WAGENINGEN UR
For quality of life

Exploring the potential of high technological and eco-efficient agriculture

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This study reviews the technologies and scientific approaches available and in development to contribute in meeting the challenge of agroproduction to feed a growing population using less natural resources as expressed in the CSD-17 Shared Vision Statement. The report provides an overview of the progress made by Wageningen UR on the different technologies and approaches, their state-of-the-art, the results to be expected on short and medium notice and the aspects underexposed in research programs until now.

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Preface

In May 2009, the Commission for Sustainable Development (CSD) chaired by the Dutch Minister of Agriculture, Nature and Food Quality, produced in its 17th session a shared vision on the future and role of agriculture, rural development, land, drought, desertification and Africa,. In this Shared Vision Statement the Chair mentions that "nothing less is needed than a revolution in ideas and a revolution in technologies, supported by a revolution in trade policies and market access and the financial means to implement it". The CSD formulated policy options and practical measures to elaborate on the Shared Vision Statement.

As a follow-up on the CSD-17 results, the Dutch government decided to further elaborate the subjects of water and highly technological and eco-efficient agriculture. This report hooks on to the second subject and is the reflection of the current and future contributions Wageningen University and Research Centre makes to the development of agroproduction systems. These agroproduction systems aim to produce enough food for a growing population and contribute to the biobased economy whilst operating sustainably with regards to the earth's limited natural resources.

This report describes the research domains of Wageningen UR that are relevant for highly technological and eco-efficient agriculture. It does not pretend to be a complete and detailed overview. The research domains described can be roughly divided into (i) basic technologies and (ii) implementation concepts that are needed to implement these technologies and bring agriculture forward in the desired direction. The report describes Wageningen UR's contribution within the international scientific context. This constitutes a mixture of fundamental and applied sciences emerging from the five science groups of the organization. The added value of Wageningen UR is its experience on both technological development as well as on processes that ensure the technologies are successful and used in society.

We expect that this report can contribute to the international research and implementation agenda. It shows how technological and eco-efficient agriculture can contribute to an increase in agricultural productivity while lowering the ecological footprint, decreasing greenhouse gas emissions and not damaging natural resources. It summarizes the tangible knowledge products that can be expected on short and medium term. Finally, the study indicates which transition pathways are available and in what way the described research domains can contribute to these pathways. Particularly the implementation concepts described in the report can be useful for policy making. These concepts specifically show that the challenges involved are multisectoral, involving all the scale levels from the international platform to the individual farms. This implies that various levels of policy-making need to be integrated.

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Samenvatting

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De verwachting is dat de landbouwproductie in de komende decennia moet verdubbelen om voedselzekerheid te bevorderen. De groei van de wereldbevolking en de veranderende eetgewoonten (meer dierlijk voedsel en luxer, meer bewerkt, voedsel) liggen hieraan ten grondslag, samen de wens om biomassa te gebruiken om fossiele grondstoffen deels te vervangen. De druk op natuurlijke hulpbronnen (land, water, nutriënten, biodiversiteit) neemt daarom toe hetgeen benadrukt wordt door klimaatverandering en toenemende bodemerosie. Niet alleen moet de landbouw zich aanpassen aan een veranderend klimaat maar ook dient de landbouw een sterke productiviteitsstijging te realiseren met een gelijktijdige sterke verhoging van de efficiëntie waarmee het gebruik maakt van natuurlijke hulpbronnen. De landbouw staat daarmee weer in de schijnwerpers temeer daar de landbouw als economische motor ook de belofte in zich draagt om in belangrijke mate bij te dragen aan het behalen van de MDG's.

Technologie heeft in de afgelopen decennia in belangrijke mate bijgedragen aan de productiviteit in de landbouw en in de afgelopen decennia ook aan het verminderen van emissies (nutriënten en gewasbeschermingsmiddelen) en verhogen van de duurzaamheid. Ook in de komende decennia zal technologie een belangrijke bijdrage gaan leveren aan de ontwikkeling van de landbouwproductie. Echter, het speelveld is complexer geworden, niet in de laatste plaats omdat de nadruk meer is komen te liggen op de relatie tussen landbouw en natuurlijke hulpbronnen die mondiaal gesourced worden en schaars zijn. Maar ook omdat sociale acceptatie zich steeds vaker en indringender doet gelden, klimaatverandering lokatiespecifiek effect heeft en de inzichten in onderlinge afhankelijkheden toeneemt. Deze complexiteit maakt dat de specifieke eisen die aan agroproductiesystemen worden gesteld in steeds hogere mate locatiespecifiek zijn. Systemen moeten zich aanpassen aan de lokale omstandigheden en dat is steeds meer bepalend voor de bijdrage van en daarmee de vraag naar technologie. De dynamiek van continue verandering, opgeteld bij het veranderende klimaat, maken dat agroproductiesystemen bij voorkeur robuust en veerkrachtig dienen te zijn en dit vraagt bij uitstek een aanpassing aan lokale omstandigheden (ook in de tijd gezien).

De uitdagingen waar de landbouw voor staat en de complexiteit van de omgeving die de ruimte bepaalt waarin de landbouw zich kan ontwikkelen, maken dat vaak forse stappen gezet moeten worden waarbij ook nog eens veel belangen tegelijk gediend moeten worden. Deze transities kunnen ondersteund worden door het proces van systeemontwerp gekoppeld aan een goede situationele analyse (bijvoorbeeld betreffende de concurrentie om hulpbronnen in tijd en ruimte). Zodoende kan richting gegeven worden aan het gewenste ontwikkelingsproces (bijvoorbeeld herontwerp van dierhouderijsystemen) en de daarbij horende technologie-ontwikkeling. De kennis over en inzichten in (co-) innovatieprocessen komen van pas zodra technologie ook daadwerkelijk geïmplementeerd wordt.

Dat neemt niet weg dat in de komende decennia enkele belangrijke basistechnologieën verder ontwikkeld worden die hun spin-off zullen vinden in door lokale omstandigheden bepaalde toepassingen. Te denken valt aan de technologieën die het mogelijk maken steeds beter, sneller en goedkoper genetische informatie te ontsluiten en die uiteindelijk breeding by design mogelijk zullen maken. De merkertechnologie maakt het steeds beter mogelijk de genetische achtergrond van complexe eigenschappen van dieren en planten te achterhalen waardoor deze eigenschappen beter en succesvoller in veredelingsprogramma's ingepast kunnen worden. De verwachting is dat op korte en middenlange termijn kennis, methoden en genen beschikbaar komen voor gebruik door bedrijfsleven die deze halffabricaten kunnen inbouwen in marktbare producten.

Bionanotechnologie en sensortechnologie zullen het mogelijk maken om steeds beter veranderingen te monitoren zodat in vroegtijdiger stadia bedreigingen van de gezondheid van dier en plant vastgesteld kunnen worden. Precisietechnologie zal het mogelijk maken dieren en uiteindelijke ook planten individueel te benaderen. Sensoren en toepassingsregels zijn nodig voor een veelheid aan toepassingen. Sommige toepassingen zijn al in de praktijk in gebruik (voorbeeld: dynamisch voeren) en andere toepassingen zijn in een ver gevorderd stadium van ontwikkeling in samenwerking met marktpartijen. Meer toepassingen zullen de komende jaren ontwikkeld worden, waarbij de ontwikkeling van een effectieve GEO informatie infrastructuur (o.a uitwisseling GPS data) randvoorwaarde is.

Op het gebied van plant- en diergezondheid is een veelheid van technologieën beschikbaar en in ontwikkeling. Dit varieert van bestrijding tot waarschuwing en preventie en er zijn technologieën beschikbaar voor alle verschillende schaalniveaus van dier en plant tot omgeving. Preventie en vroege detectie (waarschuwing) hebben de voorkeur en maken het soms nodig om tot geheel andere ontwerpen van productiesystemen te komen en tot integrale benaderingen in management systemen. Biologische en geïntegreerde productiesystemen zijn hiervan een goed voorbeeld. In innovatieprojecten wordt hier verder aan gewerkt, bijvoorbeeld het project "De Smaak van Morgen". Implementatie van dit soort systemen of delen daarvan vindt plaats in samenwerking met het bedrijfsleven. De komende jaren zal meer kennis beschikbaar komen ten behoeve van praktijkimplementatie.

Kennis en inzicht worden ontwikkeld om de natuurlijke weerbaarheid van systemen beter in te zetten en daardoor de inzet van chemische middelen te verminderen. Daarbij is vooral meer kennis nodig van de bodem en de complexiteit van de interacties tussen het biologische, chemische en fysische deel. Een gezonde bodem is immers van onschatbare waarde voor de duurzaamheid van grondgebonden landbouw. Kennis, inzichten, methoden en technieken voor een beter en meer duurzaam bodembeheer zijn voor een deel al beschikbaar gekomen, maar een nog groter deel zal in de komende jaren ontwikkeld worden in zowel in projecten die op deelaspecten inzoomen als in projecten die bodemaspecten in samenhang en bestuderen. Nieuwe bodembeheersmaatregelen kunnen verwacht worden op korte en middenlange termijn.

Water is essentieel voor groei en productie. De beperkte beschikbaarheid van water noopt tot een efficiënt gebruik. Veel kennis is al beschikbaar en kan ingepast worden in situaties met suboptimale irrigatie. Deels wordt ook nieuwe kennis ontwikkeld bijvoorbeeld door irrigatie via gebruik van sensoren plaatsspecifiek toe te passen. Technieken zijn beschikbaar en in ontwikkeling om irrigatiewater efficiënter te benutten en om waterhergebruik te realiseren. Toepassing daarvan wordt in pilots onderzocht in diverse plaatsen in Europa. Op het niveau van stroomgebieden kan planning van watergebruik tot een betere benutting voeren en seizoensvoorspellingen van neerslag kan in combinatie met productieplanning tot meer biomassa per druppel leiden. Dit soort kennis vraagt veel van het gebiedsmanagement en implementatie en staat nog aan het begin van de ontwikkeling. Verder kan zoutwater landbouw een mogelijkheid bieden om ook zonder zoet water tot biomassaproductie te komen. De kennis die hierover beschikbaar is, is momenteel nog beperkt. In het kader van het project Zilte Zoom wordt evenwel een pilot uitgewerkt die navolging kan krijgen op de korte tot middenlange termijn.

Speciale aandacht is nodig voor nutriënten en dan speciaal fosfaat. In de afgelopen jaren zijn vele maatregelen ontwikkeld om het nutriëntgebruik (met name stikstof) te verbeteren. Veel van deze maatregelen worden in de praktijk toegepast met daarbij de opmerking dat de praktijkimplementatie steeds locatiespecifieke aanpassingen vraagt. De fosfaatproblematiek staat momenteel in de aandacht van het onderzoek. Gelet op de eindigheid van fosfaat als grondstof is het van belang om fosfaat op grote schaal te recyclen. Technologieën om fosfaten te herwinnen zijn beschikbaar of worden ontwikkeld, maar pilots zijn nodig om dit kosteneffectiever te maken. Dat laat onverlet dat een groeiende urgentie van het probleem van belang is om een omkering in het denken over fosfaat te veranderen. De biobased economy waarin reststromen aan een "tweede" leven kunnen beginnen, zal het als concept mogelijk maken om fosfaten te herwinnen en opnieuw beschikbaar te maken voor gebruik in de landbouw. De scheidings-, raffinage- en enzymtechnologieën hiervoor worden ontwikkeld en zullen deels op korte en deels op middenlange termijn beschikbaar komen. Op pilotniveau kunnen de eerste toepassingen op korte termijn opgeleverd worden. Daarnaast wordt momenteel de nodige inspanning gerealiseerd om de productie van hoogwaardige moleculen in planten te ontwikkelen met het oog op bioraffinage processen. De eerste resultaten zijn op korte termijn te verwachten. Algen als grondstof voor biobased processen krijgen momenteel in diverse schaalgroottes aandacht binnen Wageningen UR. Op middenlange termijn kunnen hier spin-off van verwacht worden.

De behoefte aan technologie voor de landbouw in ontwikkelende landen als in Afrika en geïndustrialiseerde landen verschilt fors als gevolg van het verschil in o.a. het productieniveau en de structuur van de landbouw, de ketens en de R&D. Verbeteringsstappen dienen aan te sluiten bij de lokale mogelijkheden (kapitaal, kennis, organisatie) om teleurstellingen te voorkomen. Niettemin is de potentie voor productiviteitsstijging in ontwikkelend landen (en speciaal Africa) groot wanneer integrale benaderingen tot stand kunnen komen. Bouwstenen voor verbeterde productiesystemen zijn ontwikkeld en worden toegepast worden in samenwerking met lokale partners. De inspanningen op dit terrein kunnen aan omvang winnen.

Het rapport over de mogelijkheden van hoogtechnologische en eco-efficiënte landbouw geeft aan hoe bestaande en nog te ontwikkelen technologieën kunnen leiden tot een viertal transitiepaden:

- Verhoging van de productiepotentie op basis van nieuwe rassen. Technologieën die "breeding-by-design" mogelijk maken worden, zoals reeds aangegeven, op korte en middenlange termijn verwacht.
- Het verminderen van het opbrengst- en kwaliteitsverlies via verbeterde maatregelen en systemen. Dit is in veel (geografische) gebieden een ontwikkelrichting met veel potentie. Het verminderen van opbrengstverlies gaat ook direct gepaard met hogere efficiëntie van het gebruik van natuurlijke hulpbronnen als land, water of nutriënten. Het gaat hier deels om het toepassen van reeds bestaande kennis als om het ontwikkelen van nieuwe kennis, methoden en instrumenten. Bij het toepassen van bestaande kennis is het van belang om locatiespecifiek praktische oplossingsrichtingen te ontwikkelen samen met bedrijfslevenpartijen.
- Het verbeteren van de eco-efficiëntie. Dit gaat samen gaan met productieverhoging door verhoging van de productiefactoren die in het minimum verkeren. Dit kan echter ook gerealiseerd worden door systeemaanpassingen of veranderingen waarbij recycling beter gestalte kan krijgen. Slimme clustering van productieprocessen waarbij reststromen direct gevaloriseerd kunnen worden, is hierbij behulpzaam (systeemontwerp). Bij het maken van belangrijke systeemsprongen om eco-efficiëntie structureel te verbeteren, dient nog veel kennis, methoden en technieken ontwikkeld te worden, maar kunnen ook al veel bestaande technieken uitkomst bieden op korte termijn.
- Agroproductiesystemen en competing claims: met een toenemende druk op natuurlijke hulpbronnen is het van belang dat agroproductiesystemen ontwikkeld worden waarbij win-win situaties met andere claims en claimers tot stand komen. Systeemontwerp die leiden tot hogere eco-efficiëntie van de productie en raffinage concepten kunnen hierbij behulpzaam zijn, maar ook concepten voor robuuste en veerkrachtige landbouw kunnen oplossingsrichtingen bieden. Dit is een onderzoeksdomein dat nog volop tot ontplooiing gaat komen in de komende jaren.

De conclusie is dat technologie een stevige bijdrage kan leveren aan het tot stand komen van hoogproductieve landbouw die de noodzakelijke eco-efficiëntie kan bereiken. Echter, de ontwikkeling van de technologie en vooral de inpassing daarvan in de praktijk zal tot stand komen binnen het spanningsveld van sociale acceptatie, economische rentabiliteit, concurrentie om en beschikbaarheid van natuurlijke hulpbronnen, de effecten van klimaatverandering en veranderend openbare beheerssystemen en zal rekening moeten houden met locatiespecifieke randvoorwaarden voor implementatie. Integrale benaderingen zijn daarmee van groot belang bij toepassing van technologie en daarmee is het nodig bij de ontwikkeling van met name basistechnologie vroegtijdig te verkennen welke toepassingsgebieden gaan ontstaan zodat hiermee in het ontwikkelproces rekening gehouden kan worden. Wageningen UR zal hieraan haar bijdrage leveren waarbij aangetekend kan worden dat lineaire ontwikkelprocessen minder van toepassing zijn, maar participatieve processen de boventoon voeren. In die zin is en zal co-innovatie als ontwikkelrichting actueel blijven.

Summary

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It is expected that agricultural production should double in the coming decades to ensure food security. World population growth and changing diets (increase of animal protein and more luxurious food products) are at heart of this challenge, together with the increase of biomass use to replace fossile oil and gas. As a consequence, pressures on natural resources like (fertile) land, water, nutrients and biodiversity, increase amplified by climate change and increasing soil degradation. Not is agriculture challenged to adapt to a changing climate, but it also needs to increase its productivity with a substabtial simultaneous decrease in its resource use efficiencies. This has put agriculture back on the political agenda all the more because the contribution of agricultural development on MDG achievement.

In recent decades, technologies have contributed greatly to productivity increase in agriculture and in the past decades also to decrease of emissions (nutrients and pesticides) and increase of sustainability. Technology will continue its contribution to agriculture production development in the decades to come. However, the development arena has become more and more complex, not in the least owing to an increased emphasis on the relation between agriculture and natural, globally and scarce resources. Additionally, social acceptance is of increased importance, climate changes are expected to have profound local consequences and insight and knowledge in interdependencies is increasing. This complexity puts higher pressure on and standards for locally adapted agroproduction systems. The local adaptability of these systems is largely determining their contribution and technology demand. The dynamics of continous and increased intensity of change and variability owing to to a changing climate, ask for more robust and resilient agroproduction systems which on their turn ask for present and future adaptation to local conditions.

The challenges that confront agriculture today combined with the complexity of the development framework, ask for significant transitions serving multiple interests at the same time. These transitions can be supported by system design processes based on an adequate analysis of the local situation at hand (for instance regarding competition for resources in space and time). The desired development pathway (for instance redesign of animal husbandry systems) and the subsequent demand for technology development can be supported accordingly. Knowledge and insight in (co-) innovation processes can be helpful once technology is ready to be implemented.

Nevertheless, some important basic technologies will become available in the coming years and decades, which will be implemented following co-innovation processes driven by local (time and place) technology demand. Examples of these basic genomic technologies will unlock genetic information better, faster and cheaper, finally resulting in the concept of "breeding by design". Genetic marker technology will enhance the unraveling of the genetic background of complex animal and plant characteristics (like yield), allowing more spohistocated and better targeted breeding programs. It is expected that on short to midterm knowledge, methods and genes will become available for use by breeding companies who can use these intermediate products to develop commercially succesfull end products.

Basic Technologies like bionanotechnology and sensor technology will allow us to monitor and detect changes and possible threats at an increasing earlier stage enabling more timely and effectively prevention measures. Precision technology has the promise to supply animals and even plants an individually needed treatment, thus increasing efficiency of resources. Sensors and their underlying protocols can have numerous applications, some of which are already used in practice (the example of dynamic feeding of cattle) while other applications are in an advanced stage of co-development in public-private partnerships. More applications can be expected to be developed in the years to come, provided that an effective GEO information infrastructure (for example exchange of GPS data) is being developed simultaneously.

Concerning plant and animal health, a number of technologies is available or in development. This varies from technologies enabling warning, prevention or control on different scale levels from individual (animal or plant) to the environment. Prevention and early warning are preferred approaches, sometimes necessitating new and integral production system designs. Organic and integrated production systems are good examples of incorporating prevention and realy warning on production system level. In innovation projects like "Tomorrow's taste" these systems are developed further, mostly in close corporation and involvement of farmers and other stakeholders allowing more knowledge and technologies to become available in the next 5 years.

