at high crop production levels. When nutrient concentrations of the Mali study were used for the yields of the research area, in almost all cases the efficiencies were in between minimum and maximum (indicating no nutrient deficiency), and therefore more compatible with the research area. Only the water-limited potential on land unit 4 showed unrealistic nutrient use efficiencies, indicating infeasible production situations.

It is concluded that the theory of the Mali-study, i.e. increased nutrient concentrations at high production levels, is far more realistic for the study area compared to the theory of the WRR. Therefore, the nutrient concentrations which will be used in this research, are conform the Mali-study, and are listed in Table 7.5.

Table 7.5 Nutrient concentrations (% of DM) of different plant organs of 4 crops.

Yield ---> Crop	<u>potential-grain</u>			<u>potential-straw</u>			<u>limited-grain</u> ¹			<u>limited-straw</u> ¹		
	N	P	K	N	P	K	N	P	K	N	P	K
maize ²	1.4	.15	.42	.68	.09	.64	1.2	.13	.36	.52	.07	1.0
cassava ²	.63	.07	.70	2.6	.32	.85	.54	.06	.60	2.0	.25	.85
sugar ²	1.4	.15	.42	.68	.09	.64	1.2	.13	.36	.52	.07	1.0
upl rice ²	1.4	.15	.42	.68	.09	.64	1.2	.13	.36	.52	.07	1.0

¹ = either water-limited or water- and nutrient-limited

² = minimum nutrient concentrations (van Keulen & Wolf, 1986) are multiplied with 1.4 for grain and 1.7 for straw at potential yield level and multiplied with 1.2 for grain and 1.3 for straw at limited yield level.

Recovery of nutrients

Once the nutrient uptake by crops is known, the required amount of fertilizer can be calculated. The relationship between fertilizer application and nutrient uptake by the crop is a straight line. The slope of the line represents the fertilizer recovery in the above-ground plant material. The fertilizer recovery determines how much of the input is really utilized. The fraction recovered by the crop is a function of soil, weather and crop properties. Fertilizer recovery is also influenced by timing and method of fertilizer application.

Of the nutrients applied with fertilizer, only a part is absorbed by the crop. Different causes are responsible for this failure of complete recovery by the crop. Sometimes, part of the nutrients cannot reach the plant, because they do not enter into the soil solution in time; this plays a role mainly in the case of organic fertilizers and of poorly soluble fertilizers. The nutrients that enter the solution are subject to processes like leaching, fixation, immobilization and volatilization, by which they are lost for the plant. Fertilizer nitrogen applied to the soil may be distributed between five fractions: incorporated in soil organic matter, leached, lost by denitrification, volatilised or taken up by the crop. Soil erosion losses were ignored for N, P and K. The possible distribution of fertilizer P is among four fractions: fixed in the soil mineral fraction, incorporated in soil organic matter, residual P (available the year after application) and taken up by the plant (on average 10-16%). A major cause of P-losses is fixation in clay particles. The possible distribution of K is among four fractions: incorporated in soil organic matter, leaching, incorporated in the soil mineral fraction and taken up by the plant (on average 24-38%).

In this study no distinction was made between the recoveries of the different crops. Differences between crops in apparent fertilizer recovery are often related to differences in root distribution. Rooting systems differ in their efficiency of nutrient uptake (de Willigen & van Noordwijk, 1989). Qualitatively a great deal of knowledge is available with respect to the actors influencing recoveries, but reliable quantitative predictions are still difficult for many production situations.

Recovery is negatively affected by moisture stress. Shortage of water in the soil reduces availability of nutrients probably because the uptake of soil moisture solution is depressed. In the potential production situation, the soil water status is optimal throughout. Uptake of nutrients may be hampered not only under dry conditions, but also under very high soil moisture contents when uptake is reduced, and losses due to leaching and denitrification are higher. In the research area recovery is a function of soil and weather and this is reflected by the different recoveries of the different land units. Recovery values were different for LEIA (organic fertilizer) and YOA (inorganic fertilizer).

Availability of nutrients from applied farmyard (organic) manure for plant uptake depends on its rate of decomposition and its quality. The quality of manure, defined in general terms of absolute and relative nutrient content, is a function of the type of animal, the quality of its diet, the way of conservation and the time between excretion and application

Table 7.6 The recovery, nutrient concentration and the fraction of nutrient applied incorporated in stable soil organic matter for N, P and K in organic as well as inorganic fertilizer.

Yield level	Tech-logy ¹	C	C			Nitrogen			Phosphorus			Potassium		
			L	T	U	rec	conc	fr-om	rec	conc	fr-om	rec	conc	fr-om
PP	YOA	1	1	1		.75	.45	.20	.30	.20	.20	.65	.50	.15
WLP	YOA	1	1	1		.50	.45	.25	.30	.20	.20	.65	.50	.20
		1	2	1		.40	.45	.30	.25	.20	.25	.60	.50	.20
		1	3	1		.30	.45	.35	.20	.20	.30	.55	.50	.25
		1	4	1		.20	.45	.40	.15	.20	.35	.50	.50	.25
WLP	YOA	2	1	.75		.50	.45	.25	.30	.20	.20	.65	.50	.20
		2	2	.62		.40	.45	.30	.25	.20	.25	.60	.50	.20
		2	3	.62		.30	.45	.35	.20	.20	.30	.55	.50	.25
		2	4	.62		.20	.45	.40	.15	.20	.35	.50	.50	.25
WNLP	LEIA	1	1	1		.25	.017	.35	.26	.004	.25	.65	.016	.20
		1	2	1		.20	.017	.40	.21	.004	.30	.60	.016	.20
		1	3	1		.15	.017	.45	.17	.004	.35	.55	.016	.25
		1	4	1		.10	.017	.50	.13	.004	.35	.50	.016	.25
WNLP	LEIA	2	1	.75		.25	.017	.35	.26	.004	.25	.65	.016	.20
		2	2	.62		.20	.017	.40	.21	.004	.30	.60	.016	.20
		2	3	.62		.15	.017	.45	.17	.004	.35	.55	.016	.25
		2	4	.62		.10	.017	.50	.13	.004	.35	.50	.016	.25

¹ YOA is yield-oriented agriculture with use of inorganic fertilizers (urea, TSP and KCL) only while LEIA is low external-input agriculture with use of manure only.

in the field. The efficiency index is the quantity of fertilizer nutrient required for a same yield increase as is obtained by 100 kg of that nutrient in organic manure. In other words: the efficiency index indicates which fraction of the nutrient in organic manure has the same efficiency in inorganic fertilizer. The efficiency of nutrients in farmyard manure on arable land is affected by soil type, time of application, time between applications, soil fertility status, rate of application and weather conditions. Observations suggest that 40-70 kg of N from fertilizer is as effective as 100 kg of N in farmyard manure. The efficiency index for K appears to be 100% in practice. This is because K is not or hardly organically bound and can also be released without microbial decomposition. For P an efficiency index lower than 100% can be expected because P is found partly in organic components, which should be decomposed first before P is available to the crop; 85% is assumed at present in the Netherlands. For the research in this thesis the recovery of N, P and K from animal manure is assumed to be 50%, 85% and 100% of the inorganic fertilizer recoveries.

Table 7.6 neglects the possible effects of pests, weeds and diseases on nutrient uptake efficiency.

Native soil fertility

Apart from inorganic and organic fertilizer sources nutrients may be available from natural sources as well. These natural sources originate from mineralization during decomposition of old soil organic matter, from nutrients from rain, from dust, from irrigation water, from river water in flood retreat crops and from micro-organisms. However, Chapter 6 shows that all these processes only contributed little to the total nutrient supply and, since no such data for the research area were available, they were not considered. Only natural soil fertility was considered as a natural nutrient source. A method to obtain the supply from natural sources follows the QUEFTS-system, based on soil chemical characteristics (see Chapter 6). However, QUEFTS assumes that the crop production is only limited by N, P and K. Water supply during the growing season does not adversely affect crop development. These conditions were certainly not met by the water-limited crop production and the water- and nutrient-limited crop production. Therefore another method to obtain the supply of nutrients from natural sources will be used and is defined as the ratio of the required uptake of the nutrient to the fraction of the fertilizer allocated to soil organic matter. In other words, the amount of fertilizer nutrients incorporated in stable soil organic material was identical to the amount mineralized from that source. This followed from the assumption of an equilibrium situation. Table 7.6 gives the, for this study assumed, fraction of fertilizer nutrients which were distributed to the stable soil organic matter (fr-om), in relation to yield level, technology, land unit and fertilizer type. In this study it is assumed that the behaviour of nutrients in the soil was independent of their source (inorganic fertilizer or organic manure).

Calculation of nutrient uptake and fertilizer input

The nutrient uptake for the individual nutrients during the growing period was calculated as follows:

$$\text{UPT} = Y_p * \text{Conc}_p + Y_r * \text{Conc}_r$$

where Conc_p and Conc_r are the concentrations of the nutrient in the dry matter of storage organs and crop residues (excluding roots), and Y_p and Y_r are the dry weights at harvest of storage organs and crop residues (excluding roots) (kg ha^{-1}). In the equilibrium situation, the amount of nutrients incorporated in soil organic matter equalled the amount released from soil organic matter:

$$\text{NATF} = (\text{UPT} / \text{REC}) * \text{FR-OM}$$

where, 'NATF' is the natural nutrient soil fertility (kg ha^{-1}), 'UPT' is the uptake of nutrient by above-ground plant parts of a crop at maturity following fertilizer application (kg ha^{-1}), 'REC' is the apparent recovery for nutrient (-), and 'FR-OM' is the fraction of nutrient applied incorporated in stable soil organic matter (-). The latter two were derived from Table 7.6. The external requirements to achieve the target yields for each nutrient were calculated separately by:

$$\text{REQ} = (\text{UPT} / \text{REC}) - \text{NATF}$$

where, 'REQ' is the external nutrient requirement (kg ha^{-1}). The amount of fertilizer required was calculated for N, P and K separately:

$$\text{FERT} = \text{REQ} / \text{CONC}$$

where, 'FERT' is the fertilizer requirement (kg ha^{-1}), and 'CONC' is the concentration of nutrient in fertilizer (kg kg^{-1}). Based on N, P and K requirements the required amount of manure differs for the three nutrients. The maximum of the three calculated values of manure requirements was used.

Results

Crop production estimates

Calculated crop productions of maize, cassava, upland rice and sugarcane are given in Table 7.7. For each land unit the yields of the marketable product, as well as the crop residues of all 4 crops grown on CCT1, were higher compared to CCT2. Yield-oriented agriculture resulted, as expected, in higher yields compared to low external-input agriculture. When the crop production potentials of maize, with and without light reduction, were compared, it was quite clear that plant growth without light reduction gave the highest yield of each plant

Table 7.7 Calculated potential dry mass of plant organs of several crops (kg ha⁻¹) for different crop cultivation types (CCT), land units (LU) and light transmission coefficients (TC). Three yield levels are considered, potential production (PP), water limited production (WLP) and water- and nutrient-limited production (WNLP). Two production technologies considered are yield oriented agriculture (YOA) and low external-input agriculture (LEIA).

Yield level	Tech-logy	CCT			Maize		Cassava		Upland rice		Sugarcane	
		C	L	T	grain	straw	tuber	straw	grain	straw	cane	straw
PP	YOA	1	1	1	6.7	9.2	33.2	27.9	7.4	7.2	34.8	12.9
WLP	YOA	1	1	1	2.4	4.6	7.4	7.1	3.5	5.6	13.8	6.5
		1	2	1	1.8	2.5	12.7	12.7	1.4	3.7	13.8	6.6
		1	3	1	1.1	1.8	6.7	6.9	1.2	2.2	8.8	4.3
		1	4	1	0.3	0.9	1.4	1.5	0.5	1.4	3.9	2.4
WLP	YOA	2	1	.75	2.3	3.2	5.0	4.6	2.9	3.8	3.7	1.5
		2	2	.62	1.2	1.8	6.5	6.7	0.8	1.2	0.7	0.3
		2	3	.62	0.5	0.9	3.7	3.9	0.5	1.1	0.5	0.3
		2	4	.62	0.2	0.5	0.8	0.9	0.4	0.7	0.4	0.2
WNLP	LEIA	1	1	1	1.4	2.7	4.4	4.3	2.1	3.3	8.3	3.9
		1	2	1	1.1	1.5	7.6	7.6	0.8	2.2	8.3	4.0
		1	3	1	0.7	1.1	4.0	4.1	0.7	1.3	5.3	2.6
		1	4	1	0.2	0.5	0.8	0.9	0.3	0.8	2.4	1.4
WNLP	LEIA	2	1	.75	1.4	1.9	3.0	2.7	1.7	2.3	2.2	0.9
		2	2	.62	0.7	1.1	3.9	4.0	0.5	0.7	0.4	0.2
		2	3	.62	0.3	0.6	2.2	2.3	0.3	0.6	0.3	0.2
		2	4	.62	0.1	0.3	0.5	0.5	0.2	0.4	0.2	0.1

organ. Comparing the potential production of maize with the water-limited and the water- and nutrient-limited crop production indicated that grain yields were only 36 and 21 percent respectively and straw yields were only 50 and 29 percent respectively of the potential yields. With 38 percent light reduction, the yields for the water-limited crops grown on crop cultivation type 2 were reduced by 25-50% compared to crop cultivation type 1. Similar results were identified for the water- and nutrient-limited crop productions. Hardly any difference was found for yields grown on land unit 1 when CCT1 was compared with CCT2 for each of the production technologies.

For cassava, the highest plant organ masses were reached when plant growth was not restricted by reduced light transmission. With light transmission coefficients of 0.75 and 0.62, the production of each plant organ was respectively 34% and 56% of the yields of CCT1.

Upland rice production grown in CCT2 under 75 or 62 percent light transmission amounted to, respectively, 75% and 51% of crop production grown within CCT1. For sugarcane, total dry matter production was reduced by 74% and 92% if light transmission coefficients were 0.75 and 0.62 when CCT2 was compared to CCT1. It is clear that the production potential of sugarcane was reduced more than productions of the other three crops. If light transmission was 75 percent, production of sugarcane was reduced most followed by cassava, upland rice and maize; if light transmission was 62%, sugarcane was followed by upland rice, cassava and maize.

Analyses at the second crop production level took actual rainfall into account. 'Depth of soil' was indirectly considered in the crop production model. It was of importance as a distinction between land units (see above) and was introduced into the model by stipulating that the maximum rooting depth of the crop (see Appendix 3) could not surpass the soil depth of each land unit. For land units 1, 2, 3, and 4 soil depths of 200, 100, 50 and 30 cm were set. The water-limited crop production potential of maize was highest on land unit 1 for both agricultural production technologies and crop cultivation types. Crop yields for three light transmission coefficients could be compared for each land unit. The results differed for the different crops and within crops between the land units since temperature, radiation and availability of water determined crop growth. In general it is concluded that the yield reduction computed for a light reduction of 25 or 38% was less than the differences in yield between the land units 2, 3, 4 and 1.

Cassava had the highest yield on land unit 2. The production potential of upland rice was higher on land unit 1 than on land units 2, 3 and 4. Sugarcane behaved different than maize, cassava and upland rice in the sense that the highest crop productions were reached on land units 1 and 2 (hardly any difference between these two land units), if the light transmission coefficient equalled 1. A light transmission coefficient of 0.75 gave also similar yields on land units 1 and 2. For a light transmission coefficient of 0.62, hardly any differences in crop yield between the 3 land units were foreseen. Clearly, light availability had become the limiting factor. The third crop production level showed similar trends as the water-limited crop production potentials, which is due to the assumed fixed ratio between WNLP and WLP.

To validate the modelling results, data were needed that permitted one to judge if the models 'tracked' well. Statistical data were incomplete and not very reliable. Model validation, therefore, could only be done to a limited extent. Comparing the simulation results with experimental data gave an indication of the adequacy of the model equations and the input data. In this study, the relations describing physiological crop processes were not validated, but crop parameters for maize and cassava, such as dry matter partitioning fractions could be validated with data from field experiments. In the field experiments in the research area, it was a major problem to achieve the production potential of the crops because it proved very difficult to exclude all kinds of environmental effects.

Water requirements

The net amount of (irrigation) water needed for potential crop production on top of the actual input of rainfall can be calculated by diminishing the potential crop transpiration sum by the actual water-limited transpiration sum. Results of the maximum transpiration sum are shown in Table 7.8. The table presents the consumptive water needs for potential crop production and suggests that the use of water was greatest by cassava followed by sugarcane, upland rice and maize. These results reflect the different lengths of the crop cycle and its corresponding yield. An increase in the length of the crop cycle was associated with an increase in the quantity of water transpired. A decrease in light transmission lowered the quantity of water transpired which was caused by the smaller leaf area index when less light was available. Table 7.9 presents consumptive water uses for rainfed cropping, i.e. considering the actual amount of rainfall available for crop production. Again, water use was greatest for cassava followed by sugarcane, upland rice and maize. There was a strong correlation of the actual transpiration sums on the different land units with different light transmission coefficients, and the yield. The higher the yield, the greater the leaf area index and the actual water use. Calculated quantities of water required for potential crop production are given in Table 7.10.

Maize is an efficient user of water in terms of total dry matter production, and among cereals it is potentially the highest yielding grain crop. Stroosnijder (1989) calculated the cumulative potential and actual crop transpiration in the 100-day growing cycle of maize, grown in Jatikerto, East Java, for 12 different sowing dates. The cumulative potential crop transpiration values were 280-320 mm water, and the actual crop transpiration were 100-300 mm water. These results are more or less confirmed by the results from the research area.

Nutrient requirements

Table 7.11 shows the nitrogen, phosphorus and potassium uptake by above-ground plant parts of maize and cassava under two agricultural production technologies. The percentage of grain

Table 7.8 Maximum transpiration sum for potential crop production (PP) (in cm) with different light transmission coefficients (TC).

Crop	T.C.= 1	T.C.= 0.75	T.C.= 0.62
maize	21.88	12.87	7.11
cassava	109.14	96.26	83.62
upland rice	25.76	14.33	7.54
sugarcane	57.87	19.60	3.48

Table 7.9 Actual crop transpiration sums for water-limited productions (cm) for different land units (LU) and light transmission coefficients (TC).

	T.C.	Maize	Cassava	Upland rice	Sugarcane
LU1	1	10.39	27.89	13.66	23.94
LU2	1	6.76	44.50	7.75	24.33
LU3	1	4.34	25.90	5.74	15.61
LU4	1	1.78	6.08	3.34	7.51
LU1	0.75	10.45	23.47	13.20	7.90
LU2	0.75	5.72	39.77	7.24	8.69
LU3	0.75	3.80	24.01	5.15	8.11
LU4	0.75	1.67	5.55	3.26	4.88
LU1	0.62	7.00	21.94	7.00	1.36
LU2	0.62	6.45	35.21	5.48	1.90
LU3	0.62	3.29	21.29	4.22	1.51
LU4	0.62	1.53	5.11	3.05	1.23

Table 7.10 Net irrigation needs (cm ha⁻¹) required for potential crop production for different land units (LU) and light transmission coefficients (TC).

	T.C.	Maize	Cassava	Upland rice	Sugarcane
LU1	1	11.49	81.25	12.10	33.93
LU2	1	15.12	64.64	18.01	33.54
LU3	1	17.54	83.24	20.02	42.26
LU4	1	20.10	103.06	22.42	50.36
LU1	0.75	2.42	72.29	1.13	11.70
LU2	0.75	7.15	56.49	7.09	10.91
LU3	0.75	9.07	72.25	9.18	11.49
LU4	0.75	11.20	90.71	11.07	14.72
LU1	0.62	0.11	61.68	0.54	2.12
LU2	0.62	0.66	48.41	2.06	1.58
LU3	0.62	3.82	62.33	3.32	1.97
LU4	0.62	5.58	78.51	4.49	2.25

in the maize storage organ was set to 70% for both production technologies. The table shows that the uptake of nutrients decreased with a decrease in light transmission under both production technologies. Nutrient uptake was greater for yield-oriented agriculture than for low external-input agriculture due to the higher nutrient concentrations of plant organs and the higher yields, in case of the YOA compared to the LEIA. Doorenbos & Kassam (1986) mention that the fertility demands for grain maize are relatively high. High yielding varieties demand for up to about 200 kg N ha⁻¹, 50-80 kg P and 60-100 kg K ha⁻¹. These values correspond more or less with those found for the potential maize production in this thesis. Roche (1984) mentioned amounts of soil nutrients removed by maize in kg per ton harvested dry matter as 15.0 kg N, 2.9 kg P and 3.5 kg K for grain, and as 25.9 kg N, 5.4 kg P and 17.7 kg P for the total plant. These values were higher for nitrogen and phosphorus, and lower for potassium, than the nutrient concentrations used in this thesis (Table 7.5). Roche mentioned for cassava, values of 7.0 kg N, 1.6 kg P and 12.3 kg K per ton harvested tuber dry matter, and 14.7 kg N, 3.2 kg P and 17.5 kg K per ton total plant dry matter. These tuber nutrient concentrations were higher than those used in this study (Table 7.5).

The quantity of nutrients taken up by upland rice and sugarcane for the two production technologies is given in Table 7.12. The % of grain in the rice ears was set to 86% for both

Table 7.11 Calculated nutrient uptake in the above-ground plant organs of maize and cassava (kg ha⁻¹).

Yield level	Tech-no-logy	C			Maize nutrient uptake			Cassava nutrient uptake		
		T	U	C	N	P	K	N	P	K
PP	YOA	1	1	1	157	18	154	920	113	469
WLP	YOA	1	1	1	52	6	56	179	22	91
		1	2	1	35	4	33	316	39	159
		1	3	1	23	3	23	170	21	85
		1	4	1	8	1	10	36	4	18
WLP	YOA	2	1	.75	44	5	41	116	14	59
		2	2	.62	23	3	23	165	20	83
		2	3	.62	11	1	12	96	12	47
		2	4	.62	5	1	6	21	3	10
WNLP	LEIA	1	1	1	31	4	34	108	13	55
		1	2	1	21	2	20	190	23	95
		1	3	1	14	2	14	102	13	51
		1	4	1	5	1	6	21	3	11
WNLP	LEIA	2	1	.75	26	3	25	69	9	36
		2	2	.62	14	2	14	99	12	50
		2	3	.62	7	1	7	57	7	28
		2	4	.62	3	1	3	13	2	6

production technologies. For rice Roche (1984) mentioned amounts of soil N, P and K removed by grain and the total plant as, respectively, 9.6 kg N, 2.2 kg P, 4.4 kg K and 18.6 kg N, 4.3 kg P, 21.8 kg K per ton harvested dry matter. Sugarcane has high N and K needs and relatively low P requirements. For a yield of 100 ton cane per ha, requirements are 100 to 200 kg N per ha, 20-90 kg P per ha and 125 to 160 kg K per ha (Doorenbos & Kassam, 1986). These values were lower than those mentioned in Table 7.12 while the latter values included nutrient taken up from the native soil fertility.

Calculated amounts of fertilizer requirements, organic as well as inorganic, were derived by taking into account the native fertility of the soil and the recovery of the nutrients and results are shown in Table 7.13 for maize and cassava, and Table 7.14 for upland rice and sugarcane. For maize, cassava, upland rice and sugarcane it was, in all cases, the amount of nitrogen required which determined the amount of manure to be applied. This implies, that in case of an optimal nutrient balance, the supply of nutrients can never be achieved by using manure only! This result is an argument against LEIA, in which agriculture is practiced with

Table 7.12 Calculated nutrient uptake in the above-ground plant organs of upland rice and sugarcane (kg ha⁻¹).

Yield level	Tech-logy	C			Upland rice nutrient uptake			Sugarcane nutrient uptake		
		C T	L U	T C	N	P	K	N	P	K
PP	YOA	1	1	1	153	18	129	575	65	322
WLP	YOA	1	1	1	71	8	71	199	22	117
		1	2	1	36	4	43	200	23	119
		1	3	1	26	3	27	127	14	76
		1	4	1	13	2	16	59	7	39
WLP	YOA	2	1	.75	54	6	49	52	6	29
		2	2	.62	16	2	15	9	1	5
		2	3	.62	12	1	13	7	1	4
		2	4	.62	9	1	9	6	1	4
WNLP	LEIA	1	1	1	43	5	42	120	13	70
		1	2	1	22	3	26	120	14	71
		1	3	1	16	2	16	76	9	45
		1	4	1	8	1	10	36	4	23
WNLP	LEIA	2	1	.75	33	4	30	31	4	17
		2	2	.62	9	1	9	6	1	3
		2	3	.62	7	1	8	4	1	3
		2	4	.62	5	1	5	3	1	2

Table 7.13 Calculated amount of fertilizer required, based on the uptake of N, P and K in maize and cassava (kg ha^{-1}).

Yield level	Tech-logy	C			Maize fertilizer based on requirements of:			Cassava fertilizer based on requirements of:		
		T	U	C	N	P	K	N	P	K
<i>Urea, TSP and KCL requirements in kg ha^{-1}</i>										
PP	YOA	1	1	1	372	240	403	2181	1507	1227
WLP	YOA	1	1	1	173	80	138	597	293	224
		1	2	1	136	60	149	1229	585	424
		1	3	1	111	53	63	819	368	232
		1	4	1	53	22	30	240	87	54
WLP	YOA	2	1	.75	147	67	101	387	187	145
		2	2	.62	89	45	61	642	300	221
		2	3	.62	53	18	33	462	210	128
		2	4	.62	33	22	18	140	65	30
<i>Manure requirements in t ha^{-1}</i>										
WNLP	LEIA	1	1	1	6.2	2.3	2.6	21.6	7.5	4.2
		1	2	1	4.8	1.3	1.7	43.8	15.3	7.9
		1	3	1	3.9	1.5	1.2	28.8	9.9	4.3
		1	4	1	1.9	1.0	0.6	8.1	3.0	1.0
WNLP	LEIA	2	1	.75	5.2	1.7	1.9	13.8	5.2	2.8
		2	2	.62	3.2	1.3	1.2	22.8	8.0	4.2
		2	3	.62	2.0	0.8	0.6	16.1	5.4	2.4
		2	4	.62	1.2	1.0	0.3	5.0	2.0	0.6

the use of manure as a fertilizer only. For cassava and sugarcane this was followed by phosphorus, and the least manure was required when potassium needs were to be met. For maize and upland rice hardly differences were found when manure requirements for phosphorus and potassium were compared.

Yield gap analysis

The yield outcome of the models was compared with yields on farmers' fields, with experimental on-station yields, yield data from field experiments and literature. Table 7.15 summarizes calculated yield potentials of various crops grown on four land units, with a light transmission coefficient of 1 and average farmers yields recorded in the research area. In

Table 7.14 Calculated amount of fertilizer required based on the uptake of N, P and K in upland rice and sugarcane (kg ha⁻¹).

Yield level	Tech- no-logy	C			Upland rice fertilizer based on requirements of:			Sugarcane fertilizer based on requirements of:		
		T	U	C	N	P	K	N	P	K
<i>Urea, TSP and KCL requirements in kg ha⁻¹</i>										
PP	YOA	1	1	1	363	240	337	1363	867	842
WLP	YOA	1	1	1	327	107	175	663	293	288
		1	2	1	140	60	115	778	345	317
		1	3	1	125	53	74	611	245	207
		1	4	1	87	43	48	393	152	117
WLP	YOA	2	1	.75	180	80	121	173	80	71
		2	2	.62	62	30	40	35	15	13
		2	3	.62	58	18	35	34	18	11
		2	4	.62	60	22	27	40	22	12
<i>Manure requirements in t ha⁻¹</i>										
WNLP	LEIA	1	1	1	8.6	2.9	3.2	24.0	7.5	5.4
		1	2	1	5.1	2.0	2.2	27.7	9.3	5.9
		1	3	1	4.5	1.5	1.4	21.4	6.9	3.8
		1	4	1	3.1	1.0	0.9	13.8	4.0	2.2
WNLP	LEIA	2	1	.75	6.6	2.3	2.3	6.2	2.3	1.3
		2	2	.62	2.1	0.7	0.8	1.4	0.7	0.3
		2	3	.62	2.0	0.8	0.7	1.1	0.8	0.6
		2	4	.62	1.9	1.0	0.5	1.2	1.0	0.2

Chapter 6 the nutrient-limited maize yield potentials were calculated as 2.3 t ha⁻¹ on valley bottoms, 0.7 t ha⁻¹ on permanently cultivated hillsides and 1.3 t ha⁻¹ on intermittently cultivated hillsides.

The nutrient-limited maize yields are below the water-limited yields. This result indicates that nutrients are bigger growth limiting factors than water. Field experimental maize yields in 1991 and 1992 were 0.6 t ha⁻¹ and 2.0 t ha⁻¹ for unfertilized soils and 1.0 t ha⁻¹ and 2.4-4.1 t ha⁻¹ for fertilized soils (Chapter 5). Remember that yields in 1991 were low because of the severe drought faced in that year. These unfertilized maize yields are below the nutrient-limited yields calculated with QUEFTS, but slightly above the water- and nutrient-limited yields. The fertilized maize yields are somewhere in between the water-limited and the water- and nutrient-limited maize potentials.

Doorenbos & Kassam (1986) typified maize as a plant which does well on most soils but less so on very heavy dense clay soils. The soil should preferably be well-aerated and well-

Table 7.15 Summary of calculated yield potentials for land-use systems defined by crop and land unit (t DM ha⁻¹).

Crop	PP	WLP				WNLP				Farmers fields
		lu1	lu2	lu3	lu4	lu1	lu2	lu3	lu4	
maize (grain)	6.7	2.4	1.8	1.1	0.3	1.4	1.1	0.6	0.1	0.9- 1.9
cassava (tuber)	33.2	7.4	12.7	6.7	1.4	4.4	7.6	4.0	0.8	2.1- 4.3
upl rice (grain)	7.5	3.5	1.4	1.3	0.4	2.2	0.9	0.8	0.3	1.5- 4.2
sugarcane (stem)	34.8	13.8	13.8	8.8	3.9	8.3	8.3	5.3	2.4	11.1-22.2

drained as the crop is susceptible to waterlogging, especially in the early growth stage when plant growth can be severely hampered. On the other hand, drought at and after flowering hampers the grain filling. Waterlogging during flowering can reduce grain yields by 50 percent or more. Although in deep soils the roots may reach a depth of 2 meter, the highly branched system is located in the upper 0.8 to 1 meter and about 80 percent of the soil water uptake occurs from this depth. In the research area soil depth declined from land unit 1 to 4 and this explains why yields decreased as well. The importance of water availability is clearly illustrated when the much lower water-limited yields are compared with the potential yields.

The low farmers crop yields might be due to losses caused by pests and diseases. Major pests and diseases of maize in East Java include seven species of insects: Asian maize borer (*Ostrinia furnacalis*), cob worm (*Heliothis armigora*), army worms (*Spodoptera spp.*), cutworms (*Agrotis sp.*), shootflies (*Atherigona sp.*), white grub (*Phyllophaga helleri*), hedgehog beetle (*Dactylispa balyi*), and grain weevil (*Sitophilus zeamais*). Four fungi were common: downy mildew (*Peronosclerospora maydis*), eaf blight (*Helminthosporium turcicum*), smut (*Ustilago sp.*) and rusts (*Puccinia spp.*). There is no published information on crop losses in maize by pests and diseases in Indonesia. On a global scale a figure of 22% estimated yearly losses in maize production has been reported from the combined action of pests and diseases. In view of the similarities between complexes of pests and diseases species in Indonesia and elsewhere, the assumption is justified that crop loss figures in the research area are of similar magnitude.

The average cassava yield recorded at farmers sites in the research area was of the same order of magnitude as the water- and nutrient-limited crop yields. The main problem in increasing cassava production is the high gap between research yields and farmers yields, especially due to low fertilizer use. Inorganic fertilizer use was low, even though application levels on other crops, particularly rice, were high. Farmers compensated for this to a significant extent by applying manure. Although many fertilizer experiments have shown that yields of cassava respond to fertilizer application, the fact remains that few farmers use inorganic fertilizers in significant quantities. One series of fertilizer tests in Lampung gave cassava yields of 22-33 tons fresh tuber per hectare; total fertilizer applied ranged from 470

Table 7.16 Rainfed fresh cassava tuber yield tests on optimum and inferior soils (BORIF, 1986).

Avg. yield (t ha ⁻¹)	inferior soils	optimum soils
with fertilizer		
farmers fields	12.0	15.7
on-farm tests	20.1	30.7
research station	23.5	40.5
without fertilizer		
farmers fields	7.1	8.1
on-farm tests	10.6	17.8
research stations	15.4	20.1

to 550 kilograms of urea, 300-370 kg of TSP and 300 to 375 kg of lime (Table 7.16). Yields in on-farm trials (20 t ha⁻¹) were 10 tons above the average national yield in farmers fields and, as expected, were much lower than the yields at research stations (23.5 t ha⁻¹). Average monoculture yields in on-farm trials for East Java were 22.61 and intercropped 12.22 t ha⁻¹. On optimum soils and under optimum climatic conditions, the yields achieved were higher than on inferior soils. Yields in on-farm trials and in research stations were 40 to 50 percent higher with fertilizer than without. It can be concluded that there is ample potential for increasing yield through fertilizer use, especially under good soil and climatic conditions.

Low cassava yields might be due to losses caused by pests and diseases. Soetarjo Brotonegoro et al. (1986) reported pests and diseases of cassava in East Java as: 2 types of insects [white grub (*leucopholis rorida*) and scale (*pinnaaspis aspidistrae*)], one type of red spider mite (*tetranychus bimaculatus*) and 2 types of bacteria [bacterial blight (*xanthomonas manihotis*) and bacterial wilt (*pseudomonas solanacearum*)]. The traditional idea of cassava as a sturdy crop with no significant disease problems has been undermined by experimental evidence that diseases can cause serious losses.

Farmers in the research area realized yields of 1.5-4.2 ton dry grain per hectare which suggests that water availability hinders crop growth. Rice blast disease is generally considered as the principal disease of rice, because of its wide distribution and its destructiveness under favourable conditions. Another important disease in rice causing severe reduction in yield is Bacterial Leaf Blight caused by *Xanthomonas campestris* pv. *oryzae*. Stem borer is one of the main insect pests in rice.

The average sugarcane yield in the research area, recorded in the cropping season 1990-1991, on farmers' fields under traditional management, was 11.11-22.2 tons of dry cane per hectare. This was only a little below the water-limited yield potential which suggests that there was only a mild nutrient deficiency apart from the water limitation. Sugarcane does not require a special type of soil. Best soils are those that are more than 1 meter deep, but rooting to a depth of up to 5 meter is possible. Adequate available moisture throughout the growing

period is important for obtaining maximum yields because vegetative growth including cane growth is directly proportional to the water transpired. Sugar yield depends on cane tonnage, sugar content of the cane and on the cane quality. It is important that the cane is harvested at the most suitable moment when the economic optimum of recoverable sugar per area is reached. Cane tonnage at harvest can vary between 50 and 150 ton per hectare or more, which depends particularly on the length of the total growing period and whether it is a planted or a ratoon crop. Cane yields produced under rainfed conditions can vary greatly. Good yields in the humid tropics of a rainfed crop can be in the range of 70 to 100 ton per hectare. Toward maturity, vegetative growth is reduced and sugar content of the cane increases sharply. Sugar content at harvest is usually between 10 and 12 percent of the cane fresh weight, but under experimental conditions 18 percent or more has been observed. Sugar content seems to decrease slightly with increased cane yields (Doorenbos & Kassam, 1986).

Discussion

Maize substitutes for rice if water availability is insufficient for rice cultivation. It fits well in sawah and tegal cropping systems. However, care has to be taken not to grow maize in a continuous sequence, since this may result in an increase in maize pests and diseases and a gradual reduction in yield. Despite the fact that maize is less profitable per hectare than other food crops, and that maize has a negative income elasticity (decreasing demand for maize with rising income (Nijberg, 1975)), research to increase maize productivity is important. The cultivation of maize will remain popular in areas where limited water availability does not permit rice production. In these areas the crop selection by the farmers is based on food security, minimum costs and minimum risk. With improved technologies farmers can achieve the same maize production or even more on a smaller area, thereby making land available for other activities (Soetarjo Brotonegoro et al., 1986).

There is a lack of information on the suitability of particular varieties for planting of maize in mixed cropping systems. Management constraints include the absence of phosphate and potassium applications. Institutional constraints are: difficult access to certified quality seed, fertilizer and crop protection chemicals; often no labour, or lack of capital for hiring the labour needed for adequate land preparation and planting. In order to maintain soil fertility and to improve soil conservation and fertilizer efficiency, not only recommendations for maize alone have to be developed, but also for a crop sequence, including maize and other crops such as grain legumes. A major cause for low germination rates is the poor seed quality. Research has to be conducted to improve the on-farm storage of seed, and to identify the most important diseases which occur at harvest and are carried over with the seed to the next season.

Cassava is propagated vegetatively and the importance of using disease-free planting material has long been underestimated. Farmers already select their planting material

carefully, but they do not treat cuttings with fungicides, and they store them under adverse temperature and humidity conditions for periods of two to five months. As a result, many cuttings fail to sprout and must be replanted. Recently it was shown, that under traditional farming systems, yields could be more than doubled by the use of disease free planting material and improved cultural practices. Cassava usually does not receive specific land preparation. Good and deep cultivation of the soil stimulates tuber development. Improvements can be made in timing and method of fertilizer application. During a maize and cassava survey in the limestone area in the southern part of the Malang district, it was observed that only 30% of the farmers placed the fertilizer close to the cassava stem. Instead of broadcasting, the farmer should incorporate the fertilizer into the soil, close to the base of the cassava plant for maximum efficiency. Usually no crop protection measures are carried out. Varietal and management constraints are that farmers have always planted local varieties. New varieties are not available to them.

Agronomic research on cassava intercropping systems was carried out by CRIA/IRRI mainly outside Java. Similar research should be carried out for the East Java cassava production systems. This requires a detailed survey on cassava growing and delineation of recommendation domains in order to facilitate the transfer of technology derived from those studies. Elements involved are: selection of varieties suitable to local conditions, improved field spacing of crops in order to reduce competition for soil moisture and sun light, and increased use of soil moisture during drier seasons through mulching. In addition more research on fertilizer responses is needed in order to develop recommendations for the use and timing of N, P and K in mixed cropping on tegal. More emphasis should be placed on treatment of fresh cuttings for storage. A consultants mission on tubers recommended that local cassava varieties should be systematically collected and evaluated. At the same time the farmers problems with the crop have to be identified.

The validity of model results depends on many factors. These include the accuracy of the technical input/output factors, and the proper definition and quantification of the production orientations. Technical input/output factors for present production techniques often are determined with sufficient accuracy on the basis of the general body of knowledge in a region. However, there is danger that the technical input/output factors of alternative production techniques are estimated too optimistically by their advocates, and critical evaluation is, therefore, necessary.

Chapter 8

Livestock production and feed use

Introduction

In this thesis activities are well-defined agricultural production techniques with specified and quantified inputs and outputs (van Keulen, 1992). The livestock activities were defined in a target-oriented way. The feed availability (input) was defined first and the production (output) per animal, calculated with a livestock simulation model, was derived subsequently. Livestock activities for the research area were defined for cows, sheep and goats. The inputs and output were calculated with help of simulation studies.

Livestock simulation models usually deal with specific biological processes, e.g. metabolic regulation and growth in beef cattle (France et al., 1987; Danfaer, 1991; Hirooka & Yamada, 1990), or reproductive performance in beef cattle (Azzam et al., 1990; Denham et al., 1991). Only a few simulation programs embody a whole production system. Examples are the TAMU (Texas A&M University) model for beef production systems (Sanders & Cartwright, 1979 a and b), the model from Kahn & Spedding (1983), the simulation of beef cattle systems in the Llanos of Colombia (Levine et al., 1981) and the ILCA model (Konandreas & Anderson, 1982). These whole systems models have not been very accessible to other workers and are rather (beef cattle) system-specific. The models simulate herd dynamics and individual animal careers.

Therefore a Livestock PROduction and FEed (LIPROFE) model was developed for this research that distinguishes itself from many other livestock production models (Kahn & Spedding, 1983; van Duivenbooden, 1989; Zemmeling et al., 1991) in that it includes major farm household influences, particularly the influence land and land use on the feed resource and on livestock production. An additional advantage of the model is, that feed availability considers seasonality and is quantified on a monthly basis. The model quantifies the individual production of cattle, sheep and goats.

The model uses all kind of relationships taken from the literature (feed intake and energy requirements) as well as field data (feed data and animal weights). Parameters are area specific and therefore the LIPROFE model can only be applied to similar areas. However, it illustrates livestock production as a component of a farming system. Livestock production can be evaluated and possible feeding improvements can be explored.

The objective of this chapter is to: (1) to quantify the feed resource; (2) to describe a simulation model with which livestock (cattle, sheep and goat) production is computed in

relation to the feed resource; and (3) to show how the model can be used to analyze livestock production systems and to evaluate possible improvements. In Chapter 9, crop and livestock activities are judged on their ability to maintain or improve the existing resources in a sustainable way. Use is made of the inputs and outputs as are quantified in this chapter for livestock activities.

The concept

Livestock activities were defined based on two criteria: (1) animal species (cattle, sheep and goats) and (2) main production objective (meat, offspring, milk, traction). As a result, for this thesis 5 livestock units were examined:

- CU1 : Cow unit one. An adult cow, giving birth to a calf. The feed requirements for the growth of both the cow and the calf are included.
- CU2 : Cow unit two. An adult cow, producing draft power in the agricultural season and giving birth to a calf. The feed requirements for the growth of both the cow and the calf are included.
- CU3 : Cow unit three. An adult, non-reproducing and non-lactating cow, kept for meat production and producing draft power in the agricultural season.
- GU : Goat unit. An adult goat, giving birth to a kid. The feed requirements for the growth of both the goat and the kid are included.
- SU : Sheep unit. An adult ewe, giving birth to a lamb. The feed requirements for the growth of both the ewe and the lamb are included.

For cattle, sheep and goats, standard animal weights of 250 kg, 25 kg and 30 kg respectively, were used based on average adult weights of animals in the research area (recorded by weighing animals in the field (Ifar, 1996)). All livestock activities were expressed per Cattle Unit (CU), which is equivalent to a cow of 250 kg liveweight. In the definition of CU's the type of production was included but not the level of production. The latter was determined by the amount of feed available. The following animal conversion factors were used based on the metabolic weights: 1 cow = 1 CU; 1 sheep = 0.18 CU; 1 goat = 0.20 CU. Cattle producing draft power have - above maintenance - additional feed requirements. To calculate the metabolizable energy required for draught work, use was made of an animal draft power model (van der Lee et al., 1993). The energy requirements were a function of (1) force delivered by the animals, (2) its walking speed, (3) working time, (4) a soil specific parameter, (5) plough characteristics, and (6) an efficiency factor for traction. Variation was brought into the model via: (1) the number of hectares that had to be ploughed, (2) the number and category of animals (lactating cows or dry cows) that could be used for work, (3) a soil-specific parameter and (4) the choice between single or team work. Manure production was calculated from feed intake and digestibility estimates, and quantity depended

on the amount and quality of the feed and on the type of animal and type of production.

LIPROFE takes into account eight of the most common collected feeds in the area and their seasonal availability. These were: (1) non-leguminous tree leaves, (2) leguminous tree leaves, (3) elephant grass, (4) native grasses, (5) maize straw, (6) sugarcane leaves, (7) cassava leaves and (8) rice straw. A variety of tree leaves were used but the common ones were gliricidia '*Gliricidia sepium*', bayan '*Ficus bengalensis*', leucaena '*Leucaena leucocephala*', and jackfruit '*Artocarpus heterophyllus*'. The composition of the mixture depended on the type of animal for which the feed was collected. For cattle, farmers preferred to give a mixture containing mainly crop residues, for sheep and goats containing mainly leguminous tree leaves.

To quantify livestock production, two options can be followed: (1) Monthly feed availability is exogenous and livestock production is endogenous, or (2) livestock production is exogenous and monthly availability of fodder is endogenous. The first type of calculation results in the number of livestock units which can be kept on a certain amount of feed. The second type of calculation results in the amount of feed necessary to meet the requirements of the livestock units. The number of livestock units depended on the production level of the animals. On a fixed amount of feed a certain number of animals can be kept at maintenance only, but fewer animals can be kept if the animals produce above maintenance e.g. milk or liveweight gain. In the research area farmers were not aiming for a certain level of animal production. The animal production level was, however, determined by the amount of fodder collected and thus available or offered. In crop production terms we speak of source limited livestock production in which feed is the source and the livestock unit is the sink. Therefore feed availability per livestock unit was calculated first (exogenous), whereafter the animal production level was determined (endogenous).