Knowledge and insight are being developed to enhance the natural resistance of production systems and thereby diminishing the need for chemical control measures. Most of all knowledge is needed on soil quality and the underlying complex interactions between the biological, fysical and chemical aspects as well as organic matter content. A more healthy, high quality, soil is invaluable to the sustainability of land-based agriculture. Partly, knowledge, methods, instruments and tools to improve soil management are available for practice and partly will become available in the coming years. These wille be products both from studies focusing on single soil aspects or originating from integrated soil studies. New integrative and more sophisticated soil management tools can be expected on medium and long term.

Water is an essential resource for animal and plant growth and production, available in a limited amount. With increasing production demand a substantial increase in water use efficienciency is obligatory. Existing knowledge, tools and technology is available and can be of use in situations of suboptimal irrigation systems in an enabling environment. Also, new technologies (tools, methods) are being developed for instance by developing reliable sensors for site specific and demand driven irrigation. Technologies are available or in development for a more efficient irrigation management like water recycling or waiste water re-use. Regarding the last mentioned technology pilots are in progress in several places in Europe. On water catchment level water use planning has the potential to lead to improed water use efficiency while seasonal rain predictions can result in more crop per drop in combination with production planning. These approaches demand effi cient and coherent catchment area management and are in development. Also, saline agriculture can offer opportunities to produce biomass even in the absence of sweet water. Existing knowledge relating to saline agricultural production has limited availability and still needs further development. Nevertheless, in the Dutch project "De Zilte Zoom" a pilot is elaborated for efficient saline production that can be upscaled on short or medium term.

Special attention is needed for nutrient management and especially phosphate. In the past years many source, effect related and hydrological measures have been developed to increase nutrient use efficiency, especially regarding nitrogen. Many of these measures are being used in practice following local demands. At the moment, the phosphate problem regarding the limited natural resources, receives an increasing attention in research with a focus to improve large scale recyclability. Technologies to recycle phosphate are available and being developed at the moment, but pilots are needed to increase cost effectiveness together with a change of mind and an increased sense of urgency regarding this problem. The biobased economy holds promises to provide organic waiste a "second" life and thus realise opprtunities to recycle phosphate for renewed use in agriculture.

Supporting technologies for the biobased economy on separation, biorefinary and enzymes are developed and will on short to medium term become available. Biorefinary concepts on pilot level will ensure practicale availability on short term for some applications. Additionally, substantial effort is being done to produce high value molecules in plants for biorefinary processes. First results are to be expected on short term. Algae as a promising raw material for biobased processes receive proper attention on different scale levels within Wageningen UR. On medium term first spin-off of results can be expected.

The need for new technologies in agriculture differs according to development level: in Africa different (and sometimes less sophisticated) technologies are needed than in industrialized countries following differences in production level and economical and social structure of agriculture, its value chains and supporting R&D. Implementation of technologies should correspond to local capacities (knowledge, capital, organization) in order to avoid disappointments. Nevertheless, potentials for production increases in developing countries (and especially Africa) are substantial when integral approaches are taken. Building blocks for improved farming systems are being developed and are being applied in co-operation with local partners. Efforts on this field could gain in size.

This report on the possibilities and promises of high technological and eco-efficient agriculture shows how existing and developing technologies and their applications can result in transition pathways:

- Stretching production potential on the basis of new varieties. Technologies enabling the realisation of the concepts of breeding by design are being expected to lead to results on short to mid term.
- The decrease of yield and quality loss dus to improved farm management systems. In many areas and locations this transition has much potential. At the same time a decrease of yield loss can contribute to an increase in efficiency of natural resource use like land, water and nutrients. Partly, this transition requires existing knowledge and partly the development of new knowledge, methods and tools. When applying existing knowledge it is important to develop local specific and practical solutions in co-operation with industrial partners.
- The improvement of eco-efficiency. This can coincide with production increases by increasing the limited availability of production factors. Also, it can be realised by system design or by valorising the use of side products or waistes for instance by smart clustering production processes. When developing and initiating system leaps to structurally improve eco-efficiency, much knowledge, methods and technologies still need to be developed, but also many existing technologies offer decisive contributions on short term.
- Agroproduction systems and competing claims: with increasing pressure on natural resources it is important to develop farming systems offering win-win situations with other claims and claimants. System design can result in more eco-efficient production while biorefinary concepts can be helpful like concepts of more robustness and resilience. This is a research field that holds promises for the coming years.

The conclusion is that technology can result in significant contributions in realising highly productive and eco-efficient agriculture. However, technology dvelopment and above all its implementation in practice will take place in arenas with increasing pressures varying from social acceptance, economic feasibility, competition for and availability of natural resources, the effects of climate change and changing governance systems. Therfore, technology development and implementation need to account for location specific conditions. Therefore, integral approaches are indispensable and it seems advisable to identify application areas of basic technologies at an early stage, to focus the development process. Wageningen UR will contribute to this, also based on its experience in participatory approaches rather than in traditional linear developmet processes. Co-innovation as a development tool will be as preferable in future as it is now.

1. Introduction

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1.1 The challenge

The world population is currently increasing to around 9 billion people in 2050. At the same time the world economy is expected to keep growing. Both features are the main drivers for an increased demand for natural resources and an increase of emissions in the absence of reform both in policy, public awareness and innovations. Whether or not natural resources sustain further population growth in the light of food security has been debated frequently from both optimistic and pessimistic perspectives (McCalla & Revoredo, 2001). Recently, Koning et al (2008) have explored the potential for food security in 2050 in view of limiting resources like land, water and phosphate. The ecological footprint of our food is heavily in debate and central in societal discussions on ecological concerns. Wackernagel et al (2002) expressed human demand for food and goods and the production of wastes into the area required and concluded on that society as a whole was already in 1999 an overshoot situation of 20% (Figure 1.1). Off course, this approach can be debated, but the question raised was whether or not humanity is building a sustainable society on the long run. The Dutch government acknowledges this situation and the related challenges ahead and calls for transitions in global food, water and energy systems (Passenier & Lak, 2009).

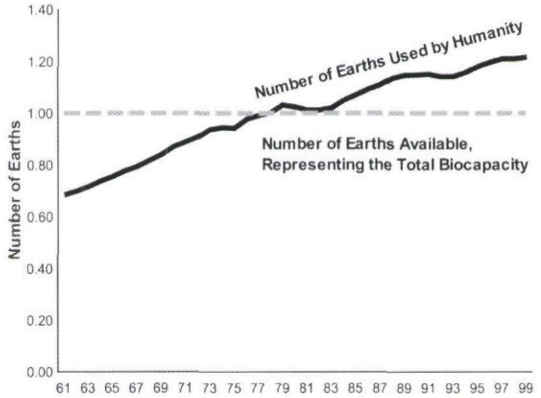

Figure 1.1. Human ecological demand according to Wackernagel et al. (2002)

Sustainability as defined by the Brundtland Commission in 1987 ("Our common future") is endangered by continuing erosion of the earth's natural resources (soil degradation, water and air pollution). At the same time, inequalities are persistent with 2.6 billion people living on less than $2 a day and more than 1 billion people malnourished (FAO, 2009). Time is running short for reaching the Millenium Development Goal (MDG) 1 on hunger and poverty in 2015 in the midst of present food abundance, giving evidence of the interconnectedness of ecological and socio-economic domains to reach a sustainable society. Ecologically speaking, it is clear that when continuing the current way of agroproduction while extrapolating present developments into the future, agroproduction is not sustainable, so the human footprint on earth needs to be diminished drastically.

> *Agriculture's large environmental footprint can be reduced, farming systems made less vulnerable to climate change, and agriculture harnessed to deliver more environmental services. The solution is not to slow agricultural development— it is to seek more sustainable production systems.* Source: World Development Report 2008

To feed the world, agriculture nowadays puts a large claim on natural resources. Agriculture uses 26% of the global land surface for grassland to feed livestock while 11.5% is used as arable land (McIntyre et al, 2009). Agriculture uses more than half the world's land surface and consumes more than 7,000 km3.yr-1 of water, an amount that is expected to grow in the coming decades. Use of phosphorus, a non-renewable natural resource of which reserves are expected to be depleted in 50-125 years depending on demand development scenario's according to rough estimates by Smit et al (2009), has increased threefold in just a few decades. Yet, it is generally recognized that agriculture has a distinctive role in addressing the world's challenges of today. For example, the 2008 *World Development Report* places agriculture at the heart of sustainable development. Rosegrant et al. (2006) have addressed the relationships between reaching the MDGs and agriculture, thus emphasizing the social function of agriculture. Recognizing that about 2,6 billion people depend on agriculture for their livelihoods, the CSD-17 shared vision statement (2009) pleads for a paradigm shift, emphasizing agriculture as part of the solution rather than part of the problem by developing ways towards the required substantial reduction of the human footprint as a prerequisite for sustainable development.

Evidently, ample food production does not automatically lead to food security but it is an essential condition for reaching it. Technology has been at the base of the strong production increase in agriculture in the past decades with a simultaneous increase of the human footprint. It must and can also strongly contribute to an agriculture that produces enough food while at the same time lowering that footprint. The challenge is to develop such technology within a socially desirable environmental and economic framework. The contribution of Wageningen UR to meeting this challenge is the subject of this report.

1.2 Eco-efficiency

Agro ecosystems produce goods like food, feed and fibers as well as emissions in using natural resources like soil, nutrients, water, energy and biodiversity. During decades of production growth of agricultural commodities, these resources have been used to yield higher production to feed a growing world population consuming more food and more resource-demanding animal products. Agriculture has been successful in doing so, but increasingly at the expense of the very resources that agriculture itself depends on and to an extent that overshoots the sink capacities to neutralize emissions. Also, natural biodiversity is declining as a consequence of conversion of forests and wetlands to agricultural area. At present, 30% of greenhouse gas emissions originate from agricultural activities, thus contributing to climate change. The negative externalities of modern agriculture have been the subject of a study by Harris (1996) in which he pleads for ecologically balanced agroproduction systems, a development pathway also expressed by Wood et al. (2000). The development pathway of a more eco-efficient agriculture can be defined as a pathway towards agricultural systems producing goods without further degradation of natural resources, and contributing to restoration of affected natural resources within and beyond agro ecosystem limits, ultimately leading to resource conservation agriculture. These production systems will show maximized nutrient recovery, minimized water and air pollution, maximized rain water use efficiency, maximum functional use of biodiversity and restoration of degraded soils, while saving natural ecosystems. This is not a plea for a development towards more traditional forms of agriculture but for a forward development into smart and innovative agroproduction systems.

Highest resource use efficiency can be defined as use of the minimum amount of natural resources needed as input (land, fertilizers, water etc.) to produce a unit of desired output, meaning lower input for the same output, the same or less input for higher output or more input for relatively more output. Higher resource use efficiency implies fewer emissions. However, a higher resource use efficiency will not necessarily result in a lower ecological footprint in absolute terms (the "number of earths" used: see Figure 1.1), if the required output level surpasses what can be gained by the realized resource use efficiency increase. Therefore, an increase in resource use efficiency in agroproduction systems will not automatically result in improved sustainability. Sustainability can only be reached, if the resources are not just used, but also renewed. Only in that case, resource use efficiency equals eco-efficiency. In ecological terms, sustainability is a state variable that could be expressed with the value of 1 in the definition of ecological footprint of Wackernagel et al (2002) (which is area-based related to food and goods demand including waste absorption) or any other definition expressing a balance between natural resource supply and demand. Any number larger than 1 will not be sustainable in the long run (Meadows et al, 2004). Translated to agriculture, ecologically sustainable (eco-efficient) agriculture is also a dynamic phenomenon (Figure 1.2; after Meadows et al. 2004). The agricultural throughput system uses resources and produces wastes and emissions that are to be processed in ecological sinks. As much as overuse at the resource side, overshoot situations on the sink-side influence the quality and quantity of resources, thus influencing agricultural throughput. Eco-efficiency implies a dynamic balance between the throughput, sources and sinks.

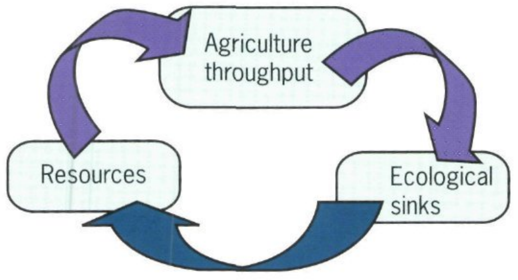

Figure 1.2. Eco-efficiency of agriculture.

The system boundaries in which we observe eco-efficiency are important for the concept to be operational. Increased eco-efficiency may be reached within agroproduction systems, but can also have strong implications across agroproduction systems. This is illustrated by Grote et al. (2005) who have mapped nutrient balances across the globe showing large continent-based imbalances and net flows. Closing nutrient loops will need collaborative actions on a global scale and cannot only be dealt with on a regional level, let alone just within agroproduction systems. Additionally, the following citation of Rees (2006) illustrates the increasing debate regarding the connection between globalization and environmental sustainability: "Global sustainability is ...... most likely to be achieved through policies that foster increased regional self-reliance, encourage greater investment in local natural capital, and favor the development of strong, diverse local economies in place". This statement implies that sustainability is a still more complex phenomenon than just pictured. It refers not only to ecological aspects but to an integrated state of three domains: planet, profit and people. As elaborated in detail in ESI (2005), environmental sustainability strongly interferes with social and economic sustainability. Economic feasibility of agriculture is a prerequisite for eco-efficiency, as is social responsibility. Indeed, if social criteria related to equity, education, culture, value and knowledge are poorly met, they are likely to negatively interfere with eco-efficiency. Therefore, both private and public partners need to take their responsibility in increasing eco-efficiency..

1.3 Yield and production increase

It goes without saying that feeding more people asks for an increase in production, especially when people's diet preferences require more luxury foods. To increase production, it is both needed to stretch yield potential and to close yield gaps. Koning et al. (2008) have linked successive increases in agroproduction complexity to increasing energy inputs in a process to attain potential production. In the past decades new varieties, artificial fertilizers and modern technology and farm management practices have boosted production and decreased yield gaps, especially in developed countries. In developing countries these processes have lagged behind or even stopped. Sub-Saharan Africa is a case in point. Much production increase can still be realized in these parts of the world (IAC, 2004). At the same time, it is necessary (and feasible) to stretch production potential, defined as the maximum theoretical production in a given physiological environment. Genomic techniques have great potential in this area, especially when connected to design processes. However, it can take many (>10)years to breed a variety that can be grown extensively in farmers' fields. This means that we have to work largely with currently available genetic material on the medium term, if we want to keep pace with the growing food demand. This means that the yield gap needs to be closed largely from better management at farm to landscape levels, in addition to breeding. However, the question is also whether natural resources can sustain a production increase that meets all demands for food in both the developed and developing countries without further expansion of agriculture into natural areas. This question has a bearing on social responsibility, too. Because of both considerations, there is an urgent need to consider multifunctional concepts of agroproduction systems.

1.4 Multifunctionality of agriculture

The interconnectedness of economic feasibility, eco-efficiency and social responsibility is not a threat to agriculture, but rather a challenge and an opportunity. Agroecosystems can produce more than just goods (food, feed and fiber; Abler, 2004), they can also "produce" ecosystem services like landscape scenery, agriculture-related biodiversity, water regulation, etc. These services should not be considered externalities sensu OECD (2005), but interrelated with the production of primary goods. These interrelationships require an integrated approach of agriculture to food security. Eroding the resources that enable agriculture to provide environmental services will ultimately also undermine food security. In contrast, by sustaining or restoring those resources, agriculture can contribute to the long-term economic and social viability of agricultural landscapes, thereby enhancing food security. To the extent that returns on investments in this direction cannot be gained on the private market, we believe that economic feasibility can only, and should be, enhanced by payments or other rewards for ecosystem services from public sources. This is also a position taken by Steinfeld et al (2006).

1.5 Diversity of agroproduction environments

Agroecosystems show large variation originating, amongst others, from differences in the environment, the availability of natural resources, governance and climatic and socio-economic conditions. Therefore, the aforementioned challenge calls for different and location-specific manifestations of eco-efficient agriculture. Roughly, land use environments can be subdivided into urban, peri-urban, rural, peri-natural and natural environments (Figure 1.3). The potentials of innovations and their nature can be expected to be different from one agricultural environment to the other, as will the ecological footprint of the produced food. For instance, soil will tend to be more costly in urban and peri-urban environments favoring products with higher added value (such as horticulture products and greenhouse production systems). Also, increasing distance between

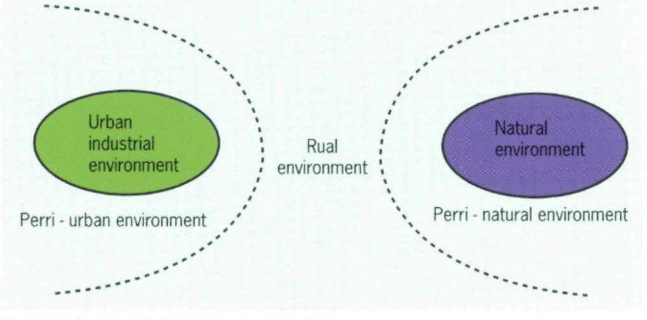

Figure 1.3. Agroproduction environments

the urban and rural environment favors less perishable products and requires good storability. Water tends to be more available in urban and peri-urban environments than in rural areas as many large cities are situated downstream in delta areas. In peri-natural environments agroproduction systems need to be balanced with their neighboring natural environments, restricting the use of some innovations that can be applied in rural areas, while fostering others, such as integration of non-timber products into livelihood strategies. The required technological developments will also differ depending on the availability and cost of human labor. In this respect, it is important to have in mind that the urban population will increase in time (to 2050) to more than 6 billion whereas the rural population will decline to below 3 billion (Figure 1.4; source: UN). This population development will have consequences for the development direction of agroproduction environments.

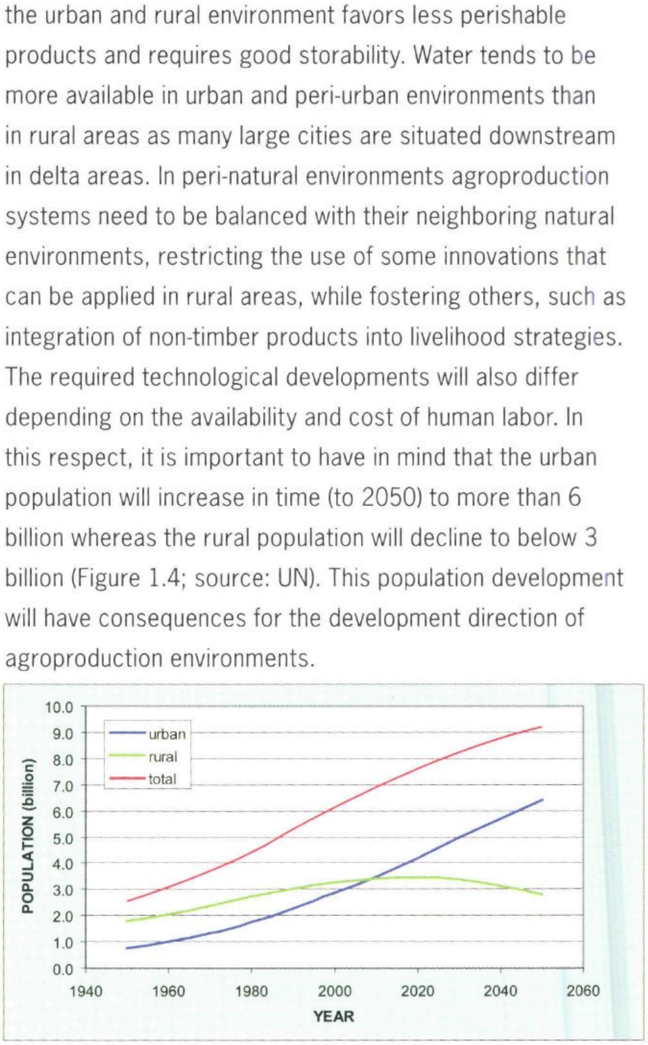

Figure 1.4. Development of total, urban and rural population

Besides geography and demography, socio-economic conditions will also determine the nature of technological innovations in the context of food security and minimizing the ecological footprint, thus contributing to diversification of agroproduction systems. The challenge differs in industrialized countries from transitional economies to least developed countries. Development pathways and the desired end-situation can be expected to differ with the Human Development Index and the economies' Gross Domestic Product (GDP). No silver bullet is imaginable looking at all these differences. Development pathways using technology to increase food production at a lower environmental footprint, thus need to be embedded in different environments making use of participatory and co-innovation approaches to enhance technology to be adequate and implemented.

1.6 Technology and sustainability in agriculture

Technological innovations have directed the development of agroproduction systems and related agri-food systems to a large extent (Lowe et al, 2008). They have contributed to the success story of food production and food price evolution but at the same time stood at the basis of negative environmental externalities. The introduction of fertilizers, mechanization, improved varieties and the introduction of crop protecting agents (agrochemicals) have sustained steady growth of agricultural production through the recent decades. This is illustrated by the case of cereal production by Cassman et al (2003). The authors use a production ecology approach to conclude on the potentials for yield increases against the background of nitrogen use efficiency and soil fertility. Not only is yield gap exploitation necessary but also an increase in yield potential, for example by breeding for animals or plants with increased potential production levels. Within the framework of this report, both developments should be considered within the boundaries of natural resource conservation.

Technology development has to be dedicated to the simultaneous upward development of yield and downward development of ecological footprint. Percy & Lubchenco (2005) expressed this by stating that "technologies that optimize food yield, nutrient loading, and water use in agriculture should produce significant value so long as appropriate care is exercised in minimizing the potential for harmful unintended consequences.".

Sustainability has become more and more a multifunctional domain with different functions interacting with each other and producing a range of negative externalities. Primarily, agriculture has the function of production of food, fibers and industrial products. Secondly, agriculture produces a number of public goods as well as negative externalities as described by Heal & Small (2002) and Abler (2004). For sustainable development it is important to understand the interdependencies and synergies and trade-offs. Conceptual frameworks have been developed to assess these relationships. The Millennium Ecosystem Assessment has published a framework in 2005 in which the interactions between ecosystem services, direct and indirect drivers of change and human well-being and poverty reduction were described. Scoones published the Sustainable Rural Livelihood framework in 1998, emphasizing the relationships between livelihood resources, livelihood strategies and their outcomes and thus depicting the complexity of sustainable development. This complexity is underlined by the Indicator Framework of the CSD (United Nations, 2007) that combines some 50 core indicators out of a total of 96, used to monitor sustainable development worldwide. However, these indicators concern state variables whereas rate variables and interdependencies are equally important to identify sustainable development strategies.

The complexity of sustainable development places technological development pathways in a wide context of multifunctionalities and their interrelationships and trade-offs. For technology to be effective within the challenge of higher production levels with simultaneous high eco-efficiency, effective systems of innovations need to be in place considering economic, political, social, organizational and institutional factors (Fagerberg et al., 2004). To increase effectiveness of these systems it is necessary to involve stakeholders in an earlier development phase of inventions. This asks for science to develop transdisciplinary research and development pathways.

Implementing technology in practice is not always straightforward. Sustainability puts high demands on the implementation process, making it necessary to prevent negative outcomes of technology implementation. Therefore, close co-operation between businesses, governments, non-government organization and science is called for. In this way the different interests are combined and risks of negative outcomes lowered. In the past decades, technology implementation went through a transformation from a linear approach from science to society to a more interactive design approach.

In our view, technology developments can be subdivided into developments within existing system limits and developments demanding change of such system limits. Evidently, the second category takes a longer time, tends to be more complex and needs involvement of more stakeholders. The challenges that are facing agriculture today necessitate technology developments beyond current system limits and thus ask for multiple involvement of stakeholders.

Recently, the International Assessment of Agricultural Knowledge, Sience and Technology for Development (IAASTD) has produced a comprehensive report "Agriculture at a crossroads" (MacIntyre et al, 2009). This report describes the role of science and technology within the future demand for food while maintaining the natural resource base of the earth. It stresses co-operation not only between natural, technical, social and economic sciences but also between science and practice as a prerequisite for development.

1.7 Agroproduction in the 21st century

Our report gives an overview of the technologies which Wageningen UR is developing and the impact they can have on a more productive and eco-efficient agriculture under sustainable use of resources and ecological sinks. Some of these technologies can contribute to an increase in yield potential and others to close the yield gaps. Some will result in an increase in eco-efficiency within the limits of existing agroproduction systems whereas others can contribute to the design, development and implementation of new systems or changing system limits. Special attention is paid to socio-technical innovations while the complexity of sustainability is addressed in the concept of competing claims. This report does not represent a limitation of technologies available and necessary for development of eco-efficient agriculture. That would not be realistic. Rather, it gives a balanced overview of the socio-technical reservoir of scientific opportunities to address the future challenges.

1.8 Sub Saharan Africa

Special attention is also paid to Sub-Saharan Africa, being one of the three themes addressed by the round table discussions of the UN Commission for Sustainable Development in New York in 2009. In this subcontinent poverty and hunger are persistent and the gap between SSA and other parts of the world increases. There is a renewed and increasing interest in agriculture in SSA as the pathway out of poverty and hunger. In SSA agriculture accounts for 34% of the GDP while 64% of the people are employed in agriculture (World Bank, 2007). The number of agriculture-based countries is largest in SSA compared to the other continents: 82% of the SSA population lives in agriculture-based countries. In these countries the highest poverty is found. The focus on agriculture for African development is stressed in many reports and the necessity is best illustrated in Figure 1.5. From this graph it is clear that the development of cereal yield in Africa has only shown little increase compared to Europe, South America and Asia between 1970 and 2007. An important constraint for further and greater yield increases in Africa is the low level of inputs like capital, fertilizer and seeds (Wiebe et al, 2001). Table 1.1 illustrates this for fertilizer use. It is clear that Africa is lagging behind many parts of the world, especially on phosphate. This had lead to soil mining, low soil fertility and increased soil degradation with severe consequences for future yield development. Rising prices for fertilizers combined with low capital access for African smallholders pose an additional threat to productivity and soil fertility leading to an increased risk of low yields and farm income.

Rosegrant et al. (2005) stress amongst others the importance

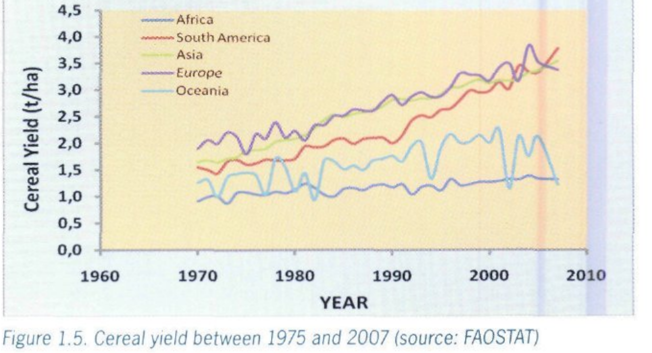

Figure 1.5. Cereal yield between 1975 and 2007 (source: FAOSTAT)

Table 1.1. Fertilizer use in different continents in 2007

continent	Nitrogen (N x 1,000 tonnes)	Phosphate (P205 x 1,000 tonnes)	agricultural area (x 1,000 ha)	N kg/ha	P205 kg/ha
Africa	2676	791	1157486	2.3	0.7
Norther America	20381	6084	478997	42.6	12.7
South America	8411	5595	580185	14.5	9.6
Asia	61571	22435	1662869	37.0	13.5
Europe	15133	4463	474274	31.9	9.4
Oceania	1089	1526	439976	2.5	3.5

Bron: FAOSTAT (2007).

of better management of crops (and livestock), land and water as well as increased agricultural research and extensions as priority areas for food and nutrition security in Africa. The poor R&D investments are also brought forward by Pardey et al. (2006). Hurni et al. (2001) indicated that in Africa 63 times less researchers were working compared to industrializes countries, measured to the number of researchers per million inhabitants. The IAC (2004) proposes a yearly increase in agricultural R&D expenditure in Africa by 10% yearly to a targeted value of 1,5% of agricultural GDP by 2015. This Figure stood at 0.7% in 2000. As a comparison, this indicator pointed at 2.4% in the industrialized countries in 2000. The IAC (2004) brought forward a traditional production ecology approach to reach yield increase and poverty alleviation in Africa, focusing on four dominant farming systems. An integrated approach, paying attention to production ecology, access to finance and markets while keeping the focus on a low ecological footprint, seems as appropriate in Africa as elsewhere in the world. In fact, looking at where SSA comes from, such an integrated approach has huge potential for raising productivity.

1.9 Content of this report

The Dutch Ministry of Agriculture, Nature and Food Quality is dedicated to follow up on the conclusions and recommendations of the CSD-17 in 2009. Highly technological and eco-efficient agriculture is one of the development strategies that in the view of the Dutch government can contribute to meet the challenges of the future. This report is an overview of technologies that Wageningen UR is working on and that will contribute to this strategy. We will pay attention not only to technologies per-se but also to scientific developments in fields where technologies and socio-economic sciences meet.Only a collaborative approach between these sciences will successfully develop inventions, implement innovations and thus meet the challenges of this time. Growth is usually associated with an increase in throughput and an increase in wastes and emissions (Meadows et al, 2004). The growth now to be realized will need to increase production while in absolute terms decreasing throughput and wastes/emissions. This asks for a paradigm shift necessitating close collaboration between natural en socio-economic sciences. The report intends to describe the contribution of the past, present and future Wageningen UR research to the development of a natural resource conservation agriculture with an adequate production level of food, fiber, feed and biobased products using technological inventions.

In the following ten chapters describe basic technological domains as well as implementation concepts in which these technologies can be applied. The basic technological domains are handled in the chapters 2-6 while the implementation concepts can be found in chapters 7-10. In chapter 2 we will introduce x-omics technologies that deal with sciences on molecular and cell levels. These technologies are the basis for new products that can be supportive to the development of highly productive and eco-efficient agriculture, like new crop and animal varieties and diagnostic systems. The interrelations between X-omics technology and ideotyping of plants, crops, animals, herds and farming systems will be addressed as a powerful combination of research areas. Chapter 3 will be dedicated to technologies that pursue and restore plant and animal health and their contribution to high productivity. With the emphasis on prevention, eco-efficiency is served by these technologies. Promotion of plant and animal health can be provided on different scales, from the individual animal or plant to crop or herd and further to farming system and ecosystem level, each with their commensurate research expertise. Chapter 4 deals with the efficiency of water use in irrigation and rain-fed agroproduction systems and with the opportunities to use brackish and salt water in saline soils (saline agriculture). Water use in agriculture is high and solutions to substantially increase water use efficiency are studied on different levels of integration, from plant to farm and watershed area. Like water, nutrients are indispensable for agroproduction (chapter 5). Nutrient availability is limited in some places while being an environmental threat in others. Special attention will be paid to phosphorus since this is a non-renewable resource. Recycling of all nutrients is a necessity to increase nutrient use efficiency in agriculture. Technologies have been developed to pursue this goal, but an integral approach of animal and plant production systems is needed to reach a substantial increase of efficiency. Highly interconnected to nutrient use is the subject of soil ecology, being the focus of chapter 6. Not only soil fertility is at stake but also carbon sequestration, water storage capacity and plant health. Soil is a production resource but at the same time a source for emissions.

To address the challenge mentioned, it is not only necessary to improve existing systems but also to develop new systems. Chapter 7 is dedicated to this field of science. To develop new systems co-operation of stakeholders is of utmost importance. Special attention is paid to Agropark developments. Design processes can lead to robust and resilient agroproduction systems which is the subject of chapter 8 and the embedding of the biobased economy as is described in chapter 9. The level beyond agroproduction systems is the study of competing claims that puts agroproduction in a multiscale context where negotiations set the conditions for technological innovations. Competing claims are the subject of chapter 10. Wageningen UR has a longstanding track record on the process of innovations. This science is dedicated to studying the process from technical inventions to societal innovation based on numerous co-innovation processes. Chapter 11 gives an overview of this knowledge field. Finally, in chapter 12 conclusions will be drawn based on the foregoing chapters, summarizing the results to be attained in the coming years as well as indicating knowledge that is lacking and needs future investments.

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2. X-omics and novel breeding technologies

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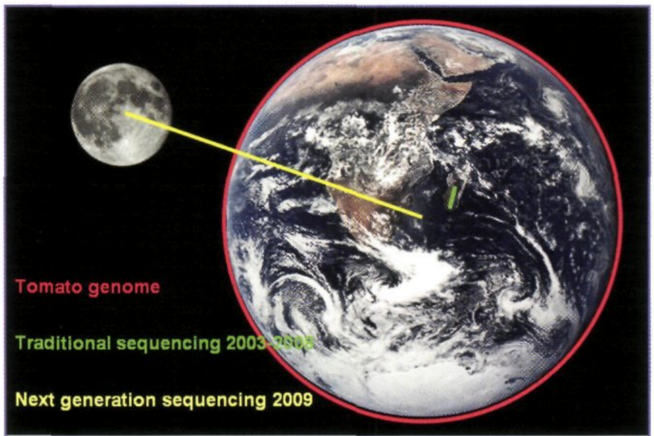
Roel Veerkamp and
Mari Smits

2.1 Introduction

A changing climate and a growing world population demand better and in particular more food from both animal and plant origin. This aspect of enhancing and securing yield and productivity can be addressed by many means, but in this chapter we will elaborate on the potential of a crop or livestock itself to produce more in a given environment or production system while simultaneously reducing their ecological footprint. This can be achieved by (i) increasing production capacity of an organism to grow or produce a particular product, resulting in an organism with an increased harvest-index. Examples of such a scenario are: improving sink-source relations, the green revolution, and improved efficiency of feed uptake. (ii) reducing the yield gap between actual and potential yield or production by increasing the tolerance to biotic and abiotic stresses during cultivation or post-harvest and the avoidance of livestock production losses by (infectious) diseases. Tolerance to abiotic stress, such as drought and salinity will potentially also enlarge the usable agricultural area by expanding into marginal land and other land not yet used for agriculture.
Modern technologies based on genetics and genomics are being used for the breeding, selection and propagation of elite cultivars and farm animal species that are robust, better adapted to their (changing) environment, high-yielded, using less natural resources and produce less waste (e.g. emission greenhouse gasses). However, novel technologies are needed to fully exploit the genetic potential and for combining the multiple traits that are underlying productivity and robustness traits. Difficulties of manipulating productivity are related to its genetic complexity; it is determined by multiple genes, it is both genetically and epigenetically determined, complex interactions between genes (epistasis), and environment-dependent expression of the traits are all factors that contribute to productivity. The novel technologies should support the concept of 'breeding by design' which takes into account the multiple quantitative and qualitative traits for creating the optimal variety ('ideotype') with respect to yield and product quality in a given environment. An important aspect of breeding by design is the predictive nature of the breeding process, which links the genotype with the phenotype, i.e. the total performance of the ideotype.
In this chapter we will discuss these technological innovations that are being developed or will be available soon for designing improved crops and livestocks for increased yield and at the same time a reduction of environmental impact. It involves genomics-related and novel genetics-related technologies for plant and animal breeding and food production. Although the technologies can be used to improve quality traits or biobased production as well, the scope is on traits for sustainable eco-efficient agriculture for the next decades.

2.2 State-of-the-art and what is coming soon

In the past, breeding has been mainly based on trial and error and on a gene-by-gene basis. Crosses are made on the basis of expert's guesses, and the best performing progeny is selected. However, the enormous technological break-throughs in genotyping and phenotyping that were achieved in the last few years, breeding is moving from an empirical towards a targeted and predictive process.
Genomics-related (X-omics) technologies are being used for genotyping, phenotyping and diagnostics. High throughput (HTP) sequencing has resulted in the elucidation of a number of genomes from agricultural important animals (e.g. chicken, pig, cattle) and plants (e.g. tomato, potato, grape, Medicago, rice). Wageningen UR contributed substantially in several of these international sequencing consortia, either as a sequence provider or in the assembly and annotation (bioinformatics) of the genomes. The Plant Sciences Group led the international initiatives on tomato and potato genome sequencing, which released the genome sequences of these important species at the end of 2009. The Next Generation DNA sequencing (NGS, box 2.1) technologies that are now available and new techniques that will be released soon, will revolutionize the genomics areas and will have a major impact on breeding strategies. These new sequencing technologies reduce the sequencing time of entire genomes of organisms



Box 2.1: Sequencing the entire genome by Next Generation Sequencing (NGS) Technologies.

A typical genome of crop plants and vertebrates contains the genetic code for approximately 30,000-40,000 genes. The genes are responsible for the genetically determined traits. Each gene is composed of DNA building blocks and the sequence of these building blocks determines the functioning of the gene. The genome of tomato consists of about 900 million DNA building blocks. An international consortium initiated the Tomato genome sequencing and achieved only a fraction of the whole genome after 5 years sequencing with traditional sequencing methods. The Next Generation Sequencing technologies changed this completely and Wageningen UR researchers together with a few additional labs succeeded in completing the genome in les than a half year time.

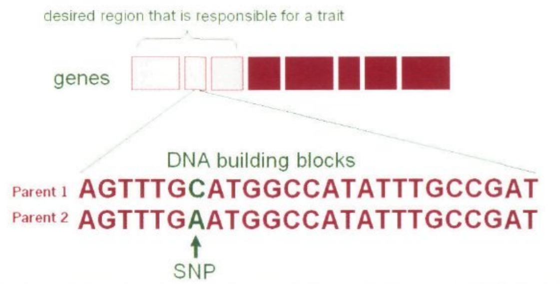
from several years to weeks with a fraction of the costs. The low costs of sequencing will allow the elucidation of genomes from many species, but once a reference genome of a species is known then individuals can be sequenced with relatively little effort (soon "the $1000 genome"). Currently the first founder sires of dairy cattle population are, for example, already sequenced individually and the sequencing of several tomato genotypes will start soon.

Comparative analysis is a powerful tool in biology. Genome sequences from related (e.g. wild relatives) and less related species are compared to identify differences and similarities in traits and genes. By this approach many genes for resistance against pathogens or tolerance to abiotic stresses have been elucidated in plants. In a similar way, comparing genomes from the same species is very powerful to explore the genetic variation and to identify the 'strong' and 'weak' alleles of important genes. Exploiting this genetic diversity requires fast and cost-effective methods for genotyping of germplasm collections, which is coming into sight by the emerging NGS technologies.

Another important aspect of genotyping as aid in breeding programs is the identification of small DNA variations (e.g Single Nucleotide Polymorphisms -SNPs) in individuals of a progeny population. These polymorphisms are associated with variation in a particular trait and can be used subsequently as molecular markers in breeding programs (box 2.2).