Livestock production, as a result of feed availability, was divided into the following production technologies:

1. Potential livestock production

Potential production is the maximum production that can be achieved. The monthly presence and the monthly amounts of feed are not constraining the livestock production. Additional feeds from outside the research area, as concentrates, are fed to the animals, to be able to reach maximum production. Livestock production is defined by the maximum growth curve of the species (genetic potential) in the research area. It is assumed that animal performance is not hampered by any health or climatic problem.

2. Actual livestock production

Actual production is the production that is being achieved at present. The livestock production is reduced by the type of feeds available in the research area, their monthly presence and their monthly amounts. Data on actual feeding practices are used. It is assumed that animal performance is not hampered by any health or climatic problem.

Because options for development were to be explored, both types of calculations needed not to be consistent with the observed situations in the field. However, since 2 types of feed

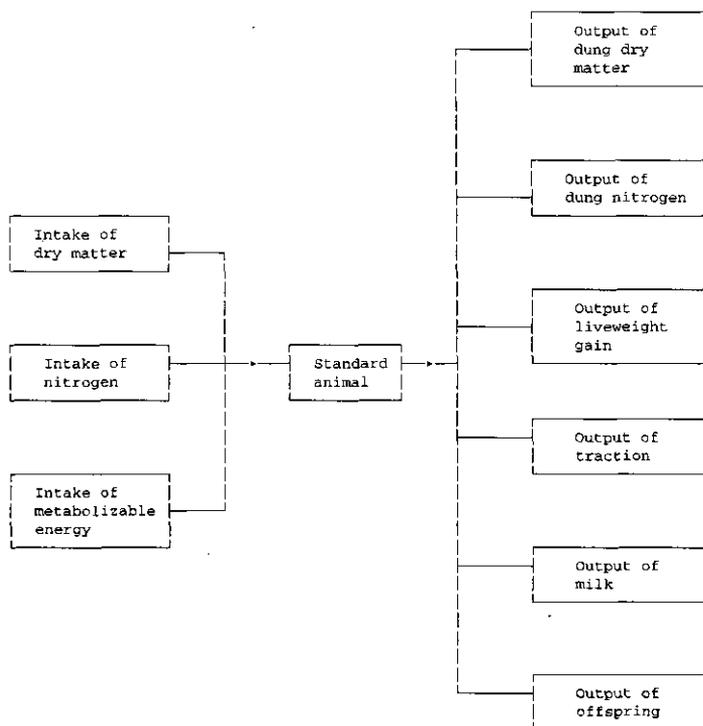


Figure 8.1 Layout of inputs and outputs calculated for a standard animal in the *Livestock PROduction and FEed (LIPROFE)* model.

production levels were distinguished, the actual and the potential, the opposite situation was indirectly explored as well. Potential feed availability means that feed is not limited but the livestock production is limited by its potential growth, genetically determined. Production situations were the combination of livestock activities and production technologies. The total number of production situations which were distinguished are 10, defined by 5 livestock units and two production levels.

Figure 8.1 shows the layout of the livestock simulation model. For the livestock activities the inputs were the amount of feed dry matter of the individual feeds, the total amount of metabolizable energy, and the amount of nitrogen in the feeds. The outputs were amount of dung dry matter, amount of nitrogen in the dung, liveweight gain, milk production (for suckling of calf), offspring and land ploughed.

Potential feed availability

In case of potential feed availability it was assumed that the amount of the individual feeds

was not limited. However evidence from literature showed that certain feeds contain anti-nutritional substances which restrict the maximum amount which can be consumed. Therefore in this research the amount of feeds available, which contain anti-nutritional substances, was corrected for possible toxic and detrimental substances by taking maximum feed intake figures from the literature. Leguminous tree leaves consisted of 95% of *Gliricidia sepium* leaves, therefore feed restriction of leguminous tree leaves was limited to this type of tree leaves only. Some potentially anti-nutritional substances have been found in *Gliricidia*. HCN content has been reported up to 4mg per kg, and cyanogen may be present. *Gliricidia* may be a 'nitrate accumulator'. This might cause health problems (Ash, 1990). Unidentified alkaloids and tannins have also been reported (Smith & Houtert, 1987). However, evidence of toxicity under practical feeding conditions has been rare. The balance of evidence suggests that the plant could be toxic to non-ruminants, but conclusive evidence of toxicity to ruminants under normal feeding is lacking. Normal *Gliricidia* feeding levels have been 1-3% of bodyweight (i.e. 2.5-7.5 kg per day fresh material to cattle of 250 kg) although goats have been fed solely on *Gliricidia* (Falvey, 1982). In conclusion for the research area it was assumed that on average a maximum of 5 kg of fresh *gliricidia* tree leaves was consumed daily by a cow of 250 kg, which is 1.5 kg DM if the dry matter content is 30% (Table 8.1).

Other leguminous tree leaves fed to the animals were the leaves of *leucaena*. *Leucaena* leaves contain a toxic glucoside mimosine, which may cause loss of hair in young cattle. The addition of iron salts decreases toxicity, and if the treated material is allowed to stand for a week before being mixed with feeds, little toxicity remains. The mimosine content can also be reduced by soaking in water and drying. When the right bacterial flora is available, the mimosine content can increase. Sheep should be introduced to *leucaena* gradually to increase their ability to detoxify the feed. The ill effects of mimosine are erratic, and sometimes no effects are observed even when *leucaena* leaves are the sole feed (Preston, 1992). In Trianti Djoharjani & Udo (1986) it was reported that in an upland area in East Java, for at least nine months of the year goats are fed only *leucaena*. Lowry & Tangewijaya (1982) concluded that in Indonesia ruminants can be fed unlimited quantities of *leucaena* since its toxic substances are being degraded in the rumen. Since only less than 5% of the leguminous tree leaves fed in the research area were *leucaena* leaves, no feed restriction was taken into account for *leucaena*.

No literature was found about feed intake restrictions of consumption of non-leguminous tree leaves. In the research area, however, farmers reported to restrict the feed intake of non-leguminous tree leaves themselves. It was assumed, based on farmers practices in the research area, that non-leguminous tree leaves composed maximum 20% of the dry matter diet (Table 8.1).

Cassava leaves contain prussic acid, which is a toxic substance. These leaves can be harvested as forage and used to provide by-pass protein to ruminants. Farmers in the research area reported awareness of toxicity of cassava leaves and therefore limited feeding of cassava leaves. In this study it was assumed that maximum 10% of the dry matter consumed were cassava leaves (Table 8.1).

Table 8.1 Feed intake restrictions; maximum amount of dry matter which can be consumed.

Type of feed	cattle BW=250 kg	sheep BW=25 kg	goats BW=30 kg
Gliricidia	1.5	0.15	0.18
Non-leguminous tree leaves	1.2	0.15	0.18
Cassava leaves	0.6	-	0.09

Sugarcane tops are low in protein and require supplementation. The principles of supplementing sugarcane-tops-based diets is satisfying the needs of rumen microbes for fermentable nitrogen (ammonia) and trace nutrients, and providing sources of protein, glucose precursors and long chained fatty acids able to bypass the rumen fermentation to balance the needs of production. With a correct balance of both rumen nitrogen and by-pass nutrients, gains of over 1 kg per day have been obtained on ad libitum sugarcane tops and molasses, but with different sources of nitrogen (Naseeven, 1988). In this thesis it was assumed that the intake of sugarcane leaves was only restricted by the maximum energy intake.

For the potential production of cattle, the type of feeds were not limited to present feeding practices only, but additional feeds were available as well. The latter were normally not used by farmers in the research area, e.g. buying of concentrates. In East Java the most common concentrates fed were ricebran, maizebran, groundnut cake and soybean cake (Hari Hartadi et al., 1980). For this exercise only the qualitative best concentrate was used, i.e. soybean cake (48% CP in DM and 1264 MJ ME in DM). Both ricebran and groundnut cake were of a low quality, i.e. low intake of metabolizable energy, and therefore hardly improving the actual diet. Appendix 4 shows the actual and potential daily amounts of the individual off-farm collected feeds offered each month of the year to a cow of 250, a sheep of 25 or a goat of 30 kg.

Model design

Voluntary feed intake

Theory of feed intake

The consumption of feed is the first step in the process which converts feed into valuable products like milk and meat. The amount of feed which ruminants voluntarily consume influences the efficiency of this conversion process. Voluntary feed intake of ruminants has been shown to vary as a function of characteristics of the feed, the animal and its environment. The commonly accepted theory is the so-called physical intake regulation

mechanism, which identifies the rumen processing capacity as the major determinant of voluntary feed intake (e.g. Conrad, 1966; Baile & Forbes, 1974). The frequent failure of animals to achieve a maximum nutrient intake would be the consequence of constraints imposed on the intake process. A physical constraint, i.e. rumen fill, is primarily held responsible for the large differences in roughage intake of low digestible feeds. On the other hand it was apparent that intake of highly digestible feeds is generally not considered physically limited but physiologically determined, i.e. dependent on the nutrient requirements of the animal.

Part of the processing in the rumen is determined by intrinsic characteristics of the feed ingested, like rate and potential extent of degradation. Other factors associated with rumen processing capacity, like tolerated level of rumen fill and rate of passage of undegraded matter from the rumen, are, however, not only determined by feed factors, but can be manipulated by the animal. There is evidence from literature that environment, physiological status of the animal, and nutrient availability may have an effect on rumen processing capacity without effect on rumen degradation (Weston, 1982; Kennedy et al., 1986). A decrease of temperature below the lower critical level, or shearing in sheep, increased intake in association with an increased rumen volume and/or rate of passage from the rumen. Lactation also increases intake of a feed in association with an increased rumen volume and/or increased passage from the rumen (Oosting, 1993). The fact that ruminants fed roughages are able to increase their rumen volume or passage rates from the rumen under certain conditions means that rumen processing capacity *per se* is not the major determinant of voluntary feed intake, but that the amount of feed that is processed in the rumen is governed by physiological mechanisms.

An alternative hypotheses of regulation of voluntary feed intake is given by Tolkamp & Ketelaars (1992). They proposed, as the primary physiological basis of all animal behaviour, including feed intake, that animals tend to minimize costs relative to benefits of an activity. The cost of feed intake is oxygen consumption which, owing to the toxic effect of oxygen radicals on tissue components, results in ageing and reduced vitality and longevity. Ruminants therefore minimize oxygen consumption per unit net energy consumed (the benefit of feed intake). The low intake of low-quality feeds relative to feeds of higher quality is explained by the lower efficiency of utilization of metabolizable energy, i.e. the higher energy expenditure and the associated higher consumption for chewing, digestion and metabolization processes.

Model of feed intake

Ketelaars & Tolkamp (1992) examined data from 831 types of roughages, basing the information on composition and intake by mature male castrated sheep. The feeds tested cover the whole range of roughage quality, with organic matter digestibility varying from 30 to 84% and with content of nitrogen in the organic matter from 0.3 to 5.6%. The relationship between feed characteristics (organic matter digestibility, nitrogen concentration) and OMI were analysed. The descriptive feed intake regulation model which gave the best fit is:

$$\text{OMI}_{\text{sheep}} = -42.78 + 2.3039 * d - 0.0175 * d^2 - 1.8872 * N^2 + 0.2242 * d * N \quad (r^2 = 0.65)$$

OMI = voluntary organic matter intake, g kg^{-0.75} d⁻¹

d = organic matter digestibility, g g⁻¹

N = nitrogen concentration of the feed organic matter, g g⁻¹

Ketelaars & Tolkamp (1992) showed that OMI does not reach a satiation level with increasing digestibility. Hence the two-component feed intake model, based on the theory of the physical intake regulation, does not apply to this compilation of roughage intake data despite the fact that many feeds had an OMD well over the value of 65-70% at which OMI is usually expected to level off. For the study described in this chapter the voluntary feed intake regulation model of Ketelaars and Tolkamp was used. This model can be used for other ruminants as well because species of different sizes are scaled via their genetic size, expressed in the metabolic weight.

Genetic size

Basically, genetic size represents *the scale of the standard life programme* that species have in common within their main taxonomic group (like mammals or birds). The genetic size of an animal is the major genetic factor that controls rate of growth from early embryonic stage to full maturity, and continues to determine rate and duration of life processes during the remaining part of life (Taylor, 1980). Genetic size is expressed at all developmental stages of growth, but is most clearly visualized by the size of the mature animal; usually genetic size is quantified by the adult weight. In 1932 Kleiber introduced the concept of metabolic weight, followed by Brody and collaborators (Kleiber, 1961; Brody, 1945). They found that variation in metabolic rate between adults of different species is proportional to their metabolic weight, which is usually calculated as (liveweight)^{0.75}. Nowadays the metabolic weight is generally used to compare breeds or species of different sizes.

The feed intake (g d⁻¹), in the model, for a cow of 250 kg bodyweight (BW) was assumed to equal the voluntary organic matter intake multiplied with the metabolic weight (MW = BW^{0.75}). A factor of 1.33 was used to convert the sheep intake equations to cattle intake, to account for the on average higher metabolism level of cattle per unit MW (Udo & Brouwer, 1993). This value is rather arbitrary and depends on the type of cattle involved. Typical dairy breeds for example have higher metabolism levels than beef or multipurpose breeds. The ratio of maintenance requirement of cattle versus sheep could give a good indication of which conversion factor has to be applied (0.512 : 0.384, see below).

$$\text{OMI}_{\text{cattle}} = \text{OMI}_{\text{sheep}} * 1.33 \quad \text{g kg}^{-0.75} \text{ d}^{-1}$$

Energy requirements for maintenance

Energy is required for the maintenance of the body and its processes. For maintenance fixed energy requirements per kg MW per day were used. Zimmelink et al. (1991) studied energy

requirements for maintenance and gain of West African Dwarf goats. The treatments included hay plus varying amounts of pelleted concentrates, causing intake of digestible organic matter (IDOM) to vary from 28.3 to 56.6 g kg^{-0.75} d⁻¹ and liveweight gain (LWG) from 2.1 to 13.1 g kg^{-0.75} d⁻¹. The two variables were related as follows: LWG = -10.1 + 0.415 IDOM (r² = 0.64). Based on this equation, maintenance requirements of West African Dwarf goats were estimated at 24.3 g digestible organic matter (DOM) kg^{-0.75} d⁻¹. To facilitate comparison of results with values reported in the literature, the following assumptions were made: 1 gram DOM is equivalent to 15.8 kJ metabolizable energy (ME) (NRC, 1981). As a result, the maintenance energy requirements of sheep and goats was 0.384 MJ ME kg^{-0.75} d⁻¹. For cattle the value of sheep and goats was multiplied with the conversion factor 1.33 resulting in 0.512 MJ ME kg⁻¹ MW d⁻¹ for maintenance.

The feeding balance

Feeding balance for 8 different feeds

For the feeds in the research area the feed intake of organic matter, digestible organic matter and energy was calculated from organic matter digestibility and nitrogen concentration data (Table 8.2). In this study qualitative ranking of the feeds was done on the basis of intake of metabolizable energy (IME, in MJ kg^{-0.75} d⁻¹). From a high to a low voluntary feed intake this resulted in (1) cassava leaves, (2) leguminous tree leaves, (3) sugar cane leaves, (4) native grasses, (5) maize straw, (6) elephant grass, (7) rice straw and (8) non-leguminous tree leaves.

Table 8.2 Feed intake properties of different feeds for cattle.

type of feed	OMD ^a %	N ^a % in OM	OMI g kg ^{-0.75} d ⁻¹	DOMI g kg ^{-0.75} d ⁻¹	IME MJ kg ^{-0.75} d ⁻¹
CL	79.5	3.04	93.90	74.65	1.180
LTL	68.7	2.67	83.98	57.70	0.912
SCL	65.3	0.89	63.61	41.53	0.656
NGR	54.8	0.97	61.05	33.46	0.529
MS	53.5	1.28	60.13	32.17	0.508
EGR	52.6	1.24	60.48	31.81	0.503
RS	50.5	0.55	50.56	25.53	0.403
NLTL	45.0	1.54	50.53	22.74	0.359

OMD = organic matter digestibility, N = nitrogen concentration, OMI = organic matter intake, DOMI = digestible organic matter intake, IME = intake of metabolizable energy; LTL = leguminous tree leaves, NLTL = non-leguminous tree leaves, NGR = native grasses and weeds, EGR = elephant grass, SCL = sugarcane leaves, CL = cassava leaves, MS = maize straw, RS = rice straw; ^a source; Ifar, 1996

A feeding balance calculates the amount of energy available from the amount of feed consumed. The amount of energy available is used for maintenance and production. Table 8.3 shows for cattle the daily amount of metabolizable energy consumed (ME) and the amount of metabolizable energy available for production ($ME_p = ME - ME_m$), such as liveweight gain, milk production, pregnancy and traction, assuming 100% fed of one feed. Table 8.3 shows that a feeding ration for cattle, which only consisted of cassava leaves, leguminous tree leaves, sugarcane leaves, or native grasses, had energy available, above maintenance, for production. A ration which only consisted of maize leaves, elephant grass, non-leguminous tree leaves or rice straw did not contain enough energy for maintenance. These feeds should always be fed in combination with another feed (CL, LTL, SCL or NGR) to prevent weight loss. The same holds true for feeding these individual feeds to the goat or sheep unit, since a constant conversion factor of 1.33 was used for intake equations.

In the research area the ration fed does not contain one feed but a combination of different feeds. Where the ration consisted of more than one feed, e.g. CL and LTL the intake was estimated based on the following OMD and N values (DM=dry matter):

$$OMD = [OMD(cl) * DM(cl) + OMD(ltl) * DM(ltl)] / [DM(cl) + DM(ltl)]$$

$$N = [N(cl) * DM(cl) + N(ltl) * DM(ltl)] / [DM(cl) + DM(ltl)]$$

This example assumes feeds are consumed in equal quantities ($DM(cl) = DM(ltl)$). A feed mixed with a higher quality feed resulted in more energy available for production. Those feeding rations which were fed in practice were illustrated in Chapter 5. In the potential production situation, apart from the eight feeds in the research area, soybean cake was also fed to the animals. The quality data and intake data for soybean cake are: 48% crude protein

Table 8.3 Feed balance of cattle assuming 100% fed of one feed.

type of feed	IME MJ kg ^{0.75} d ⁻¹	ME ^{tot} MJ d ⁻¹	ME ^p MJ d ⁻¹
CL	1.180	74.19	42.00
LTL	0.912	57.34	25.15
SCL	0.656	41.24	9.05
NGR	0.529	33.26	1.07
MS	0.508	31.94	-0.25
EGR	0.503	31.62	-0.57
RS	0.403	25.34	-6.85
NLTL	0.359	22.57	-9.62

IME = intake of metabolizable energy, ME = available metabolizable energy (total and for production)

LTL = leguminous tree leaves, NLTL = non-leguminous tree leaves, NGR = native grasses and weeds, EGR = elephant grass, SCL = sugarcane leaves, CL = cassava leaves, MS = maize straw, RS = rice straw

in the dry matter, 1264 MJ metabolizable energy in the dry matter and the intake of metabolizable energy is $1 \text{ MJ kg}^{-0.75} \text{ d}^{-1}$.

Feed intake adaptations

Growth potential

The intake level is determined by the quality of the ration, in terms of OMD and N, but also by the maturity of the animals, otherwise intake leads to unlimited growth beyond mature weight. However for this study, it was not necessary to relate feed intake to the growth stage of an animal, since the calculations were done for a standard animal covering a period of one year, with a timestep of one month. Intake was adjusted, in this study, for age or maturity of the animals by calculating only once the genetic growth potential of livestock (a standard cow of 250 kg, sheep of 25 kg or a goat of 30 kg), as was described by the logarithmic equation (Brody, 1937; Brody 1945):

$$W = A * (1 - (0.67 / (e^{0.78*(Y-0.5)})))$$

W = actual weight (kg)

A = adult weight (cattle=500 kg, sheep and goats=50 kg)

Y = age in years

With the above equation the potential bodyweight gain was calculated as shown in Table 8.4. The potential bodyweight gain of a standard cow was 15.5 kg per month, a standard sheep was 1.55 kg per month, and a standard goat was 1.24 kg per month. The difference between sheep and goats is due to the fact that they were in different stages of the growth curve, as the adult weight for both sheep and goats was estimated at 50 kg.

It was assumed that the potential bodyweight gain per month was constant, which could result in a minor overestimation of bodyweight gain in the case of a gaining animal (higher bodyweight than the standard animal), and a slight underestimation of bodyweight gain of a

Table 8.4 Calculation of potential liveweight gain for a cow, ewe and goat.

Livestock Unit	Bodyweight kg	Age days	pot. LWG kg month ⁻¹
cow	250	320	15.50
ewe	25	320	1.55
goat	30	424	1.24

Table 8.5 Calculation of maximum intake of metabolizable energy.

	Goats	Sheep	Cattle
max. LWG (kg month ⁻¹)	1.24	1.55	15.5
BW	30	25	250
MJ ME _{maint} month ⁻¹	148	129	966
MJ ME _{gain} month ⁻¹	37	46	463
MJ ME _{tot} month ⁻¹	185	175	1429
max IME MJ kg ^{-0.75} d ⁻¹	0.48	0.52	0.76

weight losing animal (lower bodyweight than the standard animal). The maximum metabolizable energy intake on the basis of maintenance plus potential liveweight gain was calculated as illustrated in Table 8.5.

Lactation

Feed intake was increased for a lactating animal. ARC (1980) stated that lactating cows consumed 35-50% more than non-lactating animals of the same breed and on the same diet. Since tropical breeds are not typical milk breeds, this study assumed a constant of 1.35 to be multiplied with feed intake for a lactating animal.

Procedure of calculations

As indicated earlier, calculations were done on a monthly basis. The unit of analysis was a cow of 250 kg, a goat of 30 kg or a sheep of 25 kg. Feed Tables were calculated for these standard animals (Appendix 4). The inputs and outputs of livestock activities varied per village for cows due to a different feeding table for the two villages, Putukrejo and Kedungsalam. Intake of metabolizable energy was calculated from the feed intake and feed energy contents. The available amount of metabolizable energy was divided over maintenance requirements, and requirements for traction, milk production and reproduction. An energy surplus resulted in an increase of liveweight, an eventual shortage went at the expense of growth and eventually traction. A schematic presentation of the calculation of inputs and outputs for livestock activities is shown in Figure 8.2.

Requirements for maintenance, reproduction and milk production were fixed. When not enough energy was available for one of these three, and when not enough energy was available for the minimum of 0.243 ha to plough, growth was reduced accordingly. The fixed monthly metabolizable energy requirements for the milk production were calculated as 10% of the kid, lamb or calf bodyweight needed in kg milk. It was assumed that a calf grew 200

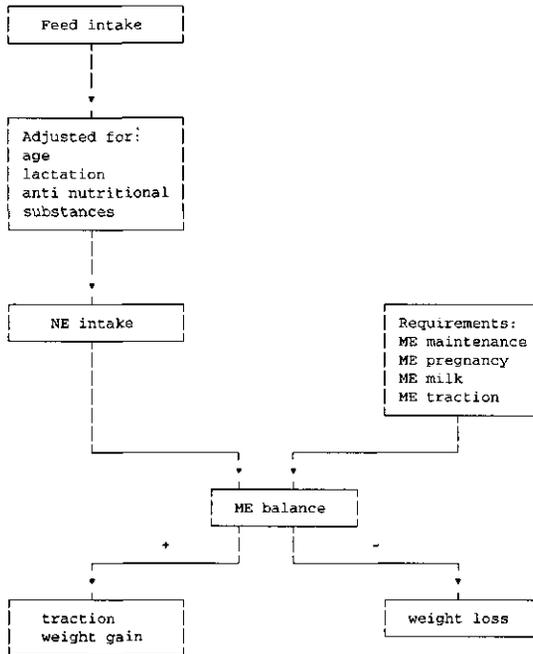


Figure 8.2 Layout of the energy balance calculations in the livestock simulation model.

g per day and that a kid and lamb grew 100 gram per day. For cows the monthly milk energy requirements were 400.5 MJ ME and for sheep and goats the monthly milk energy requirements were 61.22 MJ ME. The monthly bodyweight gain for calves was 5.8 kg, and the monthly bodyweight gain for lambs and kids was 2.9 kg. Metabolizable energy requirements for pregnancy were calculated with the Gompertz equations (Appendix 4), and increased over time. For sheep and goats the energy requirements for the 75 days in which energy for pregnancy was required were: 11.93 MJ ME for the first 30 days, 30.47 MJ ME for the second 30 days, and 26.75 MJ ME for the last 15 days. Cows, with 142 days in which energy was required for pregnancy required: 53.27 MJ ME for the first month of this period, 96.64 MJ ME for the second, 175.16 MJ ME for the third, 317.14 MJ ME for the fourth month and 386.12 MJ ME for the last 22 days (Appendix 5).

The output of dung dry matter was a result of the dry matter intake minus the digestible dry matter intake. The digestibility data were shown in Table 8.2. The higher the amount of feeds consumed with a low digestibility, the more output of dung will be excreted. The output of nitrogen in the dung dry matter was calculated by the crude protein intake, minus the digestible crude protein intake, divided by the constant 6.25 (16% nitrogen in crude protein).

Actual livestock production

Actual amounts of feed offered is determined by the type of feed available in a particular month, and by the amount, determined through field data. For leguminous tree leaves, non-

leguminous tree leaves and cassava leaves, a maximum is put to the amount offered. When less than 100% of the feeds offered were used, the quality of the ration increases because of selection. In the study area the animals were not able to select this way because the feeds were not offered in order of quality. The feeds were offered all at once and mixed so that the animal was not able to consume only the best quality feeds offered, thereafter the second best quality feed, etc.. Therefore the actual livestock production level assumed that an animal consumed the quality of the feed on offer, without making any selection. So, the quality of the feed was determined by 100% of the feeds offered. Herdsize was calculated as the total number of animals who consumed an ad libitum amount of the calculated ration. From the quality data of the available feeds the IME and the intake of dry matter was calculated, and so was the total amount of dry matter consumed for the standard animal per day. The total amount of dry matter supplied was divided by the dry matter intake of an animal and the result was the number of animals or herdsize. It is noticed that the herdsize can be the same for different values of IME and therefore the result of production differs between the two herdsize.

In some months, when 100% of the ration was used, the quality of the ration (100%) was still higher ($\text{MJ ME kg}^{-0.75} \text{ d}^{-1}$) compared to the required quality on the basis of maintenance requirements plus potential liveweight gain. For the cases where 100% of the ration was used, and feed quality (IME in $\text{MJ ME kg}^{-0.75} \text{ d}^{-1}$) exceeded the maximum quality possible, the inputs and outputs and the feed intake data were reduced with a factor ($\text{max IME/IME-ration}$).

Potential livestock production

The feeding ration for potential cattle, sheep and goat production was determined first by herdsize, and second by the quality of the feeding ration, in terms of IME. When the herdsize was 1 and the intake of ME was bigger than, in the case of cattle, $0.758 \text{ MJ ME kg}^{-0.75} \text{ d}^{-1}$, a feeding ration was chosen for which the intake of ME was equal to 0.758, and consequently the herdsize was bigger than 1. In this case, less than 100% of the feeds was used. A herdsize bigger than 1 indicates that more feed dry matter is offered to the animal than the amount of feed dry matter consumed by one animal.

Results

Livestock activities (cow, sheep and goat units throughout a year) were quantified in relation to the feed resource in terms of technical inputs and outputs. The inputs for livestock activities were: the amount of dry matter of the individual feeds, the total amount of dry matter consumed, total amount of nitrogen consumed (crude protein intake/6.25), and total amount of metabolizable energy consumed. The outputs were: total amount of manure dry matter produced (dry matter intake-digestible dry matter intake), total amount of manure nitrogen produced ((crude protein intake-digestible crude protein intake)/6.25), liveweight gain

(1kg = 29.9 MJ ME), milk production, offspring and draft power (0.243 ha = 37.74 MJ ME). Livestock production was divided into two production technologies: actual and potential.

Monthly input of dry matter

For the actual production situation, a herdsiz close to 1 was expected, since the feed tables were calculated for a standard animal. Nevertheless, herdsiz differed from 0.15 (goats in April) to 4.73 (sheep in December). A herdsiz of less than 1 indicated a feeding ration of such a low quantity insufficient to keep one animal. A herdsiz bigger than 1 indicated that the amount of feed offered was big enough to keep more than 1 animal. For the months with herdsizes of less than 1 the livestock production was reduced because of the presence and the amount of the individual feeds available. For the months in which the herdsiz was bigger than 1 the dry matter intake differed between months due to differences in availability and presence of the feeds.

Although in reality the feed was only offered to one animal, it was assumed that the ration reflected the actual production situation. The herdsiz for actual livestock production (Table 8.6) of cattle in Putukrejo was less than 1 in the months September to December, and for cattle in Kedungsalam the herdsiz was less than 1 from May to December, while in the other months the herdsiz was bigger than 1. From May onwards the herdsiz for lactating cows was lower than for non-lactating cows. The amount of feed dry matter in the research area seemed to become too short in Putukrejo from August onwards, and in Kedungsalam from May onwards. The herdsiz for sheep was less than 1 during most of the year. For goats

Table 8.6 *The herdsiz (no.) of actual livestock production with 100% of feed offered used.*

Month	Putukrejo		Kedungsalam		Sheep	Goats
	CU1&2	CU3	CU1&2	CU3		
Jan	1.32	1.32	1.26	1.26	3.35	1.00
Feb	1.53	1.53	1.14	1.14	4.62	1.00
Mar	2.33	2.33	1.00	1.00	0.93	0.93
Apr	1.41	1.41	1.14	1.14	1.00	0.15
May	1.08	1.14	0.81	0.86	0.86	0.87
Jun	1.23	1.55	0.70	0.88	0.86	0.15
Jul	1.03	1.31	0.50	0.63	0.86	0.21
Aug	0.89	1.13	0.52	0.66	0.86	0.86
Sep	0.77	0.97	0.59	0.75	2.19	0.36
Oct	0.64	0.80	0.60	0.75	0.34	0.87
Nov	0.58	0.73	0.48	0.60	0.83	0.87
Dec	0.64	0.81	0.76	0.96	4.73	1.51

a herds size of lower than 1 was found from March till November. The potential livestock production was not constrained by any feed factor.

The monthly amount of dry matter intake (Figure 8.3) varied over the year for the actual production situation, since for this production situation the presence of the individual feeds over the year varied. For potential production, with soybean cake supplemented as a concentrate, the presence and the amounts of the feeds were constant over the year. The total monthly dry matter intake differed for a lactating animal compared to a non-lactating animal. Cattle unit 1 and 2 became lactating animals from May onwards, and sheep and goats became

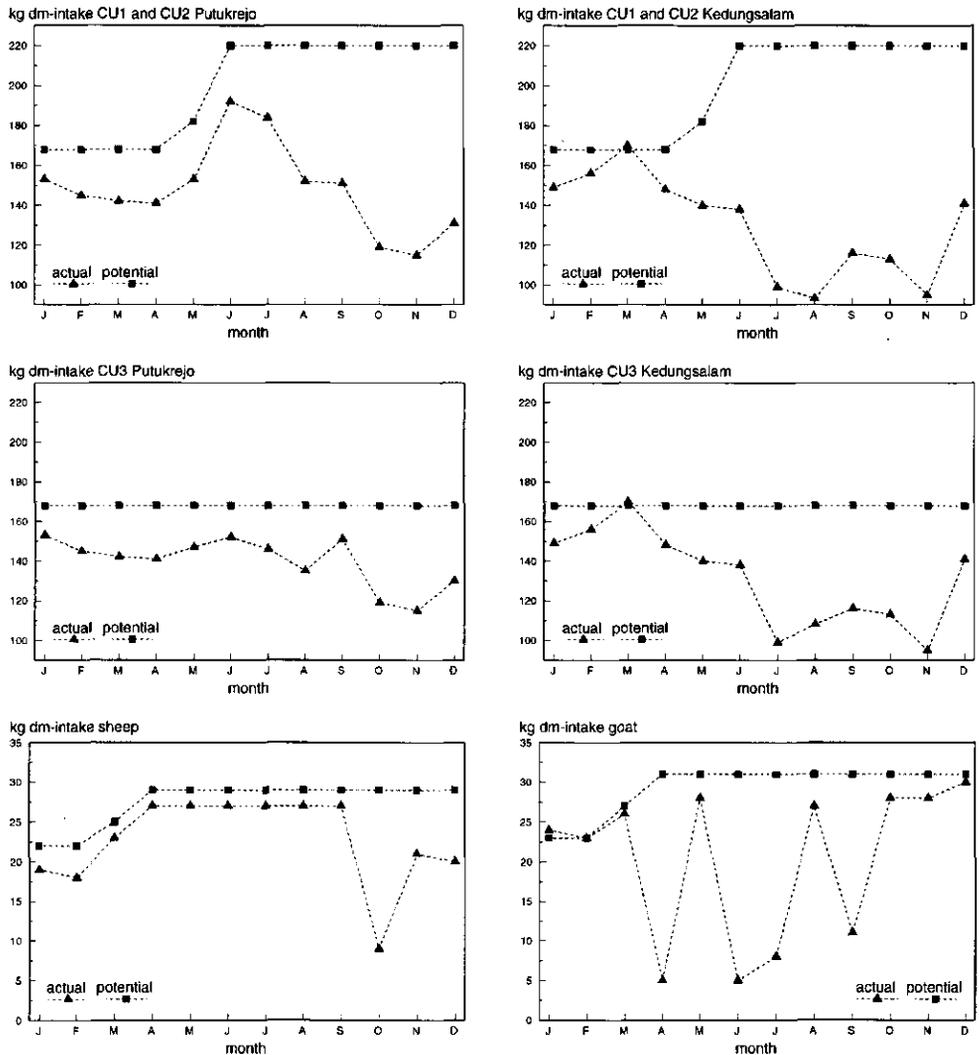


Figure 8.3 The intake of dry matter (kg) per month in 1991 for cattle (250 kg) in Putukrejo and Kedungsalam, sheep (25 kg) and goat (30 kg) for the two production situations; actual and potential.

lactating animals from March onwards. Therefore in Figure 8.3 an increase in dry matter intake was shown, after which the feed dry matter intake was constant again, for the potential production. The low sheep dry matter intake in October is caused by a low amount of leguminous tree leaves offered, compared to the other months (Appendix 1). Goats are fed leguminous tree leaves plus another component, which differs monthly. However, in April, June, July and September, only leguminous tree leaves are fed (Appendix 1), and therefore the dry matter intake is low in these months (Figure 8.3).

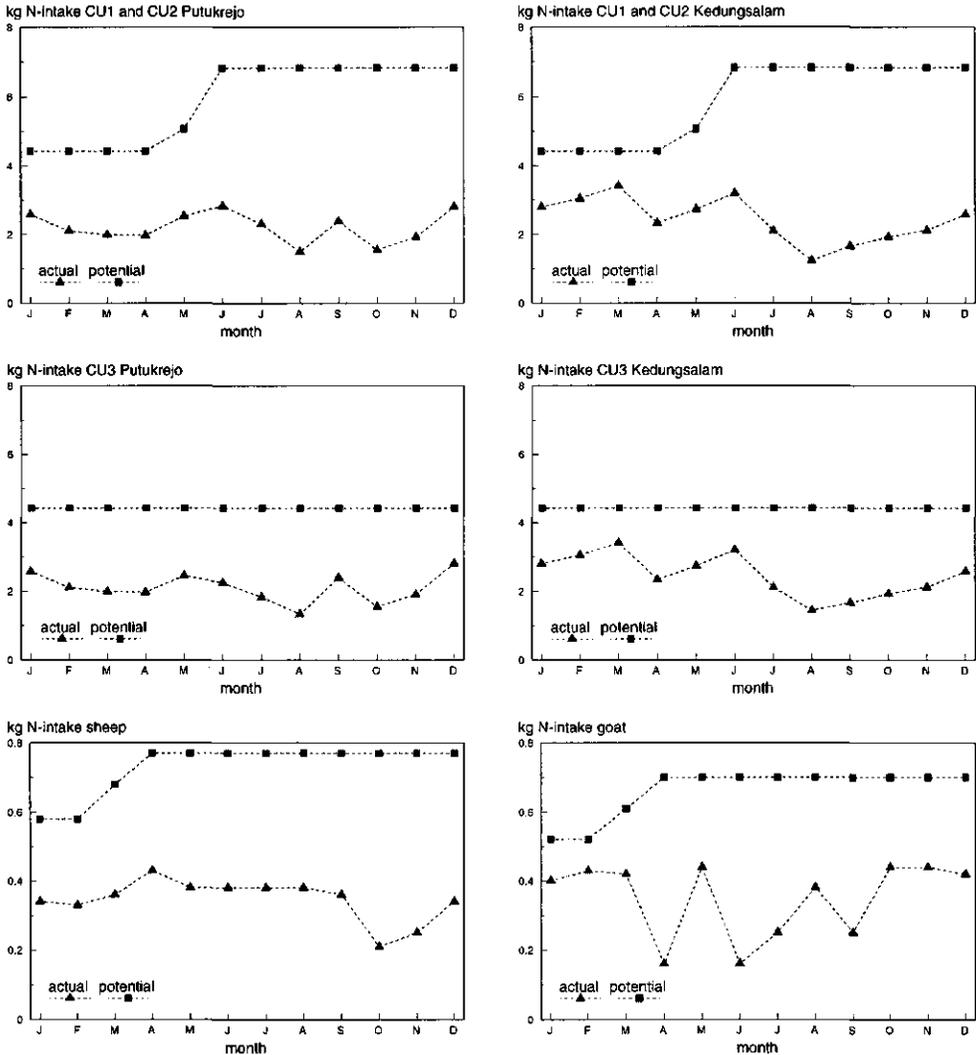


Figure 8.4 The intake of nitrogen in the dry matter (kg) per month in 1991 for cattle (250 kg) in Putukrejo and Kedungsalam, sheep (25 kg) and goat (30 kg) for the two production situations; actual and potential.

Monthly input of nitrogen

The monthly amount of nitrogen intake (Figure 8.4) was related to the amount of each individual feed consumed and the nitrogen content of that particular feed. The nitrogen content of each feed was supposed to be constant so no differences in nitrogen content over the year within a feed were taken into account. The potential livestock production always showed the highest amount of nitrogen intake over the year, caused by the very high crude protein content (48%) of soybean cake compared to the other feeds.

Monthly input of metabolizable energy

The total amount of metabolizable energy consumed for the two production technologies in the different villages for cattle, sheep and goats is shown in Figure 8.5 in relation to the amount of metabolizable energy required for maintenance. In March, actual cattle production in Kedungsalam shows a high ME intake value caused by a high amount of leguminous tree leaves consumed.

Table 8.7 shows, for actual production, the intake of metabolizable energy per kg metabolic weight per day. The maximum ME intake for non-lactating cattle was $0.758 \text{ MJ kg}^{-0.75} \text{ d}^{-1}$ and for lactating cattle it was $1.03 \text{ MJ kg}^{-0.75} \text{ d}^{-1}$. This maximum was not reached for lactating as well as non-lactating cattle. The maximum IME for non-lactating sheep was $0.522 \text{ MJ kg}^{-0.75} \text{ d}^{-1}$ and for lactating sheep $0.70 \text{ MJ kg}^{-0.75} \text{ d}^{-1}$. Sheep were lactating from March onwards. The actual sheep production showed below maximum intake all over the year. The maximum intake for non-lactating goats was $0.480 \text{ MJ kg}^{-0.75} \text{ d}^{-1}$ and for lactating goats $0.65 \text{ MJ kg}^{-0.75} \text{ d}^{-1}$. Goats were

Table 8.7 The intake of metabolizable energy of actual livestock production with 100% of the amount of feed offered used (IME in $\text{MJ kg}^{-0.75} \text{ d}^{-1}$).

Month	Putukrejo		Kedungsalam		Sheep	Goats
	CU1&2	CU3	CU1&2	CU3		
Jan	0.651	0.651	0.626	0.626	0.411	0.468
Feb	0.598	0.598	0.656	0.656	0.378	0.452
Mar	0.539	0.539	0.736	0.736	0.497	0.503
Apr	0.516	0.516	0.582	0.582	0.584	0.138
May	0.598	0.577	0.597	0.597	0.529	0.537
Jun	0.907	0.719	0.613	0.613	0.529	0.138
Jul	0.856	0.678	0.423	0.423	0.529	0.217
Aug	0.597	0.529	0.413	0.414	0.529	0.633
Sep	0.648	0.648	0.447	0.447	0.566	0.228
Oct	0.505	0.505	0.453	0.453	0.218	0.537
Nov	0.492	0.491	0.429	0.429	0.438	0.537
Dec	0.605	0.604	0.565	0.565	0.392	0.650

lactating from March onwards. For the actual goat production the IME was only maximum in December. The maintenance requirements for cows were 0.512 MJ ME per kg MW. The actual cow production in Putukrejo showed a lower than required intake of ME for lactating as well as non-lactating cows in October and November. For actual cow production in Kedungsalam the intake of ME was below the required intake of ME for maintenance from July till November. The maintenance requirements for sheep and goats were 0.384 MJ ME per kg MW. Actual sheep production showed an energy limitation in February and in October. Goat production showed an maintenance deficiency in April, June, July and September.

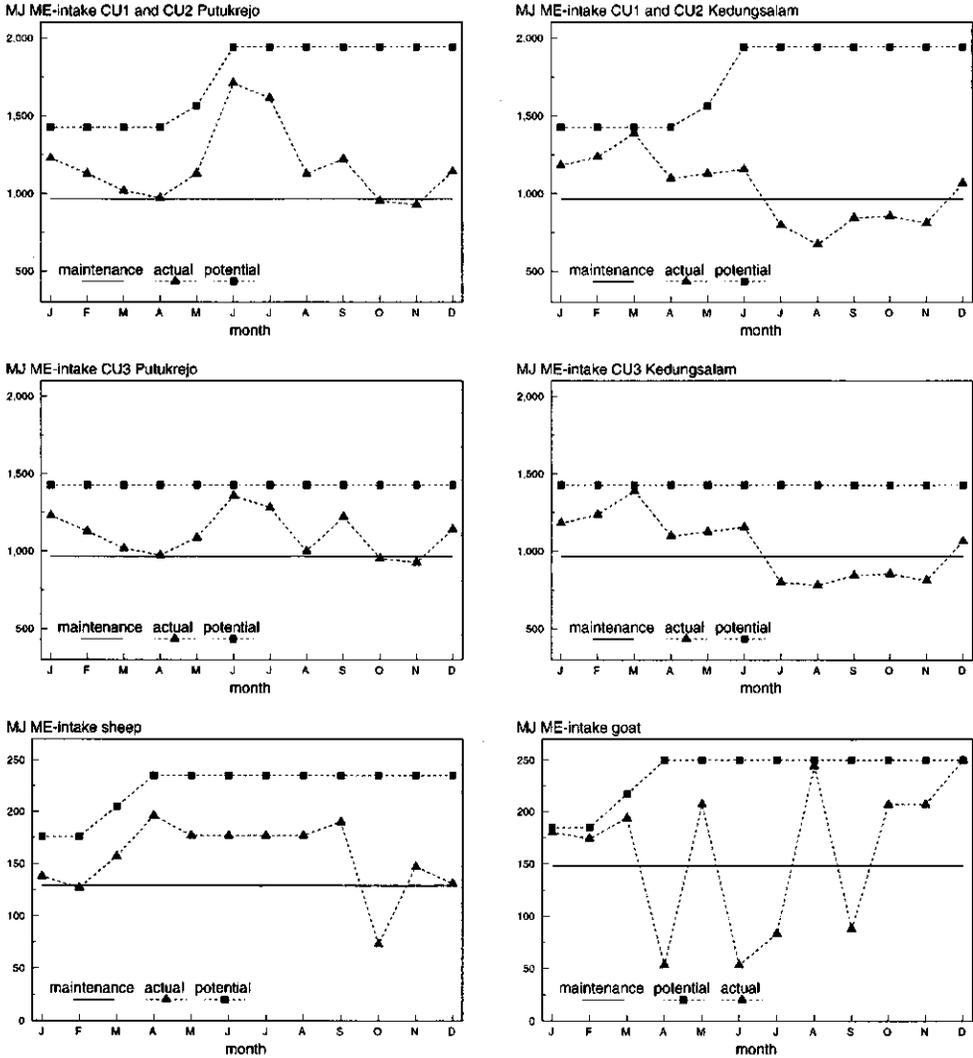
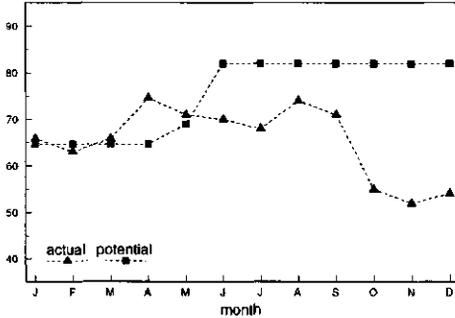


Figure 8.5 The intake of metabolizable energy (MJ) per month in 1991 for cattle (250 kg) in Putukrejo and Kedungsalam, sheep (25 kg) and goat (30 kg) for the two production situations; actual and potential.

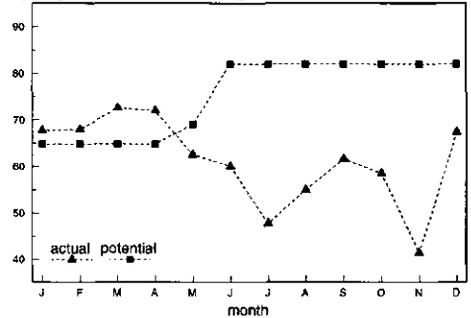
Monthly output of dung dry matter

The amount of dung dry matter was determined by the non digestible part of the feed dry matter consumed. Poor quality feeds, with a large proportion of indigestible feed, produced, per kg dry matter intake, more kg of dung dry matter, compared to high quality feeds. The dry matter intake for the potential production was highest, but the production of dung dry matter was not always the highest for the potential production (Figure 8.6). In the potential production situation animals consumed only the best quality feeds with high digestibilities, and therefore with a low dung dry matter production. In general the same pattern over the year for dung dry matter was shown compared to the dry matter intake.

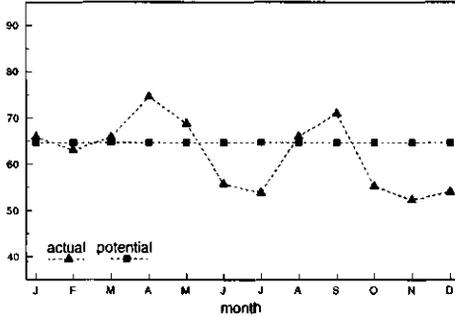
kg dung-dm CU1 and CU2 Putukrejo



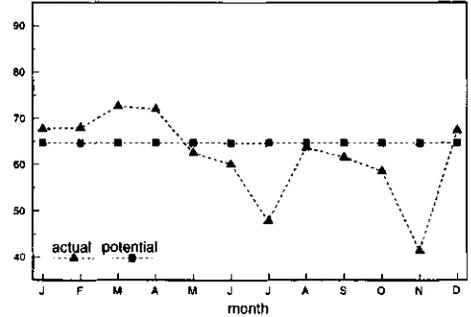
kg dung-dm CU1 and CU2 Kedungsalam



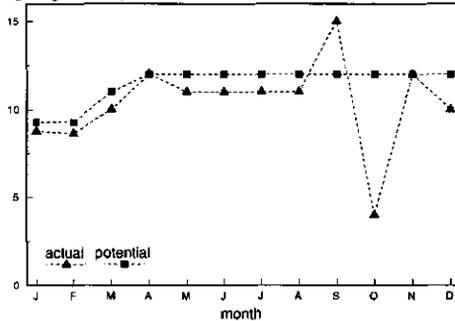
kg dung-dm CU3 Putukrejo



kg dung-dm CU3 Kedungsalam



kg dung-dm sheep



kg dung-dm goat

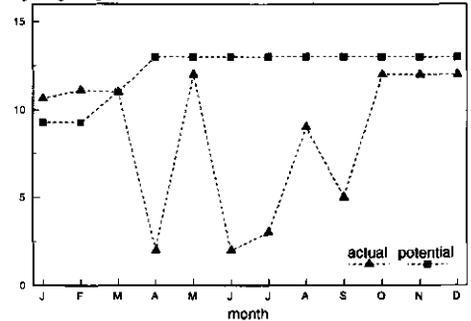


Figure 8.6 The output of dung dry matter (kg) per month in 1991 for cattle (250 kg) in Putukrejo and Kedungsalam, sheep (25 kg) and goat (30 kg) for the two production situations; actual and potential.

Monthly output of dung nitrogen

The amount of nitrogen in the dung dry matter was a result of the dry matter intake, the dry matter digestibility and the N content. The higher the DM intake, the higher the N content in the DM; and the higher the indigestible part in the feed, the higher the output of N in the dung DM. For cows in Putukrejo, and for sheep and goats, the highest amounts of dung N were shown for potential production (Figure 8.7). Actual cattle production in Kedungsalam showed higher amounts of dung N in January, February and March compared to potential production. The pattern of dung N over the year showed the same trends as the intake of N in the DM.

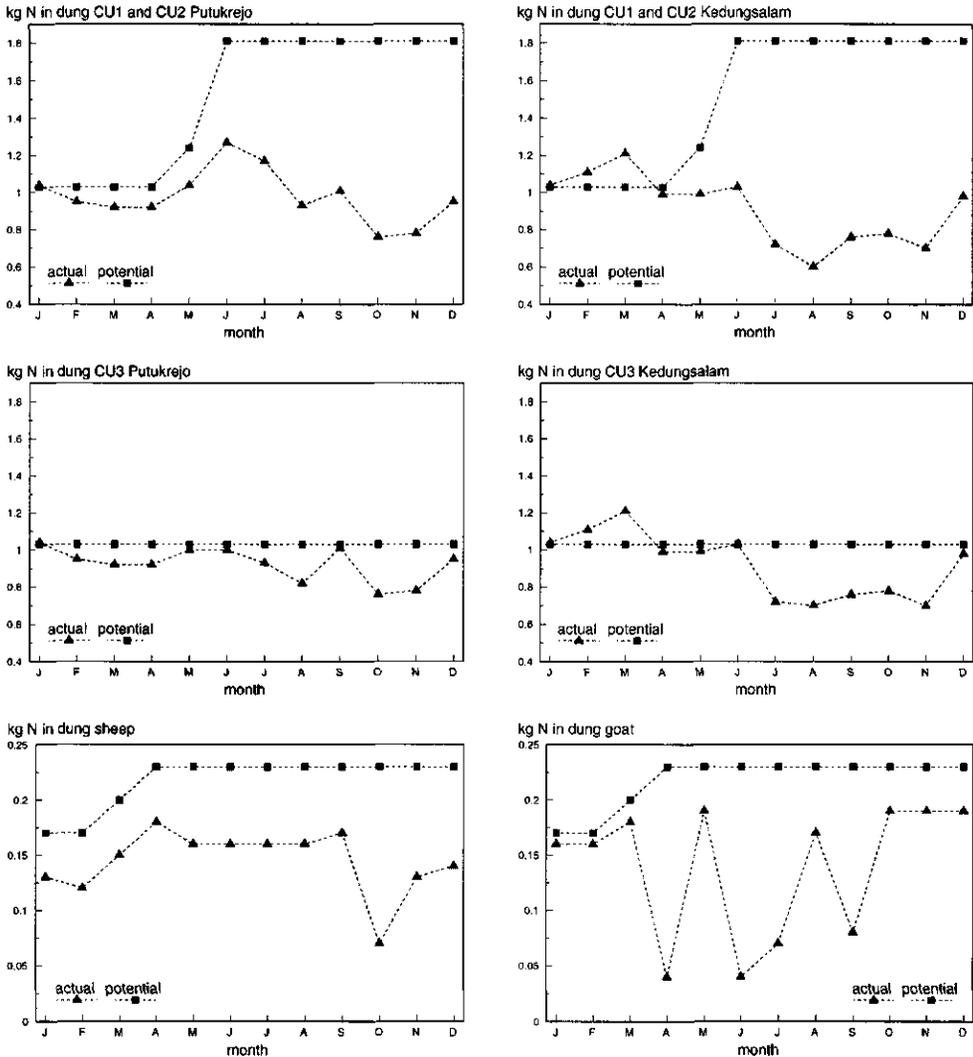


Figure 8.7 The output of nitrogen in the dung dry matter (kg) per month in 1991 for cattle (250 kg) in Putukrejo and Kedungsalam, sheep (25 kg) and goat (30 kg) for the two production situations: actual and potential.

Monthly output of liveweight gain

Figure 8.8 shows the monthly liveweight gain at the actual production levels for cattle unit 1, 2 and 3, in Putukrejo and Kedungsalam. All the actual production lines showed, in general, a decrease of liveweight gain over the months from January to December. A negative liveweight gain means a decrease in bodyweight. The liveweight gain for cattle unit 3 was always higher compared to cattle unit 1 and 2, which was due to the fact that cattle unit 1 and 2 were reproducing animals for whom less energy was left for liveweight gain. The liveweight gain for cattle unit 1 and 2 only differed between the animals for the months September to December, while in these months cattle unit 2 had to perform draft power and therefore had less energy available for liveweight gain. The potential liveweight gain for a non-lactating cow was constant and only showed a decrease in the months in which traction was performed (Figure 8.8). The lactating cows had a constant liveweight gain as well, and only decreased in liveweight gain in the months in which energy was required for pregnancy. Liveweight gain for actual sheep and goat production was negative almost every month (Figure 8.9). The actual goat liveweight gain equalled the potential gain in January, August and December.

A year was divided into a wet season, November to April, and a dry season, May to October. For the reproducing and lactating cattle, sheep and goats (CU1, CU2, SU and GU), the average daily liveweight gain in the dry season was higher compared to the wet season (Table 8.8 and 8.9). Apart from the liveweight gain data for actual cattle production in Kedungsalam, and for actual sheep and goat production, where liveweight gain in the wet season was higher compared to the dry season. The daily liveweight gain was higher for CU3 compared to CU1 and CU2 because of differences in type of production. For the non-reproducing and non-lactating cow (CU3), the average daily liveweight gain was higher in the wet season compared to the dry season in the village Kedungsalam, while the opposite was true for the village Putukrejo, in which the liveweight gain in the dry season was higher compared to the wet season.

In general, liveweight gain data for actual cattle production were more favourable, in Putukrejo than in Kedungsalam, in both dry and wet seasons. Only the actual cattle production in the wet season in Kedungsalam was more favourable compared to Putukrejo. In both

Table 8.8 The average daily liveweight gain ($g d^{-1}$) in the wet and the dry season for three types of cattle, in two different villages with two different production technologies.

Cattle Unit	Potential		Putukrejo		Kedungsalam	
	dry	wet	Actual dry	wet	Actual dry	wet
CU1	450	396	-100	-154	-521	-84
CU2	450	396	-114	-168	-535	-98
CU3	473	473	176	87	-57	144

Table 8.9 The average daily liveweight gain ($g d^{-1}$) in the wet and the dry season for sheep and goats with two different production technologies.

Livestock Unit	Potential		Actual	
	dry	wet	dry	wet
SU	50	38	-31	-28
GU	41	29	-68	-21

Table 8.10 The average intake of metabolizable energy ($MJ kg^{-0.75} d^{-1}$) in the wet and the dry season for three types of cattle, in two different villages with two different production technologies.

Cattle Unit	Potential		Putukrejo Actual		Kedungsalam Actual	
	dry	wet	dry	wet	dry	wet
CU1 and CU2	0.997	0.849	0.735	0.567	0.482	0.599
CU3	0.758	0.758	0.609	0.567	0.491	0.599

Table 8.11 The average intake of metabolizable energy ($MJ kg^{-0.75} d^{-1}$) in the wet and the dry season for sheep and goats with two different production technologies.

Livestock Unit	Potential		Actual	
	dry	wet	dry	wet
SU	0.700	0.626	0.482	0.445
GU	0.650	0.579	0.382	0.459

villages the potential for livestock production was the same because of similar feeding tables, e.g. amount and presence of feeds, and similar genetic animal potentials. The results of liveweight gain were explained by the IME data for the dry and the wet season (Table 8.10 and 8.11). A high IME corresponded with a high value for liveweight gain. The IME was on average higher in Putukrejo compared to Kedungsalam, except for the actual cattle production in the wet season in which IME was higher in Kedungsalam compared to Putukrejo. In Putukrejo the IME was higher in the dry season compared to the wet season, and in Kedungsalam the IME in the wet season was higher compared to the dry season. For actual goat production, the IME in the wet season was higher compared to the IME in the dry season, and the results were the opposite for the potential sheep and goat production.

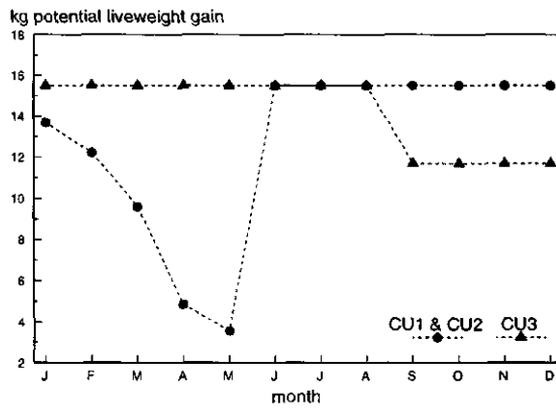
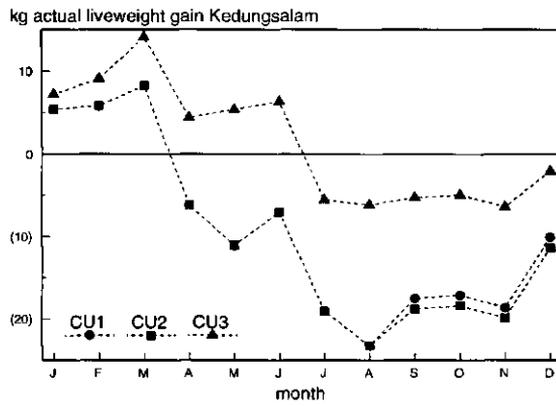
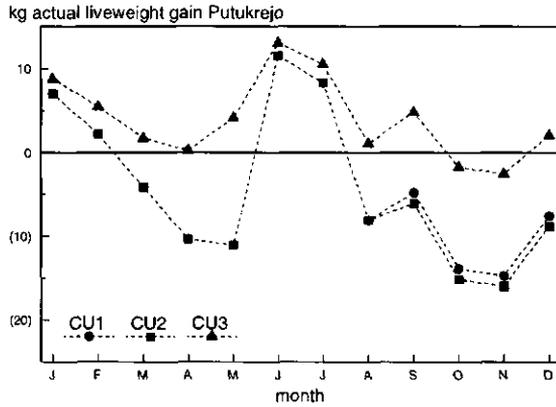


Figure 8.8 The monthly liveweight gain for cattle unit 1, 2 and 3 in the villages Putukrejo and Kedungsalam for actual production and the monthly liveweight gain for cattle unit 1, 2 and 3 for both villages for potential production.

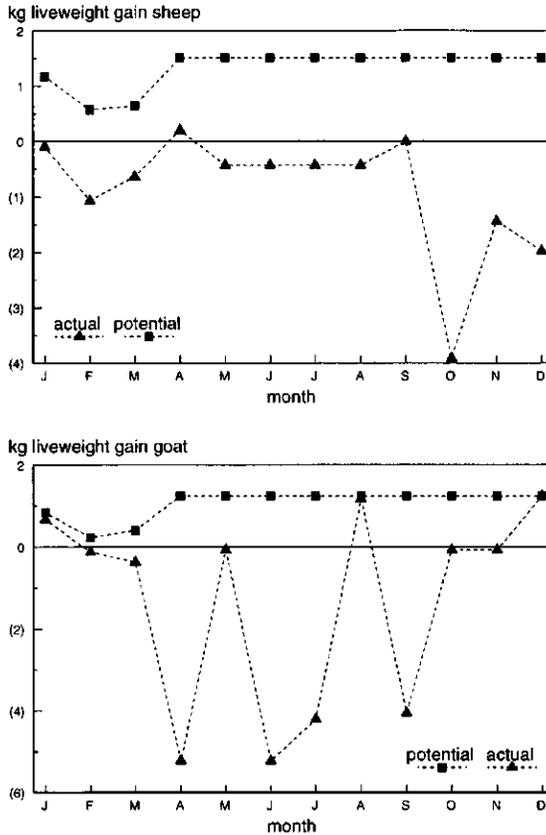


Figure 8.9 The monthly liveweight gain for sheep and goat for actual and potential production.

Monthly output of traction

Table 8.12 shows the hectares ploughed by cattle unit 2 and cattle unit 3 in the two villages for actual production. For actual cattle production the minimum target of 0.24 hectare was

Table 8.12 Traction performance (ha) by 2 different cattle units, in 2 different villages for actual cattle production.

Month	Putukrejo		Kedungsalam	
	CU2	CU3	CU2	CU3
Sep	0.24	0.73	0.24	0.24
Oct	0.24	0.24	0.24	0.24
Nov	0.24	0.24	0.24	0.24
Dec	0.24	0.73	0.24	0.24

only just reached each month for cattle unit 2 and cattle unit 3 in both Putukrejo and Kedungsalam, except for cattle unit 3 in Putukrejo in September and December.

Production gap analysis

In the study area, keeping ruminants is done for various reasons. Liveweight and manure are the most important production aspects because they bond other aspects (capital accumulation, income and insurance) which are relevant for sustaining the farm-household system. Liveweight production consists of the accumulation of liveweight through the growth of the individual animals and the increase in the number of animals through birth. Table 8.13 shows the main input and outputs of livestock production for two different production technologies. When manure is considered as production aim, it is obvious that cattle are more favourable in manure production compared to sheep and goats. For cattle, the difference between a reproducing and a non-reproducing cow is negligible. Potential production gives most of the time higher amounts of manure compared to actual production (Figure 8.6). For liveweight gain, cattle shows higher values compared to sheep and goats.

Table 8.13 Yearly livestock production data (in kg) for actual and potential production in the limestone area, south of Malang.

Production	Technology	Putukrejo		Kedungsalam		SU	GU
		CU1	CU3	CU1	CU3		
LWG	actual	-46	47	-110	16	-9	-16
	potential	152	171	152	171	16	13
DM-in	actual	1778	1676	1558	1573	272	243
	potential	2394	2016	2394	2016	330	352
DM-out	actual	784	746	734	743	124	102
	potential	902	776	902	776	138	147
N-in	actual	27	25	29	29	4	4
	potential	71	53	71	53	9	8
N-out	actual	12	11	11	11	2	2
	potential	18	12	18	12	3	3
LWG/DM-in (g kg ⁻¹)	actual	-26	28	-71	10	-33	-66
	potential	63	85	63	85	48	37
DM(out/in) (%)	actual	44	45	47	47	46	42
	potential	38	38	38	38	42	42
N(out/in) (%)	actual	44	44	38	38	50	50
	potential	25	23	25	23	33	38

However, in the actual production situation, liveweight gain of reproducing cows is negative. Obviously, farmers consider the produce of offspring more important than maintaining or improving the bodyweight of the cow. The efficiency of producing animals is expressed here as the ratio liveweight gain to dry matter intake. The potential production situation shows higher efficiencies compared to the actual production situation, with the highest efficiency for non-reproducing cattle.

Discussion and conclusions

An analysis of livestock production on the basis of feed availability is mostly done by estimating the forage production in a region and comparing the amount of fodder available with the number of animals in a certain region. This type of study is often referred to as carrying capacity analyses (Geerling & de Bie, 1986). Monthly or seasonal data are used to show differences in amount and nutrient availability over the year as a result of cropping patterns and weather conditions, like rainfall. However, these kinds of studies do not tell anything about livestock production at farm level or even in the region itself. Comparison of forage availability with number of animals assumes a closed system e.i. no feeds used from outside the region and no feed of the region used by farmers from outside the region. However, a region seldom has a closed feed-animal livestock system. Farmers within a region might have different access to certain feed sources. Analysis as it has been described above assumes that every farmer has access to the regional feed source which does not happen in practice. Therefore a livestock analysis at farm level can show completely different results compared to an analysis at regional level. The way livestock should be analysed at farm level is by looking at the farms. In the approach described in this chapter the livestock was analysed by looking at the feed tables of cattle at the farms in two different villages, Putukrejo and Kedungsalam, and by looking at the feed tables of sheep and goats at farm level averaged over the two villages.

The quality of the individual feeds, in terms of organic matter, crude protein and digestibility, were taken as constant over the year. This assumption is a generalization of the practice since the quality of the feeds may differ with, for example, temperature, radiation income, water availability, nutrient availability, exposure to pests and diseases, competition with weeds, and management factors. Since no seasonal quality data were available for the research area we were not able to include it in our study but it is noted as a worthwhile study subject for future research.

If the bodyweight of a standard animal changes over the year the feeding tables should change as well. However, this kind of feedback interaction is difficult to model. E.g. first the feeding table for January is calculated, resulting in the liveweight gain of the animal in January. The bodyweight plus the liveweight gain creates a new standard animal for which the feeding table of February is calculated. In this study, one was interested in a standard animal with its corresponding inputs and outputs, and therefore these dynamics were not yet

included.

Actual cattle production can be improved by feeding more gliricidia. Comparing the gliricidia feed intake restrictions of Table 8.1 with the amount of gliricidia fed (Appendix 1) shows in some months gliricidia intake is less than 1.5 kg dry matter. In Kedungsalam this is the case in the months April, July, August, September, October and December. In Putukrejo this is the case in all months except in September and December. That the amount of gliricidia fed to cattle is lower in Putukrejo compared to Kedungsalam is due to much more gliricidia trees growing in the Kedungsalam. There is no potential to improve sheep and goat production by gliricidia, since both are already fed at the maximum level of gliricidia consumption.

Simulated liveweight gain data for non-reproducing and non-lactating cattle (Table 8.8) are compared with measured data (Table 5.10). The latter gave daily liveweight gains (g d^{-1}) of 208 in the dry season of 1990, 16 in the wet season of 1991 and 47 in the dry season of 1991. Table 8.8 showed that for Putukrejo the liveweight gain was higher in the dry season compared to the wet season but the opposite was found in Kedungsalam. The results of Table 5.10 do not make a distinction between the two villages. However the average over the two seasons and over the two villages is 90 g d^{-1} when measured, and 88 g d^{-1} when simulated. Thus the simulated results greatly approach the one measured in the field.

It can be questioned whether it is worthwhile to look at pregnancy, milk production and animal traction with a cycle spread over the year (as it is done now). Another possibility is that every month the calculations are done for a pregnant, lactating, growing, tractive, etc. animal, independent of whether this takes place in practice in these months. However since crop cultivation is also calculated as an event over the year, this was also done for animals. Milk production of working cows is likely to decrease if more than moderate work is required. A fall in milk yield due to a shortage of energy is most likely to occur during the first months of lactation, when the energy requirements for lactation are high. When animals are in a negative energy balance, yield reductions are accompanied by live weight losses. The division of energy shortages between live weight and milk is moderated by the influences of feeding, carry-over effects to other periods, and changes in the fat content of milk. More research needs to be done so that these processes can be qualified and quantified properly.

Feed requirements for pregnancy were simulated starting in January, and, consequently, energy requirements for lactation a few months later. The effect of an earlier or later pregnancy on the feeding balance and thus on the production performance is not studied here. But from an optimization point of view it could be interesting to investigate. In the research area no general calving season was identified but it is worthwhile to study whether a preferential calving season could be introduced.

Main conclusions are as follows:

- Livestock production analysis should include quantitative as well as qualitative feed data; livestock production should be studied on a monthly basis, since yearly data hide seasonality in feed and livestock production.
- The results differed for lactating animals compared to non-lactating animals; lactating

animals showed lower liveweight gains than non-lactating animals.

- The results differed for traction performing cows compared to non-traction performing cows; non-traction performing cows showed higher liveweight gains than traction performing cows.
- Actual livestock production was negative, in terms of liveweight gain, for cows in Putukrejo (March-May, Aug-Dec) and Kedungsalam (Apr-Dec), for sheep (Jan-Mar, May-Dec) and for goats (Feb-Jul, Sep-Nov). In these months either the amount of dry matter offered to the animals or the type of feeds present was limiting. The livestock production situation could be improved by at least offering the animals more dry matter in these months, whereafter additional improvement could be reached by additional feeds.
- Potential livestock production showed the maximum production possible. Buying of concentrates such as soybean cake improved the local livestock production enormously.
- The monthly inputs and outputs for livestock production differed for the two production technologies. A whole farm analysis, including the livestock activities as well as other agricultural activities, will show which type of livestock production is the best to pursue considering the goals defined and the constraints imposed (Chapter 9).
- The feeding ration was chosen on the basis of IME in $\text{MJ kg}^{-0.75} \text{ d}^{-1}$ (the quality of the feed). Other possibilities are that the ration is chosen on the basis of minimum costs, with a price card attached to each individual feed. Or on the basis of minimum labour required (in hours per kilogram dry matter collected per individual feed) to collect feed. The basis on which the feed ration is chosen should reflect the goals defined.

Herd dynamics, i.e. mobility and replacement of the animals, may be strongly affected by the economy of the household - need for money leads to sale - and social relationships which determine the access that farm households have to animals, for example via livestock sharing systems (Ifar et al., 1996). These components of integrated farming systems, together with the market and policy decisions outside the farm unit were not dealt with in LIPROFE.

Chapter 9

The role of manure in nutrient cycling

Introduction

Nutrient cycling involves the uptake, utilisation, release and re-utilisation of a given nutrient by various processes in a system. Efficient cycling of nutrients within a farming system is a prerequisite for long-term sustainable land use. This is particularly so for low external-input systems. The complex but vital role played by livestock in regulating fluxes in the nutrient cycles is often ignored in experimentation and crop modelling exercises, although, in farming practice, the animal is an integral part of the system (Romney et al., 1994). The cycling of cropland residues and fallow vegetation through livestock, in the form of faeces and urine that fertilise the soil, is an important linkage between livestock and soil fertility in mixed farming systems. Via the feedstuffs of the animals, organic material and nutrients are brought to the farm, which would not have entered the farm if there were no animals. In the literature, four definitions for animal excreta are found: (1) faeces are animal excreta without urine, (2) dung are older excreta, (3) manure is faeces and urine, normally matured (dry matter percentage of fresh manure ranges between 23 and 40%) and (4) farmyard manure is the solid and liquid excreta, generally mixed with litter used for bedding. In this chapter, use is made of these definitions. The type, quality and quantity of available animal excreta depends not only on the type of animal and the quality and the quantity of the feed, but also upon the animal production system and the degree it is integrated into the farming system (Stangel, 1993). In addition, there is a great variation within animal species due to feed management, level and type of production, handling of manure and mode of application to the soils.

Hereafter, the quantity and quality of manure is discussed, whereafter the uptake, utilisation and release of macro nutrients, N, P and K, by livestock are elaborated. Re-utilisation of nutrients in manure and losses of nutrients from manure are discussed as well. The role of manure in nutrient cycling is quantified in order to assess the role of animal keeping, in terms of soil organic matter and soil nutrients, of the mixed farming system.

Quantity and quality of manure

Low external-input livestock systems are characterized by marked changes in seasonal feed

availability and nutritive value which affect both the quantity and quality of animal excreta. In the model LIPROFE, as was described in Chapter 8, faecal dry matter output was calculated from the feed dry matter intake and digestibility. A daily DM intake of, for example, 60 g per $BW^{0.75}$ with a digestibility of 50% will give an annual faecal dry matter production of 11.0 kg per $BW^{0.75}$, or 692 kg dry matter for an animal of 250 kg bodyweight, annually. In Mali, Dicko-Toure (1980) measured intake and faecal production by cattle (about 250 kg liveweight), and found that the average daily dry-matter intake in each month varied from 4.6 to 6.4 kg d^{-1} , whilst faecal dry-matter production ranged from 2.4 to 3.1 kg d^{-1} , or 876 to 1132 kg dry matter annually. Faecal dry matter production was lowest in the dry season when feed supplies were limited. Other literature sources mention productions of manure dry matter (kg) per year per head of cattle of 228 (Schleich, 1986), 402-803 (Powell & Mohammed-Saleem, 1987), 739 (de Vries, 1988), 750 (Heemskerk, 1994), 960 (ILCA, 1983), 1000 (Lhoste, 1987), 1000 (Dicko-Toure, 1980) and 1183 (Mulungushi, 1986). Figures from literature for amount and quality of manure are measured under different, and often poorly defined experimental conditions. Therefore, a comparison of these figures is difficult. Factors like type of feed, urine in- or excluded and age of the manure, have a large influence on these figures.

The valuation of manure in terms of the equivalent macronutrient (nitrogen, phosphorus, potassium) value of inorganic fertilizer requires that the chemical composition of manure must be known. However, the chemical composition of manure differs greatly due to many reasons, i.e. quality of the feed. Different species and classes of livestock produce excreta with varying nutrient concentrations. Young animals that are growing rapidly and dairy cows excrete manure with a lower nutrient content than fattening animals, due to a greater efficiency in extracting nutrients from feeds. Powell (1986), found much lower N and P contents in the mid-dry season than in the early dry season when crop residues predominated, or the early wet season when forage quality was higher. The partitioning of N excretion between urine and faeces can also fluctuate widely with changes in diet composition (Powell et al., 1994), and may be influenced by the degradability of the dietary protein of the rumen. In tropical feeds, this might be affected by the presence of polyphenolics, especially tannins. The presence of tannins in feeds has been shown to be negatively correlated with protein degradability (Rittner & Reed, 1992) and digestibility (Hagerman et al., 1992; Hanley et al., 1992). These effects would not only be expected to increase the amount of N excreted, but also to decrease excretion in the urine whilst increasing excretion in the faeces, as digestion is shifted from the rumen to the intestinal tract.

In Table 9.1 the concentrations of N, P and K in the animal excreta are listed for several different countries. Reasons for variation in the chemical composition of manure are mentioned above. The large variation in nutrient concentrations between the different sources is obvious. Available literature indicates that values of nitrogen content for fresh manure vary by more than fivefold. The table shows sheep and goat manure to be somewhat higher in nitrogen and phosphorus content, but it has a lower concentration of potassium. Higher nutrient N and P concentrations in sheep and goats manure result in more rapid bacterial

Table 9.1 Concentration (% of DM) of macro nutrient elements in cattle and, goat and sheep manure.

Country	Nitrogen	Phosphorus	Potassium	Reference
Cattle manure				
India	1.62	0.22	-	Deshpande et al., 1983
India	1.80	0.23	2.04	Sharma & Mittra, 1991
Burkina	1.47-2.47	0.2-0.24	1.6-4.5	Pichot et al., 1981
Mali	0-2.5	0.14-0.63	0.26-4.17	Schleich, 1986
Mali	1.10	0.20	1.30	van der Pol, 1992
Senegal	5.3	0.81	5.44	Lhoste, 1987
Senegal	1.25-1.46	0.28-0.35	1.03-1.81	Cissé, 1988
West Africa	0.60-1.89	0.15-0.27	-	Powell & Mohammed, 1987
West Africa	1.27	0.28	1.30	van Duivenbooden, 1992
Kenya	1.30	0.50	1.60	Smaling, 1993
Zambia	1.0	0.09	1.33	Heernskerck, 1994
Zimbabwe	1.48	0.81	2.17	Khombe et al., 1992
Tanzania	0.57	0.06	0.83	Budelman & van der Pol, 1992
Africa	0.5	0.22	1.25	ILCA, 1983
Peru	1.62	0.29	0.47	Winterhalder et al., 1974
general	2.00	0.66	1.66	Euroconsult, 1989
general	1.03-2.12	0.21-0.57	1.93-4.60	Webster & Wilson, 1969
Average	1.59	0.35	1.96	
Sheep & goat manure				
India	1.25-1.75	0.50-0.75	0.50-1.25	ICAR, 1969
Burkina	2.20	0.35	0.73	Quilfen & Milleville, 1983
West Africa	3.21-4.02	0.38-0.56	-	Powell et al., 1994
Peru	1.82	0.28	1.06	Winterhalder et al., 1974
general	2.00	0.66	2.50	Euroconsult, 1989
Average	2.23	0.48	1.29	

changes and formation of humus. Sheep and goat manure are in the form of pellets and thus easier to use than cattle manure.

In the model LIPROFE, the N content of the faecal dry matter is calculated from the crude protein content of the feed and its digestibility. When a feed contains 7% CP and is 50% digestible, the N content of the faeces will be 1.5% (using $dcp = 0.9 * cp - 3.2$).

Average manure nutrient concentrations from literature are often used in studies to quantify the amount of nutrients excreted by the livestock population. A remark can be made whether it is justified to use data of nutrient contents from literature without considering the

production circumstances in which they were obtained, like type of animal and the quality and the quantity of the feed. Below, the nutrient concentrations of Table 9.1 are used to quantify the nutrient concentrations in the manure of cattle, sheep and goats in the study area. The average nutrient concentrations of the manure in the research area are calculated by the average values for nutrient concentrations of cattle, sheep and goats, weighed for the total number of animals in the research area, converted to livestock units, and the daily manure production. The average nutrient concentration of cattle manure was 1.59% N, 0.35% P and 1.96% K of the dry matter, and average values for sheep and goats were 2.23% N, 0.48% P and 1.29% K of the dry matter. The average calculated number of cattle units was 479 (SRS, 1992), and 367 sheep and goat units. Daily faecal dry matter productions of 2.18 kg for cattle and 0.35 kg for sheep and goats were taken, based on the calculations of Chapter 8 with LIPROFE. The calculations resulted in average nutrient concentrations of 1.66% N, 0.36% P and 1.89% K in faecal dry matter.

Given the large variation in nutrient concentrations in the literature and the fact that there is no distinction between urine and faeces, the above figure is considered too inaccurate for the research in this thesis. Since LIPROFE is available (Chapter 8) it is worthwhile to make use of this technology to try to make more specific estimates for the research area. Therefore, below, it is elaborated how nutrients are utilised by cattle, sheep and goats and as a consequence released in urine and faeces, based on the uptake of nutrients. The nutrient concentrations of the faeces and urine, calculated this way, hopefully give more realistic values than the ones calculated above. The nutrient balance, in terms of nitrogen, phosphorus and potassium, of livestock can be defined in two ways. One way is the amount of nutrients taken up minus the amount of nutrients excreted through faeces and urine. The other way is defined as the amount of nutrients taken up minus the amount of nutrients retained. Both ways will be elaborated below.

Intake, utilisation and release of nitrogen

Intake

Nitrogen intake is related to feed dry matter intake, and is therefore calculated as

$$NI = DMI * (\% N/100)$$

in which, NI is nitrogen intake (kg), DMI is dry matter intake (kg) and % N is the percentage of nitrogen in the dry matter. The nitrogen intake for cattle, sheep and goats at two different production levels, actual and potential, is shown in Table 9.2.

Utilisation

The amount of nitrogen taken up is available for maintenance, growth, gestation and lactation.

Daily amounts of N required for the different types of production can be quantified. The NRC (1989) expresses the protein retained during growth, in Net Protein Units of Growth (NPUG) (g d^{-1}) which is a function of the concentration of Net Energy in LiveWeight Gain (NELWG) (Mcal kg^{-1}) and liveweight gain (LWG) (g d^{-1}): $\text{NPUG} = [211 - (26.2 \text{ NELWG})] \text{LWG}/1000$. The efficiency of using retained protein in absorbed units is assumed to be 0.50.

NRC (1989) expresses the conceptus protein, which is deposited in the fetus, placenta, fetal fluids, and uterus, in net units. The Daily Conceptus Net Protein Units (DCNPU) in grams after 210 days of gestation was calculated from maternal LiveWeight (LW) in kilograms as $\text{DCNPU} = 1.136 \text{ LW}^{0.70}$. The efficiency of getting conceptus protein in net units conceptus protein from absorbed units is assumed to be 0.50 (NRC, 1985). For cattle with a liveweight of 250 kg this results in a daily nitrogen requirement during the last 2 months of gestation of 61 g N in absorbed units per day, and a total of 3660 g N during these two months.

The lactation protein in units of net protein (LPN) is the protein secreted in the milk. The amount of lactation protein in units of net protein in milk may be calculated from milk fat percentage as follows: $\text{LPN} = [1.9 + (0.4) (\text{milkfat, \%})] / 100$. The efficiency of using lactation protein in absorbed units, is assumed to be 0.70. Assuming a milkfat percentage of 4, this results in 14.4 g nitrogen required per kg of milk produced.

NRC (1989) calculates an N requirement for maintenance of a growing female (small breed) weighing 250 kg and gaining 500 g d^{-1} , as 109 g N d^{-1} . For a reproducing cow of 250 kg bodyweight the amount of N required for maintenance and gestation is 629 g crude protein, or 101 g nitrogen. A lactating cow of 250 kg bodyweight requires for maintenance and lactation 249 g crude protein, or 40 g N. If milk contains 4% fat, than 14 g N per kg milk produced is required. A reproducing or lactating animal requires 51 g N per kg of liveweight gain.

Here, the N balance is defined as the amount of nitrogen taken up minus the amount of nitrogen retained. If the animals have a negative N balance, N is mobilized from body reserves. If a reproducing or lactating animal loses 1 kg of liveweight, 51 g N comes available. The maximum daily N available from weight loss is assumed to be 30 g. The reproducing cows in Putukrejo consumed, on a yearly basis, on average 79 g N d^{-1} whereas cows in Kedungsalam consumed 100 g N d^{-1} . Reproducing or lactating cows at potential production level consumed daily 633 g N. The actual N intake values indicate a severe N deficiency for reproducing as well as lactating cows in Putukrejo. If the animal loses weight, extra N becomes available above the N intake. This situation cannot continue for a too long period. The situation is slightly better for a cow in Kedungsalam compared to Putukrejo. At the potential production levels in Putukrejo and Kedungsalam, animals consume concentrate, soybean cake, and this enormously increases the N uptake and therefore no N deficiency is identified.

Release

NRC (1989) assumes that faecal N consists of four fractions: (1) indigestible bacterial protein,

(2) indigestible nucleic acids, (3) indigestible dietary protein and (4) metabolic faecal protein. They consider urinary N to include; rumen efflux N, digestible nucleic acids, maintenance N, lactation protein increment, conceptus protein increment, retained protein increment; and distract the following fractions; rumen influx N and net scurf protein. It is beyond the scope of this thesis to quantify all above mentioned fractions in order to quantify the amount of N excreted with faeces and urine. Therefore, below a simplification is made to quantify the N excreted in faeces and urine through indigestible N and through metabolic N.

The faecal nitrogen consists of Indigested Feed Nitrogen (IFN) and the so called metabolic faecal nitrogen (MFN). The formula for the apparently digestible crude protein in the feed dry matter ($DCP = 0.9 * CP - 3.2$) suggests that 10% of the consumed CP in the feed dry matter is not digested and will appear in the faeces as indigested CP. True digestibility is not constant, especially in older lignified materials in which a larger fraction of the N is associated with the cell walls N digestibility will be lower. True digestibility can range from 85-95%, and an average value of 90% is used.

$$IFN = 0.10 * NI$$

in which, NI is the nitrogen intake (kg) and IFN is the indigestible feed nitrogen (kg). Metabolic faecal nitrogen (MFN) consists of the residues of secreted enzymes, sloughed intestinal cells (epithelial mucus) and of gastro intestinal biota. The MFN on a roughage basis is approximately 0.5 g N / 100 g DM consumed. This fraction of faecal nitrogen accounts on the average for almost all of the total for roughage of low protein content to two third of the total for roughage containing 20% or more of protein on the dry basis. So, MFN represents a very large fraction of the total excretion of N with the faeces, because MFN is rather constant per kg DM consumed, particular with low protein rations.

$$MFN = 0.5 * DMI/100$$

in which, DMI is the dry matter intake (kg), MFN is metabolic faecal nitrogen (kg). This empirical relation is fundamentally weak but it describes very well the N digestibility of tropical feeds (Boekholt, 1976). Oosting (1993) regressed the DNI/OMI with the NI/OMI and found MFN values of 0.65 g N per 100 g OMI, 0.56 g N per 100 g OMI and 0.72 g N per 100 g OMI for true digestibilities of about 0.9. On basis of dry matter these values are close to the 0.5, used in this thesis, and therefore no major under- or overestimation is made of the MFN. More elaborated equations are available, which calculate the endogenous N excretion of the ileum directly, but they require the duodenal flow of non-protein dry matter. And such data are not available for the livestock in the research area.

The urinary N excretion is equal to endogenous urinary nitrogen (MUN) plus the portion of the true digestible N that cannot be utilised by the animal (IUN). For the MUN Boekholt (1976) concluded that it was clearly related to metabolic weight ($BW^{0.75}$). From literature analysis Boekholt found:

Table 9.2 The nitrogen balance (kg N y⁻¹) and Nutrient Use Efficiency (%), considering non-reproducing and non-lactating cattle (BW=250 kg) and reproducing sheep (BW=25 kg) and goats (BW=30kg) in the villages Putukrejo (PK) and Kedungsalam (KS). Actual livestock production is limited by the feed resource and potential livestock production is not limited by the feed but by the genetic growth.

Livestock unit	NI ¹	IFN ²	MFN ³	UFN ⁴	MUN ⁵	Balance	NUE ⁶	NUE ⁷
CU-PK-actual	21.50	2.15	8.38	5.81	2.26	2.90	13	6
CU-KS-actual	27.00	2.70	7.87	7.29	2.26	6.88	25	1
CU-potential	171.40	17.14	10.08	46.28	2.26	95.64	56	3
SU-actual	4.43	0.44	1.36	1.20	0.40	1.03	23	-10
SU-potential	8.36	0.84	1.65	2.26	0.40	3.21	38	4
GU-actual	4.12	0.41	1.22	1.11	0.46	0.92	22	-6
GU-potential	7.32	0.73	1.76	1.98	0.46	2.39	33	5

¹ NI is nitrogen intake; ² IFN is indigested faecal nitrogen; ³ MFN is metabolic faecal nitrogen; ⁴ UFN is urinary feed nitrogen; and ⁵ MUN is metabolic urinary nitrogen; ⁶ NUE is nutrient use efficiency (Balance / NI); ⁷ Nutrient Use Efficiency (N retained (25.4 g N per kg LWG) / NI)

$$\text{MUN} = (0.10 * \text{BW}^{0.75})/1000$$

in which, BW is bodyweight (kg) and MUN is metabolic (endogenous) urinary nitrogen (g). About 70% of the true digestible N can be used for maintenance or production, the remaining 30% of the absorbed N will be excreted in the urine. Under ideal situations the efficiency of amino acid utilisation could be 75-80%.

$$\text{UFN} = 0.3 * (0.9 * \text{NI})$$

in which, NI is the nitrogen intake (kg) and UFN is the urinary excreted indigestible feed nitrogen (kg). The total amount of excreted nitrogen is the sum of urinary nitrogen (MUN + UFN) and faecal nitrogen (IFN + MFN).

Through the above mentioned equations a nitrogen balance is calculated for the research area, with the nitrogen intake as input factor and the nitrogen in faeces and urine as output factors. The results are shown in Table 9.2. For cattle only non-reproducing and non-lactating animals are considered since the difference with reproducing and lactating animals is only a factor 1.35 of feed intake (Chapter 8). Livestock in the research area are in a positive N balance, on a yearly basis. Of the amount of nitrogen taken up, 16 to 49% is excreted through faeces and 24-38% is excreted through urine. Of the total amount of nitrogen excreted, on average 36-57% is excreted through faeces and 43-64% is excreted through urine. Of the amount of N digested, 13-56% of N stays in meat and organs or is retained in milk (Table 9.2). The latter figure is defined as the nutrient use efficiency (NUE) and is generally be

below 30% (van Bruchem, personal communication).

Nutrient use efficiencies higher than 30% are all obtained in the potential production situation for cattle, sheep and goats. Thus in these situations the amount of N excreted is underestimated. It is the UFN equation which most likely underestimates the amount of N excreted. In this equation it is assumed that 30% of the absorbed N is excreted in the urine. However, this value depends on the nutrient availability for microbial degradation in the rumen. Livestock in the potential production situation consume high amounts of soybean cake with a very high nitrogen concentration in relation to the energy availability. Therefore, nutrient availability for microbial degradation is unbalanced and less than 70% of the true digestible N is used for maintenance or production. In such a situation this value might go down to 50%. If in case of potential production situations the equation of UFN becomes $(0.5 * (0.9 * NI))$ the nutrient use efficiencies decrease to 37% for cattle, 20% for sheep and 15% for goats. These values are all in the acceptable range.

Another way to calculate the NUE is to quantify the amount of nutrients retrieved in the liveweight gain, assuming in this case 25.4 g N per kg LWG (van Bruchem, personal communication). The results are shown in Table 9.2, and range from -9.95% (the animals loose weight) to 5.58%. The results of both methods differ much and further research is required.