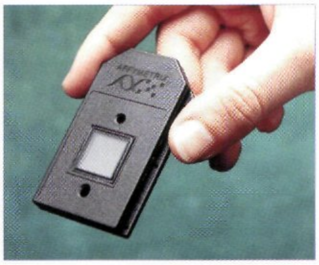
Box 2.2: Biomarker and Marker Assisted Selection (MAS)

A farmer or breeder is interested in the trait and performance of the plant or animal. However, such a trait (phenotype) may become apparent only at the adult stage (e.g meat quality, flower colour) and can not be followed during the breeding process and hence, the heritability can not be predicted. Therefore molecular markers (biomarkers) are used to pinpoint and follow the desired genes to assure that they are inherited to the progeny. The elite individuals can be selected based on the absence or presence of the marker. This type of selection is called Marker-assisted Selection (MAS). Often small DNA modifications, called Single Nucleotide Polymorphisms (SNP) are being used as markers. Parents that differ in a particular trait should differ in these markers.



Large scale SNP detection platforms are available, but will be replaced by the upcoming NGS technologies in the near future. One of the first applications of large scale SNP maps for marker assisted breeding in animal sciences is 'Genomic selection'(box 2.3). Genomic selection aims to predict breeding values for very large numbers of DNA

Box 2.3: Genomic selection



In contrast to MAS, where only one marker is used per trait, Genomic selection uses thousands of markers to predict a trait or performance of a plant or animal. This is particular interesting for complex traits. These markers (SNPs) are spotted onto a chip (micro-array, see below) as small DNA fragments and the presence of all these SNPs can be scored simultaneously. Such an array can contain 10-thousands of SNP markers

polymorphisms (markers) across the genome of a livestock species without performance records (Calus et al, 2008). Genomic selection demonstrates remarkable accuracy in predicting breeding values for highly polygenic traits (e.g productivity), because it is not based on a single marker for a single trait as conventional marker assisted selection, but is based on whole-genome dense marker maps. Selection based on these predicted values, is expected to have an enormous impact in terms of speed and reliability of breeding programs for livestock animals and crops (Calus et al, 2008 ; Heffner et al, 2009). Several breeding industries already initiated with the implementation of genomic selection procedures using whole-genome SNP patterns (> 50.000 SNPs) in animal breeding and will soon be implementing in crop breeding as well.

The genotype is translated into the phenotype, which is the appearance form of the genetic constitution of an organism and shows the functionality of the genotype. It can be analyzed at several levels, e.g. at the molecular level, the physiological level, the performance of a plant or animal in a given environment, and ultimate appearance of the organism in shape, structure and growth. Wageningen UR has a strong position in the X-omics technologies, such as Transcriptomics, Proteomics and Metabolomics of crops and breed (see Figure 2.1). Using these larges scale technologies, novel molecular bio-markers can be identified, which can be used for breeding and diagnostics. Such X-omics studies aim to fill the gap between genotype and final trait and provide insight into the composition and dynamics of biological systems that underlie the traits. In addition, they evaluate how and to what extent biological systems are influenced by environmental changes, e.g. climate, management and nutrition.

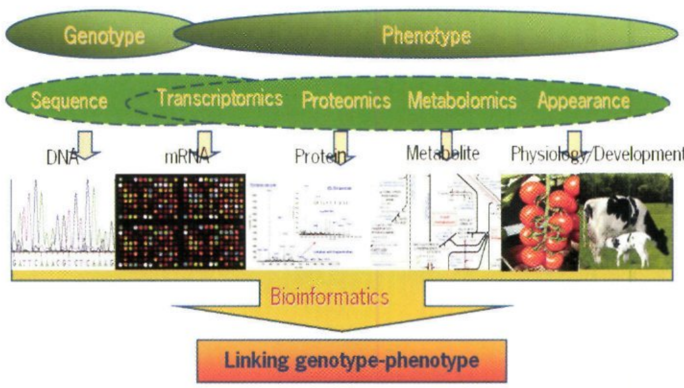


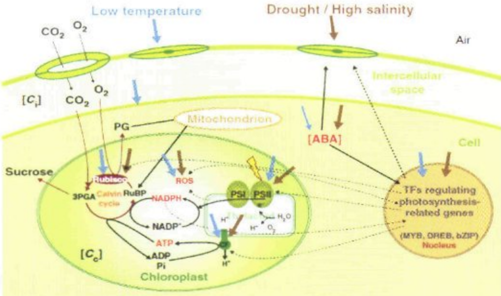
Figure 2.1. The Genomics data flow that links the genotype with the phenotype

This phenotype knowledge provides producers with tools to accurately determine the actual performance status of their animal or plants in the context of their genetic background and the historical effects of environmental factors. These tools will be based on relevant molecular "signatures" or (bio)markers (see box 2.2) exhibiting and predicting the performance of a trait. Such markers may, for instance, be used to monitor productivity and health or for the prognosis of early-stage or unknown diseases. This type of prognostic tools will also allow the farmer to determine the probability of reaching the end-point target of the trait, as well as reveal how animals and plants respond to management measures and specific treatments, thereby providing guidance to follow-up preventive treatments.

To evaluate the final performance of the plant or animal in an agricultural context is also an important aspect of phenotyping. Plant breeders still rely on the opinion of experts to judge the performance of an ideotype under certain conditions, while reliable and quantitative tools for objective monitoring of traits are largely missing. In particular, when a certain trait has an effect on another, e.g. tolerance to stresses has a trade-off on yield and productivity. In such a case, both the positive and negative effects should be accurately measured to determine the ultimate effect. For these type of measurements, non-destructive HTP imaging tools to monitor growth characteristics during the life cycle of a plant or animal need to be developed. Some methods for plants have been developed at Wageningen UR, or are under development, which measure photosynthesis parameters, growth characteristics, root and shoot architecture, evaporation, transpiration and assimilation in a dynamic mode during growth (see also www.lemnatec.com). These techniques need to be further improved to accommodate high-throughput and accurate measurements in large breeding populations both in well-controlled environments (greenhouse) and in the field in order to support fast and more targeted breeding processes.

Bioinformatics plays an essential role in the analysis of the rapidly increasing amount of data that is being generated by the large scale X-omics technologies. In particular the genotyping and comparing of genomes that are boosted by the NGS technologies (see above) will produce complex data collections that need further acquisition. In addition, statistical analysis tools and models need to be developed or adapted to work with these large datasets and to integrate them. The aim of this technology is to relate genomic information to phenotype traits in order to target breeding processes.

Because yield and productivity involves many traits and genetic factors that are interlinked in a complex genetic and molecular network, a mathematical and computational approach is needed to integrate all this information into models allowing a prediction of the behavior of the trait as a whole. It is also known that tolerance to stresses has it trade-offs, e.g. in growth (plants that have acquired a constant defense response grow slower, but are less vulnerable to pathogen attack), which illustrates that many aspects, acting both positive and negative, have to be taken into account



Box 2.4: Metabolites and hormones are involved in stresses. Metabolic compounds (e.g. sugars) and hormones control many processes in a plant and are involved in the internal responses to external stresses.

(Herms & Mattson, 1992). This requires a Systems Biology approach. Systems Biology is a new and rapidly developing scientific area that aims to understand and predict the functioning of (agricultural) systems based on the behavior of the individual components (e.g. this can be genes) and their mutual interactions. It combines different disciplines at various aggregation levels. A Systems Biology approach is particularly suited for the selection of the optimal combination of alleles and quantitative trait loci (QTLs) to further improve complex animal and plant traits, such as productivity and health.

Yield and productivity of plants:

When considering ways of increasing crop yield several approaches can be envisaged: (i) increasing intrinsic growth capacity and (ii) reducing losses during growth and post-harvest. (i) A key parameter in crop production is the source/sink balance, which is a complex genetic and environmental characteristic. Source limitation and sink demand may vary during the day depending on e.g. day-length, temperature or light harvest. Basic physiological processes, such as photosynthesis and respiration are important processes that directly affect plant growth.

Also developmental processes (e.g architecture, flowering time, root system, senescence) are important for nutrient uptake, energy balance, yield index of a plant and the harvestable organs. For instance, a variety that flowers late will produce more leaf biomass, because it will continue its growth. To understand these processes and the genetic basis underlying these processes, knowledge about (crop) physiology, development and genetics/genomics is needed. Wageningen UR plant groups are studying the genetic basis of some of these processes. For instance metabolomics techniques are being applied to determine the primary sugar metabolism in a plant or the phytohormone concentrations, both very important for source-sink relations and growth.

All these processes (developmental, metabolism, hormone biosynthesis) are controlled by 'regulatory genes'. Natural variation in these traits is often caused by small variations in these regulatory genes. Therefore, these variations are associated with a particular phenotype and hence can be used as molecular markers for marker assisted selection (MAS) or in Genetic Modification (GM) approaches.

(ii) Plant breeders aim to use plant varieties that are optimally adapted to climate conditions and are insensitive towards pests and diseases. However, these traits are not always available in the cultivated germplasm and without (molecular) markers, which are associated with these traits, it will be difficult to introduce these traits from wild varieties.

The global changes and local variations in climatic conditions that we are facing demand a better understanding of the processes and genes that determine abiotic and biotic stress tolerance. Plant groups at WUR operate at the international forefront in the field of biotic stress research and have been successful in unraveling resistance strategies of plants against various pathogens, including a major threat in potato, *Phytophtera infectans* (The Netherlands Initiative on Late Blight – NILB -).

We also need to adapt crops to new or very local climatic conditions by improving, among others, drought and flood tolerance, water use efficiency, salinity tolerance and nutrient efficiency for robust yields over years. This type of research is ongoing world-wide and for a number of abiotic stresses, tolerance genes have been isolated (Saibo et al, 2009 ; Nelson et al, 2007). The contribution of Wageningen UR to this research area is limited, but research efforts are increasing, in particular due to changing green house cultivation conditions. We need to develop high yielding crops adapted to new 'energy producing' greenhouses with a higher relative humidity and increased CO_2 concentrations in closed greenhouses, and robotized handling. Crops grown under such greenhouse conditions are more prone to become diseased and require different architecture and tolerance to higher and/or lower temperatures. Some of these aspects are incorporated in projects in the framework of TTI Green Genetics.

In both agri- and horticulture, crops often suffer at the same time from both abiotic and biotic stresses. Virtually nothing is known about the interrelationships between resistance against microbial pathogens, herbivorous insects and various abiotic stress factors. Obviously, plants that have 'developed' a thick wax layer to prevent evaporation are also less vulnerable for biotic attackers. In a similar way, particular hormones are produced when a plant is exposed to both biotic and a-biotic stresses, indicating that the perception and defense mechanisms are partly interlinked. Hence, it will be a challenge to address these aspects simultaneously. This requires a systems (or network) approach that takes multiple factors and their interactions into account. Models describing such a system will allow a prediction of the ultimate response and performance of a plant in a particular environment. In this way, it is foreseen that both negative and positive effects on yield performance of crops with various types of resistance genes or altered architecture can be investigated and predicted simultaneously using state of the art technologies.

Yield and productivity of animals:

Feeding more people with an affluent diet and a more social acceptability of livestock production calls for a considerable higher primary food production and an increased animal health and welfare. Higher livestock productivity and improved animal health is rooted in several developments: genetic improvement and the avoidance of production losses by (infectious) diseases. Precision agriculture in combination with well adapted (selected) animals will ensure an improved output / input ratio's and higher health. In addition more predictive approaches are needed that allow corrective measures to be taken at a very early stage in the production process.

Genetic improvement of farmed animals is a highly effective and cost-effective method of improving animal performance. Recent developments within the field of animal genetics and genomics, provided important research approaches to investigate how genetic and environmental variations regulate phenotypic variation in livestock, including the variation in feed efficiencies and the susceptibility to infectious diseases. The Dutch livestock breeding sector is a major player internationally and has a strong SME sector of smaller breeding organizations and service providers to the breeding industry. The sector is well placed to harness the emerging benefits of the 'genomic revolution'. These benefits will support the competitiveness, efficiency and effectiveness of farming systems, and provide consumers with better quality, more affordable and healthy food, and allow farming systems to diversify, be more flexible, and respond to changing climates and markets. Hence, NL has the industrial capacity capable to exploit this science quickly and in a way that can be responsibly controlled with clear benefits to the public whilst respecting the fundamental ethical values of society. The following three thematic priorities will drive the research in animal genomics.

1. The identification of relevant traits operating within individual levels and across levels (livestock), as well as the influence of genetics and environmental conditions (e.g. nutrition) on these traits.
2. The identification of molecular variation (genes, DNA markers) and molecular "signatures" (transcriptomic, proteomic, metabolic profiles) associated with productivity and disease susceptibility traits.
3. The development of tools and strategies to modulate biological processes underlying productivity and health traits.

2.3 *Research directions WUR and Contributions to high-technological and eco-efficient agriculture*

Wageningen UR is a significant player in the field of genomics and breeding and has played a pioneering role in developing enabling technologies and improving crops and livestock. Increasing yield and productivity for an eco-efficient agriculture is a very complex trait that should be approached in a multidisciplinary fashion. Wageningen UR has the potential to maintain this forerunner position, because it can easily access all the disciplines (genetics, breeding, genomics, physiology, statistics, etc.). Currently, the knowledge infrastructure and new technology developments within WUR rely to a large extent on investments of WUR-LNV in the Knowledge Base (KB) program, The Netherlands Genomics Initiative (NGI), TTI-Green Genetics and TTI-Food and Nutrition and the EU seventh framework program, including ERA-Plant Genomics. In particular within the NGI programs Netherlands Proteomics Centre (NPC), Netherlands Metabolomics Centre (NMC), Netherlands Centre for Systems Biology (NCSB) and Netherlands Bioinformatics Centre (NBIC) generic Genomics-related technologies and bioinformatic tools are being developed. Other (inter)national programs with participation of WUR involve more biology oriented research, such as taste and quality of tomato and potato in the Centre for BioSystems Genomics (CBSG), improving crops for changing green house conditions (TTI-Green genetics), and many EU collaborative initiatives (EADGENE, SABRE QualityPork, NADIR, RobustMilk, EPIZONE).

The overall research directions for the Plant Sciences Group and related to eco-efficient agriculture are well described in the strategic plan for TTI-GG2 (Exploiting Plant Genetics 'from genotype to phenotype and vice versa') and the research NWO proposal for a Centre for Systems Biology ("Adaptability of plants: The trade-off between growth and defence at different levels of biological integration"). Both plans focus on the exploitation of genetic diversity for improving crops with increased yield potential and adapted to adverse or variable growing conditions.

For the Animal Sciences Group (ASG) and AgroFood Sciences Group (AFSG) (both parts of Wageningen UR) the research directions focussing on intestinal health are partly described in the research plan for a Centre for Systems Biology ("The intestine as gatekeeper - Systems biology of host-food-microbe interactions").ASG is focussing on intestinal health since the gut is a key biological system that exhibits variation in efficiency of digestion and absorption of nutrients. This variation has its origin in several different factors, including genetic variation, diet and genotype interactions and variation in gut health. The knowledge on several livestock genome sequences and recent developments in the area of host-microbe interactions offer exciting new opportunities to study the interaction between the genome of farm animals, animal feed, and the microbiota of the gastro intestinal tract. Additionally, metagenomics is coming to age and offers new opportunities to study the diversity and efficiency of microorganisms in the gut. Increasing the understanding of factors that influence the functioning of the gastrointestinal tract offers new perspectives to improve the efficiency and the health of the livestock digestive systems.

Both animal and plant research groups of WUR will continue their efforts in research directions and technology developments as described in section 2.2. These involve breeding by design, genomics selection, systems biology using state-of-the-art genotyping and phenotyping methods. The bioinformatics to extract the relevant information from the large data-sets and the statistics to link the genetic diversity with traits remain essential for these research directions.

2.4 Short and medium term products/foreseen applications

1. Due to the revolution in Next Generation Sequencing platforms we expect that many new animal and plant genomes will be unraveled. It will be possible soon to sequence whole genomes of individuals for relative low costs, allowing the identification of large numbers of DNA polymorphisms (for genomic selection and marker-assisted breeding). Furthermore, comparing genetic/genomic variation among species (comparative genomics) will provide information about conservation and diversity of gene functions and traits. Bioinformatics tools will be developed to support the genome annotation and comparison.
2. High throughput and accurate phenotyping techniques, including X-omics techniques (transcriptomics, proteomics, metabolomics) and non-destructive quantitative imaging tools to produce molecular markers and monitor animal and plant performance and traits will be developed.
3. Statistical tools to handle incomplete datasets and to study quantitative traits in multiple breeding populations instead of single biparental populations; and, large datasets to find genes and traits that underlie or predict (a)biotic stress tolerance and yield index.
4. Tools and models for the integration of genetic, functional genomics and plant/animal performance to gain greater understanding of complex traits. It is of utmost importance that efficacy of traits and both synergies and trade offs are well understood. (Systems biology approach)
5. Molecular biomarkers and diagnostic tools for early warning, monitoring and screening purposes in breeding programs.
6. Knowledge about the traits responsible for productivity and yield. This knowledge can be used to optimize and modulate the biological processes underlying these traits, but can also be used to adapt the external factors (e.g. nutrition, management, health programs, growth conditions) for an optimal combination of genotype and environment.

Most of these products are knowledge, methods, markers and genes that can be used by breeding companies. Wageningen UR research groups have ample collaborations with the agro-industry to ensure an efficient transfer of this knowledge and products.

2.6 Aspects underexposed

Many traits have both a purely genetic component, i.e. lay down in the primary DNA sequence, and an epigenetic component, which is determined by mechanisms other than changes in the underlying DNA sequence, such as chromatin structure and modifications. Internal and external (environmental) conditions may change the epigenome and affect the expression of genes. Despite its importance, epigenetics has been underexposed in research and neglected in breeding programs. Therefore, the genotyping tools described in section 2 and new epigenotyping methods should be used to unravel the epigenetic components of the traits involved in yield potential (Hauben et al, 2009).

> *Box 2.5: Epigenetics is the study of changes in gene activity and functioning caused by mechanisms other than changes in the underlying DNA sequence and hence can not be detected by standard genotyping methods (e.g. SNP detection). These changes may remain through multiple generations, but may also very dynamic depending on external conditions (e.g abiotic stress). Epigenetic modifications are often methylations of the DNA or changes in the DNA-packing structure (chromatine).*

For an eco-efficient agriculture, both biotic and a-biotic stresses are important, because they affect both yield and the eco-footprint. Genetic research within WUR has been mainly focused on diseases and interactions (biotic factors), while studies on genetic components for tolerance to adverse or changing a-biotic conditions (e.g. water or drought stress, water and nutrient efficiency) remain largely unexplored. To meet the challenges of an eco-efficient agriculture in the (near) future, genetic modification (GM) strategies of plants cannot be excluded. For many pathogens and threats GM solutions have been used and resulted in a substantial decrease of losses. An example is the introduction of the Bt

toxin in most cotton, soybean and maize varieties grown in the US and Asia. In a similar way, it is expected that a major threat for potato caused by Phytophtora infection will be solved by a GM approach. World-wide many academia and companies are developing the 'second generation' GM crops with improved tolerance to abiotic stresses and modified plant architecture for increased productivity. The genomics approaches followed by WUR research groups should result in agronomical important genes and strategies that can be exploited in a GM approach, however the main emphasis so
far has been on applications in traditional breeding without GMOs.

2.7 Recommendations

- The genomics era, boosted by the Next Generation Sequencing technologies, will change the breeding and biotechnology landscape completely. It will drive new concepts in breeding, such as breeding by design and genomic selection. It will be of utmost importance that WUR keep following these new developments and contributes to innovations and improvements of crop plants and farmed animals that are highly productive with a low ecological footprint. Therefore, genomics-related technologies and infrastructure, including bioinformatics, should remain on the WUR research agenda.
- For complex traits, such as productivity and yield, a systems biology approach is needed to understand and predict the behavior of the system. This requires expertise in statistics, quantitative phenotyping and modeling. These disciplines should have full attention in the future to support the systems biology strategy.
- Reliable and quantitative phenotyping methods, preferably in a non-destructive manner should be developed to support the breeding by design concept.
- Epigenetics is an underexposed area, while the phenotype is substantially determined by epigenetic regulation. More emphasis on epigenetically determined traits is needed to understand these traits and the environmental impact fully. Emphasis on Genetic diversity-exploring the diversity-Comparitive genomics
- Given the contribution of GM crops to secure food production, research on GM technologies should continue. This includes standard GM approaches, but in particular alternative GM methods for genetic engineering of plants. Wageningen UR has pioneered the development of 'cisgenesis' that makes use of only host gene sequences (Schouten et al, 2006 ; Jacobsen & Schouten, 2009) (www.cisgenics.com) and WUR research groups have created marker-free plants without the use of antibiotic selection genes (Vetten et al, 2003). Consumer acceptance may be greater and regulatory approvals simpler for plants developed by these new technologies. Off course, exploration on this important research area and potential for further improvement, should go hand-in-hand with development of knowledge on potential risks and prevention measures because safety cannot be left unattended.
- Breeding depends on the existing genetic diversity. Tools to explore this variation (e.g. by novel genotyping methods) and breeding methods to combine the multiple strong alleles (Genomic selection) are needed to breed the elite germplasm.

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3. Plant and animal health

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Tjeerd Kimman

3.1 Introduction

The health of plants and animals is an important factor in increasing productivity and lowering the ecological footprint of agriculture. Moreover, because animal pathogens can infect humans, animal health has direct implications for human health. In addition, the occurrence of some plant diseases (pathogens, pests and weeds) can influence human health.

Based on data from 1988-1990, Oerke et al. (1994) carried out scientific calculations of potential crop yields, actual yields and estimated crop losses caused by pathogens, animal pests and weeds. They estimated worldwide potential crop yield losses to be 56-73% and actual yield losses to be 22-44%, despite the use of crop protection measures (Table 3.1). Crop protection measures are most efficient in preventing yield reductions within Western Europe, but only 8% of the total global production of rice, wheat, barley, maize, potatoes, soybeans, cotton and coffee occurs in Western Europe. Other regions with up to 44% crop losses account for 77% of global production of these crops.

Table 3.1. Comparison of potential and actual crop losses due to pathogens, animal pests and weeds and the effectiveness of crop protection measures in eight major food and cash crops in Western Europe, North America & Oceania, and all other regions (Africa, Latin America, Asia, Eastern Europe and U.S.S.R.) in 1988-90 (Oerke et al., 1994).

Region	Loss Scenario	Crop losses (%)				Actual control effectiveness (%)
		Overall	Pathogens	Animal pests	Weeds	
Western Europe	Potential	57.4	18.7	17.3	21.4	
	Actual	22.6	7.3	8.9	6.4	61
N. America & Oceania	Potential	56.3	13.0	15.5	27.8	
	Actual	31.6	9.9	10.2	11.5	44
Other regions	Potential	72.6	18.2	24.0	30.4	
	Actual	45.4	14.3	17.1	14.0	39

There are large differences in crop protection measures in different regions of the world. In particular, the importance of chemical pesticides varies from region to region. Western Europe, North America and Asia use more than three-quarters of the global consumption of pesticides. In 1991, global market usage of herbicides, insecticides and fungicides in US$ billion was 11.9, 7.8 and 5.6 respectively, a doubling in amounts since 1972 (Oerke et al., 1994). By 2008, this had increased to 19.6, 9.2 and 10.4, respectively (Anonymous, 2009).

In the case of animal production and healthcare, no comparable quantitative review addressing different areas of the world is available. The database of the World Organization of Animal Health (http://www.oie.int) contains information on the incidence of notifiable infectious diseases and the animal mortality levels associated with these. However, the database contains no information on the yield reductions due to indigenous or endemic animal diseases, which give rise to most of the veterinary medicine usage and production losses. Independent reviews are scarce and generally address only one disease, species or area, while it is difficult to find truly untreated controls in production systems (cf. Dibner et al., 2007; Wileman et al., 2009).

In addition to disease monitoring, there is a growing demand for effective methods to monitor the use of antibiotics (because of the associated risk of antibiotic resistance, which is also dangerous for humans) (Koene et al., 2009). In the Netherlands, data on animal antibiotic usage can be found in VETbase (http://www.fidin.nl). The usage has remained more or less constant at 550 tons/year, despite the fact that prophylactic usage as a feed additive was banned in 2006. In 2009 a slight decline to 520 tons/year occurred. Partly because of the high animal population density in the Netherlands, the total antibiotic usage for animals is much higher than that for humans (80 tons/year). However, antibiotics are not only used to treat real infections, but also to compensate for shortcomings in management. These include a range of implicit or explicit reasons, such as putative growth promotion, insufficient disease prevention (no or inadequate vaccinations), inadequate quality of food and housing (incl. ventilation), economic benefits, insufficient time and efforts for proper diagnosis and other interventions, routine, ease, safety, and as insurance.

The International Federation of Animal Health (IFAH) (www.ifahsec.org) presents data on annual sales of veterinary medicines globally. In 2008, the market usage of medicinal feed additives, biologicals, anti-infectives, parasiticides and other pharmaceuticals in US$ billion was 2.1, 4.7, 2.9, 5.5 and 4.0 respectively, having increased by around 10% annually during the previous 10 years. As with pesticides, more than three-quarters of the global consumption of these chemicals occurs in Western Europe, North America and Asia.

Trends in plant and animal health seem to be at least partly comparable. Highly productive agricultural areas are associated with high usage of pesticides and veterinary medicines. Rational usage of these products would increase productivity and thereby lower the ecological footprint in terms of energy, water and nutrient consumption. However the use of the products counteracts the decrease in footprint because of the emissions arising from these products (www.bestrijdingsmiddelenatlas.nl; Montforts et al., 2007).

The aim of this chapter is to investigate available measures to promote and restore plant and animal health, and to determine their contribution to high productivity and their associated ecological footprint.

3.2 Research directions

With the emphasis on prevention, eco-efficiency is served by crop and animal health protection measures. Normally the strategy for optimal crop and animal health consists of prevention, determining the need for control and implementing control measures. Promotion of plant and animal health can be carried out on different levels of scale, from the individual to crop or herd and further to farming system and ecosystem level, each with their specific research fields. Of course these levels may show considerable overlap. Figure 3.1 illustrates the most important research themes at Wageningen UR concerning crop and animal health care.

Some themes integrate the different levels of the protection strategy, aiming first at maximum prevention, determining the need for control and, if necessary, control. Such themes include precision farming, Integrated Pest Management (IPM) strategies and invention to innovation.

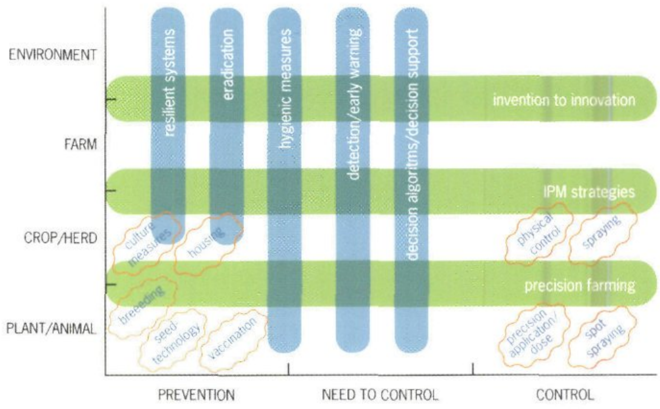


Figure 3.1. Wageningen UR research themes on crop and animal health care at different levels of scale

Precision farming operates at the level between the individual and the crop or herd, IPM strategies operate between the crop or herd and the farming system and invention to innovation addresses the actions needed for implementation of inventions, e.g. stakeholder management, co-innovation and education. This theme operates between the farm and the environment. Themes integrating different scale levels include resilient systems, eradication, hygiene measures, detection/early warning and decision algorithms/decision support. Themes aimed at protection of individuals include breeding, seed technology and vaccination. Disease prevention at the crop/herd level is mainly by culture measures and housing. The control part of the IPM strategies at the crop level consists mainly of physical control (van der Weide et al., 2008) and pesticide application by full field spraying. In precision farming, the control part consists of treating individuals or parts of the crop or herd with precision applications and dosing and spot spraying.

More information on plant and animal health research in which Wageningen UR is participating is reported in the next paragraphs and on websites like www.kennisonline.wur.nl, www.endure-network.eu, www.epizone-eu.net, www.medvetnet.org/cms/, www.pri.wur.nl/NL/onderzoek/onderzoeksthemas/Interactie+tussen+planten+parasieten+en+ziektes/bananen/, edepot.wur.nl/12499.

3.3 State-of-the-art

Technological measures to promote or restore plant and animal health involve prevention, determining the need for control and control measures. This section summarises the state-of-the-art of the most relevant technological developments. Within prevention, most developments concern the improvement of systems resilience and breeding, seed technology and vaccination. To determine the need for control, important developments have been made in detection and early warning. Important developments concerning the control stage include IPM measures and precision farming.

Improving systems resilience

Biodiversity both in time and in space is recognised as an important factor for improving the resilience of arable systems. Biodiversity in time (crop rotation) is one of the most used measures to prevent problems with soilborne pathogens, nematodes, some insects and weeds. Another way to reduce soilborne problems is to take the cultivation out of the soil. Biodiversity in space (mixed cropping/varieties, flower strips, landscape ecology) is known to slow down the rate of disease spread and to attract natural enemies of pests. In greenhouses, developments in this respect are to close the system and add natural enemies. Improving the resilience of the soil is an important research item, made possible by new detection possibilities developed recently. By improving soil structure, nutrition and soil biological quality, the stress to which plants are subjected and their sensitivity to diseases are decreased and the natural resistance of the soil to pathogen development is increased. Another important item is to anticipate climate change and the predicted more frequent periods of drought and heavy rainfall. Preparing the soil for this and reducing the energy consumption through reduced tillage or no-till in arable production will be important. However, systems required to be more climate-, production- and environment-proof will require new adapted crop protection strategies too (Kropff et al., 2008).
Concerning animal health care, stress reduction is also important and can be achieved through optimal housing, ventilation and careful management of animal life transition moments such as parturition and weaning and nutrition. Improved insights into management issues preventing animal-to-animal transmission of pathogens are also important.

Breeding, seed technology and vaccination

Breeding has always been an important measure to increase yield and also to reduce the sensitivity to diseases. The speed and scope in the breeding of resistant varieties or breeds have been increased using new biotechnology. Public acceptance of GM-technologies is increased by Cis-genesis. Seed technology has improved in that seeds can germinate and emerge earlier and the emerging plants are protected from some pests and diseases by seed coating. Improved seed technology and improved weed control have made it possible to field-sow some crop species which were formerly transplanted. This greatly reduces labour and improves the economics, but sometimes has a negative impact on the footprint through high usage of herbicides.

Box 3.1: Insecticide inputs in vegetable production in the tropics are usually high. The Wageningen UR business unit Applied Plant Research (PPO) has developed seed treatment solutions as an alternative to crop spraying. The work was carried out in co-operation with the seed company East-West Seeds, with branches in Thailand and the Philippines. Field trials showed effective seed treatment to control insect damage directly to the crop but more importantly, treatments decreased virus transmission to a major extent. East-West Seeds is currently preparing the market introduction of the first seed treatment applications.

Concerning animal health, important developments have been made in the speed and scope of the development and production of vaccines, in particular so-called DIVA vaccines, which Discriminate Infected from Vaccinated Animals. Molecular epidemiological tools and improved tracking and tracing for following animal movements are used to trace the origin of infections. Both the increased vaccination possibilities and the knowledge of the spread increase the possibility to optimally protect animals.

Box 3.2 PHEROBANK: Innovations in the use of insect pheromones for integrated pest management.

PHEROBANK research focuses on synthetic insect semiochemicals (sex pheromones) for monitoring and control of pests. Activities range from fundamental research on identification of insect pheromones to novel technologies for detection, formulation and application of insect pheromones.
The pheromone products produced in Wageningen UR are exported to over 35 countries. An example of a new development is the identification of the pheromone of the moth Duponchelia fovealis, a pest of sweet pepper. This pheromone has been used successfully since 2007 in a national monitoring programme in the Netherlands by sweet pepper growers. This has secured exports of sweet peppers to the USA and Canada, because strict control on the presence of D. fovealis was required.

Detection and early warning

During the past decade, improvements have been made at Wageningen UR in the detection and diagnosis of diseases. This is important because early detection and diagnosis make it possible to decide whether it is safe to import or export materials without the risk of introducing a new disease. However, it is also important to determine whether there is a need to control indigenous diseases and to optimally time and design control options.
Insect pheromones have been identified and are now commercially produced and used in traps to monitor insect presence (www.pherobank.com). Early detection of diseases in individuals and crops has been facilitated by biotechnological developments and innovations in sensing (Zijlstra et al., 2008; Balestrini et al., 2008 ; www.primediagnostics.com). With multiplex techniques, it is possible to test for several diseases in one test, leading to lower costs and faster results. Multiplex tests for several nematodes and soilborne diseases have been developed and will be improved. With sensing, it is possible to discriminate between crop and weed plants and in some situations to determine the health status of individual crop plants or cropping areas. Further developments in this area are expected in the near future.

There have been comparable developments concerning animal health. However, a major drawback of present day technology is that separate diagnostic tests currently need to be used for every animal pathogen. We expect that multiplex testing here will also lead to a decrease in costs and may lead to better knowledge of a herd's disease status, as a broader spectrum of pathogens is tested either in individual animals or on herd level, thus enabling treatments to be better optimized. Multiplex testing may also reduce time-to-analysis. In addition, multiplex assays can be developed for syndromes such as respiratory or gastro-intestinal problems. For the analysis of complex multifactorial diseases, host factors (biomarkers) may need to be investigated in addition to factors affecting the presence of pathogens. Suitable biomarkers will have to be identified, combined in an assay, and validated for their predictive and practical use. Biomarkers can provide information on response to infection, immune status or the functionality of certain organs, for instance the intestine or respiratory tract. Initiatives have been started to develop diagnostic tests based on blood parameters such as acute phase proteins, white blood cell markers and liver enzymes.

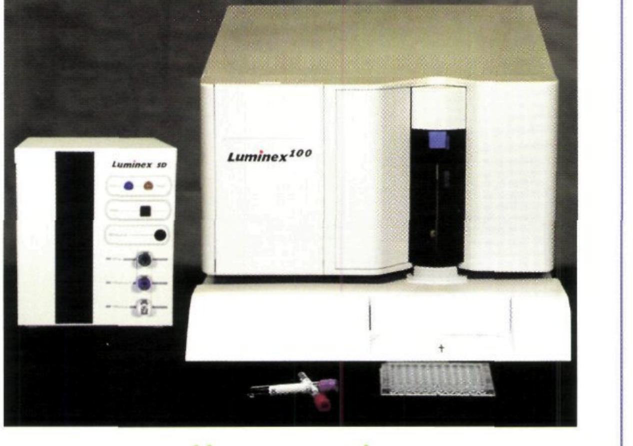
IPM strategies

Integrated Pest Management (IPM) strategies have been developed by Wageningen UR in different crop and animal production systems. These are based on integrating knowledge and monitoring information in order to maximise the effect of control measures. Improved evaluation and efficacy of preventive and control measures and insights gained from modelling the epidemiology and spread of diseases have helped the development of IPM strategies. Improved genomics tools and associated array technologies to acquire insight into the pathology of diseases have also offered new clues for prevention and IPM strategies. Integrated Pest Management (IPM) technologies include production and application technologies for antagonistic micro-organisms, macro-organisms and compounds (plant-derived compounds, insect pheromones) and physical control options (physical treatment of seeds and bulbs, mechanical weed control).

Multiplex analyses can be used in herd health monitoring programmes, which may help veterinarians and farmers set up and evaluate systematic treatment strategies employing control measures and vaccinations. Examples are screening tests for a number of animal pathogens, for instance a diagnostic platform for rapid detection and characterisation of respiratory or intestinal pathogens.

Decision rules and decision support systems have been developed and are sometimes used as part of IPM strategies. However a great shortage of (actual) knowledge on the cost-effectiveness of measures (action and economic thresholds) is a problem here. Concerning disease management in crops, with the exception of Phytophthora in potato, knowledge on actual damage relations in the light of the newly developed partially resistant varieties, improved cultivation techniques and changes in climatic conditions is lacking. New diseases, pests and weeds may become important where they were formerly not known (Meissle et al., 2010). Concerning the new diagnostic tools which make it possible to detect, sometimes in a quantitative or multiplex way, several diseases which could not be monitored before, the damage relations have not yet been determined. This leads to unnecessary control as a kind as risk reduction, where growers just did nothing before. As regards newly developed sensing tools, the relationship between the sensed value and the economically viable required action is mostly unknown. In the case of animal diseases, the cost-effectiveness of control measures has scarcely been a research item. This lack of knowledge may result in inappropriate, ineffective or uneconomic preventive and therapeutic interventions.

Box 3.3: Prime Diagnostics was created because of a need in agribusiness for fast and efficient detection technologies for plant diseases. Inspection services and companies world-wide use these products and technologies for detection of more than 90 different plant pathogenic viruses and bacteria. An example of a recent innovation is Luminex® technolog. This is a detection system for multiplex detection of a number of plant pathogens. The method is suitable for robotisation and can thus be used for high-throughput detection. This technique for the agro-sector was developed in cooperation with Luminex Inc.



primediagnostics

Precision arable and livestock farming

Precision farming is an agricultural concept relying on the existence of in-field or in-herd variability. It requires the use of new technologies, such as global positioning (GPS), sensors, satellites or aerial images, and information management tools to assess and understand variations. Collected information in the case of plant and animal health may be used to more precisely evaluate control needs and apply a site-specific control. This improves the eco-efficiency because

unnecessary usage of pesticides or veterinary medicines will decrease.
Precision farming is already used in arable production for driving straight and hoeing as close as possible to the crop rows. Concerning mechanical weeding, improvements have been made by sensing the crop plant and hoeing in between the crop rows (van der Weide et al., 2008). However this machinery should be improved or robotised to become more cost-effective for conventional production. Field sensing of crop status is possible both by satellites and by sensors on the tractor. The maps produced can be used to spray site-specifically. Kempenaar et al. (2009) have estimated that the introduction of precision techniques based on field mapping and spraying every 10 m^2 can reduce total pesticide usage in the Netherlands by 35%. Lund et al. (2008) predict even greater reductions (90-98%) for herbicide usage based on single plant application.