Intake, utilisation and release of phosphorus

Intake

The phosphorus intake is related to feed dry matter intake, and is calculated as:

$$PI = DMI * (\% P/100)$$

in which, PI is the phosphorus intake (kg), DMI is the dry matter intake (kg) and P is the percentage of P in the dry matter. The PI for cattle, sheep and goats at two different production levels is shown in Table 9.4. For dairy cattle, in the literature, minimum values of the percentage of P in the diet are indicated. Wise et al. (1958) gives 0.22%, Teh et al. (1982) gives 0.24-0.31%, Langer et al., (1985) gives 0.24-0.36%. A recommended value of 0.3% P is mentioned as minimum safe dietary allowance (Wise et al., 1958). Forage containing below 0.16% P is usually considered deficient for ewes during gestation, and 0.20% is minimum during lactation. In the research area, rice straw, maize straw and sugarcane leaves contain 0.09% P, leguminous and non-leguminous tree leaves contain 0.10% P, native grass and elephant grass contain 0.23% P, cassava leaves contain 0.32% P and soybean cake contains 0.68% P. The P levels of the feeds consumed in the research area indicate that only cassava leaves and soybean cake are above the minimum values as are mentioned above.

Table 9.3 Minimum endogenous absorbed phosphorus in different types of animals.

Source	minimum endogenous P absorbed (g d ⁻¹)	cattle 250 kg	sheep 25 kg	goats 30 kg
ARC (1980)	0.010 * BW ¹	2.50	0.25	0.30
INRA (1988)	0.025 * BW	6.25	0.63	0.75
NRC (1989)	0.0143 * BW	3.58	0.36	0.43
NRLO (1990)	0.024 * BW	6.00	0.60	0.72

¹ BW is bodyweight (kg)

Utilisation

In livestock, almost 86% of the P in the body exists in bones and teeth. The other 14% exists in soft body tissue (NRC, 1989) and in the body fluids (Underwood, 1981). In absolute terms, cattle contain about 7.4 g P per kg bodyweight (Werkgroep Uniformering, 1994). Phosphorus is required and actively involved in a great number of essential processes in energy-, fat- and protein metabolism (as a component of ATP). It is an essential component of buffer systems in the blood and other body fluids (saliva) (Cohen, 1980). P is of importance for a good functioning of micro-organisms in the rumen of ruminants, in particular those animals who have to digest cellulose (McDowell, 1992). A restriction of the P offered, expresses itself in a decrease in vitality and productivity.

P has to be taken up from the feed for maintenance, growth, lactation and gestation. Ruminants have the possibility of re-using P, because they can absorb P in the small intestine and recycle this to the rumen fermentation process via the saliva. This P fraction, which is called the endogenous P fraction, varies with the amount of saliva and the P concentration of the saliva. The endogenous P fraction can be twice the amount of P taken up via the feed. The net maintenance requirement for P, strictly spoken, is only that P which is excreted with the faeces under physiological normal circumstances, and equals the so-called minimum endogenous P fraction (Spiekers et al., 1993). This fraction exists because the P of endogenous origin (saliva) is not fully absorbed in the rumen-intestine tract. The minimum endogenous P fraction increases linearly with the P intake. The minimum endogenous P fraction is, in some standards for the P requirements of cattle, related to bodyweight (ARC, 1980; INRA, 1988; NRC, 1989; NRLO, 1990). Table 9.3 shows for various sources the way the minimum endogenous P amount is calculated. AFRC (1991) relates the minimum endogenous P fraction to the dry matter intake $((0.693 * \text{DMI}) - 0.06) * 1.6$. However, these results are derived from experiments with sheep in a negative P balance.

The absorption coefficient of P is that part of the amount of P ingested that is absorbed (Grace, 1983). P absorption (%) can be defined on basis of the type of digestibility. On basis of apparent digestibility, the apparent P absorption is $((\text{P intake} - \text{P faeces}) / \text{P intake}) * 100\%$. On basis of true digestibility, true P absorption is $((\text{P intake} - \text{P faeces} + E_m) / \text{P intake}) * 100\%$.

intake) * 100%. The Em is the minimum endogenous P fraction or net maintenance requirement. The true absorption coefficient of P varies, in literature, from 50 to 70% for adult cattle to 90% for calves (NRC, 1989). The apparent P absorption increases, with an increase in milk production and an equal P intake. The apparent P absorption decreases, with an increasing P intake and an equal milk production (AFRC, 1991). The true P absorption decreases exponentially with an increasing P intake (Braithwaite, 1984).

NRC (1989) relates the P requirements for pregnancy to the bodyweight of the animal, the stage of the pregnancy and the extent to which P is carried over from cow to foetus and uterus (g d^{-1}). However, most recommendations consider a fixed daily amount of P for pregnancy, independent of the above mentioned factors. NRC (1989) gives gestation P requirements based on slaughter data indicating that a 40 kg calf contains about 300 g of P of which 75% is deposited during the last 2 months of gestation. During the last two months of gestation the daily P requirements are calculated as:

$$P_{\text{gest}} (\text{g d}^{-1}) = [0.0047 * (1.23 \text{ BW})] / 0.5$$

AFRC (1991) gives P requirements during the last months of pregnancy of 20.4 g P per day and during the last weeks this value even increases to 26.9 g P per day. The P requirements for milk production depend on the milk production (kg d^{-1}), the fat percentage of the milk and the P content of the milk. The latter varies in literature from 0.9 to 1.0 g P per kg milk. The P requirements for growth are related to bodyweight (kg) and growth (kg per day). The NRC (1989) calculates a P requirement for maintenance of a growing female (small breed) weighing 250 kg bodyweight and gaining 500 grams per day, as 16 g P per day.

The daily amount of phosphorus required, for a cow of 250 kg bodyweight, for maintenance and gestation is 10 g P d^{-1} (NRC, 1989). For maintenance and lactation the amount of P required is 7 g P d^{-1} . If the true P absorption coefficient is 50%, the amount of P required for one kg of milk is 1.98 g P. Daily P consumption of lactating and reproducing cows of 250 kg bodyweight is 7.2 g P d^{-1} and 8.4 g P d^{-1} for Putukrejo and Kedungsalam, respectively. Potential cow production in both villages consume 37.5 g P d^{-1} on average. Based on the daily intake figures of P it seems that P intake levels are below P requirements for the actual production level but that for the potential production level, P intake is far above the P requirements.

Release

Only limited amounts of P are lost through the urine (about 2 mg per kg bodyweight (ARC, 1980)). AFRC (1991) neglects the endogenous P losses via the urine. However, neglecting these endogenous P losses with the urine is not always correct, since increased endogenous P losses via the urine are observed by cows receiving relatively large amounts of concentrates in their ration (McDowell, 1992). Manston & Vaff (1970) found increased P excretion with the urine of cows in their last weeks of the pregnancy. Through an increased dry matter availability of these animals, higher P contents were measured > 10 mg P per 100 ml urine.

Also Morse et al. (1992) found increased P content in the urine of cows receiving a high P ration; 0.52 g d⁻¹ at a P intake of 60 g d⁻¹ and 4.91 g d⁻¹ at a P intake of 112 g d⁻¹. Most of the feeds in the research area contain low P contents and therefore P intake is low as well. For this study the P excretion via the urine is neglected.

The P excretion with the faeces is the closing factor of the P balance. A higher P intake, at equal levels of maintenance and milk production, results in a higher P excretion with the faeces (Braithwaite, 1985; Morse et al., 1992; Spiekens et al., 1993). The amount of P in the faeces is therefore a measure for the fulfilment of the P requirement. P in the faeces can be split up into three fractions: (1) fraction unavailable for absorption (indigestible P fraction), (2) fraction as a result of physiological processes in the rumen-intestine tract (the minimum endogenous P fraction) and (3) the fraction of P which is fed above requirement (regulating P fraction). Based on the true absorption coefficient, faecal phosphorus is quantified as,

$$FP = PI + Em - (PI * (Pabs/100))$$

in which, FP is the amount of P in the faeces (kg), PI is the amount of P taken up by the dry matter intake (kg), Em is the minimum endogenous P fraction (0.0143 * BW), and Pabs is the true P absorption coefficient, which is considered to be 50%. The result of P intake and P excretion is the P balance or P retention. When an animal has a positive P balance, the animal can fix P in bones. If the animal has a negative P balance, P has to be used from the body reserves.

Table 9.4 gives the P balance for livestock in the research area on a yearly basis. Actual cattle production in Putukrejo and Kedungsalam show a negative P balance. P deficiency can result in insufficient bone production, bone hardness (rachitis) (Minson, 1990), and in a decrease of the reproduction (Dunn & Moss, 1991) and in a decrease of the bodyweight and the body condition.

In literature a big variation is found between animals and even within animals for the P balance. There are examples of animals who take up more than 100 g P per day and are even in a negative P balance, while other experiments show that animals just fulfil their net P requirements for lactation, but do have a positive P balance. Kemp & Geurink (1978) concluded that a negative P balance at the beginning of lactation is a physiologically normal process. Also Rajaratne et al. (1990) found, independent of the in the experiment used rations (with low and high P content), a negative relation between the P balance and the milk production in the beginning of the lactation; a high milk production resulted often in a negative P balance. Considering the essential functions P has for the metabolism, the animals should not be too long facing a negative P balance.

Powell et al. (1994) found, in sheep faeces, higher phosphorus concentrations than in the diet consumed. Livestock may actually excrete more P than the amounts they consume. The higher phosphorus concentrations in the faeces may have been caused by the excretion of endogenous P (Ternouth, 1989). Given that P is excreted almost exclusively in faeces, and is not subject to volatile losses as is N, livestock do not appear to be major vectors of P loss

Table 9.4 The phosphorus balance (kg P y⁻¹) and nutrient use efficiency (%) for cattle (BW=250 kg) and reproducing sheep (BW=25 kg) and goats (BW=30kg) in the villages Putukrejo (PK) and Kedungsalam (KS). Actual livestock production is limited by the feed resource and potential livestock production is not limited by the feed but by the genetic growth.

Livestock unit	PI ¹	FP ²	Balance	NUE ³	NUE ⁴
CU-PK-actual	2.00	2.31	-0.31	-16	18
CU-KS-actual	2.27	2.44	-0.17	7	5
CU-potential	10.15	6.38	3.77	37	12
SU-actual	0.45	0.36	0.09	20	-31
SU-potential	0.87	0.57	0.30	34	1
GU-actual	0.39	0.35	0.04	10	-18
GU-potential	0.83	0.57	0.26	31	14

¹ PI is phosphorus intake; ² FP is faecal phosphorus; ³ NUE is nutrient use efficiency (Balance / PI); ⁴ Nutrient Use Efficiency (P retained (7.4 g P per kg LWG) / PI)

in the production systems.

Of the total amount of P in the body (about 4.5 kg) is maximum 1.5 kg P mobilizable (40% of the amount of P in the bones; Benzie et al., 1959). According to the same authors, sheep were able to fully re-establish a reduce of P in the bones of 19% during the first 2 months of lactation, in the following two months of lactation. These sheep took up 70 mg P per kg of bodyweight. The amount of P which is extracted from the bones during lactation has to be added again in the dry period of the cow. If the dry period is 65 days, the animals have to add 12.5 g P per day to the bones. Benzie et al. found a maximum bone re-establishment of 0.07 g P per kg bodyweight.

Of the amount of P ingested, 63-90% is excreted (excluding the actual cattle production) and therefore -7-37% of P is retained in the body as liveweight gain. The latter figure is defined as the nutrient use efficiency (NUE) and is generally below 30% (van Bruchem, personal communication). Another way to calculate the NUE is to quantify the amount of nutrients retrieved in the liveweight gain, assuming in this case 7.4 g P per kg LWG (van Bruchem, personal communication). The results are shown in Table 9.4, and range from -30.77 (the animals loose weight) to 5.58%. The results of both methods differ but are more or less in the acceptable range.

Intake, utilisation and release of potassium

Intake

The potassium intake is related to the feed dry matter intake, and is therefore calculated as

$$KI = DMI * (\% K/100)$$

in which, KI is the potassium intake (kg), DMI is the dry matter intake (kg) and K is the percentage of potassium in the dry matter. The potassium intake for cattle, sheep and goats at two different production levels is shown in Table 9.5. In literature minimum K requirements for dairy cows are mentioned of 0.8% of the dry diet. A K deficiency occurs when percentage K in dry matter of the dry diet ranges between 0.06 and 0.15. Also K deficiency is mentioned when K values are between 0.5-0.7% K. No improvement in performance of dairy calves is found when the K increased above 0.58%. In the research area, rice straw, maize straw and sugarcane leaves contain 0.64% K, leguminous and non-leguminous tree leaves contain 1.0% K, native grass and elephant grass contain 1.5% K, cassava leaves contain 0.85% K and soybean cake contains 1.98% K. The K levels of the feeds consumed in the research area indicate that animals are not facing a K deficiency.

Utilisation

Literature about nutrients excreted by livestock greatly deals with N and to a lesser extent with P, but hardly deals with K. In general the percentage of K retained in 1 kg liveweight gain is believed to be 0.21% K₂O, or 0.17% K. One kg of milk contains 0.15% K. Because of lack of data about K utilisation, this subject is not further elaborated.

Release

Since K is solvable in water it is excreted almost fully through urine. The K retention is less than 10% and for this study it is assumed that K retention is 2.5% of the amount of K taken up. The remainder is excreted, of which 95% through urine (UKE) and 2.5% via faeces (FKE). Table 9.5 shows that the K balance is positive for cattle, sheep as well as goats, and therefore, indeed, no K deficiency is found. Of the amount of K ingested, 2.5% of K is retained in the body as liveweight gain. The latter figure is defined as the nutrient use efficiency (NUE) and is generally below 30% (van Bruchem, personal communication). Another way to calculate the NUE is to quantify the amount of nutrients retrieved in the liveweight gain, assuming in this case 2 g K per kg LWG (van Bruchem, personal communication). The results are shown in Table 9.2, and range from -1.05 (the animals loose weight) to 1.04%. Both methods do not show much difference in their results of the NUE of K.

Nutrient balance

The total amount of nutrients, N, P and K, consumed in the feed on a yearly basis (Table 9.6) is compared with the total amount of nutrients excreted through faeces and urine (Table 9.7). The N, P and K contents of the feeds are estimated at, respectively: leguminous tree leaves

Table 9.5 The potassium balance (kg K y⁻¹) and nutrient use efficiency (%) for cattle (BW=250 kg) and reproducing sheep (BW=25 kg) and goats (BW=30kg) in the villages Putukrejo (PK) and Kedungsalam (KS). Actual livestock production is limited by the feed resource and potential livestock production is not limited by the feed but by the genetic growth.

Livestock unit	KI ¹	FKE ²	UKE ³	Balance	NUE ⁴	NUE ⁵
CU-PK-actual	18.20	0.46	17.28	0.46	2.5	0.5
CU-KS-actual	14.80	0.37	14.06	0.37	2.5	0.2
CU-potential	32.78	0.82	31.14	0.82	2.5	1.0
SU-actual	3.29	0.08	3.13	0.08	2.5	-1.1
SU-potential	4.40	0.11	4.18	0.11	2.5	0.7
GU-actual	2.86	0.07	2.72	0.07	2.5	-0.6
GU-potential	4.19	0.10	3.99	0.10	2.5	0.7

¹ KI is the potassium intake; ² FKE is the K excreted through faeces; ³ UKE is the K excreted through urine; ⁴ NUE is nutrient use efficiency (Balance / KI); ⁵ Nutrient Use Efficiency (K retained (2 g K per kg LWG) / KI)

2.88%, 0.1%, 1.0%; non-leguminous tree leaves 1.76%, 0.1%, 1.0%; native grasses 1.28%, 0.23%, 1.5%; elephant grass 1.60%, 0.23%, 1.5%; sugarcane leaves 0.96%, 0.05%, 0.8%; cassava leaves 3.36%, 0.19%, 0.5%; maize straw 1.44%, 0.05%, 0.8%; and, rice straw 0.8%, 0.05%, 0.8%.

Table 9.6 shows the amount of N, P and K consumed by the livestock population in Putukrejo and Kedungsalam (EFHS (1992) covering 149 households) at two different production levels. A greater number of livestock is kept in Kedungsalam compared to Putukrejo and therefore the amount of nutrient consumed in Kedungsalam is bigger as well. At the potential production level the amount of N, P and K consumed, greatly increases because of soybean cake consumption (Chapter 8). The contribution of N, P and K through soybean cake, in the yearly consumed amount of N, P and K, for potential livestock production is respectively 59, 88 and 80% for cattle, 57, 45 and 28% for sheep and 48, 37 and 21% for goats. The soybean cake is bought outside the research area and therefore the consumption of concentrates is a source of nutrient import to the research area.

Comparing the amount of nutrients excreted with the amount of nutrients consumed shows that for the actual livestock production 78% N, 108% P and 97.5% K of the amount consumed is excreted. For the potential livestock production the amount excreted as a percentage of the amount consumed is 45% N, 63% P and 97.5% K. In principle it can be concluded that nutrient cycling through livestock is a process in which nutrients are mainly released compared to the amount taken up, and therefore not a major factor of nutrient loss. However the re-utilisation of the nutrients excreted with the faeces and urine depends on the nutrients loss during storage and application. These processes are described and quantified below.

Table 9.6 Yearly amounts of N, P and K consumed by livestock (cattle unit (CU) is 250 kg, sheep unit (SU) is 25 kg and goat unit (GU) is 30 kg) for two production levels and two villages Putukrejo (PK) and Kedungsalam (KS). Actual livestock production is limited by the feed resource and potential livestock production is not limited by the feed but by the genetic growth.

Livestock unit	no.	Amount consumed (kg animal ⁻¹ y ⁻¹)			Total amount consumed (y ⁻¹)		
		N	P	K	N	P	K
Actual production							
CU-PK	41	21.5	2.0	18.2	882	82	746
CU-KS	89	27.0	2.3	14.8	2403	205	1317
SU-PK	6	4.4	0.5	3.3	27	3	20
SU-KS	7	4.4	0.5	3.3	31	3	23
GU-PK	6	4.1	0.4	2.9	25	2	17
GU-KS	61	4.1	0.4	2.9	251	24	174
Total					3619	316	2297
Potential production							
CU-PK	41	171.4	10.2	32.8	7027	418	1345
CU-KS	89	171.4	10.2	32.8	15255	908	2919
SU-PK	6	8.4	0.9	4.4	50	5	26
SU-KS	7	8.4	0.9	4.4	59	6	31
GU-PK	6	7.3	0.8	4.2	44	5	25
GU-KS	61	7.3	0.8	4.2	445	49	256
Total					22880	1391	4602

Utilisation and losses of manure

Large quantities of the plant nutrients consumed by animals are excreted in urine and faeces. Whereas nitrogen and potassium are voided in both urine and faeces, most phosphorus is voided in faeces (Commonwealth Agricultural Bureaux, 1984; Ternouth, 1989). By controlling the storage and distribution of excreta from animals kept in stalls, a farmer can influence the proportions of nutrients returned to the soil. Losses of nutrients in storage and on application can be high. The quality of excreta is best when applied fresh, but application to crops is seasonal and, therefore, manure from animals in confinement is normally stored. Excreted mineral N is subject to volatilization from housing and storage (ammonia losses), to leaching, run-off, denitrification and volatilization (during application). P and K are not subject to volatilization. P and K can only be lost from the system through leaching and run-off. Below these processes will be described and quantified.

Table 9.7 Amount of nutrients excreted in urine and faeces by livestock (cattle unit (CU) is 250 kg, sheep unit (SU) is 25 kg and goat unit (GU) is 30 kg) at two different production levels and for two villages Putukrejo (PK) and Kedungsalam (KS). Actual livestock production is limited by the feed resource and potential livestock production is not limited by the feed but by the genetic growth.

Livestock unit	no.	Amount excreted (kg animal ⁻¹ y ⁻¹)			Total amount excreted (y ⁻¹)		
		N	P	K	N	P	K
Actual production							
CU-PK	41	18.63	2.31	17.74	764	95	727
CU-KS	89	20.15	2.44	14.43	1793	217	1284
SU-PK	6	3.41	0.36	3.21	20	2	19
SU-KS	7	3.41	0.36	3.21	24	3	22
GU-PK	6	3.21	0.35	2.79	19	2	17
GU-KS	61	3.21	0.35	2.79	196	21	170
Total					2816	340	2239
Potential production							
CU-PK	41	75.69	6.38	31.96	3103	262	1311
CU-KS	89	75.69	6.38	31.96	6736	568	2844
SU-PK	6	5.16	0.57	4.29	31	3	26
SU-KS	7	5.16	0.57	4.29	36	4	30
GU-PK	6	4.94	0.57	4.09	30	3	25
GU-KS	61	4.94	0.57	4.09	301	35	249
Total					10237	875	4485

Decomposition of manure

The nutrients present in faeces are mainly in an organic form and are, therefore, only available to plants when broken down in the soil. Decomposition is the process where the organic matter is converted by bacteria into humus. The dry matter content of the decomposed manure is higher than non-decomposed manure. Also the ash content is higher, since decomposed manure has a higher mineral content. Three decomposition pathways of stored manure have been identified (Kirchmann, 1985): (1) anaerobic fermentation, (2) anaerobic-aerobic fermentation and (3) aerobic fermentation. Anaerobic conditions can be reached by covering the manure heap. Low oxygen (anaerobic-aerobic) supply is normal when a manure heap is stacked. The lower parts of the heap have no or low oxygen. Decomposition can take up to 40% of the organic carbon (Coker et al., 1987).

In aerobic conditions the dry matter loss of the manure is larger than in anaerobic stored manure. The dry matter loss increases when straw is added. The type of decomposition affects also the concentration of mineral N in the manure. During anaerobic fermentation, up to 70% of the organic N can be converted into ammonia resulting in concentrations of 0.6-1.4% NH₄-

N in the liquid phase (Coker et al., 1987). In contrast, little or no ammonia-N is formed in aerobic and anaerobic-aerobic fermentation. Temperature also affects the decomposition of manure. High dry matter losses can be expected due to high temperatures. Dry matter losses of 50% were measured under high temperatures. These high dry matter losses resulted in a decrease in C/N ratio, as much of the loss represented mineralization of carbon (Kirchmann, 1985). Feeding straw produces manure which ferments slowly, whilst oilseed cakes and legumes give manure which ferments rapidly. Feeds high in tannins may lead to the production of manure with a low N availability.

Volatilization of manure

Due to volatilization, part of the nitrogen and organic matter is lost. The latter is being degraded by micro-organisms into carbon dioxide and water. Nitrogen is being degraded into ammonia (NH₃), which is highly volatile. Most of the nitrogen voided in urine can be lost via volatilization and leaching (Woodmansee, 1979; Floate, 1981; Russelle, 1992). Little faecal nitrogen is lost via volatilization (Ryden et al., 1987). Ryden et al. (1987) showed that ammonia losses from faeces occurred at a slower rate when compared with urine, reflecting the fact that the N present occurs mainly in bacterial cells or as undigested dietary N. To calculate ammonia volatilization from stalls and manure storage, the following assumption is made. Nitrogen present in urine is mineral N, the concentration mineral N in faeces is negligible and therefore N in faeces is assumed to be 100% organic N. Organic N is not subject to volatilization. The emission from outdoor storage depends on storage capacity, the period of storage and possible coverage (N emission factor = 0.025).

Gilbertson et al. (1981) found that the extent of the losses varied from 10% with air-dried manure to 80% for manure stored in an open lagoon. Incorporation of manure into the soil decreases the likelihood of losses in the field. N losses to the air varied from 15-30% without cultivation and varied from 1-5% with cultivation (Hanson, 1990).

During transportation N in urine and faeces will be mainly lost through volatilisation. The N in urine is present mainly as urea which in moist soil is easily hydrolysed to ammonium carbonate from which ammonia is volatilised into the air.

During application of manure on the soil, mineral N can be lost through volatilization, and the emission factor depends on the application technique (ammonia emission factor surface spreading = 0.59).

There are different factors which stimulate volatilization. Calcium carbonate stimulates the volatilization of ammonia. At higher temperatures the solubility of ammonia in water is less and the diffusion rate is greater, and thus the volatilization rate should increase. Water losses also relate to ammonia losses. Since ammonia is such a highly volatile, yet water soluble and reactive compound, its volatilization is even affected by a slight change in the environment (Verstraete, 1981). Volatilization can be reduced by fixing the N by bacteria. The bacterial protein can be mineralized after application to the soil. Bacteria, however, also decompose the manure which will result in mineralization of nutrients. Volatilization can also be reduced by keeping the temperature low.

Leaching of manure

Leaching is the infiltration of nutrients into the deep layers of the soil. Leaching is a function of manure dry matter content and rainfall. Also, pressure on the manure heap by weight has an effect on leaching. The upper layers in a manure heap will press the water out of the lower layers of the heap. Only water soluble nutrients will be lost due to leaching.

Leaching of nutrients to the soil takes place with heavy rains. Often only N and K losses are considered because they are highly soluble nutrients. Loss of K is lower in closed stored manure than in manure in open storage. Also losses are reduced at higher dry matter content of the manure, for closed and open systems. Leaching can be reduced by protecting the manure against rain. Low humidity can, however, cause a low rate of mineralization of straw and manure. This means that manure can be exposed to decomposition or volatilization. Leaching can also be reduced by increasing the dry matter content of manure with straw or feed refusal. Van der Pol (1992) found that 10% of the nutrients (N, P and K) could be lost due to leaching.

Denitrification of manure

Ammonia is converted into nitrate in two steps through the nitrification process. In the first step, ammonia is converted into nitrite by the bacteria Nitrosomas. In the second step, nitrite is converted into nitrate by the bacteria Nitrobacter. These conversions only occur under aerobic conditions (it is an oxidation process). Denitrification process is the conversion of nitrate into atmospheric N by bacteria. The atmospheric N will leave the manure in gaseous form. This process is anaerobic and requires sufficient carbon to provide the energy source for the denitrifiers. Van der Pol (1992) found that between 30 and 50% of N can be lost due to denitrification. When manure is partly decomposed, nitrate levels are generally low and therefore substantial denitrification is not expected during storage. Generally, N losses are lower from anaerobically stored manure than from aerated manure as there is less NH₃ volatilization during anaerobic decomposition. In comparison, ammonia losses from aerated manure can range from 1-60% of total N, with the amount increasing with storage time (Much & Steenhuis, 1982; Dewes et al., 1990).

When N, P and K are brought to the soil and they cannot infiltrate the soil it can be lost through run-off as well.

Discussion and conclusions

Tanner et al. (1993) concluded that in the upland regions of Java, livestock is fed for compost production, and is therefore a strategy for sustainable upland agriculture. Is this phenomena the case in the research as well? Cut-and-carry feeding is labour-intensive and the supply of forage is the most expensive input to ruminant production. Farmers in the research area collect quantities of forage in excess of the requirements of their livestock. The rationale for

excess feeding may lie in manure-compost production but may, on the other hand, lie in allowing the animals free selection. Farmers collect uneaten feed and combine the feed with faeces and urine to produce manure-compost. It is possible that farmers adjust their feeding rates to optimise total output, i.e. including manure-compost, as opposed to animal production *per se*. Manure is ranked by farmers as one of the most important outputs from livestock production. It could therefore very well be that livestock are used to produce high-quality manure and that their integration into agriculture is essential to the sustainability of mixed farming systems. It illustrates the importance of manure and the importance of a good assessment of the manure quality in terms of N, P and K.

The amount and quality of usable cattle manure depends on many factors such as the type and quantity of feedstuffs consumed, the quality of the feed, the husbandry system, the system of manure collection and the manure storage system, including the duration of storage. Consequently, the literature contains widely diverging data on the value of manure in tropical regions (Schleich, 1986). Therefore it is quite risky to use manure productions and manure nutrient concentrations from literature. Faecal dry matter and urine production should be dealt with separately as well as their nutrient concentrations. Best is to calculate faecal and urine nutrient excretions based on the intake of nutrients, as was illustrated in this chapter.

Care should be taken for the N balance, since the amount of N excreted depends on the balance of the nutrients offered to the rumen microbes. Microbes require nitrogen, true protein, energy and minerals and each of these nutrients may limit microbial degradation. Since the process of microbial degradation is complex and nutrient interactions within the rumen occur, it is questionable whether at farming systems level the nutrient excretion should be dealt with in this detail. Obviously it is a vicious circle. To quantify nutrient excretions at farming systems level more accurate, calculations are done at organ level. Lack of data and knowledge brings one back at animal or even farming systems level.

The easiest method to quantify the amount of nutrients excreted is probably the amount of nutrients consumed minus the amount of nutrients retained in the liveweight gain. Liveweight gain can be estimated or measured, and since the nutrient concentrations in the liveweight gain are low, the bias is less compared to the calculations aiming to quantify the nutrients excreted. Especially when little is known about the nitrogen degradation of the particular feeds, and the balance of the available nutrients.

Since livestock modelling exercises often quantify the faecal dry matter production, the nutrient concentrations can be calculated afterwards. For the livestock in the study area, the so-calculated nutrient concentrations are given in Table 9.8.

Knowing the quality of manure, once it is excreted by the animal, does not mean that the amount of nutrient available to the crops is known as well. Unfortunately losses in the manure occur. Losses of dry matter during storage of manure are limited. Schleich (1986) found a dry matter loss of 1.5% between the manure dry matter collected daily and the manure dry matter collected annually. Losses of nutrients during storage and application can be high. For N, P and K, Schleich (1986) found a loss of 14,3%, 26,8% and 116,8% respectively. The gain of K was not explained. Khombe et al. (1992) found a dry matter loss

Table 9.8 Nutrient concentrations in the faecal dry matter production (kg DM y⁻¹) per livestock unit

Livestock unit	Faeces	% N	% P	% K
CU-PK-actual	746	1.41	0.31	0.06
CU-KS-actual	743	1.42	0.33	0.05
CU-potential	778	3.50	0.82	0.11
SU-actual	124	1.45	0.29	0.06
SU-potential	137	1.82	0.42	0.08
GU-actual	102	1.60	0.34	0.07
GU-potential	146	1.71	0.39	0.07

of 8.4% between the 3-monthly interval collection and the annually collection of manure. He found a nutrient loss of 9.0%, 17.0% and 8.4% for N, P and K. The most feasible solution to reduce losses of manure is probably the use of straw as a carbon source.

It is worthwhile to introduce methods which reduce the losses of manure. The amount of N lost through leaching, run-off and denitrification can be partitioned in two categories, the inevitable losses and the avoidable losses. Inevitable losses can be described as follows. Organic N in the soil mineralises during the entire year. When mineral N becomes available outside the growing season this can be lost through leaching or denitrification. Hence, whenever organic N fertilizer is used, part of the organic N will be lost unavoidable. From Sluijsmans & Kolenbrander (1977) it is estimated that 18% of the total organic N that becomes available from animal manure contributes to the inevitable losses. Avoidable N losses originate from application of animal manure, artificial fertilizer or crop/harvesting losses. In an equilibrium situation total mineral N applied should equal nutrient uptake by the vegetation. All additional nutrients applied are avoidable losses.

The proportion of nitrogen excreted by ruminants in urine is highly influenced by the animal's diet (van Soest, 1987). Since most of the nitrogen in urine can be lost via ammonia volatilization and leaching, a shift from urine nitrogen to faecal nitrogen, without detrimental effects on the survival and productivity of livestock, could improve nutrient cycling in the farming systems of the research area. A decreased excretion in the urine whilst an increased excretion in the faeces, is obtained when digestion is shifted from the rumen to the intestinal tract. This is influenced by diet composition and by the presence of polyphenolics, especially tannins.

Synchronizing organic matter decomposition and nutrient release, with that of plant nutrient demands, can greatly increase the efficiency of nutrient cycling in low-input farming systems (McGill & Myers, 1987; Ingram & Swift, 1989; Swift et al., 1989). When faeces are applied to soil, micro-organisms will readily decompose the soluble nitrogen, followed by the nitrogen associated with the cell wall (Paul & Clark, 1989).

Sofar, only manure as a source of nutrients was taken into account, while generally its

main function is improvement of physical aspects of the soil. Manure improves aeration and soil moisture relationships, and provides organic matter, which is the motor of biological activity in the soil. By aiding soil aggregation, manure increase water-holding capacity of soils, and reduce losses to wind and water erosion. The benefit of manure in terms of provider of organic matter is quantified in Chapter 10. The other benefits of manure were not quantified since relevant data were not available for the research area.

Chapter 10

Towards more sustainable land use

The soils of the limestone area have a heavy clay texture, a low organic matter content and low soil nutrient contents. If soils in the area continue to be cultivated by annual crops with little to no nutrient inputs, the soil will deteriorate quickly (Chapter 6). To avoid this, and even improve the soils in the area, land use is needed which does not further deplete the quality of the soils.

Food security is the main reason for land use planning. An increase in the production is necessary to ensure food security considering local and environmental constraints. In Chapter 1 the first hypothesis was whether the soil base causes constraints to agricultural development that are difficult to overcome by presently known affordable technology. A compromise must be found between an increase in production, and measures and rules that enhance the long-term sustainable use of the soil base. Therefore in this chapter different land uses are judged by their ability to improve resource use towards a more sustainable agricultural system. The second hypothesis was that the present practice of mixed farming offers the best opportunity for such a balance between development and sustainability.

Biophysical sustainability

Biophysical sustainability in this thesis means that agricultural production is realised without lasting damage to the production system or the environment. Biophysical sustainability refers to the necessity to control resource exploitation, in order to avoid large-scale land degradation and the destruction of the resource base. Very important prerequisites of sustainable production systems are that exploitation of the ecosystem does not exceed the production capacity of one specific, most limiting, natural resource, and that soil fertility must be maintained. The definition of biophysical sustainability is then the optimal level of production that guarantees an equilibrium between renewability of a certain resource, limiting a given type of land-use, and the level of its exploitation (Geerling & de Bie, 1986). Biophysical sustainability can be considered as one aspect of sustainable land use, social and economic aspects being two of the others. The influence of social and economic aspects on resource supply and exploitation is not considered. Human carrying capacity is expressed as sustainable population densities based on maximum sustainable agricultural production levels (based on maximum sustained exploitation of natural resources).

Fresco & Kroonenberg (1992) use the term ecological sustainability, which is related to resilience of the ecosystem, and should be defined for a specific area and time-scale. Resilience refers to the ability of a system to return to an average state after disturbance. The regeneration capacity of plants and animals is fundamental to resilience. Disturbance may also include the cumulative effect of continuous human exploitation, e.g. soil nutrient depletion (Fresco & Kroonenberg, 1992). To determine the exploitation level of natural resources that is biophysically sustainable, resilience thresholds of the ecosystem should be determined, within a specified spatio-temporal scale. However, resilience thresholds are rarely known (Ludwig et al., 1993). For example, the gradual depletion of soil nutrients may continue imperceptibly, followed by a sudden dramatic fall in plant production when a certain level of soil fertility depletion has been passed. A sufficient buffering capacity, both vegetative biomass on the soil and organic matter in the soil, is a major factor in enhancing and maintaining ecosystem resilience.

Biophysical sustainability is dealt with in this thesis by three environmental conditions: (1) maintenance of sufficient vegetative soil protection to avoid excessive erosion, (2) maintenance of a sufficiently high soil organic matter content to keep the heavy clay soils sufficiently structured and (3) maintenance of a closed balance of the most limiting resource. Animal husbandry and crop cultivation are integrated and little overlap (competition) is considered between the two sub-systems. In Indonesia animals do not compete for the same land (because of stall feeding) and play a supplementary role to arable cropping. For the animal production sub system, sustainability implies stable animal numbers for each of the species, based on sustainable forage availability. Crop-livestock interactions are studied via the impact of the choice of land use on fodder availability and consequently on manure production, which is an important organic matter supplier to the soils.

Erosion control

Soil is the single most important non-renewable resource for farming in the tropics. Many forms of land degradation exist of which water erosion is the most important one. Water is the eroding agent, and water is the transporting agent for dislodged soil particles and plant nutrients. The inception of soil loss due to water erosion commences when a drop of water hits the soil surface. This process, where soil particles are dislodged from the matrix, is called splash erosion or detachment. When overland flow occurs on slopes it carries away the separated soil particles, which may be deposited temporarily on the way downhill and lifted again by rainfall impact, so-called redetachment (Rose, 1993). This process is known as sheet erosion. However, water flow can develop enough momentum to dislodge soil particles itself. The latter process is known as entrainment or rill erosion (Ellison, 1947; Meyer & Wischmeier, 1969; Rose, 1993). When rills concentrate in bigger streams, gully erosion starts, which is the most overwhelming of all erosion processes.

Excessive erosion is quantified by the criterion called soil loss tolerance, which is based on the rate of soil formation. The value is difficult to measure, because it concerns such a slow process and the values that are reported are generally quite different. Soil loss tolerance values for the USA were estimated in the early 1960's by scientists from various disciplines at 4.5 to 11.2 t ha⁻¹ y⁻¹ depending on the soil type (Wischmeier & Smith, 1978), while soil formation for Europe was estimated at 1 t ha⁻¹ y⁻¹ (Troeh & Thompson, 1993). In general, 11 t ha⁻¹ y⁻¹ is taken as tolerable soil loss (Morgan, 1986), which seems too high a standard considering the low rates of soil formation. Particularly, in tropical areas, when soils are shallow or highly erodible soil loss values of 2-5 t ha⁻¹ y⁻¹ are preferred standards (Hudson, 1986). Hence, a target value between 2 and 5 t ha⁻¹ y⁻¹ seems more realistic for the research area, although it may still be too high to stop land degradation. In fact, most rates that are currently used as erosion standard are too high to support sustainable agriculture (Lafren et al., 1990).

Soil depth varies for the four different land units. Land unit 1 and 2 have depths of 75 cm and more, land unit 3 has a soil depth of 50 till 75 cm and land unit 4 has a soil depth of less than 25 cm. For such shallow soils it is very important that erosion is low and under control. During the 1991-1992 growing season one actual measurement of erosion was carried out in the village of Putukrejo. Crops cultivated were maize and cassava intercropped on land with a slope of 6% (land unit 1). The amount of soil loss measured yielded 22.65 ton per hectare per year. The yearly amount of soil loss for other land uses was estimated with use of the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). The results of the yearly amount of soil loss for 4 different land units considering different crop cultivation types are shown in Table 10.1. The soil loss calculated with USLE for maize and cassava intercropped on land unit 1 closely resembles the value measured in the field. Soil loss is lowest for multi-storey systems. Its protection against erosion is mainly ensured by the litter and permanent vegetative cover.

Amber (1986), Wiersum (1984) and Soemarwoto (1987) have discussed various aspects of erosion in multi-storey systems and other agro-forestry systems. Actual erosion depends on several factors: amount and intensity of rainfall reaching the ground directly or via vegetation (throughfall), erosivity of this rainwater, and erodibility of the soil. The vegetation, and particularly the trees, have influence on all these factors. The amount of rain reaching the

Table 10.1 Soil loss (t ha⁻¹ y⁻¹) for different land units and crop cultivation types.

Land unit	maize+ cassava	multi-storey system	wood-land	waste-land
LU 1	18.4	-	-	-
LU 2	92.4	15.7	19.1	-
LU 3	182.9	-	-	24.9
LU 4	-	16.6	25.4	29.3

ground directly depends on the coverage by the tree canopy, lower vegetation and the litter layer, as well as the rain intensity. The litter layer and/or low vegetation is by far the most important in the protection against erosion. Removing the litter layer increases the erosion much more than removing the tree canopy (without removing the litter) (Wiersum, 1984). Amber (1986) reported increases in splash erosion in both *Acacia auriculiformis* plantation and secondary forest in West Java of 40 times, when removing litter. Removal of the herbal layer only, doubled erosion. The belief in the protective function of the tree canopy is thus only indirectly true, in that the canopy produces the majority of litter protecting the ground. According to Wiersum (1984) average erosion in multi-storey systems is only $0.06 \text{ t ha}^{-1} \text{ y}^{-1}$.

The first environmental condition to be met to achieve biophysical sustainability is to avoid excessive erosion. Table 10.1 shows that all land uses in the research area face soil losses, calculated by USLE, which are well above the tolerable soil loss of $5 \text{ t ha}^{-1} \text{ y}^{-1}$. Therefore soil loss in the research area should be controlled by management. The origin of any gully is splash and sheet erosion. It is there where the erosion starts and it is there where it should be controlled, splash erosion by soil cover and sheet erosion by barriers to avoid the runoff concentrating in rills. It is the runoff that should be controlled right where it starts: on the farmers fields (Kiepe, 1995). Good options for the research area are mulching and perennial cultivation in combination with terracing.

Maintenance of soil organic matter content

The major soil characteristic that has to be improved is soil structure, via an increase of the soil organic matter content (SOMC), leading to better soil aeration and infiltration. This comes down to an increase in the volumes of meso- and macropores. Each year, part of the organic matter in the soil is decomposed. The relationship between structure, function and dynamics of SOM is extremely complex. Knowledge on SOM turnover is a prerequisite for a sustainable exploitation of inherent soil fertility and for predicting more accurately the interaction of SOM with environmental issues such as soil erosion and nutrient leaching.

Generally, models for organic matter dynamics include pools with a rapid turnover rate and pools with a slower turnover rate (Jenkinson & Rayner, 1977; Parton et al., 1992). The pools with a rapid turnover rate are assumed to play a dominant role in soil nutrient dynamics. Microbial biomass is considered as an important pool. Soil microbial biomass has been referred to as "the eye of the needle through which all the natural organic material that enters the soil must pass" (Jenkinson, 1978), which means that the microbial biomass may be regarded as the central transformation station that takes up and converts fresh residues into new products. The range of decay coefficients in the CENTURY model of Parton et al. (1992) are defined between 0.1 and 1 y^{-1} for the active (microbe) compartment, between 0.002 and 0.02 y^{-1} for the slow compartment and $< 0.001 \text{ y}^{-1}$ for the passive compartment. Typical turnover times for a grassland site are 2, 40 and 2000 years; respectively for the active, slow

and passive pools. Elzein & Balesdent (1995) analysed soils in India, Brazil and France and found decay values for the rapid pool between 0.047 to 0.27 y^{-1} and for the slow pool between 0.0031 and 0.0174 y^{-1} .

The major environmental factors that influence decomposition are: decomposability of the litter and litter type; placement in the soil; temperature and moisture content of the soil; type and content of the clay mineral; physical structure of the soil; pH and cation balance; and CO_2 concentration in the soil. Adsorption of organic compounds to clay minerals makes them resistant to biological decomposition and the decomposition of organic materials is therefore generally lower in clay soils than in sandy soils. Models for organic matter dynamics are only useful when they can be calibrated with data of the research area. Such data are not available and therefore a simplified approach is followed.

For any given system of farming the humus content of the soil tends towards a value that is characteristic for that system on that soil, in that climate. It is nearly always possible to forecast the direction of change in the humus content, consequent upon any change made in the system of farming. The rate of fall in the humus content are based on the rate of loss of organic carbon from soil during cultivation. This loss of organic carbon is only that part of the decomposed organic matter which is mineralized. The other part of the decomposed organic material is used for the growth of micro-organisms, and is thus not lost as a carbon source.

Yearly, a part of the organic matter (OM) in the soil is decomposed. Decomposition is the process in which OM is broken down by the soil micro-organisms (MO). Most soil MO use the carbon (C) from SOM as an energy source. Approximately 2/3 of the C is dissimilated (transformed to CO_2) and 1/3 is incorporated in the body of the micro-organisms. The process in which organic C is dissimilated to CO_2 is called mineralization.

The rate of mineralization depends on environmental conditions, such as moisture and oxygen status, carbon dioxide pressure, aeration, pH, temperature (Swift et al., 1989), but also on soil type and agricultural practices, such as crop rotation and cultivation.

From research of Jenkinson & Rayner (1977) and of Ladd et al. (1985) it can be derived that a rise in temperature of 9°C doubles the relative mineralization rate: 2% at 9°C, 4% at 18°C, 8% at 27°C. Above 30°C and below 6°C this rule does not apply. The C mineralization rate for forest and pasture soils in Costa Rica were measured at depths of 5-10 cm and 20-25 cm. Monthly mineralization at 5-10 cm was on average 3.5% and at 20-25 cm 2% (van Dam, personal communication). Yearly mineralization values will be 2 to 3 times higher. The research area has a comparable climate in terms of rainfall and temperature with Costa Rica. An average yearly C mineralization value of 5% is assumed (Janssen, personal communication).

Most researchers rely on experience and rules of thumb when the relation between organic matter content and clay is required. The soil physical characteristics which mostly determine the minimum content of organic matter are aggregation stability and porosity. Light sandy soils should contain at least 1.5% OM. Per 10% clay, the % OM should be 1% higher (Janssen, personal communication). The clay content in the research area is 55% and higher.

When a 55% clay content is considered, the desired soil organic matter content is 7%. Such a high figure, however, is seldom reached in tropical agricultural systems, since it requires unrealistic high amounts of organic matter supply. The present level in the research area is only about 2%. Therefore the short- to medium-term target for biophysical sustainable land use is set at a minimum of 2%. In other words land use that lowers the present 2% is considered not sustainable.