Box 3.4: Spraying of individual potato volunteer plants in a sugarbeet crop is possible using the Weedit spraying machine. This machine can also be used to spray individual crop plants with pesticides. At the start of the growing season when the coverage of the crop plants is small, large savings in pesticide use are possible. In Wageningen UR studies, savings of 70% proved possible with the first fungicide sprayings in potato and of 50% with haulm killing .This Dutch machine (Rometron/KampsdeWild) has been exported to several European countries but also to Australia (www.gps-ag.com.au), for selective weed control on pavements but also for control of weeds between the crop rows in vineyards and weed control in no-till systems.

Concerning animal health an alternative approach is the use of diagnostic tools to assess physiological parameters including animal behavior. Monitoring criteria which can be related to the animal health status of individual cows have been described by e.g. Mulligan et al. (2006). The application of wireless sensors to gather data from biological variables (body temperature, heart rate, exhalation gases) or behavior (body position, movements, feed intake) by continuous monitoring could be valuable for early warning, as well as in establishing the effect of control measures. Such systems are also being developed for the continuous monitoring of elderly people, in which data from biological variables (heart rate, accelerometers, body temperature and galvanic skin response) and everyday habits (body position, movements) will be transmitted to a central monitoring centre. Such systems can also be a valuable tool in the monitoring of herd health. While these developments are in an early phase of development and may sound futuristic, there is a clear need for tests that warn farmers and veterinarians at an early stage that something may be wrong. Such an early warning signal may point the way to further (multiplex) pathogen-specific diagnostics, as well as to early and effective interventions before clinical disease and economic harm occur. It may lead to guided and specific treatment of only the sick animals, thus preventing the use of unnecessary antibiotic treatments of all animals present in the herd, or to improved preventive measures. This can be called 'precision livestock farming'. However, such tests obviously need to be cost-effective.

3.4 Contribution to high-technology and eco-efficient agriculture

Developments in technologies, particularly in breeding, control and knowledge of the epidemiology of diseases, have already contributed to more eco-efficient agriculture for many decades, especially in developed and emerging market countries (see also section 3.1).

Many different measures are needed to monitor and protect plant and animal health. Table 3.2 lists the most important measures for high yield and eco-efficiency in the short term and indicates whether they are important on the individual, group or community level, although of course there are also overlaps between these levels. The most important measures differ for the different diseases. For example, notifiable animal diseases and quarantine plant diseases are mainly managed by global or local eradication programmes. Indigenous animal and plant diseases are mainly managed by preventive measures at farm level, such as sanitation, hygiene, vaccination and other management measures and control. The importance ranking presented in Table 3.2 indicates whether a particular measure is likely to be important at least for a group of diseases, and relative to the other measures.

Some of these technologies have been developed for specific diseases and are not yet available for other diseases. Other technologies are just at the start of further development and usage, e.g. precision farming in relation to disease control. The potential significance of various existing measures is indicated in a qualitative manner in Table 3.2., but this simply provides an indicative overview and quantitative effects will be different for different diseases and geographical areas. Not all techniques mentioned in the previous paragraph are listed in Table 3.2. For example, new techniques which are little used at present and need further development, but can be of great importance in reducing the ecological footprint and protecting plant and animal health, are not included in Table 3.2. Recent (high) technology developments with an impact on eco-efficiency that are not included in Table 3.2 include:

Table 3.2. Importance of measures for controlling plant and animal diseases on the individual (ind.), crop/herd or farm/ecosystem (eco.) level (• slightly important, •• moderately important, ••• highly important)

Measures	Plant			Animal		
	ind.	Crop	eco.	Ind.	Herd	eco.
Prevention:						
Spread prevention by eradication of pathogens	••	••	••	••	••	•••
Hygiene measures		••		••	••	
Compartmentalisation (separation in space)		•	••	•	••	••
Mixing (crops), biodiversity or reducing density or maintaining distance		•	••			••
Breeding and choice of cultivar	•••	•••		•	•	
Vaccination or induced resistance	•	•		•••	•••	•••
Cultivation measures (tillage, rotation, timing)		•••			•	
Stress reduction (soil quality, housing, ventilation, management of transition moments such as parturition and weaning, nutrition)		••		••	•••	
Need to control:						
Detection/diagnosis	•••	•••	••	•••	•••	•••
Decision rules/ Decision support systems	•	•••		••	••	••
Control measures:						
Treatment (physical or chemical) of starting material (seeds, bulbs)	•••					
Physical control (housing)	•	••		••	••	
Preventative chemical control		•••		•••	•••	
Curative chemical control	••	•••		•••	•••	

Precision arable and livestock farming

Precision farming can be an important technique to improve eco-efficiency and high yields. For further development it is important that three aspects of it are equally addressed: detection – decision algorithms – actuation. For effective usage within five years of sensor-based spraying (Canopy Density Spraying, Sensispray), decision algorithms are needed for biomass-dependent fungicide usage and for weed control. For mechanical weeding in crop rows within five years for organic producers, machinery needs improvements on more fast actuation and detection of several crop plants. For real discrimination between a number of weed and crop species, detection should be further improved. For implementation of these new mechanical weed control devices in conventional agriculture within 10 years, the cost-effectiveness should be further improved. Multiplex diagnostic assays and sensor-based detection techniques for animals health control may be expected to reach practical application within 5 to 10 years.

New resilient systems

Several aspects concerning more resilient systems are already included in Table 3.2 under prevention. However, relatively new system shifts are not. Real system changes can have an enormous impact on plant and animal health. For example, moving arable production out of the soil will reduce problems with soilborne pathogens and weeds, but can give new disease problems, e.g. pathogens circulating with the nutrient solution. No-till arable production can reduce energy usage, erosion and emissions, but can also lead to new weed and disease problems which have to be solved.

Invention to innovation

Whether a measure is used to control a disease depends not only on its efficacy against this disease, but also on the availability of the resources required in certain regions, economic aspects, legal aspects and social aspects (willingness, social status, presumed cost-effectiveness, risk perception). In this respect economics, transition, co-innovation and stakeholder management are very important. For animal diseases, aspects such as threats to public health, animal welfare and societal acceptability of measures (culling) are also taken into account.

Research at Wageningen UR is examining several (new) techniques and measures for improving prevention and health protection, although with choices for specific diseases/aspects based on the funds and expertise available. Some of these techniques will be applicable in the long term, others can be important in the short to medium term. The most important technologies are summarised in section 3.5.

3.5 Short-term and medium-term products

The products considered to be the most useful for increasing production and decreasing the footprint in relation to plant and animal health are listed in Table 3.3.

Table 3.3. Product importance (• slight •• moderate ••• high) for increasing plant and animal yields with a decreased ecological footprint within 5 years for developed (dev) and developing countries (ing) Technologies: Developed countries Developing countries

Technologies:	Developed countries	Developing countries
Prevention:		
(Semi-)closed systems and/or soil-less farming	••	
More resistant animals by genetic selection, stress reduction, improved housing and nutrition	••	••
More resilience by improved soil quality and biodiversity in soil and environment	••	••
Resistant varieties	•••	•••
(DIVA) vaccines	•••	•••
(Innovative) cultivation and culture methods	•••	•••
Need to control:		
Early detection methods in the chain	•••	
Fast, cheap and reliable diagnostic tools (and detection methods for pests and diseases (molecular, serological, multiplex, pheromones, traps, sensors, cameras)	•••	••
Decision support systems including action thresholds	•••	••
Control measures:		
Physical control methods, especially for weeds	••	•••
Precision application and dosing (also for antibiotic treatment of animals)	•••	•••
Protection of individual plants (seed coating)	•••	•••
Protective agents of natural origin (macrobials, microbials, plant-compounds, pheromones, etc.)	•••	•••
Integration:		
Precision farming	•••	•
IPM strategies	•••	•••
Stakeholder management and co-innovation	•••	•••
Education	•••	•••
Knowledge in magazines and on the internet	••	••

Some products are primarily useful for developing countries, which have much to gain by reducing yield losses due to diseases (section 3.1). Breeding for resistant varieties, seed coating, vaccines, cheap diagnostic tools, innovative cultivation methods, physical weed control and (precision) application of control agents are important measures to integrate towards IPM strategies together with stakeholder management, co-innovation and education. Other products that are more appropriate for developed countries to reduce the footprint and maintain or increase crop yields include early detection methods in the chain and sophisticated detection methods, decision support systems and sophisticated precision farming techniques. Knowledge and technologies concerning organic agriculture, such as increasing resilience, resistant varieties and physical control, can be useful in both developing and developed countries. The products listed are expected to be of importance within the next five years, provided there is sufficient funding for the research and transition stages.

3.6 Under-investigated aspects

Several aspects concerning plant and animal health in the area of increasing agricultural production and decreasing its footprint have not received sufficient attention to date. The most important of these are listed below.

Quarantine and notifiable diseases versus indigenous diseases

Because of the great social impact on human and animal welfare and the economic impact in terms of product exports, research on quarantine plant diseases and notifiable animal diseases has received much more attention and funds than research on indigenous diseases. There is a relative lack of relevant information on indigenous plant diseases (e.g. weeds, various pathogens in cereals, insects in vegetables) that have a serious impact on yield and cause serious emission of pesticides to the environment. There is also insufficient knowledge of the environmental impact of animal diseases, emission of antibiotics and veterinary medicines but also additional greenhouse gasses emission, production losses and efficient of use of natural resources. Relevant endemic animal diseases in this respect include a range of enteric and respiratory diseases, parasitic infections and disorders such as mastitis and claw disorders. Animal husbandry must also urgently start producing antibiotic-free produce to the greatest extent possible. Such a development will require major changes in the day-to-day practices, attitudes and behaviour of all participating stakeholders in animal husbandry. These changes may be facilitated by new technical solutions and the re-design of animal husbandry systems with the aims of optimal pathogen elimination and disease prevention. Simple solutions will not suffice to reduce antibiotic use in animal husbandry, so integrated, multidisciplinary and comprehensive approaches will be absolutely essential to progress.

Population genetics of plant pathogens

Most resistance genes in plants are only active against a pathogen with a corresponding avirulence or effector gene. Under field conditions resistance will provoke a strong selective pressure on the pathogen population in favour of individuals with an altered effector gene, as only such individuals can infect and propagate. Information in this area is currently available for only a few fungi. These organisms have several hundred different effector genes, so there is huge potential to circumvent plant resistance genes. An example is *Phytophthora infestans* in potato. Due to genetic rearrangements in the Phytophthora population, about 11 resistance genes which had been deployed in potato cultivars during recent decades appear to be broken. Even new resistance genes appear to be broken rapidly after deployment in potato.

A similar mechanism is responsible for the development of pathogen resistance to (chemical) pesticides. It is known from experience that fungi can become resistant to fungicides within a few years of practical application. An example is *Mycosphaerella graminicula*, the main fungal disease in wheat, which became resistant to the new class of fungicides strobulurines in a few years, due to genetic rearrangements in its genome.

The consequence is that IPM can fail as two important pillars upon which it is based, plant resistance and the efficacy of pesticides, are rapidly eroded. At present, much research is being carried out on the genomics of the main plant diseases. However, focus is also needed on functional genomics, notably on effector genes and resistance mechanisms to pesticides. For example for Phytophthora, diagnostic tools

are being developed, based on assaying mutants of effectors. Screening of field populations for emerging mutants will be an essential input for future DSS in applying fungicides, and an important tool for resistance management.
In conclusion, knowledge of the genes involved in infection and in fungicide resistance, and knowledge on the spread of such genes in field populations of the pathogens are crucial for development and management of host plant resistance as well as pesticide management and discovery. This will enable effective and durable use of plant resistance and pesticides in concert resulting in crop protection with minimal inputs.

Resilient IPM strategies

IPM strategies integrate preventive measures, need-to-control and control methods. Important knowledge for IMP strategies are yield-damage relations. Many yield-damage relationships used for determining the thresholds at which it is economically viable to control pests/diseases, if available at all, are based on old data. The diagnostic possibilities we have now were not available when these thresholds were established and yields were often lower. Appropriate relationships and economic calculations are lacking, leading to unnecessary use of control agents just to prevent risks (see also section 3.3, IPM strategies). In addition, the system is changing due to climate change but also due to increasing resilience in systems.
Such changes also influence the yield-damage relations. For example, weeds give less yield reduction in organic systems than in conventional systems (Ryan et al, 2009). Expected problems in no-till system are often less profound, while other problems have to be solved.
Much research is needed to obtain the knowledge for resilient IPM strategies. New technology such as GPS harvesting with site-specific yield estimations combined with additional monitoring with (new) diagnostic tools and data mining can be used to collect data efficiently.

Knowledge for optimal usage of precision farming in crop and animal protection

New technologies in precision farming, such as global positioning systems (GPS) on farm equipment, biomass sensors, soil mapping, satellite pictures, GEO information in farm management systems, new multiplex diagnostics and innovative application techniques, are under development. However, to make such techniques more profitable, answers are needed to the following questions:

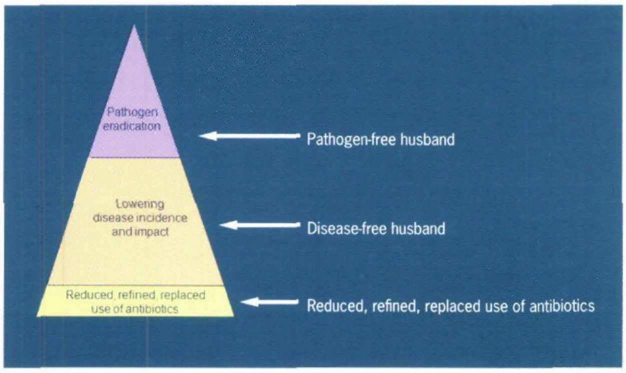
- Which sensors and diagnostic methods can be used to detect diseases, pests and weeds in a fast, cheap, and site-specific way?
- Which sensors can detect disease-relevant parameters on individual animals?
- How can physiological data be interpreted and used with regard to animal health?
- How can (satellite) maps or specific animal measurements be interpreted in terms of the underlying causes and the consequences for prevention and control?
- What are the validated decision rules needed for precision applications?
- What techniques can be used for further innovation in site- or animal-specific applications?
- How can precision crop and animal protection be automated and robotised?

Developments in eco-efficient, high yielding crop and animal production

Energy-efficient farming and soil-less crop production are new developments within eco-efficient and high yielding farming. Research on these issues in glasshouses is currently at the front line globally. However, in the Netherlands and Western Europe we are lagging far behind the emerging market countries and North America as regards energy efficiency in open cultures. At Wageningen UR, we are just starting research with no-till, direct drill in (green manure) crops and reduced, ridge or strip tillage. In these altered systems, crop protection (especially weed control) is a very important factor influencing yield and eco-efficiency and this area requires research and adjustment for local conditions. The soil-less cultivation of outdoor crops is just starting and although this has many benefits concerning soilborne diseases, it will give rise to other disease problems. Without control measures, such diseases will be easily spread within the system with the hydroponic solution. Research is needed to predict, prevent and control these crop diseases.

Genetically modified crops can be another tool giving real system changes and challenges for research as regards optimal usage and integration in eco-efficient systems.

Because the challenges in controlling animal diseases are difficult and complex, it is important to develop and examine an integrated approach consisting of combined veterinary, zootechnical, genetic, economic, cultural and societal approaches. Problem-solving efforts must be aimed at the overall system, in which components of the animal husbandry system and related disease prevention system function in the context of each other and with other systems, rather than in isolation. The results must contribute to more robust future animal husbandry in which sustainable disease prevention is an integral and central activity.



Box 3.5: For preventing the emergence of antibiotic resistance we consider it important to work on the following research aims:

A. *Reduction of the need to use antibiotics in livestock production by designing a "pathogen-free" husbandry,*
B. *To diminish the impact of those infections that cannot be avoided, by designing a "disease-free" animal husbandry, where fewer infections occur, and where animals have the genetic, physiological and behavioural possibilities to combat infections with minimal clinical signs and economic losses should infection nonetheless occur.*
C. *Reducing, refining, replacing methods of application of antibiotics to minimize the risk of resistance in bacteria.*

Stakeholder management and co-innovation for emerging market and developing countries

In the past decades agricultural production in the Netherlands has witnessed great improvements on animal and crop health management with less pesticide use, less emissions and more use of system resilience. In this development, Wageningen UR has contributed substantially. However, at the same time Wageningen UR has experienced that changes in farming practice are not only depending on technological inventions. To be effective these inventions need to be embedded in co-innovation processes involving all stakeholders. This knowledge and experience can be useful in transition processes in other countries faced with the need to make agricultural production systems environmentally less harmful and thus more sustainable. However, blueprints for such processes are non existing and local knowledge is indispensable to make progress in practice.

Box 3.6: In many developing countries weeding is still done by hand. Labour availability is becoming a problem, e.g. due to HIV/AIDS in Africa (Mashingaidze, 2004). Very high yield reductions caused by weeds often occur. Co-innovation based on local knowledge and on knowledge of prevention and physical control measures gained in organic production systems and research in the Netherlands could be of value. Further education (tools) and stakeholder management together with Dutch companies active in Africa (e.g. http://rumptstadaf.kingsquare.nl/home) could be used to obtain insights and solutions to the problems.

3.7 Recommendations

There is much to be gained from research, co-innovation, stakeholder management, knowledge dissemination and international cooperation concerning increasing yields and the footprint associated with plant and animal health care. Therefore it is very important to facilitate the additional research needs for the products mentioned in section 3.5 and the additional needs listed in section 3.6. Funds for this should be increased and more attention should be devoted to indigenous diseases and joint actions taken in emerging market countries and developing countries.

To increase yields and simultaneously decrease the ecological footprint, investment is recommended in the areas of:

1. Stakeholder management and co-innovation, including for emerging market and developing countries.
2. Resilient IPM strategies based on detection methods throughout the chain coupled with research on damage thresholds, resulting in decision support systems that tell the farmer how and when to apply control methods proportionally to the problem (both for plant and animal diseases).
3. Innovative concepts (closed greenhouse, soil-less culture, reduced tillage, specific pathogen free animal husbandry) in order to close energy and nutrient loops. These new concepts will give rise to crop protection challenges that need to be solved in order to profit fully from these new concepts.
4. A systems design approach to animal husbandry aimed at producing 'pathogen-free' wherever possible, in order to reduce the losses associated with endemic diseases and to reduce or eliminate the use of antibiotics and to integrate requirements with respect to animal welfare, animal health and public health.
5. Precision technology that helps the farmer apply pesticides or alternative control options on exactly the right spot at the right time and thus prevent waste (both for plant and animal diseases). This also holds true for vaccination strategies of animals diseases guided by diagnostics and epidemiological insight.
6. Insights into the population genetics of plant and animal pathogens, which are needed for more efficient breeding and resistance management.

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4. Irrigation and water use in agro-production system

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4.1 Introduction

Tomato growers have achieved spectacular improvements in water productivity, first by shifting production from the open field to greenhouses and then by improving the technology through cultivation on substrate. Producing 1 kg of fresh tomatoes in the open field requires beween 100-300 liters, against 22 liters in greenhouses and 15 liters when the drainage water in greenhouses is recirculated. Recovering condensation water can save another 4 liters/kg (Van Kooten et al., 2008) and probably more (Speetjens, 2008). Even higher efficiency and productivity gains can be made by combining agricultural production and post-harvest processing (Smeets, 2009). Yet on a global scale water use efficiencies are much lower, although savings of over 60% can also be reached in Ethiopian greenhouses (Van Os et al., 2009).