Below, some calculations illustrate how much organic material is required to keep a constant soil organic matter content and how much is required to increase the soil organic matter content (after Janssen, 1993). It is assumed that organic material only enters the topsoil. The amount of organic material that exists in the topsoil depends on the supply and loss. In one year, part of the freshly supplied organic material is humified and the remaining disappears in this process. The rate of humus supply amounts to:

$h * X$ in which,

h is the humification coefficient (-), which describes that part of the fresh organic material which is left over after one year as 'effective organic material', and X is the supply of fresh, organic material per year ($\text{kg DM ha}^{-1} \text{ y}^{-1}$). A small amount of the already existing humus reserves are also mineralized. The rate of humus loss amounts to:

$k * Y$ in which,

k is the mineralisation rate (y^{-1}), i.e. the part of humus reserves mineralized in one year, and Y is the humus reserve (kg ha^{-1}). If the rates of supply and loss are equal, the steady state situation is valid and the humus reserve of the topsoil is constant:

$$h * X = k * Y$$

This relation is used to estimate how much organic material supply is required to keep the humus reserves at a constant level. As well as to estimate the level of the humus reserves (Y) which will be in the steady state situation when a yearly similar amount of organic material is supplied.

Appendix 2 gives the organic carbon values for the four different land units. It was already concluded that there is hardly any difference in soil chemical values between land units, since they were classified on the basis of soil physical data only. Therefore, one (average) organic carbon value for the soils in the research area is used. Organic matter content is calculated from the organic carbon value by multiplying the latter with 1.7, resulting in an organic matter content of 2%. The topsoil (0-30 cm) with a bulk density of 1.0 kg dm^{-3} has a mass of $3 * 10^6 \text{ kg}$. The humus reserve (Y) in steady state amounted to $60\,000 \text{ kg ha}^{-1}$. In that layer the relative mineralisation rate in these heavy soils was estimated at 0.05 y^{-1} . The rate of humus loss is $k*Y$ and equals $3000 \text{ kg ha}^{-1} \text{ y}^{-1}$. There is no adequate data to show how long

it takes for the added fresh organic matter to be incorporated into the stable humus fraction. The required supply of fresh organic material to keep the humus reserve constant, in straw, roots of crops, farmyard manure and tree leaves are 10, 8.6, 6 and 5 t ha⁻¹, when humification coefficients of 0.30, 0.35, 0.50 and 0.60 respectively are assumed. Land use is judged on the ability to increase the soil organic matter content. For annual crops via the root production and through the combination of root mass and straw. The straw is in the present land use used for animal feed and nothing is left in the fields after harvesting. In mixed farming it can be studied what the effect would be if not all of the crop residues were removed from the field and consequently returned to the soil. On the other hand, keeping livestock results in manure as a source of organic matter to the soil. In Figure

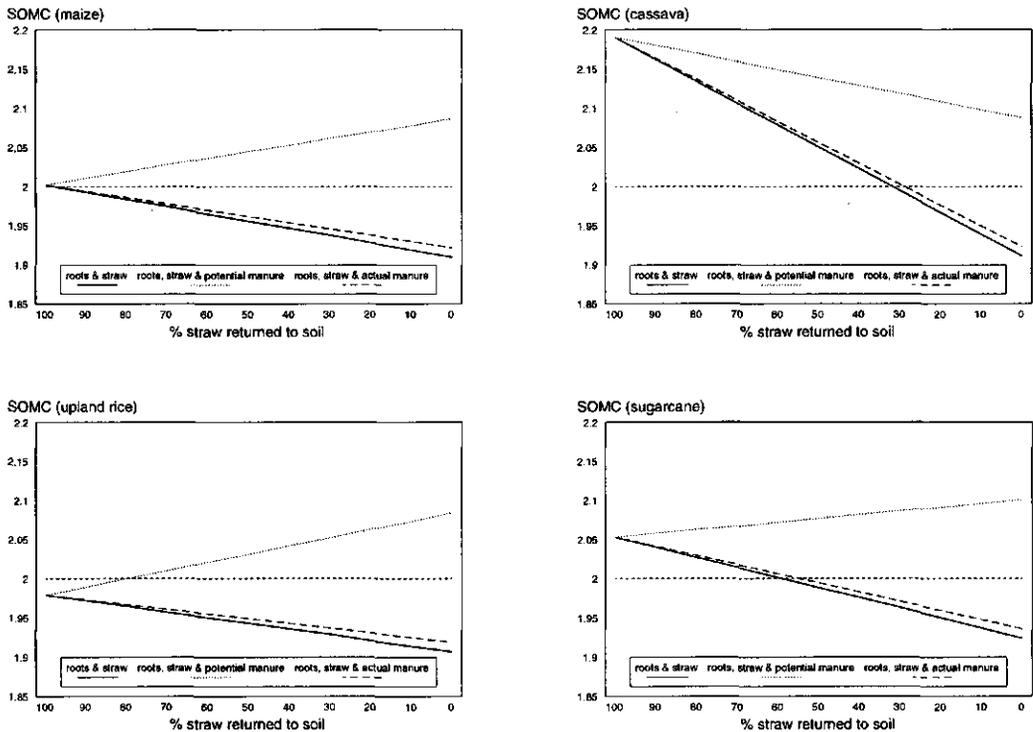


Figure 10.1 Soil organic matter content (SOMC) after one year with humus supply through potential production of roots and crop residues of maize, cassava, upland rice or sugarcane or through a combination of manure and crop residues. The percentage of crop residues, returned to the soil is decreased from 100 to 0%. Actual livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 1 cattle, 1 sheep and 1 goat per ha with 0% crop residues. Potential livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 10 cattle, 10 sheep and 10 goats per ha with 0% crop residues. Starting point is a SOMC of 2%.

10.1 to 10.5, the contribution of humus supply of different land uses and the resulting SOMC is shown. The amount of crop residues returned to the soil is decreased from 100 to 0%. The latter indicates that 100% of the crop residues is used as feed for livestock. Actual livestock production has on average 1 cattle, 1 sheep and 1 goat available per hectare (Chapter 5). Therefore for the actual livestock production the number of cattle sheep and goats ranges from 0 to 1 per ha. At the same time the amount of crop residues returned to the soil ranges from 100 to 0%. The number of livestock in the potential production situation is increased from 0 cattle, sheep and goats to 10 cattle, 10 sheep and 10 goats. Their corresponding amount of manure combined with a decrease in crop residues returned to the soil and the contribution via humus supply to the SOMC is shown as well.

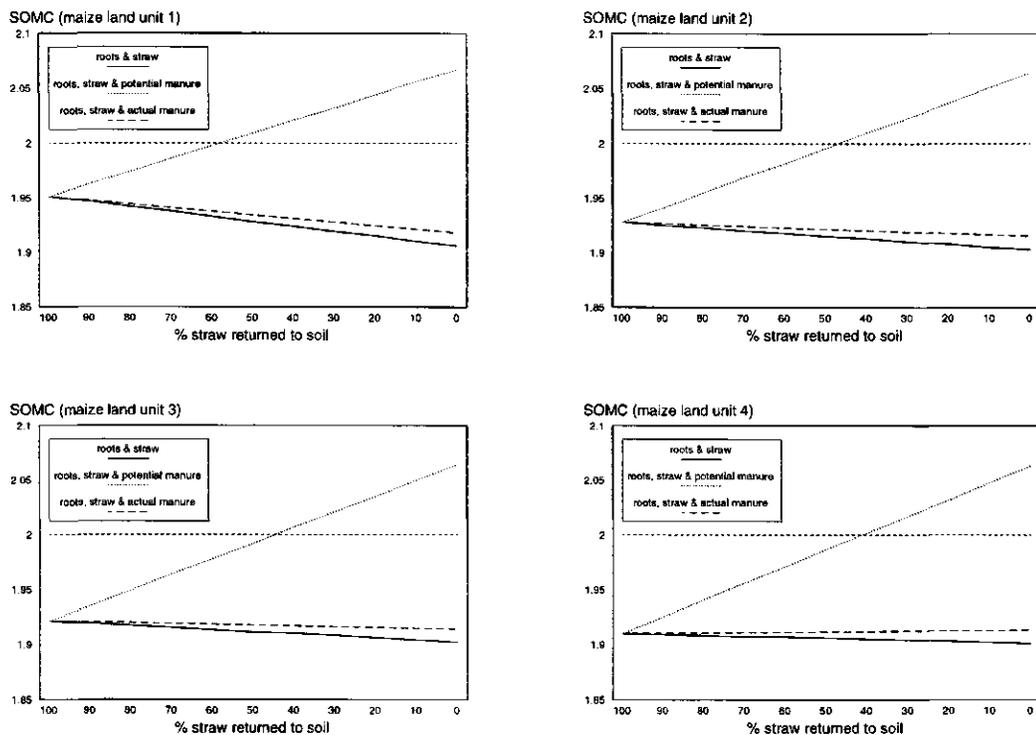
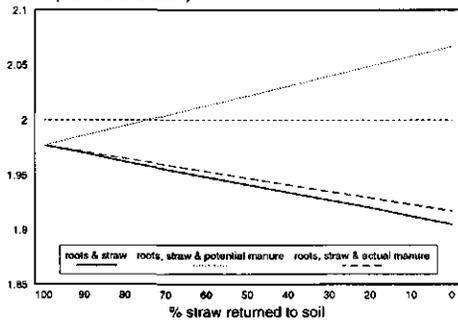


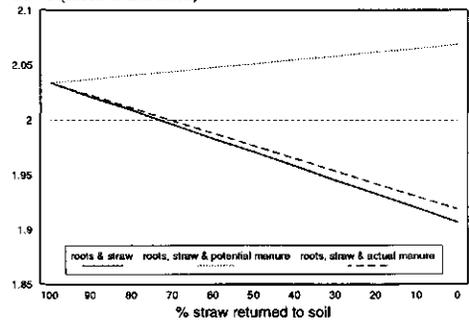
Figure 10.2 Soil organic matter content (SOMC) after one year with humus supply through water-limited production of roots and crop residues of maize or through a combination of manure and crop residues. The percentage of crop residues, returned to the soil is decreased from 100 to 0%. Actual livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 1 cattle, 1 sheep and 1 goat per ha with 0% crop residues. Potential livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 10 cattle, 10 sheep and 10 goats per ha with 0% crop residues. Starting point is a SOMC of 2%.

One of the second environmental conditions, to achieve biophysical sustainability, is to maintain or improve the existing SOMC of 2%. The results show that the root mass of all four annual crops, independent of land unit, are insufficient to fulfil the humus supply requirement of 3000 kg ha⁻¹ y⁻¹. Adding straw to the soils improves the humus supply. However, there are only a few land uses which can keep the SOMC at 2% or even increase the existing SOMC. Potential cassava and sugarcane production and actual cassava production grown on land unit 2, increase the present SOMC when 100% of the crop residues are returned to the soil. These results indicate that the existing SOMC will decrease in the future as long as yield levels are below the potential ones. Cassava offers the best opportunity to increase the SOMC, but it will take a long time before a SOMC of 7% is reached.

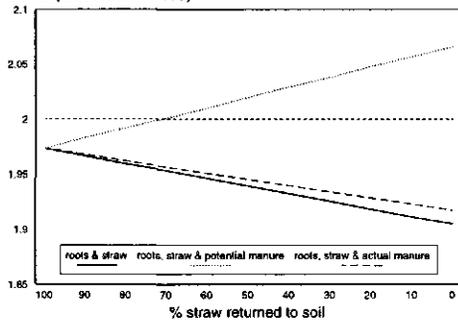
SOMC (cassava land unit 1)



SOMC (cassava land unit 2)



SOMC (cassava land unit 3)



SOMC (cassava land unit 4)

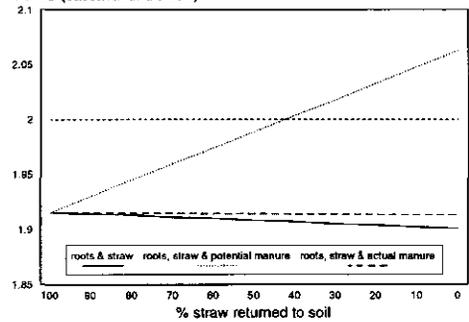


Figure 10.3 Soil organic matter content (SOMC) after one year with humus supply through water-limited production of roots and crop residues of cassava or through a combination of manure and crop residues. The percentage of crop residues, returned to the soil is decreased from 100 to 0%. Actual livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 1 cattle, 1 sheep and 1 goat per ha with 0% crop residues. Potential livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 10 cattle, 10 sheep and 10 goats per ha with 0% crop residues. Starting point is a SOMC of 2%.

The amount of cassava crop residues fed to livestock can be up to 20% for the water-limited yield and still maintain the SOMC of 2%. Potential cassava production enables 60% of the crop residues as animal feed, and potential sugarcane production 40% of the crop residues as animal feed and still maintain a SOMC of 2%. All the other land use systems are not sustainable, even not when 100% of the crop residues is returned to the soil. High animal numbers are required per hectare to maintain a SOMC of 2%. Mixed farming offers the best opportunity for sustainable production systems but not at present number of animals per ha. For mixed farming systems the SOMC increases with an increase in the number of animals and a decrease in the percentage of crop residues returned to the soil. An exception is the potential cassava production, where the SOMC decreases with an increase in animal number

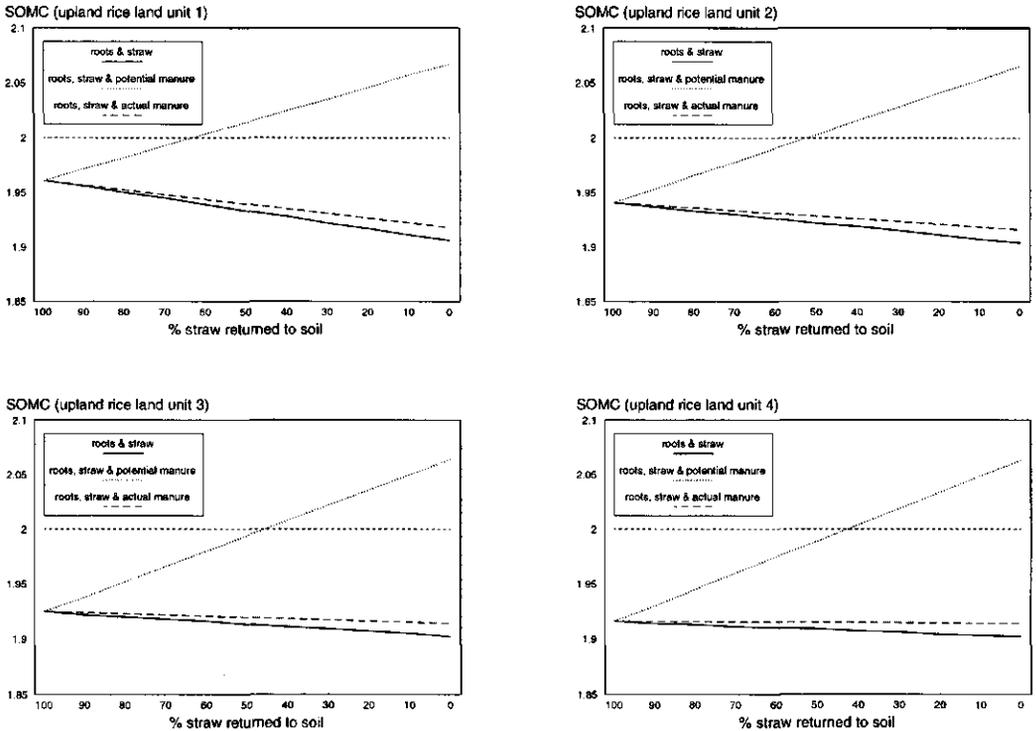


Figure 10.4 Soil organic matter content (SOMC) after one year with humus supply through water-limited production of roots and crop residues of upland rice or through a combination of manure and crop residues. The percentage of crop residues, returned to the soil is decreased from 100 to 0%. Actual livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 1 cattle, 1 sheep and 1 goat per ha with 0% crop residues. Potential livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 10 cattle, 10 sheep and 10 goats per ha with 0% crop residues. Starting point is a SOMC of 2%.

and a decrease in percentage of crop residues returned to the soil. In this case the amount of crop residues is thus high that it outranges the manure production by livestock.

The quantity of manure produced and the corresponding humus supply to maintain a soil organic matter content of 2%, is quantified for actual and potential livestock production. Since the difference in manure production between these two production levels is only little, the different results are obtained by the difference in number of animals per ha. The required number of livestock is on average 6 head of cattle, 6 sheep and 6 goats per hectare to maintain the SOMC by manure only. The actual number of cattle, sheep and goats per hectare in the research area was 1.3, 0.7 and 0.6. This means that increasing the soil organic matter content only by the use of manure requires high numbers of animals per hectare.

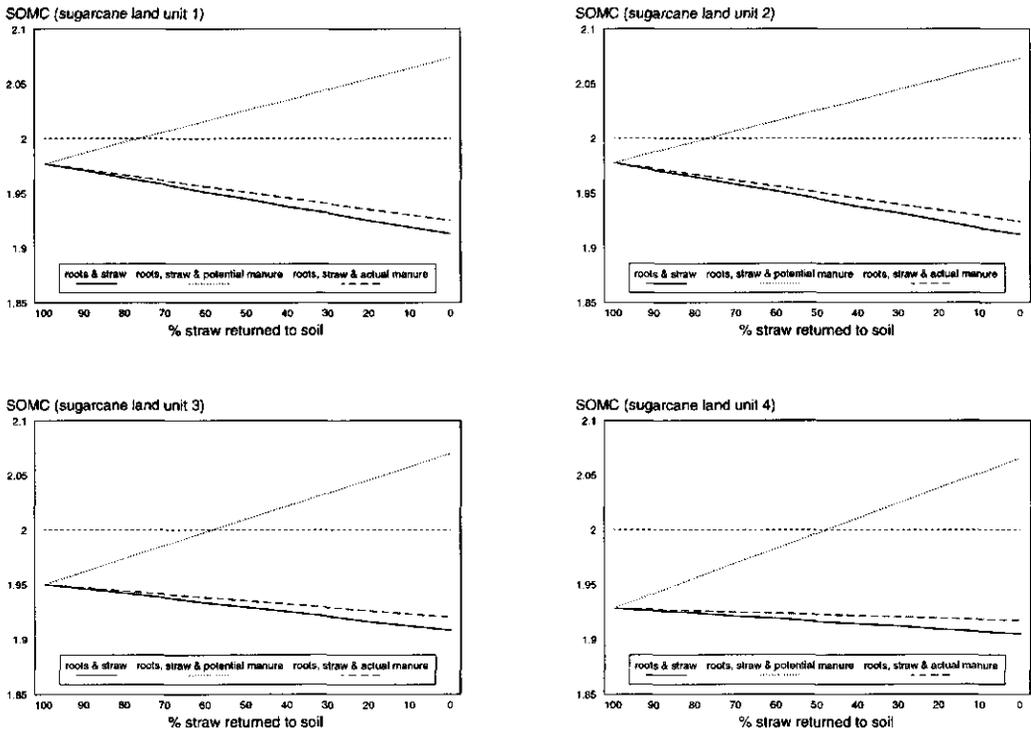


Figure 10.5 Soil organic matter content (SOMC) after one year with humus supply through water-limited production of roots and crop residues of sugarcane or through a combination of manure and crop residues. The percentage of crop residues, returned to the soil is decreased from 100 to 0%. Actual livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 1 cattle, 1 sheep and 1 goat per ha with 0% crop residues. Potential livestock production ranges from 0 cattle, 0 sheep and 0 goats with 100% crop residues to the manure production of 10 cattle, 10 sheep and 10 goats per ha with 0% crop residues. Starting point is a SOMC of 2%.

For tree crops, the soil organic matter content is increased via root mass and through the combination of root mass and litter production (Table 10.2). The standing biomass of perennial crops produce litter biomass. Bruijnzeel (1983) measured amounts of litter biomass in the 35-year-old agathis dammara plantation as well as in the 25-year-old tectona plantation of 4.4 t ha⁻¹ dry biomass. Toky et al. (1989) found litterfall production in a leucaena leucocephala stand of 5.0 t ha⁻¹ (leaf), acacia glauca (leaf) 4.1 t ha⁻¹, and a calliandra caloth stand with a litterfall of (leaf) 3.4 t ha⁻¹. Jensen (1990) measured in the homegarden an annual litterfall of 10.0 t ha⁻¹. In the research area no litterfall had been measured. In Chapter 5, for crop cultivation type 2 and 3, above ground dry matter allocation factors were based on data of Jensen (1990) and those for crop cultivation types 4 and 5 on the data of Bruijnzeel (1983). Litterfall data for the research area have been used of Jensen and Bruijnzeel as well.

Table 10.2 shows that only the multi-storey system reached a relatively high soil organic matter content of 2.21% after one year of high inputs. Therefore, the present soil organic matter content could only be increased if the input of organic materials to the farm increased (at the expense of land where it comes from), or if the annual crops were (partly) replaced by perennials, or if crop residues were not fed to animals. It was not feasible, however, to increase soil organic matter content to levels that were optimum for such heavy soils. Under perennials, including forest trees, the soil structure is much better than in fields used for annual crops. Both the permanent presence of living roots and the activity of soil fauna contribute to this good structure. Occupation of the research area with perennials would solve or circumvent the above mentioned soil constraint.

Table 10.2 The rate of humus supply (kY in kg ha⁻¹ y⁻¹) through the production of perennial roots or roots and litter, resulting in a new Soil Organic Matter Content (SOMC) (the present SOMC is 2%). The existing rate of humus loss is 3000 (hX in kg ha⁻¹ y⁻¹).

Crop Cultivation Type ¹	Site	Humus supply of perennial roots		Humus supply of perennial roots and litter	
			SOMC		SOMC
CCT2	valley	525	1.92	2025	1.97
	hillside	630	1.92	2130	1.97
CCT3	valley	3360	2.01	9360	2.21
	hillside	3395	2.01	9395	2.21
CCT4	valley	1645	1.95	4045	2.03
	hillside	1015	1.93	2815	1.99
CCT5	hillside	875	1.93	2675	1.99

¹ 2=tegal, 3=multi-storey systems, 4=woodlands and 5= tanah bongkor

Maintenance of soil fertility

Native soil fertility was studied in Chapter 6. With QUEFTS nutrient-limited maize yields of 0.7 to 3.6 t ha⁻¹ were calculated, with highest yields at the forest soils and lowest yields at the permanent cultivated hillsides. The growth-limiting nutrient was potassium for forest soils, permanently cultivated hillsides and fallow hillsides. Valley bottoms and intermittently cultivated hillsides showed that phosphorus was the growth-limiting nutrient. Hereafter the nutrient removal of annual and perennial crop harvest is illustrated for the growth-limiting nutrient of valleys, which was phosphorus, and of permanent cultivated hillsides, which was potassium.

In Chapter 7 the nutrient contents of the harvested products and the crop residues were given for the potential, water-limited, and water- and nutrient-limited production situations for maize, cassava, upland rice and sugarcane. Nutrients in trees are quantified according to nutrient concentrations of the different organs found in the literature. Jordan (1985) compared data on nutrient concentrations in leaves and wood in 21 different forests. Forests were subdivided into four groups: tropical lowland, montane forest and temperate angiosperm and gymnosperm forest. Although variation for most elements was quite large, no clear general differences between the four groups could be identified, except that gymnosperm wood on average was lower in N and K and the leaves higher in P. Based on the findings of Jordan, an average nutrient content of N, P and K was calculated for wood (stems + branches) and leaves of the trees as well as for litter. These were 1.00% N, 0.09% P and 0.24% K for wood, and 1.47% N, 0.11% P and 0.86% K for leaves (Bruijnzeel, 1983; Lundgren, 1978; Whitmore, 1984). Calculated amount of P in trees and annual crops grown in different crop cultivation types on valley bottoms, and K, stored in the above-ground biomass of different crop cultivation types grown on permanent cultivated hillsides, are shown in Table 10.3 and 10.4. For annual crops a distinction was made in yield-oriented and low external-input agriculture.

Tables 10.3 and 10.4 present also data on the nutrient content of the above-ground plant parts of annual crops expressed as a percentage of the respective plant 'available' nutrient reserve in the 0-20 cm mineral soil (natural fertility) (Chapter 6). Valley bottoms had a plant-available phosphorus reserve of 8.4 kg per ha, and permanently cultivated hillsides had a plant-available potassium reserve of 109 kg K per ha. Only the nutrient contents of annual crops was expressed as a percentage of the plant 'available' nutrient reserve, because these crops are fully harvested at the end of the growing season. Yield-oriented agriculture takes up higher amounts of nutrients from the soil (natural fertility + fertilizers) compared to low external-input agriculture which is due to higher crop yields. Nutrient amounts taken up by cassava and sugarcane were high compared to the amounts taken up by maize and upland rice. Compared to K, proportionally higher quantities of P on valley bottoms were immobilized in the biomass.

Table 10.3 The amount of phosphorus (P) (kg ha⁻¹) stored in the above-ground biomass of trees (wood, leaves and litter) and of annual crops grown on valley bottoms.

Crop Cultivation Type ¹	Annual crop	P in trees	YOA ²	LEIA ³	P in annual as % of available	
			P in annual	P in annual	P in 0-20 cm mineral soil	
					YOA	LEIA
CCT1	maize	-	6	4	71	48
	cassava	-	22	13	262	155
	upland rice	-	8	5	95	60
	sugarcane	-	22	13	262	155
CCT2	maize	15	5	3	60	36
	cassava	15	14	9	167	107
	upland rice	15	6	4	71	48
	sugarcane	15	6	4	71	48
CCT3	-	85	-	-		
CCT4	-	46	-	-		

¹CCT1 = open field, CCT2 = tegal, CCT3 = multi-storey system, CCT4 = woodlands

² YOA = yield-oriented agriculture

³ LEIA = low external-input agriculture

The fraction of green fertilizers consists of leftovers from harvest, and bushes and weeds cut for light. Weeds in the research area are often cut twice, irrespective of the crop cultivation type. Cuttings (or prunings) are left wherever they fall, and consist mainly of coconut leaves and shells, leaves and twigs from *Hibiscus tiliaceus*, and banana leaves. Jensen (1990) measured an amount of green fertilizer in a homegarden of 7.5 t DM per hectare, including weeds and leaves, shells and twigs of trees. Recycling of nutrients is only of importance for trees. On a yearly basis very large amounts of nutrients were returned in litterfall, and this was definitely the most important pathway for retaining the soil fertility (Table 10.5).

The nutrient concentrations of ground litter used were 1.28% N, 0.07% P and 0.26% K (Bruijnzeel, 1983; Lundgren, 1978; Whitmoore, 1984). The concentrations of nutrients in the ground litter are higher, except for K, than in the fresh litterfall. The higher concentrations in the ground litter of N and P, as compared to fresh litterfall, has to do with the invasion and growth by micro-organisms and other decomposer fauna. This is a generally observed phenomena (Swift et al., 1989). The very mobile K is rapidly lost from decomposing leaves, and therefore its concentration in ground litter is found to be lower compared to fresh litterfall.

Table 10.4 The amount of potassium (K) (kg ha^{-1}) stored in the above-ground biomass of trees (wood, leaves and litter) and of annual crop grown on permanent cultivated hillsides.

Crop Cultivation Type ¹	Annual crop	K in trees	YOA ²	LEIA ³	K in annual as % of available K in 0-20 cm mineral soil	
			K in annual	K in annual	YOA	LEIA
CCT1	maize	-	56	34	51	31
	cassava	-	91	55	83	50
	upland rice	-	71	42	65	39
	sugarcane	-	117	70	107	64
CCT2	maize	55	41	25	38	23
	cassava	55	59	36	54	33
	upland rice	55	49	30	45	28
	sugarcane	55	29	17	27	16
CCT3	-	300	-	-		
CCT4	-	96	-	-		
CCT5	-	83	-	-		

¹CCT1 = open field, CCT2 = tegal, CCT3 = multi-storey system, CCT4 = woodlands, CCT5 = fallow

²YOA = yield-oriented agriculture

³LEIA = low external-input agriculture

Table 10.5 Amount of litterfall (DM), nutrient contents of the litterfall and nutrients stored in the plant, expressed as percentage of the available nutrient reserve of the mineral soil.

Crop cultivation type ¹	DM t ha ⁻¹	N kg ha ⁻¹	P kg ha ⁻¹	K kg ha ⁻¹	Nutrients in litter (% of 0-20 cm soil) ²		
					N	P	K
CCT2 - valley	2.5	32	2	7	1	24	3
CCT2 - hillside	2.5	32	2	7	1	16	6
CCT3 - valley	10.0	128	7	26	4	83	10
CCT3 - hillside	10.0	128	7	26	3	56	24
CCT4 - valley	4.0	51	3	10	1	36	4
CCT4 - hillside	3.0	38	2	8	1	16	7
CCT5 - hillside	3.0	38	2	8	1	16	7

¹CCT1 = open field, CCT2 = tegal, CCT3 = multi-storey system, CCT4 = woodlands, CCT5 = fallow

²valley : 3500 kg N, 8.4 kg P and 257 kg K per ha, permanently cultivated hillsides : 4600 kg N, 12.6 kg P and 109 kg K per ha

Crop-livestock nutrient interactions

The crop-livestock interactions are studied through the factors humus supply and nutrients. Above the humus supply through manure and crops residues, and their competition was discussed. Here the supply of nutrients through manure and the consumption of nutrients through crops residues is discussed. The average holding size of animals for each farmer is often too small to fulfil annual manure requirement in order to maintain a soil organic matter content of 2%, to maintain the natural fertility and to supply nutrients for food crops. On the other hand, forage availability will be too low if the animal holding size is increased. Therefore these commodities have to be kept in balance depending on the natural potential of the area.

The extent to which manure fulfils the nutrient requirement by annual crops at village level is studied. Data used for the analysis are based on the EFHS, 1991, including a sample of 149 households in Putukrejo and Kedungsalam. The sample in Putukrejo has 31.5 ha of land cropped with annual crops whereas the sample in Kedungsalam cultivates 47.4 ha of land with annual crops (Table 4.7). Considering the number of cattle, sheep and goats in both villages and the amount of manure they produce, including the amount of nutrients, the amount supplied to one hectare of land cultivated with annual crops is established. The number of cattle, sheep and goats is 41, 6 and 6 respectively for Putukrejo and 89, 7 and 61 respectively for Kedungsalam. Table 10.6 shows the amount of faecal dry matter available per hectare of land cropped with annual crops for two villages and two different production levels for annual cropping.

A comparison is made between the amount of N, P and K available per hectare of land and the amount of N, P and K required for one hectare of maize, cassava, upland rice or sugarcane. In Chapter 7 the yields of these crops were calculated and their subsequent nutrient requirements to be supplied by manure in the case of low-external input agriculture. Table 10.7 summarizes the LEIA yields of these 4 crops and the N, P and K requirements. When these nutrient requirements are compared with the nutrient availability it is clear that actual livestock production does not produce enough nutrients to fulfil the requirements. Potential livestock production shows an increase in amount of N, P and K available compared to actual livestock production. This is mainly due to the consumption of concentrate, i.e. soybean cake. The potential livestock production and their corresponding amount of N, P and K available, closely resembles the nutrient requirements of maize and upland rice but is still insufficient for the nutrient requirements of cassava and sugarcane.

How many animals a family must have access to, or maintain, in order to obtain the required manure for its crops? If the manure production for cattle of actual livestock production is used for fertilization, the number of animals required to fulfil the manure fertilizer requirements can be calculated. The amount of N, P and K excreted through faeces and urine by a cow in Kedungsalam, on a yearly basis, is 20.15 kg N, 2.44 kg P and 14.43 kg K. Based on the N, P and K fertilizer requirements of crops grown within crop cultivation

Table 10.6 The amount of faecal dry matter, N, P and K (kg ha⁻¹) available per hectare of land cropped with annual crops (based on the present number of livestock).

village	production level	faeces kg dm ha ⁻¹	Nitrogen		Phosphorus faeces	Potassium	
			faeces	urine		faeces	urine
Putukrejo	actual	1014	14	11	3	1	24
Kedungsalam	actual	1545	22	20	5	1	30
Putukrejo	potential	1067	37	64	9	1	42
Kedungsalam	potential	1669	56	95	13	2	64

Table 10.7 Low-external input agriculture crops yields (t ha⁻¹) of maize, cassava, upland rice and sugarcane and their N, P and K (kg ha⁻¹) requirements.

Crop	Yield	Nitrogen	Phosphorus	Potassium
Crop cultivation type 1, valley bottom, 100% light				
maize	1.4	81	12	42
cassava	4.4	281	38	68
upland rice	2.1	112	14	52
sugarcane	8.3	312	38	86
Crop cultivation type 2, hillside, 38% light reduction				
maize	0.7	42	7	19
cassava	3.9	297	40	67
upland rice	0.5	27	3	12
sugarcane	0.4	18	3	4

type 1 on valley bottoms (Table 10.7), maize requires 4, 5 and 3 number of cows, cassava requires, 14, 16 and 5 number of cows, upland rice requires 6, 6 and 4 number of cows and sugarcane requires 15, 16 and 6 number of cows. The required number of animals is higher for phosphorus than for nitrogen.

The above indicates that when the average landholding size of a farm household is one hectare of land, the crop fertilizer requirements could never be met by a single cow. Since the amount of N, P and K produced by sheep or goats is less than the amount produced by cows, the number of animals required to fulfil the manure requirements with sheep or goat manure is much higher. More animals require more feed, and since feed is already a limiting factor in the research area it seems realistic to assume that introduction of inorganic fertilizers in the research area seems justified for maintenance of a closed nutrient balance.

The yearly crop residue consumption, maize straw, cassava leaves, rice straw and

Table 10.8 Yearly crop residue consumption ($t\ ha^{-1}$) by the total sampled number of livestock in Putukrejo and Kedungsalam at two different livestock production levels.

Village	maize straw	cassava leaves	rice straw	sugarcane leaves
<i>actual livestock production</i>				
Putukrejo	5.3	1.4	12.3	12.2
Kedungsalam	12.3	6.4	26.8	2.7
<i>potential livestock production</i>				
Putukrejo	0.8	9.0	-	0.4
Kedungsalam	4.2	47.6	-	4.2

sugarcane leaves, of the total number of cows, sheep and goats in Putukrejo and Kedungsalam is summed for two different production levels. The results are shown in Table 10.8. Seasonality is indirectly taken into account since it is included in the actual feed consumption table. Crop residues are only fed and consumed in the months in which they are available.

The crop residue yields per hectare of maize straw, cassava leaves, rice straw and sugarcane leaves are summarized in Table 10.9 for the potential, water-limited and water- and nutrient-limited crop production at two different sites. Comparing the amount of crop residues required with the amount of crop residues available gives the false impression that whatever crop production level is taken, only a few hectares of land need to be cultivated in order to fulfil the crop residue requirements of livestock. Note that in Putukrejo 31.5 ha of land are cropped with annual crops and 47.4 ha of land in Kedungsalam. It is concluded that in order to feed livestock at present feeding practices, the required area for rice cultivation was highest, followed by sugarcane in Putukrejo and by maize and cassava in Kedungsalam. Least was required for cassava in Putukrejo and for sugarcane in Kedungsalam. Intercropping of annual crops with trees indicates less light available for the growth of the annuals and consequently lower yields of the annuals. Therefore when light was reduced, the area required to meet feed demands of the animals was increased, often more than twice. Potential crop production results in higher yields, and therefore less area needed to be cultivated in order to meet the feed demands of the cows. Potential livestock production, as was shown in Chapter 8, required only leguminous tree leaves, cassava leaves, concentrates and little maize straw and sugarcane leaves. The high cassava consumption of the potential livestock production required therefore more hectares of land cultivated with cassava compared to the actual livestock production.

From the comparison of amount of crop residues required with the amount of crop residues available the impression exists that availability of crop residues is not a limiting factor. It should however be realized that the seasonal availability of the crop residues and their feed quality, which is expressed in daily amount consumed, limits in their own way the

Table 10.9 Yield ($t\ ha^{-1}$) of maize straw, cassava leaves, rice straw and sugarcane leaves for different crop production levels grown at valley bottoms or hillsides.

Crop residues	Potential production	WLP-YOA		WNLP-LEIA	
		valley ¹	hillside ²	valley ¹	hillside ²
maize	9.2	4.6	1.8	2.7	1.1
cassava	6.6	2.0	2.0	1.2	1.2
rice	7.2	5.6	1.2	3.3	0.7
sugarcane	12.9	6.5	0.3	3.9	0.2

¹ crop cultivation type 1, 100% light, ² crop cultivation type 2, 38% light reduction

optimal use of available crop residues. A solution can be the storage of crop residues, but the implementation of such measures is still far from application.

Carrying capacity

Biophysical carrying capacity, expressed as sustainable population densities, is estimated for the two villages, Putukrejo and Kedungsalam, based on the actual crop productions and the actual consumption patterns (van der Molen, personal communication). The results below focus on the consumption of staple foods only, while it was aimed to link those amounts with annual crop produce as was calculated in Chapter 7. Out of the 149 households of the EFHS, 74 households, containing children aged below 10 years, were selected for a consumption pattern study. Households not having a child below the age of 10 years were excluded. The 74 households were asked about the quantitative consumption of 40 food items in the week prior to the visit (July 1992). Later on they were asked how many months of the year a specific food item, or mix of food items, were consumed. First, household consumption units were calculated using standard values of the WHO (1985). These standard values regard males, aged between 14 and 50, as 1 household consumption unit, and females, aged between 18 and 50, as 0.8 household consumption unit. Below the age of 18 for females and 14 for boys the consumption unit decreased and was only 0.25 for baby's. Males and females over the age of 60 were assumed to match 0.8 and 0.7 consumption units respectively. From the consumption survey it was known how much kg rice, cassava and maize were consumed per household per day in July. Consumption, per consumption unit per year, was calculated by multiplying the daily values of July by the number of months (and the 30 days per month) for which the specific item was consumed. Results are listed in Table 10.10.

Sajogyo (1977) investigated the income distribution on Java. His poverty line was based on the minimum daily amount of energy required by an average person on Java. This amount was established at 1200 calories (or 5040 kJ), represented by 120 kg of rice per capita per

year. He increased this very basic volume by an amount of rice representing the other food and non-food needs (including clothes, shelter, etc.). Thus, for the rural areas, the following three thresholds were determined: (1) poor, i.e. less than 320 kg rice equivalents per capita per year, (2) very poor, i.e. less than 240 kg rice equivalents per capita per year, and (3) destitute, i.e. less than 180 rice equivalents per capita per year. In a regional agricultural planning study in Matara district, Sri Lanka (Polman et al., 1982; Fresco et al., 1989) one consumer equivalent consumed about 180 kg of rice per year, which was equal to 7332 kJ per consumer equivalent per day. Nibbering (1991) calculated the average consumption of staple foods (rice, maize and cassava) per person per year for three villages in west Java,

Table 10.10 Several consumption characteristics, regarding the staple crops, rice, maize and cassava, for two different villages, measured in 1992.

Characteristics	Putukrejo	Kedungsalam
household size	3.96	4.85
consumption unit	3.07	3.86
rice consumed per hh (kg d ⁻¹)	0.60	0.85
maize consumed per hh (kg d ⁻¹)	0.89	0.55
cassava consumed per hh (kg d ⁻¹)	0.02	0.33
Number of months consumed:		
rice only	5.37	2.48
maize only	1.08	-
cassava only	-	-
rice + maize	3.28	4.25
rice + cassava	1.14	5.10
maize + cassava	0.15	0.13
rice + maize + cassava	0.98	0.03
rice consumption (kg y ⁻¹)	126	98
maize consumption (kg y ⁻¹)	53	30
cassava consumption (kg y ⁻¹)	11	36
Tot. staple consumption (kJ d ⁻¹) ¹	7652	6605

¹ The FAO food consumption table for East Asia (FAO, 1972) gives the following calorie and protein composition per 100 grams edible portion of rice, maize and cassava:

	water (%)	calories	protein (grams)
rice (milled, polished)	11.8	354	7.6
maize (grain)	13.6	349	9.1
cassava (fresh root)	65.5	135	1.0
cassava (peeled and dried)	12.0	349	0.5

Indonesia, and found values ranging from 177 to 191 kg. These values were comparable to 7692 and 7128 kJ consumed staple per person per day. A study performed in the Sahel, west Africa (Kessler, 1994; Breman, 1992) estimated human energy and protein requirements at 250 kg of grains, per person, per year, or the off-take of 3 Tropical Livestock Units (a hypothetical animal of 250 kg). Veeneklaas et al. (1991) gave for subsistence needs, daily minimum energy requirements, based on FAO/WHO (1973), of 7810 kJ per capita. Table 10.10 shows that average daily energy consumption of staples per consumption unit were 7652 kJ and 6605 kJ for Putukrejo and Kedungsalam respectively. These values were far above the minimum value as was given by Sajogyo (1977), but below the values used by Veeneklaas et al. (1991).

The total number of consumption units for both villages in the sample were 150 for Putukrejo and 343 for Kedungsalam. Table 10.11 shows that consumption was, in general, below the amount produced, except for the rice consumption in Putukrejo. Probably the households in Putukrejo earned enough cash money, via e.g. the cultivation of sugarcane, to buy rice at the market. The rice consumption in Kedungsalam was close to the rice production. The difference was most likely used for gifts at traditional ceremonies. Households in Kedungsalam adjusted their rice consumption to their rice production and probably did not earn enough cash money to buy rice at the market. In both villages the maize and cassava consumption was far below the production.

Table 10.11 The actual crop productions and the actual consumption of the actual population density.

Crop	Area (ha) cultivated	Total (t) production ¹	Total (t) consumption ²
<i>Putukrejo</i>			
maize	12.7	31.75	7.95
cassava	12.7	53.34	1.65
rice	2.4	10.20	18.90
<i>Kedungsalam</i>			
maize	33.5	83.73	10.29
cassava	33.5	140.66	12.35
rice	13.4	40.23	33.61

¹ Yields of maize, cassava and rice are 2.5, 4.2 and 3.0 t DM ha⁻¹ respectively; ² In Putukrejo 49 households consist of 150 consumption units and in Kedungsalam the 100 households consist of 343 consumption units.

Improved land use

Land use and management determine, to a great extent, erosion. The multi-storey system (including the homegardens) has been used by several authors as an example of a sustainable production unit, which benefits the environment, in addition to its socio-economic functions. The latter is beyond the scope of this thesis. The protective function of the multi-storey system was related to the ability of a large biomass (forest) to regulate the hydrological balance and the effective recycling of nutrients, as well as a ground litter layer for protection against erosion. Proper placement of the multi-storey system in the agricultural landscape is important. Now homegardens are placed on flat, terraced land. Since the multi-storey systems have a permanent treecover and do not involve any physical soil treatment, it may be better suited for gently sloping land. Amber (1986) identified 8° as the critical slope for homegardens.

Annual crops can best be cultivated on valley bottoms where moisture reserves are higher and nutrient uptake better. Where the limestone rock is porous, immediate absorption of water takes place. On compact karst, lacking intergranular porosity, water flows over the surface until it encounters planes of weakness. On the hillsides, the combination of shallow soils and porous limestone results in moisture stress fairly soon after rainfall ceases. On shallow soils plant roots cannot go deep and do not have the moisture reserves which crops on deeper soils can tap at greater depth during dry periods. The soil depth from which crops can take up nutrients on shallow soils is more limited.

If annuals are only grown on valley bottoms (land unit 1), not enough food for consumption is produced for Putukrejo. Only rice cultivation on land unit 1 (rice is the most preferred staple) with a yield of 3.5 t ha^{-1} (WLP) resulted in a total production for Putukrejo of 22 t and for Kedungsalam of 64 t. The quantity consumed was calculated for Putukrejo as 27 t, and as 62 t for Kedungsalam, when a yearly consumption of 180 kg rice per person was assumed. As a result Putukrejo should always cultivate annual crops on land unit 2 as well, when it aims to be self sufficient in food. Kedungsalam was self sufficient in food when only land unit 1 was used to grow annual crops. However, the excess of food was small and therefore not much scope for expansion of the population was available.

Figure 10.1 to 10.5 showed that the soil organic matter content was improved when both roots and crop residues supplied the soil with humus compared to the situation in which only roots supplied the soil with humus. However, in only a few cases the soil organic matter content reached 2%. Figure 10.1 to 10.5 further showed that the required number of cattle per hectare to maintain the soil organic matter content of 2% is about 8. Table 10.8 and 10.9 illustrate that crop residue consumption is far below the crop residue produce at village scale. Since animals efficiently utilise nutrients of feed and excrete them via manure, livestock is considered to play a vital role in organic matter and nutrient supplier which is a prerequisite for long term sustainability.

Bottlenecks in the research area are low crop yields due to a heavy soil structure, low

organic matter and nutrients, and high erosion figures. A negative nitrogen, phosphorus and potassium balance is found for maize and cassava cultivated on valley bottoms, permanently and intermittently cultivated hillsides. The main chemical soil constraint was low availability of phosphorus or potassium. There is no technical reason why chemical soil fertility constraints cannot be removed by fertilizer application. However, apart from the negative nutrient balance the soils in the research area are also low in organic matter. Because the nutrient holding capacity, and thereby the protection against leaching of nutrients, is particularly related to the amount of organic matter in the soil, emphasis should be on organic fertilizers. Organic fertilizers should not be replaced by inorganic fertilizers.

Usually the soil structure is best improved via split application of organic materials. Split application results, on average, in a higher structural stability than one single application per year. Especially in the dry period structural stability is better under split application than when the organic matter is applied only once a year (Effendi, 1980; Soetarjo Brotonegoro et al., 1986). However, one might ask what the advantage is of a good structure during that time of the year. The main profit might be that at the start of the rainy season the soil is more porous than if no organic matter was recently applied, and hence water can infiltrate more easily, thus diminishing the risks of waterlogging and runoff. However, the latter is questionable at very heavy clay soils. More infiltration might cause more waterlogging and less runoff but maybe the erosion hazard increases due to structural instability leading to landslides. During the dry season, the organic materials may best be laid on top of the soil (mulching). This suppresses the evaporation and might keep soil fauna alive so that they continue to loosen the soil during the dry season. Further the mulch serves directly and indirectly as feedstuff for the soil fauna. The above is rather speculative. Field experiments are required to test whether in the research area split application of the limited quantity of organic materials is indeed an advantage. The opposite might be true as well. Splitting might result in such low rates of application that there is no noticeable effect at all.

Apart from increasing the nutrient fertility of the soils by applying greater quantities of fertilizer, the fertility is also increased by improving the fertilizer efficiency. Fertilizer efficiency is adversely affected in the research area by: (1) poor rootability of the soil, (2) runoff and washing away of fertilizers and (3) volatilization of NH_3 originating from urea. The efficiency is increased by placement of the fertilizer at 2 to 5 cm below, and 3 to 5 cm beside the seeds (Krantz et al., 1978; Chowdhury & Bhatia, 1971). Nutrient input from natural sources can be increased by intensifying nitrogen fixation. Several leguminous tree species with high potentials for nitrogen fixing were already available in the research area, like *Gliricidia* and *Leucaena Leucocephala*. There was no information on the exact abilities of these species to fix nitrogen under conditions in the research area. A stand of *Leucaena Leucocephala*, grown at the IITA in Nigeria, was able to fix 98-134 kg N ha⁻¹ in 6 months, but rates as high as 500 kg N ha⁻¹ have been reported (Dommergues, 1987). Trees with multipurpose functions are preferable, like: *Parkia speciosa*, *Tamarindus indica*, *Albizia falcata* and *Leucaena leucocephala*. These all provide various products like edible seeds, timber or fodder, in addition to their nitrogen fixing abilities. Many other potentially good

choices exist, the above is just an example.

Integration of trees, especially nitrogen fixing trees, into land use systems can make considerable contribution to sustainable agriculture by (1) restoring and maintaining soil fertility (2) combating leaching and erosion and (3) providing timber and fuelwood. Nitis et al. (1989 and 1990) introduced a Three Strata Forage System (TSFS) which is a technique of planting and harvesting grass, ground legume, shrub and fodder trees, so that ruminant feeds are available all year round. A piece of land of 0.25 ha is divided into a core of 0.16 ha, cropped with annual crops, a periphery of 0.09 ha and a circumference of 200m. The periphery is subdivided into lots of 45 m² and each lot is planted with an improved grass or ground legume. The circumference is planted with shrub legumes and fodder trees. The rationale is that the 1st stratum which consists of grass and ground legume is to supply ruminant feed during the wet season; the 2-nd stratum which consists of shrub legume is to supply ruminant feed during the mid-dry season; while the 3-rd stratum which consists of fodder trees is to supply livestock during the late dry season. Grass species used are buffel grass (*Cenchrus ciliaris* cv. Gayndah) and green panic (*Panicum maximum* var. Trichoglume). The three ground legume species used are common stylo (*Stylosanthes guianensis* cv. Graham), centro (*Centrosema pubescens*) and Caribbean stylo (*Stylosanthes hamata* cv. Vereno). The three types of fodder trees planted are ficus (*Ficus poacellie*), lannea (*Lannea corromandilica*) and hibiscus (*Hibiscus tilliaceus*). The two types of shrub legumes planted are gliricidia (*Gliricidia sepium*) and leucaena (*Leucaena leucocephala*). A total of 14 fodder trees of each different species is planted and 1000 shrub legumes of each species.

Since the graham stylo is a volunteer species it is replaced with *Urochloa mosambisensis* which is more persistent. Since centrosema is a cropping legume, the shrubby stylo (*Stylosanthes scarba* cv. seca) is planted to provide the centrosema with a climber. Since leucaena yield is low due to attacks of *Heterophsylla cubana* attack, *Acacia villosa* is sown along the row of the leucaena. Nitis et al. (1989) observed an increase of the quality of livestock feed since ground and shrub legumes were included in the system. A faster growth rate of cattle during the dry season was observed. And soil erosion was reduced since grasses, legumes, shrubs and trees reduced the rain water runoff.

The Three Strata Forage System could be a system worthwhile to introduce in the study area. It takes care of a year round quantity and quality of feed for livestock, but it should be studied what the livestock carrying capacity of such a system is. Cultivation of part of the area with grasses, legumes, shrubs and trees would definitely reduce erosion and increase the SOMC, but the extent to which erosion is reduced depends on the management strategy. The same holds for the core which is cropped with annual crops, under what input level (fertilizers) and which management strategy (% crop residues returned to the soil) should this cropping system be operated.

Conclusions

Actual land use, under low-external input agriculture, is not sustainable. The low soil organic matter content of 2% is hardly maintained, and therefore the optimal soil organic matter content of 7% is far out of reach. Increase of annual crop production to potential levels and their corresponding humus supply in the form of roots and crop residues just maintains the present soil organic matter content. Since at present practices, crop residues are not returned to the soil, also potential crop production levels are not sustainable. Only multi-storey systems are able to slightly improve the soil organic matter content, but it still will take years before the optimum soil organic matter content is reached. Improving the soil organic matter content through manure, requires animal numbers which are too high to be realistic. Therefore it is concluded that constraints of the soil base are indeed difficult to overcome by presently known affordable technology.

Three major aspects of a more biophysically sustained land use have been studied in this chapter; erosion, soil organic matter and nutrient balances. A pre-supposition in the analysis has been the self-supportance (in food) of the present population in the area. So, no out-migration will be considered. Elsewhere in this thesis the extreme production orientations LEIA and YOA have been distinguished with their specific technologies; LEIA (relying on manure only) and YOA (relying on inorganic fertilizers only). Finally the hypothesis that biophysical sustainability profits from the integration of food and animal production has been considered. Farmers keep animals amongst others for the production of manure. Via the feedstuffs of the animals, organic material and nutrients are brought to the farm, which would not have entered the farm if there were no animals. Because organic matter was a limiting factor of the farms, the significance of the animals lies in the supply of organic materials to the farm. The question is raised whether the need for organic materials indeed makes it necessary to keep cattle, and whether direct application of feedstuffs like grasses and crop residues would not have the same result as the application of organic manure formed from these stuffs. Animals consume biomass but produce manure; the question is what affects biophysical sustainability more, the loss of biomass or the gain of manure? In this conclusion all these elements come together.

All present types of land use show erosion rates which are far too high. Alternative technology (more terraces) and management practices (more cover) are needed to keep soil loss below a supposed tolerable level of $5 \text{ t ha}^{-1} \text{ y}^{-1}$. Systems with perennials, YOA-systems and systems with potential cattle production leave more biomass than at present thus creating more cover, litter and mulch.

The level of soil organic matter content (SOMC) that guarantees a good physical structure (with probably less erosion) of the heavy clay soils in the area have been estimated at 7%. To improve the present level of 2% in the direction of the target is virtually impossible. Therefor the short- to medium-term target for biophysical sustainable land use is set at a minimum of 2%. In other words land use that lowers the present 2% is considered not

sustainable. When all above-ground biomass is removed from the fields (to be used in stall feeding) all types of land use contribute to a lowering of the soil organic matter and are thus judged as non-sustainable. However, the existence of animals provide a (limited) amount of manure that can also be used to increase SOMC. The situation where 100% of the crop residues is used as cattle feed, so that there is a maximum manure production, shows a higher equilibrium SOMC than the other extreme where 100% of the crop residues is left on the fields and no animals are kept. The effect of increasing the number of cattle, sheep and goats from 0 to 10 on the SOMC is bigger than decreasing the percentage of crop residues returned to the soil from 100 to 0%. Therefore the combined result is an increasing SOMC, with as starting point the SOMC in case 100% of the crop residues is returned to the soil.

Actual crop production, returning 100% of the crop residues to the soil, in all cases show a SOMC of below 2%. The only exception is cassava, grown on land unit 2. Potential crop production, returning 100% of the crop residues to the soil, shows a SOMC of 2% or more in case of maize, cassava and sugarcane. Upland rice shows in this case a SOMC of below 2%. Decreasing the percentage of crop residues returned to the soil and at the same time increasing the number of animals shows an increase in the SOMC, except for cassava. The latter indicates that the effect of decreasing the percentage of crop residues returned to the soil is bigger than the effect of increasing the number of animals. In conclusion, actual crop production systems without cattle are not sustainable, except cassava grown on land unit 2. Depending on land unit and type of crop the actual crop production systems require 3 to 6 cattle, sheep and goats per hectare in order to be sustainable, e.g. maintain a SOMC of 2%. Except for rice, potential crop production systems are sustainable in itself, when 100% of the crop residues are returned to the soil in case of maize, and when at least 40-50% of the crop residues are returned to the soil in case of cassava and sugarcane. Hence, systems with perennials, YOA-systems and systems with cattle leave more biomass than at present on the fields creating more source material for soil organic matter.

The sub question of the larger biophysical sustainability question, i.e. whether the actual natural fertility is sustained is only of relevance in case of LEIA based agriculture. This is because in LEIA-systems crops extract nutrients that have to be supplied by manure. Calculations in this chapter show that the requirements of annual crops (at present production levels) are far higher than the amount of nutrients supplied in the manure. This manure is not only made out of crop residues but also of material that is cut and carried from outside the crop fields. Remember that at present practices, 80% of the livestock feed is collected off-farm and 20% on-farm. So, even with a transfer of fertility from outside the farm to the farm this system is far from sustainable. The only conclusion can be that inorganic fertilizers must supplement natural and carried-in fertility. Even when the present livestock number is fed with concentrates the subsequent increase in the quantity and the quality of the manure is not enough to compensate for nutrients in the harvested product removed from the system. Theoretically it would be possible to increase livestock numbers till the amount of nutrients in the manure matches crop requirements. In practice this seems not a realistic option. At present livestock numbers are limited by (seasonable) limited forage supply. Of course when

concentrates could be used in much larger quantities a situation can be reached that sufficient nutrients are produced in manure, e.g. in Dutch agriculture even more nutrients are produced than required.

At present the area provides more food than is needed for its own population. So, its biophysical carrying capacity is not threatened. In the strive for biophysical sustainability (leaving the prerequisites of social and economic sustainability out of sight for the moment) this leaves room for alternative land use that better preserves the natural resources. Reforestation of slopes is one of such possibilities. The creation of more multi-storage like systems, in order to create more soil cover, and stimulation of more leguminous trees are other examples. Better residue management in terms of total amount as well in the timing of application (e.g. split-application) is an example of an improved management practice. Whether these changes are economically viable is left out of sight in the present biophysical discussion.

The area suffers from an excess of erosion and a shortage of nutrients and organic matter. Systems with more perennials, YOA-systems and systems with cattle leave more biomass than at present thus creating more cover, litter and mulch. Given the already rather efficient way of cycling nutrients via manure back into the fields in the present semi-LEIA systems, a further optimization of this system does not seem sufficient to make agriculture sustainable. An increase in the use of inorganic fertilizers seems the only viable direction towards more biomass production. Of course, when increasing the application of inorganic fertilizers, optimum use should be made of the already existing mixed-farming system. Increased fertilizer use will improve the quantity and quality of crop yields as well as of crop residues for animal husbandry. Since never 100% of crop residues will be used in animal husbandry effort should be paid to the returning of the left-overs to the soil in order to maintain or increase the soil organic matter content, i.e. better residue management. The extra manure both in terms of quantity and quality will also contribute to the latter goal. Finally, the higher SOMC will improve the physical state of the heavy clay soils thus improving its water holding capacity, it will lower the soil's erodibility and improve nutrient use efficiency. So, inorganic fertilizers will trigger a cascade of effects that all point in the direction of a more sustainable use of the natural resources.

The above conclusion only holds for the biophysical aspects of land use. In that respect the analysis presented in this thesis can only be a partial analysis of a complex problem. As said earlier true sustainability is much more complex and more elaborate tools such as modelling should be used (Chapter 2, 3 and 11).

Chapter 11

General discussion

In the limestone area, south of Malang, East Java, Indonesia, food security is the main reason for land use planning. Low food production is caused by the low productivity of traditional agricultural production systems and unfavourable climatic conditions. Farmers practice a form of agriculture primarily based on the use of local resources with modest use of external inputs, leading to degradation of these resources. Options for more sustainable agricultural production systems were studied through research with the central questions 'what happens' and 'what is possible'.

The method

In answering the question 'what happens', the current situation is described and characterized. The analysis aims to understand how outputs are determined by production ecological and environmental factors and inputs. In the explorative study, input-output relations are considered from the question 'what is possible' considering a chosen time horizon. The feasibility of various options is based on the bio-physical and technical limitations and possibilities that determine the potential production of crops and livestock. The results of the explorative study does not show blueprints for future land use nor the pathway for development, but may help to define strategic policy choices. It shows the boundaries from a technical and bio-physical point of view within the limits defined by agricultural or ecological preferences and thus serves to widen the perspective on future land use and natural resource management. In the explorative study socio-economic factors are purposely treated as exogenous parameters.

A new method (QFSA; van Rheenen, 1995) is developed for land use planning at farm level. In this thesis only that part of the method is presented which analyses and explores crop and livestock production at farm level. The crop and livestock production systems were studied in relation to their productivity and demand on natural resources.

The approach used in this thesis, does not consider socio-economic constraints, like ownership of the means of production, distribution of income and uncertain economic behaviour. This analysis avoids the very complex problems associated with these aspects of development and allows for full, untrammelled analysis of a wide range of technically feasible development options including innovative, unexpected ones. As a consequence, the results may raise too optimistic expectations for development in a region. For instance, a

development option may require common use of scarce resources, which are only possible through policy measures aiming at promoting or even forcing cooperation, and legislation is required to regulate such cooperation. Here the political dimension comes into play and the analysis can help to define the technical based benefits and costs that could motivate desirable change (de Wit et al., 1988).

Is the approach and the tool described in this thesis a panacea for rural development? Certainly not, and one should not attempt to use it for that purpose. It shows the various stakeholders in rural development which options are, in principle, possible - but it does not present a blueprint plan as to how one can reach these objectives. Before these options can be realised several constraints will have to be removed and these might very well lie outside the spheres of influence of the actors in the system being studied. A clear example of this is prices because individual farmers are only price takers. The approach is still a 'partial approach'. It analyzes the agricultural sector of a region at different levels, but it isolates this sector from other economic sectors (e.g. industry and services) and regions in a country. Therefore, it might overlook problems and opportunities in the non-agricultural sectors, as well as comparative (dis)advantages of other regions.

The analysis presented in this thesis should be followed by a farm household study as well as on-farm research. Farm household studies focus on ways to change the current situation in directions which have been depicted in explorative studies. In farm household studies, socio-economic factors are treated as endogenous variables. The results of farm household studies are indicative for the pace and directions of change in the particular farm type within the region.

The analysis

The activity concept (Chapter 3) forms a simple and flexible approach to describe crop and livestock systems. With simulation models 'possible' production levels are explored. To enable comparison of different crop production systems, livestock activities are quantified in a similar structure as crop activities, facilitating an integrated analysis of farm households. Interactions can exist between different cropping and livestock activities, either visible or invisible. A visible interaction is e.g. the application of manure to crops. In this case the inputs and outputs of both productions systems are quantified and balanced on farm level as well as village level. Invisible interaction is the case e.g. with the carrying over of enhanced soil fertility within catenas from a land unit at the upper slope to a land unit below.

In the present analysis only one yield figure is given per crop per production level, based on average conditions. To indicate the spread around this average, the standard error could be included in the analysis and the risks involved with each cropping system could be calculated. The same holds for the livestock systems, which do not take into account the variation of feed quality and quantity between years.

The static, descriptive crop and livestock activities are discrete points in a continuous space of input-output relations. This may cause problems when these activities are offered to

an optimisation model. The resulting optimal combination of activities is then not necessarily the 'true' optimal land use. For example, in the present analysis only one planting and harvesting date is given per crop per production level. It could well be, based on the labour availability, that earlier or later planting/harvesting is more suitable. Again, the same holds for the livestock system, in which a fixed conception date is taken. Considering e.g. the availability of labour, this is not necessarily the ideal date.

Dynamic models (as were used in this thesis), are relational models representing a part of reality, designed to explore the dynamics of certain behaviour or processes through simulations. These models are not concerned with the institutional context at inter-household level in which natural resource management takes place and, treat farm households as completely uniform entities. As a consequence, there are several points in these models which, from a village level point of view, are grossly simplified or even completely ignored, but which may nevertheless be crucial to both the understanding and the development of resource use and management on village level (Nibbering, 1995).

It is implicitly assumed that access to resources is uniform and static and resource use is only subject to physical constraints. Consequently, there is no place for such phenomena as differential access to (natural) resources by different groups in the community. At the village level differentiation between farm households are very important in understanding and planning for natural resource management. While generally no differentiation is made between household types, no differentiation is made within households either.

All models incorporate the input-output links between crop husbandry and animal husbandry by which these activities support one another. However, those situations in which these or other activities may hamper or obstruct one another are not accounted for.

Sustainability being one of their principal concerns, all models have incorporated the effects of human action on the physical environment in one way or another. However, these effects are in all cases restricted to on-site effects. Any environmental spill-over to other places, be it positive or negative, is not taken into account. Examples are: run-off, sedimentation, enrichment of nutrients, changes in the water table. In order to deal with sustainability in a comprehensive way, these spatial connections should be part of both predictive and evaluative simulation models dealing with resource utilization and management.

How to develop a village model that incorporates differential access to individual and shared resources, different farm household types, internal farm household dynamics, low compatibility of resource utilization, and, environmental interactions? The only way to model for households or groups of these, which have both individual resource endowments and access to shared resources and which may be different in other respects as well, is to enable these units or groups of units to operate independently in the model. They should, however, be permitted to interact in such a way that whenever there is collaboration or conflict, the gains and losses for all the groups concerned can be shown. This will be the case when there are one or more shared resources involved (Nibbering, 1995).

The activities constructed are not necessarily sustainable. Sustainability in this thesis was defined in terms of organic matter, nutrient balances and erosion. These sustainability criteria

are incorporated at land unit level, which restricts a full analysis of land use. If interactions occur between alternative forms of land use (such as crops with a high fertiliser input succeeding a crop with a lower fertiliser input on the same land unit) the sustainability of both might compensate each other. In this way a non-sustainable crop activity might be selected in one year, followed by another so that on the long term still sustainable land use is achieved. Sustainability has agricultural, socio-economic and ecological dimensions. The design of options for sustainable land use requires normative weighing of more or less conflicting objectives. The difference between the options for sustainable agricultural production systems show the trade-off between the various dimensions of sustainable development.

Data

Data gathering often causes problems since, research at farm level requires more detailed data compared to e.g. regional level, and the higher the costs. Agricultural research with a farming systems perspective usually suffers from the collection of masses of baseline data, in the mistaken belief that data-gathering is always useful (Morris, 1991). Data collection will always be an important part of the procedure, but it should be clearly imbedded in research questions and therefore be selective. Uncertainty as to the usefulness of data at the start of a research effort should be reduced by means of pre-scanning studies that will point out the topics on which to concentrate. Likewise, more and better qualitative work will reduce the need for excessive quantitative work, and a number of small, but focused surveys are preferable to a comprehensive one trying to cover everything.

A point of criticism is that data collection procedures are time consuming and that it often results in a great degree of detail of work that is not reflected in the final conclusions. Data collection should be increasingly geared to properties that are functional to agricultural production and resource management. The gathering of field data often causes a delay in the research development and operationalizing of models, as was the case in this thesis. With more and more good data bases available, increased thought should be given during the research preparation about which data can be taken from literature and which have to be obtained from field experiments.

It is advisable to keep the modelling research methodology as simple as possible and its gestation period as short as possible. Simplicity will make it easier for stakeholders to work with the method and to interpret its outputs. The sooner one has agreed on general development perspectives, the sooner one can proceed to the setting of research priorities, like data gathering, on-farm testing etc.. Development paths can then be designed, which tackle the various obstacles to development, while taking into account short term considerations that stakeholders may have. This may require additional field studies. For the method, presented in this thesis, this means that quick and inevitably sometimes dirty methods to find the necessary data input on farm household resources, farm household objectives as well as input-output coefficients, will have to be used to speed up the entire research and development

process.

The validity of the models used in this thesis depends on many factors. These include the accuracy of the technical coefficients and the proper definition and quantification of the production orientations. Technical coefficients for present production techniques often are determined with sufficient accuracy on the basis of the general body of knowledge in a region. However, there is danger that the technical coefficients of alternative production techniques are estimated too optimistically by their advocates and critical evaluation is, therefore, necessary. Equally important are the goal variables, which are often difficult to identify, difficult to translate into terms suitable for the model and difficult to quantify. The main shortcoming of the calculation procedure is that values of some input and output determinants varied largely in literature, for example manure nutrient contents. Validation of the models was difficult because of the lack of independent data sets.

The results

Palte (1989) discusses several land use systems practiced in Java's uplands. With data from various case studies, he shows convincingly the ecological and economic superiority of mixed gardens over systems with predominantly annual crop cultivation. The successful planting of trees have revealed that damage inflicted to the productive capacity of the land has not been as great and irreparable as thought. This planting keeps degradational effects at a much reduced level, sufficiently low to maintain the present productive capacity for a considerable time to come. However he seems to rule out the possibility that within each land use system, land management can be practiced in a range of forms, with varying intensities. This thesis explores different crop yield levels and different types of management.

There is a potential for the improvement of field crop production on valley bottoms, which can be achieved with higher cash inputs, but that might expose farmers to greater financial risks. The possibilities for increasing the productivity of field crops on hillsides appear small. Here, expansion of garden crop cultivation may be an alternative avenue to achieve higher incomes for hillside cultivation in combination with agro-forestry aimed at the production of firewood, charcoal and perhaps timber for sale.

Agricultural production in marginal areas is usually described by stereotypes of low production and productivity. Ellis (1988) distinguishes two approaches with regard to technical change in agriculture: the improvement approach and the transformation approach. The improvement approach assumes that farmers are technically inefficient and that farmers education and extension has a major role to play in development. The transformation approach assumes that peasants are efficient within the constraints of existing technology, and that a dramatic change in technology is necessary for development. Crop production is done most efficiently, especially regarding perennials, and therefore in this case only the transformation approach is applicable. Farmers participating in the research can be considered as inefficient regarding actual livestock production, and technical change can be achieved through the improvement approach. The latter conclusion is explained below.

Farmers select the type of forage that should be offered to their cattle. The resulting ration comprised a mixture of a range of forage qualities. The composition and amount are changing over time due to daily access to the resources. The feeding balance data in this thesis show that there is scope to improve lower quality forage by supplementing it with better quality feeds. However, farmers in the research area have the attitude of utility maximizers rather than profit maximizers. Their practice is to offer all of the daily accessible forages to the animals. The use of feeding standards to match the feed offered with the production target of different cattle classes is a complex procedure. The bottleneck for farmers is probably the high variability of the system, expressed in the physiological status and history of the animals, highly variable feed offer, selective consumption and composition of the produce. Also, it could be quite complex for farmers to monitor when the marginal cost equals the marginal return for maximum profit from individual cattle as compared to the simple premise that the bigger the cattle the more money can be obtained.

Potential livestock production can be achieved through the transformation approach, in which transformations outside the livestock production system, like infrastructure, are also required. In this thesis it was concluded that the use of concentrates gave much higher production figures compared to the actual feeding practices. Why has this technology not yet practiced in the research area? The inability of farmers to finance the cost of a new technology is a problem whether it is for crop improvement, soil conservation or ruminant production programmes (van Duivenbooden, 1995; Smaling, 1993; van Rheenen, 1995; Kaasschieter et al., 1992). Ifar (1996) observed that cost is not the only factor that may hinder the acceptance of a new technology. Ownership of the cattle may play a role in the implementation of new technology as well. Farmers with shared cattle may be reluctant to pay the cost of the new technology if half of the outputs must go to the owner of the cattle.

Explanations for the composition of a diet are diverse. Begon et al. (1990) describe the "optimal foraging theory" which specifically applies to range animals. The aim of optimal foraging theory is to predict the foraging strategy to be expected under specified conditions. In the case of stall fed animals it is the household members who gather feed for the animals. The question is whether the optimal foraging theory applies to people in search of food for animals in the study area. Easiness is certainly a factor that is also taken into account by farmers in collecting forage. Especially, farmers in Putukrejo mentioned that they prefer to collect crop residues instead of grasses or tree leaves.

Research agenda

Sustainability should become an integral part of land use policies in Indonesia. Integrated nutrient management should become practice, and development activities that address components of integrated nutrient management (increased fertilizer use efficiencies, agro-forestry, soil conservation, N-fixing species) should be appreciated as serving sustainable land use. Farmers indigenous practices should also be seen in this context. Fertilizer recommendations to farmers should be according to the requirements of both crops and soils.

Research on agro-forestry performance should be increasingly judged on its contribution to sustainability, implying both collection of technical data (species performance, contribution from N-fixation), and data on farmers adoption rates. The latter should be compared with performance of indigenous systems, in order to assess whether suggested additional investments by farmers will endure once project structures usually involved with incentives are abolished.

The nutrient balance is quantified using primary data, estimates and assumptions. To improve the quality and reliability of such nutrient balances, further research is needed on nutrient losses by processes which have been poorly quantified in the field, and which at the same time have a substantial impact on the nutrient balance. Such processes are the uptake of nutrients by different crop species under different land units and crop cultivations types, leaching, denitrification and erosion.

Modelling approaches in general should be centered more on implementation and user application, to ensure proper management decisions. Too few models are actually used by others than the developer.

Spatial variability at field level showed that extrapolation of research results to a regional level is difficult. Adapted research is needed on how to tackle this variability in order to still extrapolate survey results. 'Scaling up and down' is a challenge not only for agricultural scientists but for policy decision makers at the different hierarchical levels in the agricultural society as well.

Although simulation models are useful tools during the analysis of the bio-physical sub-system, none are available as yet that deal with the effects of pests, weeds, diseases and different operations concurrently. The development of more comprehensive models combining specified operation sequences with crop growth modelling is therefore a research priority. The analysis of land use should include multiple years to account for interactions which occur between alternative forms of land use, since the sustainability of the different land uses might compensate each other.

References

- AFRC, 1991. A reappraisal of the calcium and phosphorus requirements of sheep and cattle. In: Nutrition abstracts and reviews (Series B). September 1991. Commonwealth Agricultural Bureaux, London, England, p. 573-612.
- Amber, S., 1986. Aspect of vegetation and land use in the erosion process in the Jatiluhur lake catchment, West Java. MSc-thesis, Padjadjaran University, Bandung, Indonesia.
- ARC, 1980. The nutrient requirements of ruminant livestock. Technical review by an agricultural research council working party, Commonwealth Agricultural Bureaux, Slough.
- ASAE, 1975. Agricultural machinery management data. Agricultural Engineers Yearbook. American Society of Agricultural Engineers, St. Joseph, MI, p. 347-354.
- Ash, A.J., 1990. The effect of supplementation with leaves from the leguminous trees *Sesbania grandiflora*, *Albizia chinensis* and *Gliricidia sepium* on the intake and digestibility of Guinea grass hay by goats. *Animal Feed Science Technology* 28: 225-232.
- Azzam, S.M., Kinder, J.E. & M.K. Nielsen, 1990. Modelling reproductive management systems for beef cattle. *Agricultural Systems* 34: 102-122.
- Baile, C.A. & J.M. Forbes, 1974. Control of feed intake and regulation of energy balance in ruminants. *Physiological Reviews* 54: 160-214.
- Begon, M., Harper, J.L. & C.R. Townsend, 1990. Ecology: individuals, populations and communities. Blackwell Scientific Publications.
- Benzie, D., Boyne, A.W., Dalgarno, A.C., Duckworth, J. & R. Hill, 1959. Studies on the skeleton of sheep. II. The relationship between phosphorus intake and resorption and repair of the skeleton in pregnancy and lactation. *J. of Agric. Sci.* 52: 1-12.
- Bessembinder, J., 1995. Uncertainties in input-output coefficients for land use optimization studies: an illustration with fertilizer use efficiency. *Neth. J. of Agric. Sci.* 43: 47-59.
- Biro Pusat Statistik, 1992. Sensus Pertanian, Jakarta.
- Boekholt, H.A., 1976. De stikstofhuishouding van het melkrund en de betekenis van de gluconegenese uit aminozuren. PhD-thesis. Wageningen Agricultural University, The Netherlands.
- BORIF, 1986. Bogor Research Institute for Food Crops. Unpublished data.
- BPS, 1986. Sensus Pertanian. Biro Pusat Statistik, Jakarta.
- Braithwaite, G.D., 1984. Some observations on phosphorus homeostasis and requirements of sheep. *J. of Agric. Sci.* 102: 295-306.
- Braithwaite, G.D., 1985. Endogenous faecal loss of phosphorus in growing lambs and the calculation of phosphorus requirements. *J. of Agric. Sci.* 105: 67-72.

- Breman, H., 1992. Agro-ecological zones in the Sahel: potentials and constraints. In: *Poverty and Development*. 4. Sustainable development in semi-arid sub-saharan Africa. Royal Tropical Institute, Amsterdam, p. 19-36.
- Brody, S., 1937. Relativity of physiologic time and physiologic weight. *Growth* 1: 60-67.
- Brody, S., 1945. *Bioenergetics and growth*. Reinhold Publishing Corporation, New York.
- Bruijnzeel, L.A., 1983. Hydrological and biogeochemical aspects of man-made forests in South-Central Java, Indonesia. PhD-thesis. Free University, Amsterdam, The Netherlands.
- Budelman, A. & F. van der Pol, 1992. Farming Systems Research and the quest for a sustainable agriculture. *Agroforestry Systems* 19: 187-207.
- Burrough, P.A., 1989. Matching spatial databases and quantitative models in land resource assessment. *Soil Use Management* 5: 3-8.
- Byerlee, D. & M.P. Collinson, 1980. Planning Technologies appropriate to farmers: Concepts and Procedure. CIMMYT, El Batan, Mexico.
- Census Penduduk, Kantor Statistik Malang, 1990
- Chowdhury, S.L. & P.C. Bhatia, 1971. Ridge planted kharif pulses yield high despite waterlogging. *Indian Farming* 21(3): 8-9.
- Cissé, L., 1988. Influence d'apports de matière organique sur la culture de mil et d'arachide sur un sol sableux du Nord Senegal. II. Développement des plantes et mobilisations minérales. *Agronomie* 8: 411-417.
- Cohen, R.D.H., 1980. Phosphorus in rangeland nutrition: a review. *Livestock Production Science* 7: 25-37.
- Coker, E.G., Hail, J.E., Cariton-Smith, C.H. & D.D. Davies, 1987. Field investigations into manural value of lagoon-matured digested sewage sludge. *Journal of Agricultural Science (Cambridge)* 109: 467-478.
- Collinson, M.P., 1987. Farming Systems Research: Procedures for Technology Development. *Expl. Agric.* 23: 365-386.
- Commonwealth Agricultural Bureaux, Agricultural research Council, 1984. The nutrient requirements of ruminant livestock, Supplement no. 1 Lavenham Press, Lavenham, UK.
- Conrad, H.R., 1966. Symposium on factors influencing the voluntary intake of herbage by ruminants: physiological and physical factors limiting feed intake. *Journal of Animal Science* 25: 227-235.
- Conway, G.R., 1985. Agro-ecosystem Analysis. *Agricultural Administration* 20: 31-55.
- Conway, G.R., 1987. The properties of agroecosystems. *Agricultural Systems* 24: 95-117.
- Dames, T.W.G., 1955. The soils of east Central Java, with a soil map 1:250000. Contributions of the General Agricultural Research Station No. 141, Bogor, Indonesia.
- Danfaer, A., 1991. Mathematical modelling of metabolic regulation and growth. *Livestock Production Science* 27: 1-18.

- Denham, S.C., Larsen, R.E., Boucher, J. & E.L. Adams, 1991. Structure and behaviour of a deterministic model of reproductive performance in beef cattle. *Agricultural Systems* 35: 21-36.
- Deshpande, A.N., Patil, S.S. & S.Y. Daftardar, 1983. Effect of application of rock phosphate incorporated in farmyard manure on phosphorus uptake and yield of lowland rice. *Indian Journal of Agriculture and Chemistry* 15: 163-167.
- Dewes, T., Schmitt, L., Valentin, U. & E. Ahrens, 1990. Nitrogen losses during the storage of liquid livestock manures. *Biological Wastes* 31: 241-250.
- Dicko-Toure, M.S., 1980. Measuring the secondary production of pasture: An applied example in the study of an extensive production system in Mali. In: *Browse in Africa. The current state of knowledge*. H.N. Le Houerou (ed). ILCA, Addis Ababa, Ethiopia, p. 247-252.
- Diepen, C.A. van, Keulen, H. van, Wolf, J. & J.A.A. Berkhout, 1991. Land evaluation: from intuition to quantification. *Advances in Soil Science* 15: 140-197.
- DIPERTA, 1990. Dinas Pertanian. Surabaya.
- Dommergues, Y.R., 1987. The role of biological nitrogen fixation in agroforestry. In: *Agroforestry: a decade of development*. P.K.R. Nair & Stepler (eds.). ICRAF, Nairobi, p. 245-271.
- Dongen, R.P.M. van, 1991. The use of geo-statistics on behalf of farming systems analysis in East Java. INRES-project. MSc-thesis. Wageningen Agricultural University.
- Doorenbos, J. & A.H. Kassam, 1986. Yield response to water. *FAO irrigation and drainage paper* 33. FAO, Rome.
- Driessen, P.M. & N.T. Konijn, 1992. Land-use systems analysis. Wageningen Agricultural University. Department of Soil Science and Geology: Malang, INRES.
- Duivenbooden, N. van, 1989. Contributions of various feed components to feed availability in integrated barley/livestock systems in the north-western coastal zone of Egypt: a simulation study. *Journal of Arid Environments* 16: 217-228.
- Duivenbooden, N. van, 1992. Sustainability in terms of nutrient elements with special reference to West-Africa. Agricultural Research Department. Centre for Agrobiological Research. Report 160.
- Duivenbooden, N. van, 1995. Land use systems analysis as a tool in land use planning: with special reference to North and West African agro-ecosystems. PhD-thesis. Wageningen Agricultural University, The Netherlands.
- Dunn, T.G. & G.E. Moss, 1991. Effects of nutrient deficiencies and excesses on reproductive efficiency of livestock. *Journal of Animal Science* 70: 1580-1593.
- Edmundson, W.C. & S.A. Edmundson, 1983. A decade in village development. *Bull. Ind. Econ. Studies* 29 (2): 46-59.

- Efdé, S.L. & T. van Rheenen, 1994. Quantifying livestock production of farming systems in the limestone area of east-Java. In: Biological basis of sustainable animal production. E.A. Huisman, J.W.M. Osse, D. van der Heide, S. Tamminga, B.J. Tolkamp, W.G.P. Schouten, C.E. Hollingworth & G.L. van Winkel (eds.). EAAP publication No. 67, Wageningen Pers, Wageningen, The Netherlands.
- Effendi, 1980. The efficiency of fertilizer use by non-rice crops. Central Research Institute for Agriculture. Bogor.
- EFHS, 1992. Expanded Farm Household Survey. Interdisciplinary Research Project. Malang. Indonesia.
- Ellis, F., 1988. Peasant Economics. Farm households and Agrarian Development. Cambridge, Cambridge University Press.
- Ellison, W.D., 1947. Soil erosion studies - part I. Agric. Eng. 28: 145-146.
- Elzein, A. & J. Balesdent, 1995. Mechanistic simulation of vertical distribution of carbon concentrations and residence times in soils. Soil Sci. Soc. Am. J. 59: 1328-1335.
- Erenstein O.C.A. & R.A. Schipper, 1993. Nutrient availability classification of soils used for maize in Rio Jimenez district, Atlantic Zone of Costa Rica. Field report 35, Convenio CATIE/MAG/WAU.
- Euroconsult, 1989. Agricultural compendium for rural development in the tropics and subtropics. Elsevier, Amsterdam.
- Falvey, J.L., 1982. *Gliricidia maculata* - a review. International Tree Crops Journal 2: 1-14.
- FAO, 1972. Food consumption table for use in East Asia. Washington, D.C.
- FAO, 1976. A framework for land evaluation. FAO Soils Bulletin, 32. FAO, Rome, Italy.
- FAO, 1983. Guidelines: land evaluation for rainfed agriculture. FAO Soils Bulletin, 52. FAO, Rome, Italy.
- FAO, 1984. Land evaluation for forestry. FAO Forestry Paper, 48. FAO, Rome.
- FAO, 1991. FARMAP 5.0, Farm Analysis Package. Farm management and Production Economics Service (AGSP). Rome, Italy.
- FAO/WHO, 1973. Energy and protein requirements. Technical Report Series No. 522, Geneva.
- FHS, 1990-1992. The farm household survey. Interdisciplinary Research Project. Malang, Indonesia.
- Floate, M.J.S., 1981. Effects of grazing by large herbivores on nitrogen cycling in agricultural ecosystems. In: Terrestrial nitrogen cycles. F.E. Clark & T. Rosswall (eds.). Ecol. Bull. 33, Swedish Natural Research Council, Stockholm, p. 585-601.
- France, J., Gill, M., Thornley, J.H.M. & P. England, 1987. A model of nutrient utilization and body composition in beef cattle. Animal Production 44: 371-385.
- Fresco, L.O., 1986. Cassava in shifting cultivation. A systems approach to agricultural technology development in Africa. Royal Tropical Institute, Amsterdam.
- Fresco, L.O., 1988. Farming Systems Analysis, an introduction. Tropical Crops Communication. No. 13. Dept. of Tropical Crop Sciences, Wageningen Agricultural University, P.O. Box 341, 6700 AH Wageningen, The Netherlands.

- Fresco, L., Huizing, H. van Keulen, H., Luning, H. & R. Schipper, 1989. Land evaluation and farming systems analysis for land use planning. FAO guidelines: Working document. Rome, Italy.
- Fresco, L.O. & S.B. Kroonenberg, 1992. Time and spatial scales in ecological sustainability. *Land Use Policy* 14: 155-168.
- Geerling, C. & S. de Bie, 1986. The concept of carrying capacity and land-use. *Neth. J. of Agric. Sci.* 34: 339-347.
- Gilbertson, C.B., Doran, J.W. & R.M. Hill, 1981. The effect of total solids content, temperature and storage depth on nitrogen content of stored beef cattle manure. In: *Livestock waste. A renewable resource.* Am. Soc. Agric. Eng., St Joseph, MN, p. 395-398.
- Grace, N.D., 1983. The mineral requirements of grazing ruminants. *New Zealand Society of Animal Production.*
- Hagerman, A.E., Robbins, C.T., Weerasuriya, Y. & T.C. Wilson, 1992. Tannin chemistry in relation to digestion. *J. Range Management* 45: 57-92.
- Hanley, T.A., Robbins, C.T., Hagerman, A.E. & C. McArthur, 1992. Predicting digestible protein and digestible dry matter in tannin-containing forages consumed by ruminants. *Ecology* 73: 537-541.
- Hanson, A.A., 1990. *Practical handbook of agricultural sciences.* CRC Press, Boca Raton, FL.
- Hari Hartadi, Soedomo Reksodiprodjo, Soekanto Lebdosukojo, Tillman, A.D., Kearn, L.C. & L.E. Harris, 1980. *Tables of feed composition for Indonesia.* Universitas Gadjah Mada, Yayasan Rockefeller. International Feedstuffs Institute, Utah Agricultural Experiment Station, Utah State University, Logan, Utah, USA.
- Heemskerk, W., 1994. *Manure use in Western Province.* Unpublished. KIT. Amsterdam.
- Heemst, H.D.J. van, 1988. Plant data values required for simple crop growth simulation models: review and bibliography. *Simulation Report CABO-TT nr.17.* Wageningen. The Netherlands.
- Hengsdijk, H. & G. Kruseman, 1993. Operationalizing the DLV program: an integrated agro-economic and agro-ecological approach to a methodology for analysis of sustainable land use and regional agricultural policy. *DLV report 1, DLO/WAU, Wageningen.*
- Hirooka, H. & Y. Yamada, 1990. A general simulation model for cattle growth and beef production. *Asian-Australian Journal of Animal Science* 3: 205-218.
- Hudson, N., 1986. *Soil conservation.* Revised reprint. Batsford, London.
- ICAR, 1969. *Handbook of Agriculture.* Indian Council of Agricultural Research. New Delhi.
- Ifar, S., Solichin, A.W., Udo, H.M.J. & G. Zemmeling, 1996. Access to cattle via sharing for subsistence farmers in the limestone area of East Java, Indonesia. *Asian-Australian Journal of Animal Science.* (accepted)
- Ifar, S., 1996. *Relevance of ruminants in upland mixed farming systems in East Java, Indonesia.* PhD-thesis. Wageningen Agricultural University, The Netherlands. (in preparation)

- ILCA, 1983. Rapport de recherche no. 1. Tendances et perspectives de l'agriculture et de l'élevage en Afrique sub-saharienne. Addis Ababa, Ethiopia.
- Ingram, J.A. & M.J. Swift, 1989. Sustainability of cereal-legume intercrops in relation to management of organic matter and nutrient cycling. *Farm. Syst. Bull. East Southern Africa* 4: 7-21.
- INRA, 1988. Alimentation des Bovins, ovins et caprins. Edited by R. Jarrige. INRA Publications. Versailles, France, p. 95-111.
- Janssen, B.H., Guiking, F.C.T., Eijk, D. van der, Smaling, E.M.A., Wolf, J. & H. van Reuler, 1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). *Geoderma* 46: 299-318.
- Janssen, B.H., 1993. Integrated nutrient management: the use of organic and mineral fertilizers. In: H. van Reuler & W.H. Prins (eds.). *The role of plant nutrients for sustainable food crop production in Sub-Saharan Africa*. Dutch Association for Fertilizer Producers (VKP), Leidschendam, The Netherlands, p. 89-105.
- Jenkinson, D.S., 1978. The soil biomass. CSIRO Report.
- Jenkinson, D.S. & J.H. Rayner, 1977. The turnover of soil organic matter in some of the Rothamsted classical experiments. *Soil Sci.* 123: 298-305.
- Jensen, M., 1990. Nutrient budget of a javanese homegarden. A study in Soreang, west Java. MSc-thesis. Institute of Plant Ecology. Copenhagen University.
- Johnson, A.K.L., Cramb, R.A. & J.R. McAlpine, 1994. Integrated land evaluation as an aid to land use planning in northern Australia. *Journal of Environmental Management* 40: 139-154.
- Jordan, C.F., 1985. Nutrient cycling in tropical forest ecosystems. Principles and their application in management and conservation. John Wiley and Sons.
- Kaasschieter, G.A., Jong, R. de, Schiere, J.B. & D. Zwart, 1992. Towards a sustainable livestock production and health in developing countries. *Vet. Quart.* 14: 66-75.
- Kahn, H.E. & C.R.W. Spedding, 1983. A dynamic model for the simulation of cattle herd production systems: Part 1 - General description and the effects of simulation techniques on model results. *Agricultural Systems* 12: 101-111.
- Kemp, A. & J.H. Geurink, 1978. Grassland farming and minerals in cattle. *Neth. J. of Agric. Sci.* 26: 161-169.
- Kennedy, P.M., Christopherson, R.J. & L.P. Milligan, 1986. Digestive responses to cold. In: Control of digestion and metabolism in ruminants. L.P. Milligan, W.L. Grovum & A. Dobson (eds.). *Proceedings of the sixth international symposium on ruminant physiology*, Banff, Canada, p. 285-306.
- Kessler, J.J., 1994. Usefulness of the human carrying capacity concept in assessing ecological sustainability of land-use in semi-arid regions. *Agriculture, Ecosystems and Environment* 48: 273-284.
- Keulen, H. van, & H.D.J. van Heemst, 1982. Crop response to the supply of micronutrients. *Agricultural Research Report* 916. Pudoc, Wageningen, The Netherlands.