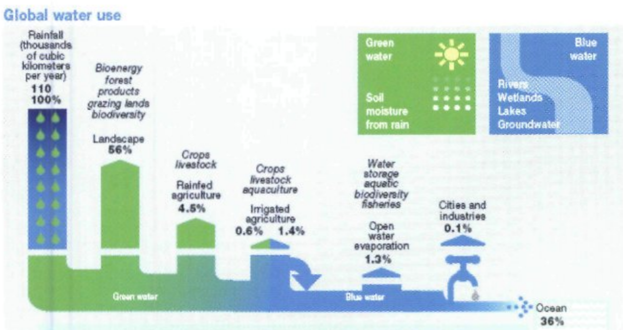

Figure 4 1. Global water use (Source: Molden, 2007, reprinted with permission from copyright holder)

Today, only 16% of the world's croplands are irrigated, but those lands produce about 36% of the global harvest. Although other input use efficiencies have increased in most parts of the world, average irrigation efficiency in public systems hardly improved over the last 75 years. Irrigation is the largest user of freshwater withdrawals – representing 70-80% of total withdrawals. Further increases of water withdrawals from surface reservoirs and rivers or groundwater resources may create serious environmental damage. Increasing water withdrawals may even lead to river basin closures (Molle et al., 2010), where responses to avoid ecosystem degradation are urgently needed.

All the water that is available for food production originates from rainfall. Desalinated water is too expensive to be used in food production. A schematic overview of the global use of the available rainfall illustrates that rain is used by the landscape, rain fed agriculture, irrigation and other users (Figure 4.1). In fact the amount of freshwater withdrawals used for irrigation is only a minor fraction of the total rainfall. A better understanding of how water can be used more efficiently in agro-production systems can help bridging the gap between high-tech greenhouse production and global realities.

4.2 Irrigation efficiency in the last century

The irrigation efficiency concept was defined in 1932 by American pioneer irrigation scientist Orson W. Israelsen, who wrote a handbook that covered the agricultural aspects of irrigation which – according to the author – 'are not considered in works on irrigation engineering.'
Even earlier, other authors had pointed out that in developing irrigated agriculture, the emphasis should be on agriculture, rather than on engineering:

- 'Getting a fair return from the irrigated lands is much more difficult than planning and building the irrigation works' (Newell, 1916);
- 'Up to now, irrigation in India has been looked upon largely as an engineering problem.....but the real value of irrigation depends largely upon a proper appreciation of the needs of the crops irrigated.' (Howard, 1953);
- ' [public]Irrigation systems should be headed by an agriculturist.' (Den Berger, 1915).*

In reviews on irrigation efficiency, Israelsen (1932) is commonly credited as the first to have defined the concept (e.g. Wolters, 1992; Perry, 2007; Jensen, 2007). What most reviewers do not mention is that Israelsen places the irrigation activities in the context of plant biology and agronomy. Less known, he also presents the concepts of transpiration ratio and transpiration efficiency and discusses the classical container experiments of Briggs & Shantz (1914) for determining the relationships between transpiration and production of many plant species. Their theories and experiments were later elaborated upon by C.T. de Wit in his seminal work 'Transpiration and crop yields' (1958).

Israelsen's irrigation efficiency strings together the various steps in the trajectory of the irrigation flow between the point of water diversion and the atmosphere:'With a given quantity of water diverted from a river, the larger the proportion that is stored in the soil of the irrigated farm and there held until absorbed by plants and transpired from them, the larger will be the total crop yield. The expression irrigation efficiency (Ei) is here defined as the water transpired by the crops of an irrigation farm or project to the water diverted from a river or other natural water source into the farm or project canal or canals.'

This (overall) efficiency (Ei) concept is the product of three partial efficiencies (or output/input ratios) associated with different water movements:

- The conveyance and delivery efficiency (Ec), the ratio of the volume of water delivered to farms and the volume diverted from the river;
- The water application efficiency (Ea), the ratio of the volume of irrigation water stored in the soil and the volume delivered to the farm;
- The consumptive-use efficiency (Eu), the ratio of the volume transpired by the crop and the volume of irrigation water stored in the soil.

Heavy investments in irrigation have been made. In the period 1950-2000, irrigation and drainage investments absorbed 30-33% of total lending for rural development (World Bank, 2003). In order to achieve the rate of return required by the Bank, planners of new irrigation projects tried to save on investment costs. Apart from using optimistic estimates of irrigation efficiency, planners achieved considerable cost savings by leaving out the end part of the delivery system. Instead of bringing the water to the individual farm, a delivery point is shared by a group of farmers. This approach is at the expense of individual control over soil moisture conditions, which Newell (1916) already considered a key attribute for the performance of irrigated agriculture. The limitations of this approach were also expressed by irrigation experts within the World Bank (e.g. Plusquellec, 2002). Other consequences of the investment criterion are a preference for arid and semi-arid regions and for perennial irrigation systems: Arid regions, because the difference in agricultural production with and without the project is higher compared to areas with more rainfall. Perennial irrigation, because providing irrigation water throughout the year produces the highest return on investment.

The consequence, however, is that large amounts of irrigation water are used in dry locations or seasons, where water productivity tends to be low. Once planners had arrived at a rate of return that made the irrigation system eligible for funding, the permission for withdrawing the water was more or less automatically given, especially in the case of public irrigation systems. The efficiency of irrigation schemes reported by Wolters (1992) in two worldwide surveys on irrigation efficiency (Table 4.1). The overall efficiencies found by Wolters are surprisingly low. Some of the various uses and ways to describe the term water use efficiency are given by Jones (2004) and Jensen (2007).

Group	No of schemes	Average overall efficiency (%)
Arid and semi-arid regions	33	37-42
Humid regions	30	23

It is only in the last decades of the 20th century, that water came to be considered as valuable, even when it did not fulfil some well-defined productive functions such as for agriculture, industry, urban water supply, navigation, etc. By the time that people realized that irrigation used 70-80% of total water withdrawals (Bhatia & Falkenmark, 1992) many countries had already allocated the major part of their water resources to irrigation on the basis of earlier studies that never considered the value of water and water productivity.

4.3 State of the Art: Consider rain and not water withdrawals

By the year 2000 science realized that freshwater increasingly became a scarce resource, which should be managed with care. The question arose whether water needs to be used for productive purposes at the expense of ecosystems and their associated goods and services. To resolve this question, the international research community embarked on a 'comprehensive assessment (CA) of water use in agriculture' in order to assess the water needs to feed the world without compromising the ecosystems. After four years of research by some 700 scientist concluded: ***'Yes we can, but only if we change the way we think about water and agriculture.'.*** This change in paradigm considers rain as the ultimate source of water instead of rivers and groundwater, breaks down the divides between rain fed and irrigated agriculture and links better fishery and livestock practices to water management (Molden, 2007). This shift in perspective – from the water to the rain – requires a parallel shift in thinking about water productivity towards identifying the mix of uses that together make the best use of the rainfall in a given catchment. The global water use (Figure 4.1) serves to illustrate that policy implications of this recommendation can be huge. While international water resources policy in the last few decades criticised the agricultural sector for taking too much water for irrigation (70 – 80% of total water withdrawals), it must be realized that from the available rain, most is not used by agriculture but used in the landscape for forests and biodiversity. Most of the water is used for evapotranspiration, i.e. the vapour flow from the land and vegetation that is returned to the atmosphere. The partitioning of the rainfall into evapotranspiration (often called 'green water') and water that ends up in rivers, lakes and in groundwater (often called 'blue water') depends on the characteristics of the landscape – both the agricultural and the natural- and the way the land is used. Landscape and land use not only influence the volumes of the inflow into rivers and groundwater, but also their timing and quality. The consequence of recognizing rain as the primary source of water, therefore, is that land use management has to be a major aspect of water management. It is from this perspective that irrigated agriculture should be considered. Figure 1 also shows that irrigated agriculture uses only 2% of total rainfall. Rain fed agriculture uses approximately twice as much as irrigated agriculture does. To improve rain fed production potentials of crops requires better understanding and forecasting of the stochastic components in rainfall and optimizing the water buffering capacity of the soil during the growing season of crops. Supplemental irrigation is an option to overcome short periods of drought during the cultivation of rain fed crops. To facilitate supplemental irrigation in practice better forecasting models and tools are required to determine periods of drought.

Farmers still do not have the possibility to manage within their farm their water use in many full fletched irrigation schemes. The result is that they often use more water than necessary and have no incentive to maximize water productivity. Redesign of such schemes and using this water for supplementary irrigation would allow for a much higher agricultural production with the same amount of water in many areas. However investors still need to absorb the consequences, as illustrated by a key sentence in World Bank (2005): 'Unlike full irrigation, the timing and amount of Supplemental Irrigation cannot be determined in advance owing to rainfall stochastic.'

4.4 Contribution to efficient use of water in high-technological and eco-efficient agriculture

Agricultural water management is not restricted to irrigation but also implies that drainage of water requires careful consideration (Ritzema, 1994). Wageningen UR experience (Ritzema et al., 2007) clearly illustrates the impact of drainage on agricultural productivity. In a drainage project involving 2 million ha, building on Wageningen UR expertise, it was shown that an investment of 1000 million US$ resulted in a contribution to the GDP of about 900 million US$ per annum (Ali et al., 2001). Research programmes conducted in Egypt, India and Pakistan helped to modernize subsurface drainage practices and considerable savings are being achieved by introducing new methods of investigation, design, planning, installation (including new materials and equipment) and operation and maintenance. Efficient use and management of water resources is also encouraged by economic incentives for the users of the water. This involves not only proper pricing of the water being used, but can also include paying for services provided by farmers that contribute to overall water management. Such payments for environmental services are based on the concept that farmers through their management practices provide services to other sectors that compensate these farmers in cash or in kind. Examples of hydrological services for which payment for environmental service schemes have been developed include improved water quality through watershed protection programs, i.e. 'Green water credits' (Dent and Kauffman, 2007). Commonly, eroded soil of upstream areas ends up as sediment in downstream hydropower reservoirs, shortening their effective life-span. In this case, the energy sector can pay upstream farmers for changed land management practices resulting in reduced soil erosion and less sediments downstream. Instruments that pay for ecosystem services (e.g. Jansen et al., 2007), where biodiversity is maintained by proper soil and water management of farmers, can also be used to farmers to apply eco-efficient techniques.

Agricultural water productivity can be improved but require strategies that consider complex biophysical and socioeconomic factors (Molden et al., 2010). An approach to reach such productivity gains can be a "Dialogue". An example of such an approach is the Advisory Panel between the Egyptian and Dutch Government, where Wageningen UR is involved from the start in 1976. There was a growing need on the part of the Egypt for experience, insight and knowledge from other societies in delta regions. The agenda of the Panel evolved from drainage and irrigation to other areas of knowledge such as groundwater and water quality over time, institutional reform and policy development (El Guindy et al., 2004). In more traditional production systems new drainage techniques with variable drainage depths for field crops are being introduced (Stuyt et al., 2009) enhancing water retention and water buffer capacity and control of moisture in the root zone. As a consequence less irrigation is needed and it also saves nutrients.

Rice is a very important staple crop with a global production exceeding 650 million ton per year (FAOSTAT, 2008) and providing food to a major part of the world population. About 75% of total rice production is produced under inundated conditions, i.e. in fields with a standing water layer of 5 to 15 cm during the major part of the growing season. Rice consumes some 24 to 30% of global water withdrawals suggesting that water savings in rice production can have a big impact on the water availability for other users (Bouman, 2007). Since the beginning of the 21st century various water saving technologies for rice production systems have been developed (Bindraban et al., 2006). Research by Wageningen UR showed that an irrigation regime of alternate wetting and drying of the soil surface has great opportunities to substantial reduce water use in current rice production. For example, in Southeast Asia water use in rice production could be reduced by 20% without a negative effect on yield using this modified irrigation regime (Belder et al., 2004), while in Sahelian environments reductions up to 40% were realized with no or little yield loss (De Vries et al., 2010). Although both illustrations indicate that the potentials are high to reduce water input in rice production, a range of socio-institutional conditions should be satisfied enabling wide-scale adoption, such as the redesign of existing irrigation schemes and fair pricing mechanisms for the use of water.

For the future it is important to notice that two assumptions that have been made implicitly by Molden (2007) are being challenged by recent research at Wageningen UR:

- Agricultural production is limited by the availability of freshwater resources;
- All evapotranspiration must be considered as inevitable loss.

More technological progress is being realized in more fully controlled environments, especially greenhouses. Water and energy are major issues in greenhouse production control (Van Henten and Bontsema, 2009). Recent Wageningen UR research showed that water used in plant production and released as either drainage water or as water vapor can be recycled. To reach high production levels with low water requirements automatic control of water and nutrient supplies is applied in greenhouse crops. A common technology is to work with standard nutrient solutions. Frequent analyses of the nutrient solution concentration in the root zone of the plants that is feed back in the dispersion of nutrients. The reuse of drainage water can further reduce the water and nutrient requirements but requires measures to prevent the spreading of pathogens in such recirculation systems. Available disinfection systems include heat treatment, UV radiation, slow sand filtration, ozonization and membrane filtration. With recirculation of drainage water it is also important to avoid accumulation of nutrients and ions in the water. Parameters to be controlled include pH and electrical conductivity (EC). Concentrations of ions that are hardly absorbed by plants like Na and Cl must be controlled in such systems by monitoring (off-line or on-line with ion specific sensors) and diluting with fresh water.

The recapturing of water evaporated by plants is technically feasible as shown in the EU-project Watergy. The Watergy system condenses water vapour that is released from greenhouses in a separate unit before the air is released to the atmosphere. About 30% of the water present in the air leaving the greenhouses can be recovered with this technique. Apart from looking at the production site, major steps in sustainability also become available when different production systems are combined and output (e.g. heat, water, carbon dioxide) from one production process is used as input for another production process. Often located near urban centres, Agroparks combine several agricultural production and processing functions. Smeets (2009) studied agroparks in the Netherlands, Shanghai (Greenport Shanghai) and India (Greenport Nellore) and defined such parks as spatial configurations of agrofunctions and related economic activities. Agroparks bring together highly productive plant and animal production and processing in industrial mode combined with the input of high levels of knowledge and technology. In both animal and plant production, energy and water are inputs and outputs of the processes. In agroparks further processing can be integrated, again processes where water and energy play a major role. With skilful engineering these processes can be physically linked with each other. The overall efficiency in the use of water and energy can therefore reach important gains.

Irrigation water is not necessarily based on rain or the withdrawal of water from freshwater resources, but it can also be produced on site, for example with the Dutch Rainmaker. Especially in more remote areas the Dutch Rainmaker allows to produce clean water from either water vapor in the atmosphere or from briny or brackish water. The Dutch Rainmaker is based on a wind turbine that powers an evaporator and a condenser. For applications using water vapor from the air, the wind turbine forces the water vapor through a heat exchanger, while using briny or brackish water the Dutch Rainmaker contains an evaporator in a high-vacuum tank after which the moist air is condensed in a heat exchanger powered by the wind turbine (Van der Sandt, 2008). For both applications the production of clean water takes place in the heat exchanger, where the air is cooled, and condensation takes place.

Figure 4 2. Concept of Zilte Zoom

Saline environments can develop when evaporation exceeds precipitation or when saline water enters the area through seawater intrusion or percolation. In such saline environments agricultural production systems exist in a wide variety. In the Netherlands (Brandenburg, 2006) new crop options like Glaswort (Salicornia) and Sea Aster (Aster tripolium) are explored that are salt tolerant and can be grown in the "Zilte Zoom" (Figure 4.2), an area with salt water intrusion often close to marine environments. Instead of investing in the expensive fight against salt water intrusion, the saline environment is changed into an opportunity to produce new crops as part of a diversified food system. Such an approach not only requires new production techniques but also substantial market development to create the demand for the new 'saline' products. Aquaculture as a way of producing protein can be further exploited in saline agriculture. In the world over 2.3 million ha are used for brackish water fish ponds (Verdegem and Bosma, 2009), where especially in coastal mud flats yields can be high. To make aquaculture systems more sustainable a number of areas need attention, including reducing sedimentation in brackish water fish ponds to reduce losses in pond areas, and aquafeed development, to reduce pollution. If such conditions are met, tripling of the production in fish ponds should be possible without increasing total freshwater use (Verdegem and Bosma, 2009). In very dry areas soil salinity can reach levels that reduce or prevent crop growth and productivity. To prevent salinization of the soil micro irrigation may be applied that ensure root zones of plants have low salt levels. To control salinization drainage techniques that flush away excess salt levels are available (Ritzema, 2006). High-Tech nutrient management with e.g. fertigation can ensure good production circumstances with low water consumption.

Several EU projects in which Wageningen UR has a leading role are producing deliverables that will play in tackling the challenge to increase water efficiency in food production. This can be at land use planning level and policies like, the MIRAGE project addressing water quality improvements at catchment levels, the XEROCHORE project addressing drought policies and the NEWATER project addressing communication and ownership issues. At farm level the FLOW-AID project contributes to sustainable irrigated agriculture by developing a deficit irrigation management system. It integrates innovative sensor technologies into a decision support system. It focuses on innovative, simple and affordable, hard- and software concepts; particularly a maintenance free tensiometer, a wireless and low-power sensor network; an expert system for farm zoning and crop planning in view of expected water availability and quality; and an irrigation scheduler for allocation of multiple water sources.

4.5 Research gaps

In many parts of Africa or elsewhere yields at regional scale or (sub) catchment scale can be increased by better exploiting water buffers. In many situations multiple objectives need to be taken into account. The use of precipitation to maintain sustainable ground water levels and fill hydropower reservoirs can be combined using part of the precipitation for both agricultural production and for ecosystems. In some catchments this will be increasingly important as climate change projections predict less and/or more erratic rainfall. The total availability of water at regional or catchment level can be enhanced e.g. by water harvesting techniques (Boers, 1994). In the African context this is especially relevant when this is used to produce more biomass per drop than just more crop per drop, as it helps in regreening Africa (Stroosnijder, 2009). When water is used efficiently in such areas it also provides further scope for high production systems that are capital intensive. In capital intensive systems adequate water supply must be ensured to reach a stable production level that can be linked to market opportunities. The size of such high production systems must therefore be designed in such a way that in years with low rainfall, still the minimum water requirements of such systems can be guaranteed. In years with more rainfall, water use for recharge purposes, used for additional production and/or other purposes can be planned. The opportunities to buffer green water (in-situ or ex-situ) can be quantified based on information on soil texture, soil depth, rainfall surplus (precipitation-evapotranspiration), topography, groundwater depth and land cover, as illustrated for a region in Figure 4.3. Such information can subsequently be used in further planning.

For sustainable use of the available land and water, harvest security and livelihood opportunities can be assured by using production systems that have guaranteed water quality and quantity available. This allows aiming at high yields in these systems and because of secure returns such systems may also attract associated investments that increase yields. In years with plenty of water to meet the annual requirements, extra water can be buffered or, when extra land is available, produce additional biomass, but with lower added value. How the water is best used for supporting livelihoods and regional development is best decided between all stakeholders in the region.