- Keulen, H. van, & J. Wolf, 1986. Modelling of agricultural production: weather, soils and crops. Simulation Monograph, Pudoc, Wageningen.
- Keulen, H. van, 1992. Options for agricultural development: a new quantitative approach. In: F.W.T. Penning de Vries & P.Teng (eds.). Systems approaches to agricultural development. Kluwer, Dordrecht, The Netherlands.
- Khombe, C.T., Dube, I.A. & P. Nyathi, 1992. The effects of kraaling and stover supplementation during the dry season on body weights and manure production of Mashona steers in Zimbabwe. *African Livestock Research* 1: 18-23.
- Kiepe, P., 1995. No runoff, no soil loss: soil and water conservation in hedgerow barrier systems. PhD-thesis. Wageningen Agricultural University, The Netherlands.
- Kirchmann, H., 1985. Losses, plant uptake and utilization of manure nitrogen during a production cycle. *Acta Agriculture Scandinavia. Supplementum* 24.
- Kleiber, M., 1961. The fire of life. An introduction to animal energetics. John Wiley and Sons, Inc., New York, London.
- Konandreas, P.A. & F.M. Anderson, 1982. Cattle herd dynamics: an integer and stochastic model for evaluating production alternatives. ILCA Research Report No. 2, International Livestock Centre for Africa, Ethiopia.
- Koning, G.H.J. de, Janssen, H. & H. van Keulen, 1992. Input and output coefficients for various cropping and livestock systems in the European Communities. Working document 62. Netherlands Scientific Council for Government Policy, The Hague, The Netherlands.
- Krantz, B.A., Kampen, J. & S.M. Virmani, 1978. Soil and water conservation and utilization for increased food production in the Semi Arid Tropics. *International Society of Soil Science Abstract* 1: 327.
- Kuyper, J. & W. Mellink, 1983. Supply, demand and consumption of fuelwood for rural households in central Java. Department of Forestry Management. Wageningen Agricultural University.
- Lafren, J.M., Lal, R. & S.A. El-Swaify, 1990. Soil erosion and sustainable agriculture. In: C.A. Edwards, R. Lal, P. Madden, R.H. Miller and G. House (eds.). Sustainable agricultural systems. Soil Water Cons. Soc., Ankeny, Iowa, p. 569-581.
- Ladd, J.N., Amato, M. and J.M. Oades, 1985. Decomposition of plant material in Australian soils. III. Residual organic and microbial biomass C and N from isotope-labelled legume material and soil organic matter, decomposing under field conditions. *Australian Journal of Soil Research* 23: 603-611.
- Lanen, H.A.J. van, 1991. Qualitative and quantitative physical land evaluation: an operational approach. PhD-thesis Wageningen Agricultural University, The Netherlands.
- Langer, D.L., Jackson, J.A., Hemken, R.W. & R.J. Harmon, 1985. Effect of level and source of phosphorus fed to dairy calves. *J. of Dairy Sci.* 68 (Suppl. 1): 136.

- Lawrence, P.R., 1985. A review of the nutrient requirements of draught oxen. In: *Draught animal power for production*. J.W. Copland (ed.). Proceedings of an international Workshop held at James Cook University, Townsville, ACIAR Proceedings no. 10, p. 59-63.
- Lawrence, P.R. & R.J. Stibbards, 1990. The energy costs of walking, carrying and pulling loads on flat surfaces by Brahman cattle and swamp buffalo. *Animal Production* 50: 29-39.
- Lee, J. van der, 1991. Dierlijke trekkracht, een uitgerekende zaak - Ontwerp en validatie van een trekkrachtmodule voor PCHerd. MSc-thesis. Department of Tropical Animal Production. Wageningen Agricultural University. Internal Publication.
- Lee, J. van der, Udo, H.M.J. & B.O. Brouwer, 1993. Design and validation of an animal traction module for a smallholder livestock systems simulation model. *Agricultural Systems* 43: 199-227.
- Levine, J.M., Hohenboken, W. & A. Gene Nelson, 1981. Simulation of beef cattle production systems in the Llanos of Colombia - Part 1. Methodology: an alternative technology for the tropics. *Agricultural Systems* 4: 37-48.
- Lhoste, P., 1987. L'association agriculture-elevage: evolution du systeme agropastoral au Sine-Saloum (Senegal). IEMVT, Paris.
- Li, Changsheng, Frohling, S. & T.A. Frohling, 1992. A model of nitrous oxide evolution from soil driven by rainfall events: 1. Model structure and sensitivity. *Journal of Geophysical Research* 97 (D9): 9759-9776.
- Loon, E. van, 1992. Soil to till, hoe to plough, cow to rest & task to time. Land preparation in south-west Malang, Java. MSc-thesis. Department of Agricultural Engineering. Wageningen Agricultural University. Internal Publication.
- Lowry, J.B. & B. Tangewijaya, 1982. Induction of leucaena detoxification in Australian goats. In: *Research report for 1982, Project for animal research and development, BPT, Ciawi*, p. 37-38.
- Ludwig, D., Hilborn, R. & C. Walters, 1993. Uncertainty, resource exploitation, and conservation: lessons from history. *Science* 260: 17-18.
- Lundgren, B., 1978. Soil condition and nutrient cycling under natural and plantation forest in Tanzanian highlands. Report in forest ecology and forest soils. Dep. of forest soils, Swedisch University of Agricultural Sciences.
- Manston, R., & M.J. Vagg, 1970. Urinary phosphate excretion in the dairy cow. *J. of Agric. Sci.* 74: 161-167.
- Mathers, J.C., Pearson, R.A., Sneddon, J.C., Matthewman, R.W. & A.J. Smith, 1985. The use of draught cows in agricultural systems with particular reference to their nutritional needs. In: *Milk Production in Developing Countries*. A.J. Smith (ed.). Proceedings of a conference held in Edinburgh. Centre for Tropical Veterinary Medicine, Edinburgh, p. 476-496.
- Meyer, L.D. & Wischmeier, W.H., 1969. Mathematical simulation of the process of soil erosion by water. *Trans. Am. Soc. Agric. Eng.* 12(6): 754-758, 762.

- McDowell, L.R., 1992. Minerals in animal and human nutrition. Department of Animal Science. University of Florida. Gainesville, Florida, U.S.
- McGill, N.B. & R.J.K. Myers, 1987. Controls on the dynamics of soil and fertilizer nitrogen. In: Soil fertility and organic matter as critical components of production systems. R.F. Folett, J.W.B. Stewart & C.V. Cole (eds.). Systems. Special Publ. 19, SSSA, Madison, p. 73-99.
- Minson, D.J., 1990. Phosphorus in ruminant nutrition. In: Forage in ruminant nutrition. Commonwealth Scientific and Industrial Research Organisation. St. Lucia, Queensland, Australia, p. 230-264.
- Molen, P. van der, & J.W. Schultink, 1994. Nutritional consequences of different land utilisation types and different income sources. In: L.O. Fresco, L. Stroosnijder, J. Bouma and H. van Keulen (eds.). The future of the land; mobilizing and integrating knowledge for land use options. Chichester, John Wiley & Sons, p. 161-171.
- Morgan, R.P.C., 1986. Soil erosion and conservation. Longman, Harlow, UK, 298 pp.
- Morris, R.S., 1991. Information systems for animal health: objectives and components. Rev. Sci. Tech. Off. Int. Epiz. 10: 13-23.
- Morse, D., Head, H.H., Wilcoz, C.J., Horn, H.H. van, Hissem, C.D. & B. Harris., 1992. Effects of concentration of dietary phosphorus on amount and route of excretion. J. of Dairy Sci. 75: 3039-3049.
- Much, R.E. & T.S. Steenhuis, 1982. Nitrogen losses from manure storage. Agric. Wastes 4: 41-54.
- Mulungushi, S.J., 1986. Agricultural land use in Mongu South. MSc-thesis. ITC, Enschede.
- Naseeven, R., 1988. Sugarcane tops as animal feed. In: Sugarcane as feed. Sansoucy, R., Aarts, G. & Preston, T.R. (eds.). FAO Animal Health and Production Paper no. 72, 106-122.
- Nibbering, J.W.S.M., 1991. Hoeing in the hills. Stress and resilience in an upland farming system in Java. PhD-thesis. The Australian National University. Canberra, Australia.
- Nibbering, J.W., 1995. Modelling of resource utilization and management. Models presented at the PSS/DLV/ESPGRN-Sikasso workshop in Niono from 18-20 September 1994. Document de projet 27. Wageningen Agricultural University.
- Nijberg, A.J., 1975. Outlook for the Indonesian maize industry. Rockefeller Foundation.
- Nitis, I.M., Lana, K., Suarna, M., Sukanton, W. & S. Putra, 1989. Implementation of on-farm agroforestry research in Indonesia. In: Developments in procedures for farming systems research. S. Sukmana, P. Amir & D.M. Mulyadi (eds.). Proceedings of an international workshop, Bogor, Indonesia.
- Nitis, I.M., Lana, K., Suarna, M., Sukanton, W. & S. Putra, 1990. Three strata forage system. Role of the grass, shrub legume and fodder trees in increasing the productivity of smallholder dryland farming area. In proceedings of the seminar "Production and utilization of shrub legumes in the tropics", Den Pasar, Bali, Indonesia.
- Norman, D.W., 1978. Farming systems research to improve the livelihood of small farmers. Amer. J. Agric. Econ. 60: 813-818.

- NRC, 1981. Nutrient requirements of goats: Angora, dairy and meat goats in temperate and tropical countries. National Academy Press, Washington, D.C..
- NRC, 1985. National Research Council. Ruminant nitrogen usage. National Academy Press. Washington, D.C..
- NRC, 1989. Nutrient requirements of domestic animals. Nutrient requirements of dairy cattle. 6th revised edition. National Academy Press, Washington, D.C..
- NRLO, 1990. Handleiding mineralenonderzoek bij rundvee in de praktijk. 4de druk. Commissie Onderzoek Minerale Voeding. Nationale Raad voor Landbouwkundig Onderzoek, Den Haag.
- Nye, P.H. & D.J. Greenland, 1960. The soil under shifting cultivation. Technical communication no. 51. Commonwealth Bureau of soils, Harpenden.
- Oosting, S.J., 1993. Wheat straw as ruminant feed. Effect of supplementation and ammonia treatment on voluntary intake and nutrient availability. PhD-thesis. Wageningen Agricultural University. The Netherlands.
- Palte, J.G.L., 1989. Upland farming on Java, Indonesia. A socio-economic study of upland agriculture and subsistence under population pressure. Nederlandse geografische studies 97. Amsterdam/Utrecht.
- Parton, W.J., McKeown, B., Kirchner, V. & D. Ojima, 1992. Users guide for the CENTURY model. Natural Resource Ecology Laboratory. Colorado State University.
- Paul, E.A. & F.E. Clark, 1989. Soil microbiology and biochemistry. Academic press, New York.
- Pearson, R.A., 1993. Resource requirements for draught animal power. In: Proceedings of the British Society of Animal Production. Occasional Publication no. 16 on Animal Production in Developing Countries. Wye College.
- Perdock, U.D. & G. van de Werken, 1980. Grondbewerking. Relatie grondsoort vermogens- en arbeidsbehoefte (1). Landbouwmechanisatie 31(6): 66-71.
- Pichot, J., Sedogo, M.P., Poulain, J.F. & J. Arrivets, 1981. Evolution de la fertilité d'un sol ferrugineux tropical sous l'influence de fumures minérales et organiques. Agronomie Tropicale 26: 122-134.
- Pol, F. van der, 1992. Soil mining: an unseen contributor to farm income in southern Mali. Royal Tropical Institute, Amsterdam.
- Polman, F.J., Samad, M. & K.S. Thio, 1982. A demonstration of resource based socio-economic planning in Matara district. Agrarian Research and Training Institute, Colombo, Sri Lanka (Report No. 1 in: Regional Planning for Agricultural Development in Sri Lanka).
- Powell, J.M., 1986. Manure for cropping: a case study from central Nigeria. Expl. Agric. 22: 15-24.
- Powell, J.M. & M.A. Mohammed-Saleem, 1987. Nitrogen and phosphorus transfer in a crop-livestock system in West-Africa. Agricultural Systems 25: 261-277.

- Powell, J.M., Fernández-Rivera, S. & S. Höfs, 1994. Effects of sheep diet on nutrient cycling in mixed farming systems of semi-arid West Africa. *Agriculture, Ecosystems and Environment* 48: 263-271.
- Preston, T.R., 1992. The role of multipurpose trees in integrated farming systems in the wet tropics. In: Legume trees and other fodder trees as protein sources for livestock. In: Speedy, A.W. & Pugliese, P.L. (eds.). FAO, Animal Production and Health Paper. Rome, p. 193-209.
- Proyek Brantas, 1989. Working document, Malang, Indonesia.
- Quilfen, J.P. & P. Milleville, 1983. Residus de culture et fumure animale: un aspect des relations agriculture-elevage dans le nord de la Haute-Volta. *L'Agronomie Tropicale* 38: 206-212.
- Rajaratne, A.A.J., Scott, D., Buchan, W., & A. Duncan, 1990. The effect of variation in dietary protein of mineral supply on calcium and phosphorus metabolism in lactating ewes. *British J. of Nutrition* 64: 147-160.
- Rheenen, T. van, 1995. Farm household level optimal resource allocation. An explorative study in the limestone area of East Java. PhD-thesis. Wageningen Agricultural University. The Netherlands.
- Rittner, U. & J.D. Reed, 1992. Phenolics and in vitro degradability of protein fibre in West African browse. *J. Sci. Food Agric.* 58: 21-28.
- Robinson, P.J. & I.S. Thompson, 1988. Methodological issues in determining growth, yield and value of MPTS. In: Multipurpose tree species for small-farm use. D. Withington (ed.). Proceedings of an International workshop 1987. Thailand. Winrock International/IDRC.
- Roche, F.C., 1984. Production system. In: W.P Falcon, W.O. Jones & S.R. Pearson (eds.). Cassava economy of Java. Stanford University Press.
- Romney, D.L., Thorne, P.J. & D. Thomas, 1994. Some animal-related factors influencing the cycling of nitrogen in mixed farming systems in sub-Saharan Africa. *Agriculture, Ecosystems and Environment* 49: 163-172.
- Rose, C.W., 1993. Erosion and sedimentation. In: M. Bonell, M.M. Hufschmidt and J.S. Gladwell (eds.). Hydrology and water management in the humid tropics: hydrological research issues and strategies for water management. Unesco and Cambridge University Press, p. 301-343.
- Russelle, M.P., 1992. Nitrogen cycling in pasture and range. *J. Prod. Agric.* 5: 13-23.
- Ryden, J.C., Whitehead, D.C., Lockyer, D.R., Thompson, R.B., Skinner, J.H. & E.A. Garwood, 1987. Ammonia emission from grassland and livestock production in the U.K. *Environ. Pollut.* 48: 173-184.
- Sajogyo, 1977. Golongan miskin dan partisipasi dalam pembangunan desa, *Prisma* 6(3): 10-17.
- Sanders J.O. & T.C. Cartwright, 1979a. A general cattle production systems model. I: structure of the model. *Agricultural Systems* 4: 217-227.

- Sanders J.O. & T.C. Cartwright, 1979b. A general cattle production systems model. Part 2 - Procedures used for simulating animal performance. *Agricultural Systems* 4: 289-309.
- Schleich, K., 1986. The use of cattle dung in agriculture. *Natural Resources and Development* 23: 53-87.
- Shaner, W.W., Philipp, P.F. & W.R. Schehl, 1982. *Farming Systems Research and Development: guidelines for developing countries*. Westview Press, Boulder, Colorado, USA.
- Sharifi, M.A., 1992. Development of an appropriate resource information system to support agricultural management at farm enterprise level. PhD-thesis, WAU, Wageningen.
- Sharma, A.R. & B.N. Mitra, 1991. Effect of different rates of application of organic and nitrogen fertilizers in a rice based cropping system. *J. of Agric. Sci.* 117: 313-318.
- Singh, N. & V.D. Mudgal, 1985. Energy and protein requirements of goats for their maintenance and milk production. A review. *Indian J. Dairy Science* 38 (2): 156-163.
- Sluismans, C.M.J. & G.J. Kolenbrander, 1977. The significance of animal manure as a source of nitrogen in soils. *Proceedings International Seminar on Soil Environment and Fertilizer Management in Intensive Agriculture (Tokyo)*, p. 403-411.
- Smaling, E., 1993. An agro-ecological framework for integrated nutrient management, with special reference to Kenya. PhD-thesis. Wageningen Agricultural University. The Netherlands.
- Smith, O.B. & M.F.J. van Houtert, 1987. The feeding value of *Gliricidia sepium*. A review. *World Animal Review* 62: 57-68.
- Soemarwoto, O., 1987. Homegardens: a traditional system with a promising future. In: *Agroforestry: a decade of development*. P.K.R. Nair & Steppeler (eds.). ICRAF, Nairobi, p. 157-170.
- Soest, P.J. van, 1987. *Nutritional ecology of the ruminant*. Cornell University Press, Ithaca, NY.
- Soetarjo Brotonegoro, O.J. Laumans & J.Ph. van Staveren, 1986. Food crops other than rice in east Java agriculture. Palawija. Malang Research Institute for Food Crops. Indonesia.
- Soil Research Centre Bogor, 1983. A land evaluation study.
- SOW, 1981. Summary description of Thailand agricultural model, THAM-1. Research report SOW-80-2. SOW, Amsterdam.
- Spiekens, H., Brintrup, R., Ballmelli, M. & E. Pfeffer, 1993. Influence of dry matter intake on faecal phosphorus losses in dairy cows fed rations low in phosphorus. *J. Anim. Physiol. and Anim. Nutr.* 69: 37-43.
- Spitters, C.J.T., Keulen, H. van, & D.W.G. van Kraalingen, 1989. A simple and universal crop growth simulator: SUCROS87. In: R. Rabbinge, S.A. Ward & H.H. van Laar (eds.). *Simulation and systems management in crop protection*. Simulation Monographs, PUDOC, Wageningen, p. 147-182.
- SRS, 1992. Single Rounded Baseline Survey. Interdisciplinary Research Project. Malang. Indonesia.

- Stangel, P.J., 1993. Nutrient cycling and its importance in sustaining crop-livestock systems in sub-Saharan Africa - an overview. In: Proceedings of the international conference "Livestock and sustainable nutrient cycles in mixed farming systems of sub-Saharan Africa", held on 24-26 November 1993. Addis Ababa. Ethiopia.
- Stomph, T.J., Fresco, L.O. & H. van Keulen, 1994. Land use system evaluation: concepts and methodology. *Agricultural Systems* 44: 243-255.
- Stoops, G. & M.C. Cheverry, 1992. New challenges for soil research in developing countries: a holistic approach. *Pedologie* 42 (3): 209-216.
- Stoorvogel, J.J. & E.M.A. Smaling, 1990. Assessment of soil nutrient depletion in sub-Saharan Africa, 1983-2000. Report 28, Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO).
- Stroosnijder, L., 1989. Maize growth in a tropical environment. Part II. Rainfed production. Department of hydrology, soil physics and hydraulics. Wageningen Agricultural University, The Netherlands.
- Stroosnijder, L. & T. van Rheenen, 1993. Making farming systems analysis a more objective and quantitative research tool. In: F.W.T. Penning de Vries, P. Teng & K. Metselaars. *Systems approaches to agricultural development*. Kluwer Academic Publishers and IRRI, The Netherlands, p. 341-353.
- Stroosnijder, L., Efdé, S.L., Rheenen, T. van, & Liliek Agustina, 1994. QFSA: a new method for farm level planning. In: L.O. Fresco, L. Stroosnijder, J. Bouma and H. van Keulen (eds.). *The future of the land; mobilizing and integrating knowledge for land use options*. Chichester, John Wiley & Sons, p. 95-121.
- Swift, M.J., Frost, P.G.H., Campbell, B.M., Hatton, J.C. & K. Wilson, 1989. Nutrient cycling in farming systems derived from savanna: Perspectives and challenges. In: *Ecology of arid lands*. M. Clarholm & M. Berstrom (eds.). Kluwer, Dordrecht, Netherlands, p. 63-76.
- Tanner, J.C., Holden, S.J., Winugroho, M., Owen, E. & M. Gill, 1993. Feeding livestock for compost production: A strategy for sustainable upland agriculture on Java. In: *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa*. J.M. Powell, S. Fernández-Rivera, T.O. Williams & C. Renard (eds.). Proceedings of an international conference. Volume II: technical papers. International Livestock Centre for Africa. Addis Ababa, Ethiopia, p. 115-128.
- Taylor, St C.S., 1980. Genetic size-scaling rules in animal growth. *Animal Production* 30: 161-165.
- Teh, T.H., Hemken, R.W. & L.S. Bull, 1982. Evaluation of urea ammonium polyphosphate as a phosphorus source for dairy calves. *J. of Anim. Sci.* 55: 174.
- Ternouth, J.H., 1989. Endogenous losses of phosphorus by sheep. *J. of Agric. Sci.* 113: 291-297.
- Tillman, A.D., 1981. *Animal Agriculture in Indonesia*. Winrock International. Arkansas. USA.

- Toky, O.P., Kumar, P. & P.K. Khosla, 1989. Structure and function of traditional agroforestry systems in the western Himalaya. In biomass and productivity. *Agroforestry Systems* 9: 47-70.
- Tolkamp, B.J. & J.J.M.H. Ketelaars, 1992. Towards a new theory of feed intake regulation in ruminants 2. Costs and benefits of feed consumption: an optimization approach. *Livestock Production Science* 30: 297-317.
- Trianti Djoharjani & H.M.J. Udo, 1986. Goat production performances in an upland area of East Java. *Tropical Animal Health and Production* 18: 76-80.
- Troeh, F.R. & L.M. Thompson, 1993. *Soils and soil fertility*. Fifth edition. Oxford University Press, New York.
- Udo, H.M.J. & B.O. Brouwer, 1993. A computerised method for systematically analysing the livestock component of farming systems. *Computers and Electronics in Agriculture* 9: 335-356. Elsevier Science Publishers B.V., Amsterdam.
- Underwood, E.J., 1981. *The mineral nutrition of livestock*. Commonwealth Agricultural Bureaux, London, England.
- Veeneklaas F.R., Cissé, S., Gosseye, P.A., Duivenbooden, N. van, & H. van Keulen, 1991. Competing for limited resources: the case of the fifth region of Mali. Report 4: Development scenarios. CABO-DLO/EPSR, CABO-DLO, Wageningen.
- Verstraete, W., 1981. Nitrification. In: F.E. Clark & T. Rosswall (eds.). *Ecological Bulletin* no. 33. Terrestrial Nitrogen cycles: processes, ecosystem strategies and management impacts. Swedisch Natural Science Research Council, Stockholm, p. 303-314.
- Verweij, J., 1987. Consumption of fuelwood and agricultural wastes in rural households in Gunung Kidul, FONC Project Communications 1987-1988, Fakultas Kehutanan Universitas Gadjah Mada, Yogyakarta, Indonesia.
- Vries, H. de, 1988. The influence of manure on maize production in Masese. Mongu, Zambia.
- Webster, C.C. & P.N. Wilson, 1969. *Agriculture in the Tropics*. Longman, London. 639 pp.
- Werkgroep Uniformering, 1994. Standaardcijfers rundvee, schapen en geiten, 1990 t/m 1992. In: Uniformering berekening mest en mineralen. *Werkgroep Uniformering Mest en Mineralen*. (in press)
- Weston, R.H., 1982. Animal factors affecting feed intake. In: *Nutritional limits to animal production from pastures*. J.B. Hacker (ed.). Commonwealth Agricultural Bureaux, Farnham Royal, Slough, UK, p. 183-198.
- Whitmore, T.C., 1984. *Tropical rain-forest of the far east*. Clarendon, Oxford. 2-nd edition.
- WHO, 1985. Report of a joint FAO/WHO/UNU expert consultation. *Technical Reports Series* 724, WHO, Geneva.
- Wiersum, K.F., 1984. Surface erosion under various tropical agroforestry systems. In: *Proceedings of symposium "effects of forest land use on erosion and slope stability"*. O'Loughlin & Pearce (eds.). Environment and Policy Institute. East-West Center, Honolulu, Hawaii, p. 231-239.

- Willigen, P. de, & M. van Noordwijk, 1989. Rooting depth, synchronization, synlocalization and N-use efficiency under humid tropical conditions. In: J. van de Heide (ed.). Nutrient management for food crop production in tropical farming systems. Institute for Soil Fertility and Universitas Brawijaya, p. 145-156.
- Winterhalder, B., Larsen, R. & R.B. Thomas, 1974. Dung as an essential resource in a highland Peruvian community. *Human ecology* 2 (2): 89-104.
- Wischmeier, W.H. & D.D. Smith, 1978. Predicting rainfall erosion losses from cropland. A guide for selection of practices for soil and water conservation. Washington DC. *Agricultural Handbook* 282.
- Wise, M.B., Smith, S.E. & L.L. Barnes, 1958. The phosphorus requirement of calves. *Journal of Animal Science* 17: 89.
- Wit, C.T. de, & H. van Keulen, 1987. Modelling production of field crops and its requirements. *Geoderma* 40: 253-265.
- Wit, C.T. de, Keulen, H. van, Seligman, N.G. & I. Spharim, 1988. Application of Interactive Multiple Goal Linear Programming Techniques for analysis and planning of regional agricultural development. *Agricultural Systems* 26: 211-230.
- Wit, C.T. de, 1992. Resource use efficiency in agriculture. *Agricultural systems* 40: 125-151.
- Woodmansee, R.G., 1979. Factors influencing input and output of nitrogen in grasslands. In: *Perspectives in grassland ecology*. N.R. French (ed.). Springer, New York, pp. 117-134.
- WRR (Netherlands Scientific Council for Government Policy), 1992. Ground for choices, four perspectives for the rural areas in the European Community. Reports to the Government no. 42, Sdu, The Hague.
- Zemmelink, G., Tolkamp, B.J. & N.W.M. Ogink, 1991. Energy requirements for maintenance and gain of west African dwarf goats. *Small Ruminant Research* 5: 205-215.
- Zemmelink, G., Brouwer, B.O. & S. Ifar, 1991. Feed utilization and the Role of Ruminants in Farming Systems. Proceedings International Seminar on Livestock and Feed Development in the Tropics. Universitas Brawijaya, Malang, Indonesia.

Summary

Over the past 20 years Indonesia's efforts in agriculture predominantly aimed at increasing the productivity of sawah land. Uplands often have a higher population pressure but a lower agricultural production than the rice producing lowlands. The Government of Indonesia would like to see an agricultural development in the uplands similar to that which took place in the lowlands. Therefore an interdisciplinary study started in one of the poorest upland areas of the densely populated island of Java, the limestone area south of Malang. This area is dominated by low-input farming systems i.e. farms that utilize few external inputs or soil conservation measures.

The heavy clay texture and low organic matter content of the soils are considered as the main technical obstacle to improvement of agricultural production in this area. Other constraints are climatic, such as long-lasting dry periods and high-intensity rains, resulting in cracks, and waterlogging and erosion respectively. The steep slopes further aggravate the situation. The aim of this thesis was to determine whether and how it is possible to increase production on the one hand, and to improve the sustainable use of the resource base on the other hand.

Quantified Farming Systems Analysis was developed as a methodological tool to assist in planning land use systems. It is a combination of Land Use Systems Analysis and Farming Systems Analysis. It is used to explore options for sustainable cropping and livestock systems, without considering socio-economic constraints. The analysis allows for a wide range of technically feasible development options.

Land use systems in the research area are characterized by annual crops grown in association with perennial crops, either on valley bottoms or on hillsides. A classification of the soils into main land units on the basis of five soil characteristics was made: (1) soil depth, (2) soil texture, (3) degree of terracing, (4) slope and (5) position.

The complex land use systems were classified based on the spatial arrangement, density and species composition of their tree component. Five Crop Cultivation Types were defined: (1) irrigated and non irrigated land with sparse to no trees, (2) tegal (non irrigated agricultural land) with trees on the border of the field, at the edges of terraces or randomly distributed, (3) multi-storey systems, (4) woodlands and (5) "bongkor", land not used for annual or perennial cultivation. Four annual crops within crop cultivation type 1 and 2 were dealt with: (1) maize, (2) cassava, (3) upland rice and (4) sugarcane. Light transmission coefficients take into account the competition for light in such multiple land-use systems. For these complex land use systems quantitative production estimates were determined, either empirical (by on-farm and on-station research) or by using (field validated) crop simulation models.

Three annual Crop Production Levels were considered, (1) potential, (2) water-limited potential and (3) water- and nutrient-limited potential. Multiple levels need to be considered

to investigate future prospects of increased productivity. Two agricultural technology types were distinguished: 'Yield-Oriented Agriculture' attempts for the highest yield possible under the prevailing conditions, and 'Low External-Input oriented Agriculture' which seeks to restrict the use of inputs from outside the farm. Inputs and outputs indicate the extent to which certain activities draw on the available resources and enables comparison of the different land use systems. Inputs are water use and nutrient input (N, P and K); output is the crop yield.

Calculated total above-ground tree stem biomass ranged between 11 and 68 t ha⁻¹. The multi-storey systems showed the highest number of trees followed by woodlands. Least tree densities were found for tegal especially on valley bottoms. The number of trees closely corresponded with the calculated stem biomass. Multi-storey systems had the highest amount of tree stem biomass.

Farmers yields were well below the potential yields. The average maize grain yield was 0.9-1.9 t dry grain ha⁻¹, almost the same as the water-limited yield potential on land unit 1. The average cassava yield recorded at farmers sites was 2.1-4.3 t dry tubers ha⁻¹ which was of the same order of magnitude as the water and nutrient-limited crop yields. Farmers realized upland rice yields of 1.5-4.2 t dry grain ha⁻¹ which suggested that water availability hinders crop growth. The average sugarcane yield under traditional management, was 11.1-22.2 t of dry cane ha⁻¹. This was only little below the water-limited yield potential which suggests that there is only a mild nutrient deficiency apart from the water limitation.

Maize, cassava, upland rice and sugarcane were hampered by water and nutrient deficiency. The growth limiting nutrient was potassium for forest soils, permanently cultivated hillsides and fallow hillsides. Valley bottoms and intermittently cultivated hillsides showed that phosphorus is the growth limiting nutrient. Harvested products form the most important nutrient output. Research elsewhere in Indonesia has shown that the overall productivity of traditional upland intercropping systems can be improved through a combination of interventions, such as the introduction of suitable varieties, improved timing, improved field spacing designed to reduce plant competition, and increased and more balanced application of fertilizers and pesticides, the use of mulches to retard weed growth and to conserve soil moisture. However, much research is yet to be done on upland cropping in general, and in particular on upland cropping in a limestone environment.

Livestock units were distinguished based on animal species (cattle, sheep and goats) and main production objective (meat, offspring, milk, traction). The livestock production (output) per animal, calculated with a newly developed LIVestock PROduction and FEed simulation model, was defined first and the requirements (inputs) to realize that production were derived subsequently. Two target production levels were defined; potential livestock production and actual livestock production. For the livestock activities the inputs are the amount of feed dry matter of the individual feeds, the total amount of metabolizable energy and the amount of nitrogen in the feeds. The outputs are amount of dung dry matter, amount of nitrogen in the dung, liveweight gain, milk production, offspring and land ploughed.

Actual livestock production, in terms of liveweight gain, achieved at present is negative

in many months, for lactating cattle, sheep and goats. In these months either the amount of dry matter offered to the animals or the type of feeds present is limiting. The livestock production situation can be improved by at least offering the animals more dry matter in these months whereafter additional improvement can be reached by additional feeds. Potential livestock production showed the maximum production possible. Buying of concentrates such as maizebran or soybean cake may improve the local livestock production enormously.

Biophysical sustainability was dealt with by three conditions: (1) maintenance of sufficient vegetation cover to give soil protection and avoid erosion, (2) maintenance of a sufficiently high soil organic matter content and (3) maintenance of a closed balance of the most limiting resource. Present land uses did not maintain a soil organic matter content of 2%. Only the multi-storey system reached a relatively high soil organic matter content of 2.21%. Therefore the present soil organic matter content can only be increased if the input of organic materials to the farm increases (returning crop residues to the soil) or if the annual crops are (partly) replaced by perennials. It is not feasible, however, to increase soil organic matter content to levels that are optimum for such heavy soils. Annual crops can best be cultivated on valley bottoms where moisture reserves are higher and nutrient uptake better. The conservational effect of the multi-storey system refers particular to the reduction of outputs. This involves the protection against erosion ensured by the litter cover and low vegetation, the reduction of potential leaching by ensuring a high nutrient holding capacity of the soil and by preventing acidifying of the soil.

Manure production is a very important motive for farmers to keep ruminants. Via the feedstuffs of the animals, organic material and nutrients are brought to the farm, which would not have entered the farm if there were no animals. Manure is not sold in the research area. Because organic carbon is a limiting factor of the farms, the significance of the animals lies in the supply of organic materials to the farm. However, the number of cattle per ha would have to be increased to unrealistic high numbers to maintain a sufficiently high soil organic matter content and to maintain a closed nutrient balance.

If annuals are only grown on valley bottoms, not enough food for consumption is produced for Putukrejo. Only rice cultivation on valley bottoms (rice is the most preferred staple) with a yield of 3.5 t ha⁻¹ results in a total production for Putukrejo of 22 t and for Kedungsalam of 64 t. The quantity consumed is calculated for Putukrejo as 27 t and as 62 t for Kedungsalam, when a yearly consumption of 180 kg rice is assumed. As a result Putukrejo always should cultivate annual crops on hillsides if it aims to be self sufficient in food. Kedungsalam is self sufficient in food when only valley bottoms are used to grow annual crops. However, the excess of food is small and therefore not much scope for expansion of the population is available.

In the explorative study described in this thesis, input-output relations were considered from the question 'what is possible'. The results of the explorative study does not show blueprints for future land use. It shows the boundaries from a technical and bio-physical point of view within the limits defined by agricultural or ecological preferences and thus serves to widen the perspective on future land use and natural resource management.

Samenvatting

De afgelopen 20 jaren heeft Indonesië zich vooral ingespannen om de productiviteit van bevoeid laagland (*sawah*) te vergroten. De hoger gelegen gebieden hebben vaak een grotere bevolkingsdruk, maar een lagere landbouwproductie dan de laaglanden. De Indonesische regering zou graag een soortgelijke ontwikkeling willen zien in de hoger gelegen gebieden als die heeft plaatsgevonden in de laaglanden. Daarom werd een interdisciplinaire studie gestart in een van de armste hoger gelegen gebieden van het dichtbevolkte eiland Java: het kalksteen gebied ten zuiden van Malang. In dit gebied vindt men voornamelijk boerenbedrijfjes met een lage graad van investering: dit betreft zowel het aankopen van middelen, als het nemen van bodembeschermende maatregelen.

De zware klei en het lage organische stofgehalte van de bodem worden beschouwd als de belangrijkste technische belemmering om te komen tot een verhoging van de landbouwproductie. Het klimaat is ook een van de beperkende factoren, zoals bijvoorbeeld de langdurige droge periode en hoge regenval, die respectievelijk leiden tot scheuren in de bodem enerzijds en het onderwater staan van het land en de daarmee gepaard gaande erosie anderzijds. De steile hellingen verergeren dit proces alleen nog maar. Het doel van dit proefschrift was om te bepalen of, en zo ja, hoe, de productie kan worden verhoogd terwijl tegelijkertijd de duurzame beschikbaarheid van de natuurlijke hulpbronnen behouden kan blijven.

De kwantitatieve bedrijfssysteemanalyse is een methode om het plannen van landgebruikssystemen te ondersteunen. Deze wordt gebruikt om mogelijkheden te verkennen voor duurzame landbouw- en veeteeltssystemen, waarbij in dit proefschrift geen rekening is gehouden met sociaal economische factoren. De analyse laat een groot bereik toe aan de technisch haalbare ontwikkelingsmogelijkheden.

Het onderzoeksgebied kenmerkt zich door het naast elkaar groeien van eenjarige en overblijvende gewassen, zowel in de valleien als op de hellingen. Er werd een bodemclassificatie gemaakt aan de hand van vijf bodemkenmerken: diepte van de bodem, textuur van de bodem, mate waarin terrassen zijn aangelegd, hellingspercentage en ligging in het landschap.

De complexe landgebruikssystemen werden geclassificeerd op basis van de ruimtelijke rangschikking, de dichtheid en de soortensamenstelling van de bomen. Op deze manier werden vijf landgebruiksvormen gedefinieerd:

1. geirrigéerd en niet geirrigéerd land met weinig of geen bomen
2. niet geirrigéerd land met bomen langs de rand van het land, langs de randen van de terrassen of willekeurig gerangschikt
3. overblijvende gewassystemen (grote boomedichtheid met veel verschillende soorten)
4. bossysteem

5. land dat niet gebruikt kan worden voor de groei van eenjarige- of overblijvende gewassen (*bongkor*).

Binnen de landgebruiksvormen 1 en 2 worden 4 soorten eenjarige gewassen verbouwd: mais, cassave, droge rijst en suikerriet. De mate waarin licht door de bomen wordt doorgelaten werd gemeten om zodoende de verdeling van het licht over de gewassen in de veelvormige systemen te berekenen. Voor deze complexe landgebruiksvormen werd de productie van biomassa bepaald, zowel empirisch (door middel van veldonderzoeken) als door middel van gevalideerde gewasgroei simulatiemodellen.

Drie gewasproductieniveaus werden beschouwd: potentieel, water gelimiteerd en water en nutriënten gelimiteerd. Meerdere niveaus moeten worden doorgerekend om de vooruitzichten van een toegenomen productie te kunnen onderzoeken. Er werden twee landbouwbeleidsvormen gedefinieerd. "Opbrengstgerichte landbouw" waarin naar de hoogste mogelijke opbrengst wordt gestreefd onder de heersende omstandigheden. En "lage-externe-input-gerichte landbouw" waarin gezocht wordt naar een zo gering mogelijke toepassing van inputs van buiten het bedrijf. De verhouding tussen inputs en outputs geeft aan in welke mate een bepaalde activiteit een beroep doet op de bestaande hulpbronnen en maakt het mogelijk om de verschillende landgebruiksvormen met elkaar te vergelijken. Inputs zijn gebruik van water en minerale toediening (stikstof, fosfaat en kalium). De output is de gewasopbrengst.

Het bovengrondse stamvolume van de bomen varieerde van 11-68 t ha⁻¹. De hoogste boomedichtheden werden gevonden in de overblijvende gewassystemen gevolgd door het bossysteem. De minste bomen werden aangetroffen op niet geïrrigeerd land, vooral in de valleien. Het aantal bomen was positief gecorreleerd met het berekende stamvolume. De overblijvende gewassystemen scoorden de hoogste stamvolumes.

De door de boeren gerealiseerde gewasopbrengsten van eenjarige gewassen waren behoorlijk lager dan de berekende potentiële opbrengst. De gemiddelde korrelopbrengst van mais bedroeg 0.9-1.9 t ha⁻¹, wat ongeveer overeen komt met de water gelimiteerde productie. De gemiddelde knolopbrengst van cassave bedroeg 2.1-4.3 t ha⁻¹ droge stof, wat ongeveer overeen komt met de water en nutriënten gelimiteerde opbrengst. De boeren realiseerden voor rijst een korrelopbrengst van 1.5-4.2 t ha⁻¹ droge stof, wat erop duidt dat de waterbeschikbaarheid de limiterende factor is. De gemiddelde opbrengst van suikerriet bedroeg 11.1-22.2 t ha⁻¹ droge stof. Deze opbrengst lag net iets onder de berekende opbrengst met waterbeschikbaarheid als limiterende factor, wat erop duidt dat er slechts een gering nutriëntentekort aanwezig was.

Mais, cassave, droge rijst en suikerriet werden beperkt in hun groeiomstandigheden door de beschikbaarheid van water en nutriënten. Kalium was het beperkende nutriënt voor het bossysteem, de permanent bebouwde hellingen en braakliggende hellingen. Voor de valleien en de niet permanent bebouwde hellingen was fosfor het groeibeperkende nutriënt. De afvoer van nutriënten bestaat voornamelijk uit het gedeelte in de geooogste gewassen. Uit onderzoek dat elders in Indonesië heeft plaatsgevonden is gebleken dat de totale productiviteit van traditionele gemengde gewasgroeisystemen in hoger gelegen gebieden kan worden verbeterd

door een combinatie van interventies. Zoals de introductie van aangepaste variëteiten, op tijd planten en wieden, een verbeterde ruimtelijke rangschikking van de planten om de onderlinge competitie te verminderen, een hogere en beter uitgebalanceerde toediening van kunstmest en pesticiden, het gebruik van groenbemesters om de onkruidgroei te remmen en om een goed vochtige grond te behouden. Toch zal er nog veel onderzoek gedaan moeten worden naar de verbouw van gewassen in hoger gelegen gebieden in het algemeen en naar hoger gelegen kalksteen gebieden in het bijzonder.

Het vee werd ingedeeld naar soort (koe, schaap of geit) en naar de belangrijkste reden van het houden ervan (vlees, voortplanting, melk, trekkracht). De dierlijke productie per dier werd berekend met een nieuw ontwikkeld simulatiemodel, waarna werd berekend welke inputs er nodig waren om deze outputs te bereiken. Er werden twee veeteeltproductieniveaus onderscheiden: de potentiële productie en de actuele productie. De inputs bestaan uit de hoeveelheid aan opneembare energie van het voer en de hoeveelheid stikstof opgenomen met het voer. De outputs bestaan uit de hoeveelheid droge mest, de hoeveelheid stikstof in de mest, gewichtstoename, melkproductie, voortplanting en de hoeveelheid geplougd land.

De gewichtontwikkeling zoals deze in de praktijk werd waargenomen liet gedurende vele maanden van het jaar een gewichtsafname zien voor lacterende koeien, schapen en geiten. In deze maanden is òf de hoeveelheid droge stof die werd aangeboden niet toereikend, òf de beschikbare voersoort was beperkend. De dierlijke productie kan verhoogd worden door in de betreffende maanden er in ieder geval voor te zorgen dat de dieren voldoende droge stof aangeboden krijgen waarna een verdere verbetering kan worden bereikt met extra (andersoortig) voer. Het voeren van aangekocht krachtvoer zoals maisslijpsel of sojakoek zou de huidige dierlijke productie enorm doen toenemen.

Qua biofysische duurzaamheid werd gekeken naar: (1) het behoud van voldoende plantaardige bodembedekking om de erosie te verminderen, (2) het behoud van een voldoende hoog organisch stofgehalte van de bodem en (3) het behoud van een gesloten balans voor de meest beperkende nutriënten. Het huidige landgebruik resulteert in een organisch stofgehalte van de bodem van minder dan 2%. Alleen in de overblijvende gewassystemen werd een relatief hoog organisch stofgehalte gevonden van 2.21%. Daarom zou het organische stofgehalte kunnen worden verhoogd door meer gewasresten op het land te laten of door meer bomen tussen de eenjarige gewassen te laten groeien. Het is echter onmogelijk om een organisch stofgehalte te bereiken dat optimaal zou zijn voor dergelijk zware kleigronden. Eenjarige gewassen kunnen het best worden verbouwd in de valleien waar de vochtreserves groter zijn en de opname van nutriënten beter verloopt. Het beschermende karakter van de overblijvende gewassystemen zit hem vooral in de vermindering van de verliezen. Dit komt onder meer door de beschermende werking tegen erosie ten gevolge van een betere bodembedekking. Verder wordt de bodemstructuur verbeterd zodat nutriënten beter behouden blijven en niet weglekken. Tenslotte wordt zo de verzuring van de bodem tegengegaan.

De mestproductie is een zeer belangrijk motief voor de boeren om vee te houden. Via de veevoerders komen veel organisch materiaal en nutriënten het boerenbedrijf binnen die zonder vee niet zouden zijn binnengekomen. Mest wordt niet verkocht in het

onderzoeksgebied. Een groot belang van het houden van dieren ligt daarom in de voorziening van organisch materiaal, één van de bodem-gewassysteem beperkende factoren. Echter, het aantal dieren per hectare dat gehouden zou moeten worden om een voldoende hoog organisch stofgehalte van de bodem te verzekeren, voor een duurzaam gesloten systeem, is onrealistisch hoog.

Wanneer de eenjarige gewassen alleen in de valleien zouden worden verbouwd, zou niet genoeg voedsel worden verkregen om de mensen in Putukrejo te voeden. Rijst is het meest geliefde basisvoedsel in Indonesië. Wanneer alleen rijst in de valleien zou worden verbouwd zou 22 ton rijst in Putukrejo en 64 ton in Kedungsalam kunnen worden verbouwd. Uitgaande van een consumptie van 180 kg rijst per hoofd per jaar kan worden berekend dat in Putukrejo 27 ton en in Kedungsalam 62 ton rijst wordt geconsumeerd. Teneinde zelfvoorzienend te kunnen zijn in rijst moet in Putukrejo ook rijst worden verbouwd op de hellingen. Dit zou in Kedungsalam nog niet nodig zijn, maar het verschil is dermate klein dat de bevolking in Kedungsalam niet veel meer zou mogen groeien.

De verkennende studie van de input-output relaties die in dit proefschrift is beschreven, is uitgegaan van de vraag 'wat is mogelijk'. Het resultaat van deze verkenning is geen pasklaar antwoord op de vraag wat het beste landgebruik zal zijn in de toekomst. Deze studie geeft echter aan wat er binnen de technische en biofysische grenzen mogelijk is en gerealiseerd kan worden en waarbij rekening is gehouden met landbouwkundige of ecologische voorkeuren. Dit verruimt de blik op toekomstig landgebruik en het verstandig omgaan met de natuurlijke hulpbronnen.

Nawoord

Het voelt alsof ik tussen de bedrijven door een proefschrift geschreven heb, maar het is af gekomen. Ook al kwamen er 2 kinderen tussendoor en ook al ging het schrijven dat jaar in Pakistan langzamer dan ik had gedacht. Thuiswerken, zonder collega's en met op de achtergrond de geluiden van je kinderen, is niet inspirerend en leidt af. Bovendien komt het verhuizen naar Indonesië, weer naar Nederland, naar Pakistan, weer naar Nederland en naar Costa Rica de rust om te werken niet ten goede. Dat het onderzoek van september 1990 tot december 1992 in Indonesië is uitgevoerd lijkt inmiddels heel lang geleden.

Met het hele onderzoeksteam in Indonesië hebben wij ons met veel enthousiasme op het veldwerk gestort. Onder het mom van, hoe meer data je verzamelt, hoe groter het detail dat je krijgt, deden wij uitgebreide surveys en veldproeven. Maar tijdens het veldwerk kom je erachter dat veel gegevens met een dusdanige spreiding en onzekerheid worden verkregen, dat je ze net zo goed via expert knowledge of literatuur had kunnen verkrijgen. Of het veldwerk had nog veel uitgebreider en gedetailleerder moeten zijn, maar dan loop je tegen de factor tijd aan. Achteraf bekeken, hadden we eerst goed onze modellen en methode van analyseren moeten uitkristalliseren. Dat maakt dat je vervolgens veel gericht je data verzamelt.

Mijn INRES collega's ben ik dankvoor voor hun teamgeest waarmee we in Kedungsalam en Putukrejo samen alle data hebben verzameld en gedeeld. Wij zijn het bewijs dat je met 1 gemeenschappelijke database best 6 afzonderlijke proefschriften kunt schrijven, met ieder zijn eigen focus. Teunis, onze tijd in Indonesië was erg gezellig, en ook al moesten we door een diep dal, we zijn er toch gekomen. Ik heb veel gehad aan je opbeurende woorden en je altijd positieve instelling. Widiyanto, Ifar, Sunaryo en Solichin wens ik veel succes met de laatste lootjes. Liliek Agustina, Gerrit Zemelink en Waluyo Nibbering bedankt voor alle steentjes die jullie aan mijn proefschrift hebben bijgedragen. Bij een project van de Landbouwniversiteit in een mooi land horen natuurlijk praktijkstudenten. Velen kwamen bij ons langs en ik wil met name de studenten Tamme van der Wal, Emma Schotveld, Emiel van Loon, Oscar Vonder, Sjaak Dieleman, Flip van Helden, Ton Cornelissen en Jacqueline Blom bedanken voor het door hen gedane veldwerk.

Terug in Wageningen begon het modelleren, analyseren en opschrijven van de resultaten. Met name door de discussies en ideeën van Rudy Rabbinge en Leo Stroosnijder kreeg de opzet van mijn proefschrift vorm en inhoud. Rudy, bedankt voor je betrokkenheid met mijn onderzoek en je sturende werking. Leo Stroosnijder is de motor achter mijn proefschrift geworden. Leo, jij weet de hoofdstukken te beoordelen op hun inhoud, zit er een rode draad in en wat mist er. Dit soort zaken zijn onontbeerlijk in de becommentariëring en ik kon ze goed gebruiken. Daarnaast ervaar ik jouw persoonlijkheid als stimulerend en motiverend. Henk Udo is van het begin af aan bij mijn onderzoek betrokken geweest. Henk, jouw

commentaar lag grotendeels bij de analyse van de data. Ook details zijn belangrijk, en daar moest jij mij vaak op wijzen. Ik zie jouw als een daadkrachtige persoon en ik bewonder je snelle werkwijze. Het cynisme en relativerend vermogen van Paul Driessen houd een mens op de been. Paul, jou wil ik bedanken voor onze 'buurtpraatjes' maar toch ook voor al het meedenken en meewerken aan het modelleren van de gewassen.

Een breed onderwerp behandelen betekent dat je ook bij veel mensen aanklopt om van hen iets meer te horen over bepaalde onderwerpen. Wat dan opvalt is dat de mensen binnen een vakgroep vaak niet op één lijn zitten. Misschien is men op het ogenblik wel teveel 'interdisciplinair' gefocussed en vergeet men disciplinair samen te werken.

Mijn brede onderwerp heeft er ook voor gezorgd dat ik op verschillende vakgroepen gehuisvest ben geweest. In Wageningen heb ik collega's gehad op de vakgroepen Bodemkunde en Geologie, Tropische Veehouderij en Theoretische Productie Ecologie. Bedankt voor jullie gastvrijheid ook al was het lang niet voor iedereen duidelijk waar ik nu eigenlijk bij hoorde of onder viel. De AIO-overleg groepjes waar ik, tussen de verblijven in het buitenland door, aan deelnam zijn tijdrovend maar hebben wel degelijk een grote motiverende functie gehad.

Gelukkig heb ik de afgelopen jaren ook de nodige afleiding gehad, alleen al door de vele toeristische uitstapjes in Indonesië en Pakistan. Maar ook door mijn vriendinnen Margot, Imke, Dorine, Joke, Eline en Madeleine, die ik wil bedanken voor hun steun en de nodige afleiding. Fré Pepping noem ik voor zijn grote interesse in de voortgang van het project, de proefschriften en mijn persoonlijke wel en wee. Alle vrienden in Pakistan die altijd nieuwsgierig en geïnteresseerd waren naar mijn vorderingen. Kathleen Hummelen, thanks for the extensive, time consuming editing of the whole text. I am glad we have met in Islamabad.

Tenslotte Paul, realiseer ik me dat jij de enige bent van wie ik kan zeggen "zonder jou was dit boekje er niet gekomen". Alleen al doordat jij de zorg en de opvoeding van Famke en Myrte voornamelijk voor jouw rekening neemt. Maar ook door alle data die je voor mij hebt uitgerekend, alle print outs die je in Pakistan moest maken en alle andere klusjes die je voor mijn proefschrift hebt gedaan. Onze ouders verdienen het laatste dankwoord, want zij hebben regelmatig en vaak moeten inspringen als wij weer eens oppas voor de kinderen nodig hadden. Zij zijn het die ons er op wijzen dat het hebben van kinderen in het buitenland voor hen een dure hobby is en dat daarom niet ons salaris maar hun salaris gecompenseerd moet worden.

Curriculum vitae

Stella Louise Efdé werd geboren op 21 juli 1965 te Groningen. Na het behalen van het VWO-diploma aan het Drachtster Lyceum begon zij haar studie Zoötechniek in september 1984 aan de Landbouwniversiteit te Wageningen. Binnen deze studierichting koos zij voor de oriëntatie Tropische Veehouderij. Het eerste afstudeervak, gedaan in Wageningen had als titel "Feed quality evaluation of crop residues from India with several different levels and types of supplementation". Haar praktijktijd bracht zij door in India waar zij binnen het project "The bioconversion of crop residues" vooral heeft gewerkt binnen de Farming Systems Research component van het project. Voor hetzelfde project deed zij voor Voorlichtingkunde een afstudeervak getiteld " A study of Bharatiya Agro Industries Foundation's dairy cattle development programme in relation to the role and tasks of the woman in mixed farms". Het was het werk in India dat haar bewust maakte van kwantitatieve modellen op bedrijfsnivo en dat haar deed beseffen dat haar de kennis van gewassen ontbrak. Terug in Wageningen is ze toen een gecombineerd afstudeervak gaan doen voor de vakgroepen Theoretische Productie Ecologie en Landbouwplantenteelt en Graslandkunde. Dit resulteerde in het afstudeer onderzoek "Quantitative and qualitative growth simulation of maize".

Vlak voor haar afstuderen in maart 1990 kreeg zij een Assistent In Opleidings baan aan de Landbouwniversiteit met als onderwerp "de fysieke productie analyse van het kalksteengebied op oost Java". Deze baan begon in juni 1990 waarvoor zij onderzoek heeft gedaan binnen een interdisciplinair team, waarvan de eerste twee en een half jaar in Indonesië. Eind 1992 liep het project in Indonesië af en ging het afronden van het proefschrift door in Nederland. Het onderzoek uitgevoerd in Indonesië was een samenwerkingsproject van de Landbouwniversiteit Wageningen, de Rijksuniversiteit van Leiden en de Universitas Brawijaya in Malang, Indonesië. Het project, Interdisciplinary Research project, werd gefinancierd door NUFFIC. Vanaf december 1995 is zij werkzaam als "agro-ecoloog" op het steunpunt van de Landbouwniversiteit in Costa Rica voor het project "Research programme on sustainability in agriculture".

Appendix 1 - Feed tables

Table 1. Daily weight of feed (kg DM) offered to a cow of 250 kg bodyweight in Putukrejo, East Java, Indonesia (data of 1991).

Month	ltl	nltl	ngr	egr	scl	cl	ms	rs	tot
January	1.16	0.74	2.08	-	1.43	0.42	0.71	0.20	6.74
February	0.61	0.05	1.76	-	1.57	0.17	2.95	0.28	7.39
March	0.64	0.23	5.17	-	0.26	-	4.15	0.57	11.02
April	1.07	1.20	1.55	0.03	-	-	0.10	2.67	6.62
May	1.23	1.23	2.23	0.03	0.30	-	-	0.56	5.58
June	1.25	0.29	0.58	-	5.38	0.36	-	-	7.86
July	0.09	0.36	0.48	-	5.03	0.39	-	-	6.35
August	-	0.61	0.08	-	2.29	-	-	2.07	5.05
September	1.60	0.12	0.01	-	1.26	0.10	-	1.93	5.02
October	0.77	0.03	-	-	1.60	0.03	-	1.53	3.96
November	1.36	0.10	0.49	-	0.75	-	0.04	1.08	3.82
December	2.42	0.49	0.24	-	0.75	-	-	0.45	4.35

ltl = leguminous tree leaves constitute up to 2% of bodyweight (250 kg), in fresh material, which is equal to 1.5 kg dry matter (30 %DM); nltl = non-leguminous tree leaves constitute up to 20% of the potential dry matter intake (6 kg); ngr = native grasses; egr = elephant grass; scl = sugarcane leaves; cl = cassava leaves constitute up to 10% of the potential dry matter intake (6 kg); ms = maize straw; rs = rice straw

Table 2. Daily weight of feed (kg DM) offered to a cow of 250 kg bodyweight in Kedungsalam, East Java, Indonesia (data of 1991).

Month	ltl	nltl	ngr	egr	scl	cl	ms	rs	tot
January	2.00	0.34	0.56	0.53	-	-	2.32	0.49	6.24
February	2.09	0.69	2.46	-	-	0.09	0.63	-	5.96
March	5.00	0.01	1.76	-	-	0.19	0.32	0.39	7.67
April	1.24	0.06	1.07	0.50	-	-	1.40	1.31	5.58
May	2.16	0.05	1.65	-	-	-	-	0.80	4.66
June	2.49	0.92	0.26	0.94	-	-	-	-	4.61
July	0.49	1.14	0.43	-	-	0.81	-	0.43	3.30
August	-	-	-	-	-	3.43	-	0.81	4.24
September	0.17	0.04	1.29	0.03	-	0.60	-	1.74	3.87
October	1.39	0.53	0.16	-	-	-	-	1.70	3.78
November	1.77	0.37	0.13	-	0.04	-	0.53	0.34	3.18
December	1.28	0.82	0.63	1.08	-	-	0.47	0.43	4.71

ltl = leguminous tree leaves constitute up to 2% of bodyweight (250 kg), in fresh material, which is equal to 1.5 kg dry matter (30 %DM); nltl = non-leguminous tree leaves constitute up to 20% of the potential dry matter intake (6 kg); ngr = native grasses; egr = elephant grass; scl = sugarcane leaves; cl = cassava leaves constitute up to 10% of the potential dry matter intake (6 kg); ms = maize straw; rs = rice straw

Table 3. Daily weight of feed (kg DM) offered to a goat of 30 kg bodyweight in the combined villages of Putukrejo and Kedungsalam, East Java, Indonesia (data of 1991).

Month	ltl	nltl	ngr	egr	scl	cl	ms	rs	tot
January	1.73	-	0.44	-	-	-	0.26	-	2.43
February	2.57	-	-	0.35	-	-	-	-	2.92
March	2.68	-	0.70	-	-	-	-	-	3.38
April	2.35	-	-	-	-	-	-	-	2.35
May	1.77	-	0.52	-	-	-	-	-	2.29
June	1.44	-	-	-	-	-	-	-	1.44
July	1.44	-	-	-	-	0.41	-	-	1.85
August	1.78	-	-	-	0.93	-	-	-	2.71
September	1.60	0.54	-	-	-	-	-	-	2.14
October	1.62	-	0.18	-	-	-	-	-	1.80
November	1.69	-	0.06	-	-	-	-	-	1.75
December	2.63	-	-	-	0.24	-	0.05	-	2.92

ltl = leguminous tree leaves constitute up to 2% of bodyweight (30 kg), in fresh material, which is equal to 0.18 kg DM (30 %DM); nltl = non-leguminous tree leaves constitute up to 20% of the potential dry matter intake (0.9 kg); ngr = native grasses; egr = elephant grass; scl = sugarcane leaves; cl = cassava leaves constitute up to 10% of the potential dry matter intake (0.9 kg); ms = maize straw

Table 4. Daily weight of feed (kg DM) offered to a sheep of 25 kg bodyweight in the combined villages of Putukrejo and Kedungsalam, East Java, Indonesia (data of 1991).

Month	ltl	nltl	ngr	egr	scl	cl	ms	rs	tot
January	0.44	0.72	0.75	-	-	-	0.19	-	2.10
February	0.55	1.49	0.27	0.41	-	-	-	-	2.72
March	1.85	-	2.52	-	-	-	-	-	4.37
April	1.06	0.65	1.24	-	-	-	-	-	2.95
May	0.75	-	1.43	-	-	-	-	-	2.18
June	0.83*	-	1.09*	-	-	-	-	-	1.92
July	0.91	-	0.74*	-	-	-	-	-	1.65
August	2.58	-	0.40	-	-	-	-	-	2.98
September	0.47	-	0.32	-	-	-	-	1.16	1.95
October	0.38	2.25	-	-	-	-	-	-	2.63
November	2.20	-	-	-	-	-	-	0.16	2.36
December	-	2.59	-	-	-	-	0.57	-	3.16

* = missing data, estimates are used

ltl = leguminous tree leaves constitute up to 2% of bodyweight (25 kg), in fresh material, which is equal to 0.15 kg dry matter (30 %DM); nltl = non-leguminous tree leaves constitute up to 20% of the potential dry matter intake (0.075 kg); ngr = native grasses; egr = elephant grass; ms = maize straw; rs = rice straw

Appendix 2 - Chemical soil data

Chemical soil characteristics for the 0-20 cm soil in the research area.

Land form	pH	orgC %	totN %	P-Olsen ppm	exch-K me 100g ⁻¹	size ha
Land unit 1						
1	6.5	1.88	0.18	1	1.29	0.15
6	6.3	1.04	0.09	2	1.09	0.18
6	6.5	1.31	0.12	2	-	0.10
7	6.3	1.08	0.09	2	0.24	0.25
7	6.5	0.70	0.07	7	0.67	0.12
11	6.3	1.16	0.10	1	0.74	0.05
11	6.9	1.03	0.08	1	0.46	0.20
11	7.4	1.27	0.09	1	0.21	0.05
11	6.3	1.13	0.09	2	-	0.18
17	7.4	1.26	0.11	5	0.25	0.31
17	7.2	1.42	0.12	1	0.23	0.16
18	7.1	1.48	0.10	1	0.66	0.16
18	6.7	0.82	0.09	1	0.61	0.30
Land unit 2						
2	7.0	0.98	0.08	2	1.58	0.18
2	.6	1.08	0.11	1	1.32	0.22
3	6.5	0.95	0.09	1	1.29	0.05
3	6.4	0.92	0.09	1	0.45	0.46
3	7.6	1.08	0.12	1	1.32	0.28
4	6.5	0.95	0.08	1	1.29	0.15
4	7.0	0.92	0.08	2	1.58	0.23
8	6.9	1.49	0.11	4	4.53	0.07
8	6.5	0.64	0.08	3	0.35	0.08
8	6.1	0.86	0.09	5	3.13	0.24
8	6.5	0.70	0.08	7	0.67	0.21
8	6.9	0.77	0.09	10	1.22	0.19
9	5.7	0.79	0.08	2	2.67	0.09
9	6.1	0.86	0.08	5	3.13	0.25
9	6.5	0.98	0.09	1	1.57	0.15
10	5.7	0.79	0.09	2	2.67	0.04

10	6.5	0.70	0.07	7	0.67	0.06
10	6.7	0.80	0.07	5	3.69	0.01
12	6.6	1.21	0.13	1	0.27	0.09
12	6.6	1.21	0.09	1	1.08	0.18
12	7.0	0.91	0.08	2	1.32	0.31
12	6.5	0.97	0.08	1	0.73	0.05
13	6.6	1.21	0.09	1	0.27	0.11
13	6.8	1.28	0.11	1	0.59	0.69
13	6.9	1.33	0.11	14	0.74	0.07
13	6.4	0.79	0.08	9	0.28	0.34
13	6.3	1.64	0.12	3	2.10	-
22	6.8	0.94	0.12	1	0.43	0.29
Land unit 3						
5	6.5	0.95	0.10	1	1.29	0.36
5	7.0	1.64	0.12	2	1.11	0.91
5	6.4	0.92	0.09	1	0.45	0.93
14	6.9	0.73	0.06	1	0.46	0.14
14	6.6	1.21	0.09	1	0.27	0.14
16	6.3	1.16	0.09	1	0.74	0.14
16	7.3	2.04	0.12	1	2.30	0.51
21	7.1	1.13	0.10	1	0.31	0.75
21	7.3	1.09	0.09	1	0.71	0.38
21	7.0	1.10	0.09	2	-	0.41
21	7.1	1.28	0.09	1	0.66	0.76
23	6.7	0.82	0.08	1	0.61	0.20
Land unit 4						
15	6.9	0.73	0.07	1	0.46	0.14
15	7.1	2.26	0.15	1	0.72	0.26
15	7.3	1.94	0.12	1	0.84	0.08
15	6.6	1.21	0.10	1	1.08	0.14
15	7.3	2.04	0.13	1	2.30	0.24
19	6.4	0.94	0.07	3	-	0.19
20	7.1	1.48	0.13	1	0.66	0.18
20	7.4	1.41	0.09	1	0.31	0.46
20	6.7	0.96	0.08	1	0.61	0.01
24	6.1	0.91	0.08	4	-	0.22

Means and their standard deviations for different soil chemical parameters for different land units.

	pH	Org.C %	tot.N %	P-Olsen ppm	Exch.K me 100g ⁻¹
LU 1	6.72 (.43)	1.20 ^b (.30)	0.10 (.03)	2.08 (1.85)	0.50 ^b (0.40)
LU 2	6.65 (.50)	0.99 ^a (.24)	0.09 (.02)	2.64 ^a (2.21)	1.47 ^a (1.13)
LU 3	6.81 (.33)	1.09 (.25)	0.09 (.01)	1.18 ^b (0.40)	0.60 ^b (0.37)
LU 4	6.84 (.43)	1.32 ^b (.51)	0.10 (.03)	1.56 (1.13)	0.52 ^b (0.37)
Avg.	6.72 (.44)	1.10 (.32)	0.10 (.02)	2.10 (1.85)	0.96 (0.93)
F	0.60	3.10	0.90	2.07	6.46
P	0.62	0.03	0.45	0.11	0.0008

¹ values between brackets are standard deviations

^{a,b} mean values with different superscripts are significantly different (P<0.05)

Appendix 3 - Crop and soil parameters

Table 1. Crop parameter data for maize, cassava, upland rice and sugarcane.

Parameter	maize	cassava	upland rice	sugarcane
Tb	10	10	11	10.5
TSUM	1400	4820	1700	5400
TLEAF	750	1100	850	900
TLOW	5	8	5	7
RDSroot	.70	.26	.75	.90
RDm	100	100	80	150
RDint	5	15	10	20
PSIleaf	17000	16000	14000	18000
SLAMAX	21	22	26	12
SLAMIN	14	18	17	9
ke	.60	.80	.40	.31
TCM	1.15	1.15	1.1	1.15
RLEAF	.013	.012	.03	.0134
RRT	.01	.01	.01	.01
RSTEM	.01	.004	.015	.0029
RSO	.01	.003	.01	-
ECLEAF	.72	.72	.72	.72
ECROOT	.72	.72	.72	.72
ECSTEM	.69	.69	.69	.72
ECSO	.72	.81	.74	-

Tb = threshold temperature for development ($^{\circ}\text{C}$); SUM = heat requirement for full crop development ($^{\circ}\text{C}\text{d}$); TLEAF = heat requirement for full leaf development ($^{\circ}\text{C}\text{d}$); TLOW = threshold temperature for growth ($^{\circ}\text{C}$); RDSroot = relative development stage at which root growth ceases; RDm = maximum rooting depth (cm); RDint = equivalent rooting depth at germination or planting (cm); PSIleaf = critical leaf water head (cm); SLAmax = maximum specific leaf area ($\text{m}^2 \text{kg}^{-1}$); SLAmin = minimum specific leaf area ($\text{m}^2 \text{kg}^{-1}$); ke = extinction coefficient for visible light; TCM = maximum turbulence coefficient; R(org) = relative maintenance respiration rates ($\text{kg kg}^{-1} \text{d}^{-1}$); EC(org) = efficiencies of conversion (kg kg^{-1})

Table 2. Assimilate partitioning in maize

dvs	.00	.21	.37	.53	.69	.80	1.0
frleaf	.32	.48	.35	.13	.07	.00	.00
frroot	.38	.13	.13	.06	.06	.00	.00
frstem	.30	.39	.52	.42	.22	.18	.00
frso	.00	.00	.00	.39	.65	.82	1.0

Source : field experimental data (Widianto, personal communication)

Table 3. Assimilate partitioning in cassava

dvs	.00	.07	.17	.26	.36	.46	.66	1.0
frleaf	.20	.22	.20	.18	.18	.16	.10	.08
frroot	.47	.44	.21	.03	.03	.02	.02	.02
frstem	.33	.34	.44	.43	.40	.36	.36	.32
frtuber	.00	.00	.15	.36	.39	.46	.52	.58

Source : field experimental data (Widianto, personal communication)

Table 4. Assimilate partitioning in upland rice

dvs	.00	.08	.30	.38	.45	.60	.75	1.0
frleaf	.38	.40	.48	.47	.42	.21	.00	.00
frroot	.60	.32	.08	.08	.07	.06	.00	.00
frstem	.02	.28	.44	.45	.51	.73	.00	.00
frso	.00	.00	.00	.00	.00	.00	1.0	1.0

Source : van Heemst, 1988

Table 5. Assimilate partitioning in sugarcane

dvs	.00	.14	.45	.90	1.0
frleaf	.20	.25	.38	.20	.00
frstem	.20	.25	.10	.03	.03
frroot	.60	.50	.52	.77	.00

Source : van Heemst, 1988

Table 6. Soil data of 4 land units

Parameter	LU1	LU2	LU3	LU4
Zt	2	20	20	30
SM0	0.52	0.57	0.52	0.52
GAM	0.0082	0.0085	0.0070	0.0070
PSImax	307	223	330	330
K0	1.1	18.7	6.4	5.3
ALFA	0.025	0.025	0.025	0.025
AK	0.08	0.02	0.03	0.03
S0	8.42	13.64	16.66	16.66
KTR	2.50	4.73	1.47	1.47

Zt = depth to groundwater (m); SM0 = total pore fraction ($\text{cm}^3 \text{cm}^{-3}$); GAM = texture-specific constant (cm^{-2}); PSImax = texture specific suction boundary (cm); K0 = saturated hydraulic conductivity (cm d^{-1}); ALFA = texture specific geometry constant (cm^{-1}); AK = texture specific empirical constant ($\text{cm}^{-2.4} \text{d}^{-1}$); S0 = reference sorptivity ($\text{cm d}^{-0.5}$); KTR = hydraulic permeability of transmission zone (cm d^{-1})

Appendix 4 - Potential crop production

Calculated potential production of dry storage organs (kg ha⁻¹) of various crops in the research area, using several planting dates.

Crop	Planting dates:						
	50	100	150	200	250	300	350
Maize	5938	4392	5400	9063	<u>9619</u>	8176	7927
Cassava	31980	32968	<u>33197</u>	32512	30856	29124	29329
Upland rice	5694	4749	5874	<u>8660</u>	8248	7672	7695
Sugarcane	32689	33589	<u>34810</u>	33440	29879	27215	29590

Calculated potential production of dry storage organs (kg ha⁻¹) with 0.7 light transmission.

Crop	Planting dates:						
	50	100	150	200	250	300	350
Maize	2280	1473	1809	3648	<u>4372</u>	3354	3107
Cassava	22288	<u>23685</u>	23537	23176	21929	20265	20082
Upland rice	2095	1476	1855	3633	<u>3945</u>	3232	3124
Sugarcane	5532	6787	8421	<u>8950</u>	7268	5166	4738

Calculated potential production of dry storage organs (kg ha⁻¹) with 0.6 light transmission.

Crop	Planting dates:						
	50	100	150	200	250	300	350
Maize	953	593	712	1499	<u>1928</u>	1410	1279
Cassava	15687	16778	<u>17058</u>	16935	16015	14489	14236
Upland rice	750	495	615	1356	<u>1619</u>	1220	1154
Sugarcane	547	697	979	<u>1234</u>	1014	679	530

Calculated water-limited potential production of dry storage organs (kg ha⁻¹) of various crops in the research area, using several planting dates.

Crop	LU	Planting dates:						
		50	100	150	200	250	300	350
Maize	1	1758	2613	1309	<u>3376</u>	2551	2707	429
	2	767	-	614	<u>2634</u>	1827	-	593
	3	308	69	305	-	<u>1567</u>	-	437
	4	211	-	188	-	<u>387</u>	-	17
Cassava	1	4526	5761	5934	6543	6409	<u>7402</u>	7218
	2	-	-	8984	11923	<u>12740</u>	-	4535
	3	2440	3949	4675	6169	<u>6718</u>	5409	3415
	4	957	1000	1212	1208	<u>1447</u>	1382	1305
Upland rice	1	2031	617	610	1113	<u>4091</u>	71	700
	2	-	-	443	1187	<u>1626</u>	-	-
	3	339	224	303	1001	<u>1450</u>	428	938
	4	-	-	203	<u>602</u>	95	-	247
Sugarcane	1	13069	<u>13814</u>	12006	5068	10313	6852	7862
	2	-	10590	<u>13787</u>	10323	3412	-	-
	3	6957	7327	7933	<u>8773</u>	6704	3011	3023
	4	2782	3579	<u>3925</u>	3508	2794	2271	2191

Calculated water-limited potential production of dry storage organs (kg ha⁻¹) with 0.71 light transmission. (- means crop failures)

Crop	LU	Planting dates:						
		50	100	150	200	250	300	350
Maize	1	446	971	1604	<u>3216</u>	2767	1254	176
	2	225	-	521	<u>1720</u>	1690	-	264
	3	114	14	234	-	<u>1059</u>	-	167
	4	90	-	138	-	<u>306</u>	-	6
Cassava	1	3064	<u>4978</u>	4258	4813	4710	4596	4321
	2	-	-	6059	7822	<u>8878</u>	-	2946
	3	1582	2883	3507	4302	<u>5030</u>	3888	2552
	4	760	758	<u>934</u>	837	837	791	926
Upland rice	1	550	1209	725	1059	<u>3364</u>	94	152
	2	-	-	366	892	<u>1193</u>	-	-
	3	194	157	265	605	<u>935</u>	169	303
	4	-	-	169	<u>534</u>	69	-	145
Sugarcane	1	2229	<u>3704</u>	2653	1374	764	326	236
	2	-	<u>3979</u>	2974	1673	660	-	-
	3	3501	<u>3714</u>	2883	2331	1745	1139	1095
	4	<u>2160</u>	1760	1258	1153	848	714	870

Calculated water-limited potential production of dry storage organs (kg ha⁻¹) with 0.55 light transmission. (- means crop failures)

Crop	LU	Planting dates:						
		50	100	150	200	250	300	350
Maize	1	190	400	712	1499	<u>1882</u>	554	90
	2	347	-	568	1138	<u>1703</u>	-	109
	3	53	6	286	-	<u>778</u>	-	77
	4	48	-	130	-	<u>243</u>	-	3
Cassava	1	2309	<u>3986</u>	3224	3850	3062	3441	3030
	2	-	-	4471	6046	<u>6514</u>	-	1877
	3	1120	2162	2756	3095	<u>3707</u>	2784	1790
	4	643	670	714	689	<u>577</u>	467	<u>771</u>
Upland rice	1	171	417	625	1257	<u>1389</u>	289	49
	2	-	-	355	<u>901</u>	667	-	-
	3	93	125	258	570	<u>633</u>	73	126
	4	-	-	159	<u>450</u>	114	-	43
Sugarcane	1	204	439	<u>440</u>	292	185	96	54
	2	-	576	<u>661</u>	437	188	-	-
	3	317	475	<u>497</u>	434	271	170	121
	4	287	384	<u>393</u>	347	221	132	104

Appendix 5 - Energy requirements for livestock production

Models do not pretend to cover the whole complexity of real situations. Time necessary to conduct experiments can be reduced by making use of models. They are generally used to: (1) predict the impact of specific interventions; (2) validate assumptions and draw conclusions about input-output relationships in field situations; and (3) identify the gaps in our knowledge about essential processes that require experimental research.

Energy requirements for production

The amount of energy for production was used for pregnancy, milk production, liveweight gain and draft power. Hereafter the calculation of energy requirements for each type of production is described.

Energy requirements for pregnancy

For the first 140 days of pregnancy of cattle and for the first 73 days of pregnancy of sheep and goats, no extra energy requirements were calculated. After day 140 for cattle, and day 73 for sheep and goats, energy requirements were based on the Gompertz equations of the Agricultural Research Council (1980):

$$\text{cattle : NEpr} = \text{energy} * 0.0201 * e^{(-0.0000576 * X)}$$

NEpr = net energy requirements for pregnancy (MJ)

$$\text{cattle : log(energy)} = 151.665 - 151.640 * e^{-0.0000576 * X}$$

$$\text{sheep and goats : NEpr} = \text{energy} * 0.07372 * e^{(-0.00643 * X)}$$

$$\text{sheep and goats : log(energy)} = 3.222 - 4.979 * e^{-0.00643 * X}$$

where X is the number of days from conception. This equation was fitted for calves with a birth weight of 40 kg, and for kids and lambs with a birth weight of 4 kg. Because birth weights of tropical breeds are lower, the requirements were adjusted in the equation by multiplying them by the factor EB/SBW, where EB = birth weight of the simulated breed and SBW = standard birth weight. Average calf birth weight in the research area was 20 kg and the gestation length of cows was taken as 270 days. Average lamb and kid birth weight in the research area was 2 kg and the gestation length of sheep and goats was taken as 140 days.

The equations below give the daily energy requirement for pregnancy at day X from conception.

$$\text{cattle : NEpr} = (\text{EB}/40) * 10^{\{151.665 - 151.640 * e^{(-0.0000576 * X)}\}} * 0.0201 * e^{(-0.0000576 * X)}$$

$$\text{sheep and goats : NEpr} = (\text{EB}/4) * 10^{\{3.222 - 4.979 * e^{(-0.00643 * X)}\}} * 0.07372 * e^{(-0.00643 * X)}$$

$$\text{MEpr} = \text{NEpr} / 0.133$$

MEpr = metabolizable energy requirements for pregnancy (MJ)

Energy requirements for milk production

The following equation (ARC, 1980), based on the fat content of milk, was used to calculate energy requirements for milk production:

$$\text{ME}_{\text{milk}} = (40.6 * \text{fat} + 1509.0) / 0.6 * 1000 \text{ MJ kg}^{-1} = 5.83 \text{ MJ kg}^{-1}$$

Using the average fat content of 49 g per kg of milk, the energy requirements for one kg of milk amounted to 5.83 MJ metabolizable energy. The above mentioned equation is primarily for a cow, but the result is comparable with recommended values for goats, 5.02 MJ ME (Singh & Mudgal, 1985) and 5.17 MJ ME (NRC, 1981) per kg of milk. Wide variations in the milk composition of sheep and goats are reported due to breed, nutrition and stage of lactation. In this study a value of 5.83 MJ ME per kg of milk produced was used for cattle, as well as sheep and goats.

Energy requirements for growth

The energy required for 1 kg growth, changes as composition of gain shifts from lower energy components (water, minerals and protein) to the high energy component (fat) when the animal matures. Ideally the estimations of bodyweight gain composition should be based on observations concerning the breeds involved in simulation. As these observations were not available for the research area, it is desirable to have a more general relation. As a first approximation of such a general relation, the ARC (1980) relations were used as they were based on observations covering a wide range of breeds.

$$\log(\text{protein}) = -0.5037 + 0.8893 * \log(\text{EBW})$$

$$\log(\text{fat}) = -2.6570 + 1.7880 * \log(\text{EBW})$$

EBW = empty bodyweight (kg)

The mature weight for these medium size breeds was not explicitly stated; the data source tables however indicated a mature weight of about 550 kg as observed for the Friesians which

were used in some trials. The model corrects for variations in mature weight by scaling the empty bodyweight with the ratio between the breed mature weight (BW/adult weight (AW)) and 550 kg. It was assumed that the local potential cattle breed mature weight was 500 kg and the bodyweight of the standard cow was 250 kg.

$$EBW = 0.91 * BW * 550 / AW$$

it was assumed that $BW/AW = 0.5$

The composition of bodyweight change was estimated by differentiating the equations above:

$$dprotein/dEBW = 0.2788 / (EBW^{0.1107})$$

$$dfat/dEBW = 0.0039388 * EBW^{0.7880}$$

$$dprotein/dEBW = \text{protein content of 1 kg gain (kg kg}^{-1}\text{)}$$

$$dfat/dEBW = \text{fat content of 1 kg gain (kg kg}^{-1}\text{)}$$

The energy value of gain, with differentiation between sexes, was estimated as follows (ARC, 1980).

$$\text{gain female} = 27.14 * \text{prot} + 45.20 * \text{fat} \quad \text{MJ NE kg}^{-1} \text{ gain}$$

$$\text{gain male} = 20.06 * \text{prot} + 33.41 * \text{fat} \quad \text{MJ NE kg}^{-1} \text{ gain}$$

For female animals gain was 17.92 MJ NE kg⁻¹ gain, which was equal to 29.9 MJ ME kg⁻¹ gain. It was assumed that energy requirements for 1 kg of bodyweight gain were independent of species or breed, and thus were the same for cattle, sheep and goats.

Energy requirements for traction

Traction requirements

For this research, parts of an animal traction model developed by van der Lee et al. (1993) were used. The model starts with calculation of the energy requirements for traction. The required force is the product of the volume of soil material moved and the soil resistance. The force calculated this way is the horizontal component of the required force. The actual required force is obtained by division of the cosine of the angle of pull (H) (Lawrence, 1985). The soil material moved is numerically equivalent to the intersection of the moved soil bar (Perdock & van de Werken, 1980). Often not all material in this square is actually moved and therefore the intersection Working Width (WW) times Working Depth (WD) is multiplied by the WW * WD-fraction (WDF), to obtain the effective intersection (EI). The WDF has a rather constant value per implement. The same holds true for the relation between WD and WW, which means WD can be estimated from WW. Soil resistance varies for different soils

and should therefore be measured per land unit. The specific soil resistance (SSR) of a soil varied with working speed and soil moisture content. According to ASAE (1975), the SSR did not significantly vary in the range of speeds occurring in animal traction (0.5 - 1.2 m s⁻¹).

$$F_{\text{req}} = (WW * WD * WDF * SSR) / \cos(H)$$

F_{req} = force required (N)

WW = working width (m)

WD = working depth (m)

WDF = fraction of width * depth which is actually moved (m² m⁻²)

SSR = specific soil resistance (dependent on soil moisture capacity) (N m⁻²)

H = the angle of pull (degrees)

The work to be performed increased with plot area (PA). However, the layout of the plot determined the number of turning times, and thus the distance actually covered. The extra distance covered was incorporated by addition of a certain turning overhead (TO) to the distance covered per plot (DP, multiplication of distance covered per hectare and PA).

$$W_{\text{req}} = (F_{\text{req}} * DP)$$

W_{req} = work required (Nm)

DP = distance covered per parcel (m)

$$DP = DH * PA$$

PA = plot area (ha)

DH = distance covered per hectare (m ha⁻¹)

$$DH = 1/(WW + SBF) * 10000 * NP * (1 + TO)$$

DH = distance covered per hectare (m ha⁻¹)

WW = working width (m)

10000 = m² ha⁻¹

NP = number of passes (-)

TO = fraction of distance covered per hectare which is extra covered due to turning on the plot (%)

SBF = space not cultivated between two furrows (within a pass) (m)

Energy requirements

Nutrient requirements of working animals for traction mainly concern energy. Requirements for protein, vitamins and minerals are negligible (Pearson, 1993; Lawrence, 1985). Once

traction is assigned, energy requirements can be calculated, for which the factorial approach of Lawrence (1985) was used. In this approach energy requirements were subdivided in fractions for the horizontal traction component, the vertical traction component, walking and elevation. ME-values used were derived from Lawrence & Stibbards (1990) and Mathers et al. (1985): (i) ME cost of pulling (horizontal component) was $33 \text{ J kg}^{-1}\text{m}^{-1}$, (ii) ME cost of elevation was $28 \text{ J kg}^{-1}\text{m}^{-1}$, (iii) ME cost of carrying loads and LW (vertical component) was $2.6 \text{ J kg}^{-1}\text{m}^{-1}$ and (iv) ME cost of walking was $2.0 \text{ J kg}^{-1}\text{m}^{-1}$.

$$W_{\text{wlk}} = LW * DP * 9.8$$

W_{wlk} = work accomplished by moving LW (J)

9.8 = conversion from kilogram to Newton (N kg^{-1})

$$W_{\text{elv}} = [(LW * 9.8) + (F_{\text{req}} * \sin(H))] * SL/100 * (DP/2)$$

W_{elv} = work accomplished by raising LW and load (J)

DP/2 = distance covered on parcel, to be divided by two because only half of the furrows go uphill (m)

SL = slope of the walking surface, meter raised per 100m (m m^{-1})

$$\begin{aligned} NE_{\text{hor}} &= W_{\text{req}} * \cos(H) * k_t * ME_{\text{hor}} / 9.8 \\ &= W_{\text{req}} * \cos(H) \end{aligned}$$

NE_{hor} = net energy for the horizontal component (MJ)

k_t = NE proportion of the ME ($\text{J NE J}^{-1} \text{ME}$)

$$NE_{\text{ver}} = W_{\text{req}} * \sin(H) * k_t * ME_{\text{ver}} / 9.8$$

NE_{ver} = net energy for the horizontal component (MJ)

$$NE_{\text{wlk}} = W_{\text{wlk}} * k_t * ME_{\text{wlk}} / 9.8$$

NE_{wlk} = net energy for walking (MJ)

$$NE_{\text{elv}} = W_{\text{elv}} * k_t * ME_{\text{elv}} / 9.8$$

NE_{elv} = net energy for elevation (MJ)

$$NE_t = NE_{\text{hor}} + NE_{\text{ver}} + NE_{\text{elv}} + NE_{\text{wlk}}$$

NEt = total net energy for traction (MJ)

Traction supply

Work requirements had to be met by suitable animals: animals that could supply draught force for a certain period. To decide whether the animal could perform the task, the potential draught force (N) was calculated (using a factor of 9.8 to convert from kilograms to newtons):

$$F_{\text{pot}} = \text{LW} * \text{LWP}/100 * \text{TE} * 9.8$$

F_{pot} = potential draught force (N)

LW = liveweight (kg)

LWP = liveweight percentage (%)

TE = team efficiency (%)

The potential draught force depended on the liveweight of an animal, and was expressed as a percentage of liveweight:

$$\text{LWP} = 8 + \text{CS} + \text{HS}$$

CS = condition score (-)

HS = harnessing score (-)

The condition score was assigned according to the condition of an animal. The equation estimated body condition by the ratio of actual weight (LW) to optimal weight (OW).

$$\text{CS} = 5 * (\text{LW}/\text{OW}) - 0.4$$

OW = optimum weight (kg)

The different methods of harnessing available showed differences in the efficiency of transfer of draught force from animal to implement. LWP was adjusted for this efficiency, using a harnessing score (HS) ranging from 1 to 3 (1=inefficient; 2=average; 3=efficient). In addition to CS and HS, a factor called team efficiency (TE) was included in the calculation for potential draught force, because efficiency of draught force use diminished with increasing team size (TS):

$$\text{TE} = 1 - (\text{TS} - 1) * 0.075$$

TS = team size

An example

The implement used in the research area for ploughing was a plough called *brujul*. Van Loon (1992) described some features of the *brujul*, a hook or ard plough, which were used in the

calculations. From a sample of 26 ploughs the working-width appeared to be approximately 11.4 cm, and the working-depth an average value of 9.5 cm, thus the working-width/working-depth rate would be 1.20. Van der Lee (1991) performed a regression analysis to estimate the relation between working-width*working-depth and the "true cross-section" of the cultivated soil. Theoretically the cross-section of the cultivated soil was equal to the product of working-width and working-depth. In practice, however, this cross-section was smaller because the working-width in the lower part of the furrow was smaller compared to the upper part. Therefore a width-depth fraction had to be used to correct for this inequality. A theoretical value of 0.60 was used for the *bruJul*. The angle of the drawbar was always fixed at about 15° from the horizon. The Turning Overhead was estimated to be 1%. The space not cultivated between the furrows was 0. Calculation of the potential draught force of one animal, with a CS and a HS of 2 resulted in a LWP of 12, and of the required total work force for two animals, resulted in:

$$F_{pot} = 250 * 12/100 * 0.925 * 9.8 = 271.95 \text{ N (for 1 animal)}$$

$$F_{req} = 0.114 * 0.095 * 0.60 * 80\ 000 / \cos(15) = 538.18 \text{ N (for 2 animals)}$$

The above calculation showed that the draught force required could be delivered by two animals with a liveweight of 250 kg each. The metabolizable energy, for a cow of 250 kg bodyweight, which was required when an average parcel had to be ploughed with a specific soil resistance of 80 000 N m⁻² (moderate heavy clay) and three different slopes, is given in Table 1. The average parcel size was calculated as 0.243 ha (PA), based on the landsize data of 150 farmers included in an Expanded Farm Household Survey (EFHS). Only those lands which were cultivated with annual crops were considered relevant for animal traction. It was assumed that once land was ploughed the parcel was ploughed as a whole.

$$F_{req} = 269.09 \text{ N}; DP = 21528.95 \text{ m}; W_{req} = 5.79 \text{ J}$$

Table 1. Energy requirements for ploughing 0.243 ha of land.

SSR (N m ⁻²)	ME MJ for traction					Tot
	slope	walk	lift	hor	ver	
80 000	5	10.76	3.87	18.83	0.40	33.86
80 000	10	10.76	7.75	18.83	0.40	37.74
80 000	15	10.76	11.62	18.83	0.40	41.61

Traction was performed from September to December, with on average 10 days per month in which the animals were used for ploughing (calculated from field survey data). Ploughing was always done in pairs. A parcel was usually ploughed by several pairs of animals, several

times. It was assumed that, in total, the energy requirements of one cow in a pair were equal to ploughing the whole parcel once, spread over 3 days, and that at minimum one parcel of 0.243 hectare and at maximum 3 parcels were ploughed per month (since 3 parcels already take 9 days in a month).