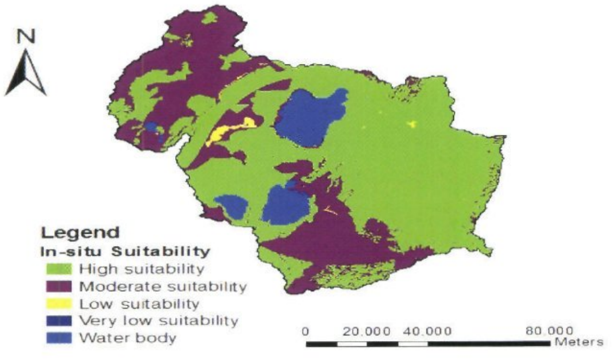

Figure 4 3. Water buffering capacity in a region that can be used to increase the resilience of agricultural production systems to extreme rain conditions.

More research is needed on adaptation of high-tech production systems, mainly designed for countries with fairly even distribution of rainfall, to situations in areas like Africa and South Asia, where the different environment needs proper selection and adaptation to systems that perform well with the specific set of available human skills, crops, and natural resources including water and climate conditions.

Current harvest predictions based on remote sensing techniques (Huber et al, 2009; Supit et al., 2010) are already available that can help farmers in optimizing their inputs of water and nutrients for their crops that are growing. Further benefits could be realized when remote sensing techniques are combined with seasonal climate predictions, whereby rainfall will be predicted for the next months with improved climate models (Ludwig et al., 2009). By transferring the information on expected rainfall and water availability to farmers, they can anticipate their crop and variety selection, their use and timing of inputs of water and nutrients and hence arrive at more eco-efficient production techniques.

To resolve salinization issues too little information on the build-up of Ca, Mg, (bi) carbonates, Na and Cl is available in relation to soil type and irrigation techniques. Only then appropriate combinations of irrigation technique, crop type and soil type can be selected for systems that ensure sustainable production (Van Bakel et al., 2009).

4.6 Recommendations

1. Global agricultural production can benefit from water saving techniques as developed in the Netherlands under a number of conditions. A basic condition is that to recover the higher investments per m^2, the value of the production obtained per m^2 must be high. As a consequence the technology is mainly applied in industrialized countries to vegetable and fruit production as well as ornamental plants rather than in staple foods, where returns per m^2 are limited. The potential to contribute to vegetable and food production can be expanded to less industrialized countries, when a number of obstacles are addressed. Good market access including the logistics involved is necessary. The risks associated with high tech agriculture are high, also requiring management that reacts swift and adequately on any change. Taking the above considerations into full account the options for more high tech production in less industrialized countries with erratic rainfall patterns should be taken up to utilize the vast potential to use less water in food production by utilizing appropriate elements of the current available technologies.

2. The development and utilization of early warning systems based on seasonal climate models will allow for enhanced efficiency in the use of water and other inputs. Such an approach will not only increase world staple food production but will also have a positive effect on water quality as less nutrients and pesticides will be emitted to the environment. Ecosystems and other users will therefore benefit from this approach.

3. Redesign of full fletched irrigation schemes, that account for 6% of cultivated area in Africa, to systems where water is used at the demand of the crop and supplemented by irrigation when rain and water available in the soil alone would limit crop production needs to be done to reach large water savings, providing also better availability of water for ecosystems and other uses.

4 Living with salinity: As rising sea levels and mismanaged irrigation schemes have created large areas with salt intrusion and salinity problems, systems that are actually based on saline water, rather than fighting salinity, provide new opportunities that need further development.

5 Research programmes should be fully embedded in implementation programmes as this maximizes the return on investment in more comprehensive approaches. In such programmes opportunities to maximize water retention in order to produce more biomass, including food should be incorporated.

Following the recommendations above will eventually ensure harvest security for the global and local population, while at the same time generate a strong local driver for further economic development.

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5. Nutrient recycling

Author: Jaap Schröder and Bert Smit

5.1 Introduction

In the pre-industrial period, production, processing and consumption of food, feed and fiber were closely related in space and time. Wastes, if looked upon as that at all, were recycled. Depletion of nutrients was compensated or masked by nitrogen (N) fixation via clovers, regular flooding, weathering, shifting cultivation and/or supplementation via livestock grazing on surrounding rangeland (Figure 5.1). The gradual increase of yields per unit area and worker required less labor and allowed migration to towns where science, education and industrial production started to flourish. Knowledge and technologies coming out of these towns and industries helped to further expand the area under tillage and increase yields per hectare, not the least due to the advent of manufactured N and phosphorus (P) fertilizers. Moreover, fertilizers alleviated the necessity to recycle the N and P leaving farms in the form of marketed products. Increased agricultural production allowed human population to grow and afforded mankind a more affluent diet (Brown, 2003). However, this all came at the expense of fossil reserves and biodiversity. Human expansion also lead to the loss of environmental quality due to global N and P emissions (Erisman, 2009), as the increase of the use efficiency (kgs NP output per kg NP input) at farm level has been offset by greater NP inputs per unit area and the ever increasing area under cultivation (Schröder & Bos, 2008).

There are other reasons not to mistake 'efficient' for 'clean' or 'sustainable'. By partial externalization of underlying processes i.e. by changing system boundaries, the remaining system may appear to have augmented its efficiency. A landless livestock farm, for instance, exporting all its manure may seem very efficient as it will, theoretically, only lose some gaseous N. Similarly, an arable farm using no more P fertilizer than the amount of P exported in produce has a high efficiency too. N and P losses and hence the inefficiencies

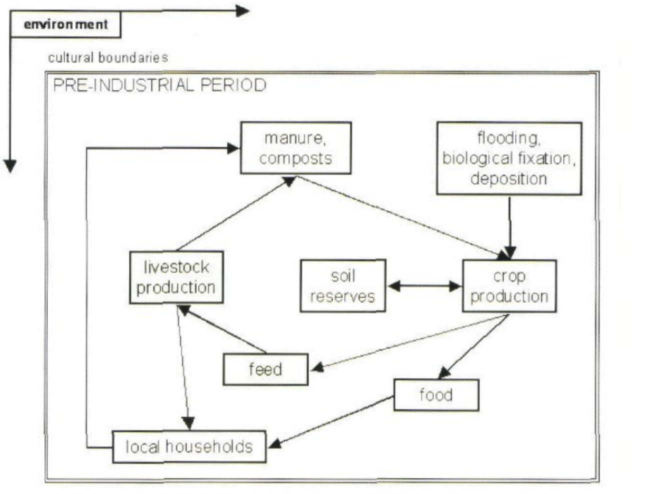

Figure 5.1. Nutrient flows between producers, processors and consumers in pre-industrial, pristine subsistence agriculture

associated with preceding processes (e.g. fertilizer manufacturing, feed production) or subsequent processes (e.g. recycling of manure, processing and consumption of food) are obscured by the administrative disruption of systems into subsystems (Figure 5.2), in contrast to what the situation was like in pre-industrial mixed farms and homesteads (Schröder et al., 2003).

Much if not most of the N and P applied to soils is accumulated in soils, lost to the surrounding environment or exported to societies after which it ends in landfills, in

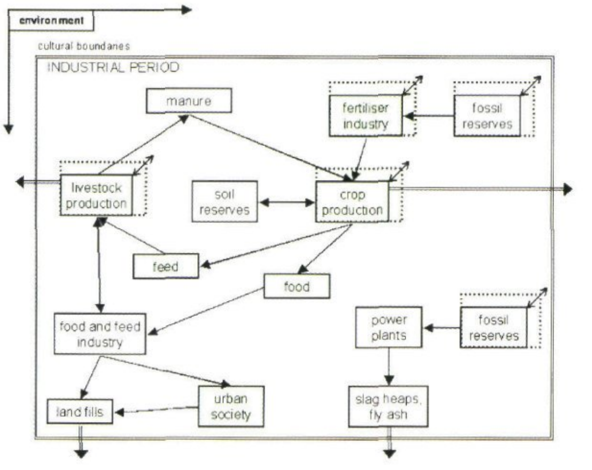

Figure 5.2. Nutrient flows between producers, processors and consumers in industrial agriculture, characterized by disrupted cycles and reliance on finite resources

incinerator ashes and eventually in building materials, or in the sediments of lakes and oceans. The consequential requirements of subsequent crops are usually met with fossil reserve-based industrial N and P, at best with livestock manure, but only to a limited extent with nutrients returning from societies. Recycling of human excrements could contribute to a better use efficiency. However, it would only stop leaks to a limited degree as five times more P is annually used as mineral fertilizer than eventually eaten (Smit et al., 2009).

Most of the P is apparently accumulated or lost between 'mine and fork'. Affluent societies, not being preoccupied with hunger and poverty, increasingly acknowledge the detrimental side-effects of agriculture: the negative impact that agriculture has on the local and global environment (water, air, climate, and landscape), its depletion of finite fossil reserves (phosphate, energy, fresh water), and the far from complete recycling of residues. The agricultural industry and research are expected to formulate alternatives for the unsustainable 'once through' fate of nutrients. Recycling is not just an option; it will become a must for affluent and less developed societies alike, as the P-reserves considered economically minable will be depleted in around 100 years from now (Smit et al., 2009).

5.2 *Research directions*

Livestock is still considered a useful means to exploit vegetations and industrial residues that can not directly be consumed by man. In the past livestock was also looked upon as a means to collect nutrients from rangeland for the improvement of soil fertility of the arable fields around settlements. However, ample availability of manufactured mineral fertilizers made farmers, and researchers for that matter, treat manure quite indifferently. Recycling in general and mixed farming in particular were as from then no longer a condition sine qua non. With the introduction of environmental legislation, however, there is renewed need to address recycling issues. Attention for recycling starts, logically, with the residues produced on the farm itself, manure from livestock being one of the most prominent examples of that. Research efforts are increasingly directed at developing methods to improve the utilization of animal feed and the nutrients it contains in order to reduce the amounts of excreted N and P as much as possible. However, the generation of residues is to some degree inevitable, wherever crops are harvested and processed. Hence, there is a renewed interest to use the nutrients in these residues as a fertilizer source, either or not via treatment techniques, amendments of their composition, adjustments of their handling to better match supplies with the temporal and spatial demands of crops, as well as via a more precise appreciation of the long term fertilizer value of residues including manures (Schröder, 2005).

Besides, a few more general changes of direction can be discerned. More than ever, farmers expect research to provide tools enabling them to substitute affluent, routine applications of nutrients to either animals or crops by restricted and reasoned applications. However, measures should not be restricted to the level of individual crops and animals. Instead, evaluations should preferably extend beyond these boundaries. At this moment this broadened system analysis is followed at the level of individual farms and cooperating polarized farms. Thinking along these lines is gradually expanded to the analysis of nutrients fluxes between rural and urban regions and those between continents (Neeteson et al., 2003.; Schröder & Bos, 2008; Smit et al., 2009).

5.3 *State of the art*

Based on the information provided by research, modern farmers know how they can keep manure production per unit output to a minimum. P excretion by monogastric animals, for instance, is reduced by supplying less feed-P the older the animal gets (phase feeding), by tuning the daily ration of individual animals to their actual production level (www.dynamischvoeren.nl), and by the use of artificial enzymes (phytases) that improve the availability of feed-P (phytate). N excretion by ruminants, and in particular the excretion of ammonium-N, has been reduced by taking better account of the energy-protein ratio in feed and by reducing protein contents of rations in general (e.g. Schröder et al., 2004).

As for the nutrition of crops too, the better-safe-than-sorry attitude has been largely replaced by conditional applications. The utilization of N and P in the manure has been strongly improved by the postponement of applications to spring and by the substitution of surface spreading with injection techniques.

Effective dissemination of the findings of research has partly taken place through projects such as Farming with a Future and Cows and Opportunities (Oenema et al., 2001). As a result of this type of projects, the N surplus of Dutch dairy farms has decreased by approximately 200 kg N per ha in the past 25 years (Van der Ham et al., 2007). Reliance on fertilizer P on an average Dutch farms went down from approximately 40 kg P2O5 per ha around 1985 to approximately 20 kg P2O5 per ha in 2008 (www.statline.nl). Instead, P demand is to a large extent met with manure nowadays. Note, however, that the production of this manure is sustained with feed-P imports from abroad, the production of which is not based on recycled P but on fossil P which, in turn, is derived from yet other countries. As accumulation and depletion often occur in different continents and regions, P use hence has strong geo-political dimensions (Smit et al., 2009).

5.4 *Contribution to high technological and eco-efficient agriculture*

Undoubtedly, technology can contribute to a further improvement of the utilization of N and P and, as necessary for P, a full recycling. These technologies are being developed, tested and implemented by research institutes among which groups within Wageningen UR, including ASG, PSG, ESG, AFSG and SSG. A recent review of ASG, for instance, indicated that even productive livestock could do with at least 20% less P than currently recommended (Van Krimpen et al., 2010). This could further reduce manure production. The utilization of N and P in manures could benefit from treatments that could range from simple techniques that separate slurries into liquid and solid fractions or by keeping the two excrements separated right from the start via adjustments in animal housing, to complex physico-chemical techniques upgrading manure into mineral fertilizer-like products, as recently shown by Wageningen UR (Oenema & Schoumans, 2009). Note, that these types of processing require manure to be collected as a result of which animals can no longer range freely. However, the Cow Power project of ASG (http://www.duurzameveehouderij.wur.nl/UK/projects/cowpower/), has demonstrated that technology can, as yet in theory, reconcile these apparently contrasting interests to a certain degree.

Current fertilizer recommendations still seem to take little account of the fact that annual crops in particular, are in need of ample nutrient supplies at a young growth stage only. PSG, ASG and ESG have demonstrated that lower P inputs could suffice, provided that they are applied at a more appropriate place and time, possibly as a component of fertigation or sub-surface row applications (e.g. Neeteson et al., 2006). By definition it remains extremely difficult to predict how many nutrients become available to crops via mineralization from soil organic matter. Wageningen UR, the ESG group in particular, is strongly involved in the quest for reliable indicators. Split applications based on novel sensing techniques may contribute to a further reduction of the common 'insurance' applications (Olfs, 2009). The PSG group within Wageningen UR is currently exploiting the potential of these aspects of precision farming.

As for the crops themselves, their constituents including nutrients may so far not be exploited as good as possible. Ongoing work within the AFSG group, suggests that high-tech bio-refinery of whole crops could contribute to a better utilization of resources among which nutrients (Oenema

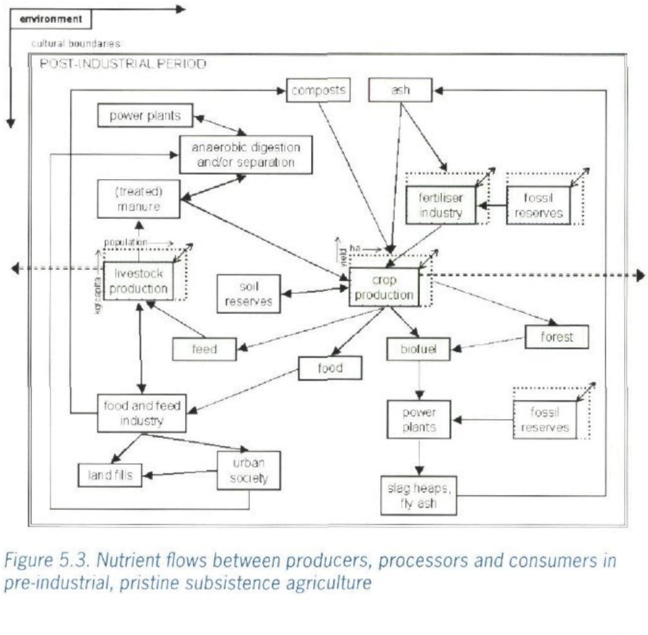

Figure 5.3. Nutrient flows between producers, processors and consumers in pre-industrial, pristine subsistence agriculture

& Schoumans, 2009). Note that crop residues that are presently thought of as invaluable and left in the field, may still contribute to the maintenance of soil fertility. Harvesting them for bio-refinery could hence carry a price.
For the time being our thinking about eco-efficient technologies appears to be limited to the 'agricultural box'. The future need for recycling, however, urges to extend our thinking outside that box (Figure 5.3). Sooner or later agriculture will be in need of the P that now ends its life in landfills, in incinerator ashes and eventually in building materials or in the sediments of lakes and oceans. An example of this approach is the work that ESG is currently doing on the recovery of P from human excrements.

5.5 Short and medium term products

As for measures that improve the use efficiency, we can safely say that better software and hardware allowing both arable and livestock farmers to apply nutrients much more precisely i.e. better tuned to what individual animals, sites and crops need at a certain moment, becomes available constantly. Besides, more than ever, animal manures will be processed into tailored fractions that are better suited to specific crops and soil types. Initiatives have started to extend this kind of processing to urban sewage sludge too. However, waste treatment almost literally boils down to the removal of water for which large amounts of energy are needed. The price of energy will hence determine to what degree manures and other wastes will eventually be upgraded to 'fertilizer-like' products. Surely, waste treatment could also include the production of this energy via e.g. heat exchangers, incineration or anaerobic digestion, but in many cases this energy can be employed just as well for alternative destinations. Energy production is therefore not a unique merit of recycling per se. Hence, avoiding wastes generally seems more efficient than treating wastes.
Whenever a resource is nearing depletion, people typically call for more efficient use. Fortunately, there appears to be much scope for a reduction of accumulation in and losses from soils, as well as a reduction of the losses taking place between harvests and the plates on our table at home. There is nothing wrong with this pursuit, bearing in mind that as

Box 5.1: Productive dairy farming without any mineral fertilizer!

Too good to be true? Yes and no. Intensive dairy farms import feed because requirements exceed the amount of home-grown feed. These imports contain more phosphorus (P) than the amount of P exported in milk and meat. Consequently, there is no need to maintain soil P levels with additional mineral fertilizer P on this type of farm. Note that the import of feed is still sustained with mineral fertilizer P inputs, be it somewhere else on this planet.
For nitrogen (N) the situation is slightly more complicated. Crops generally contain more N per unit P than the amount of N supplied per unit P in dung and urine. This shift reflects the inevitable N losses from housing, from manure storage, from manure excreted during grazing and from manure application. Consequently, almost any cropping system is in need of N provided by either biologically fixed N ('clovers') or mineral fertilizer N. Intensive dairy farms in particular, find themselves in a suitable position to refrain from mineral fertilizer N use. First, they can reduce N losses by technological adjustments of housing, feeding and manure handling equipment (reduced grazing, manure collection systems, low N components in feed rations, low emission manure spreading). Second, they produce so much manure that they can afford to separate the manure into a liquid fraction relatively rich in N and a solid fraction relatively rich in P. By exporting just the solid fraction they are left with a treated manure that matches the N to P ratio of feed crops much more closely. The need for mineral fertilizer N supplements is thus reduced. Remaining needs can be met with biologically fixed N from grass-clover mixtures. Note that the attending savings of mineral fertilizer N on this type of dairy farm, is partly offset by an increased need for fertilizer N on the farms receiving the solid fraction instead of untreated slurry relatively rich in N. So, dairy farming without fertilizer use does exist, but not without trade-offs somewhere else.
Intensive dairy farms in The Netherlands use less and less mineral fertilizer indeed. Annual fertilizer use of P fertilizer, for instance, went down from 14 kg per ha in 1998 to 10 kg per ha in 2006 and even 1 kg P per ha among participants of the Cows and Opportunities Project. This kind of reduction results from tightening legislation, effective knowledge transfer and novel techniques. Experiments have shown, for instance, that the application of mineral starter P to silage maize, once thought of as indispensable to grow maize in temperate climates, can be fully skipped if manure is placed close to the anticipated position of the maize rows instead of evenly spread.

yet five times more P is used in the form of fertilizer than what is eventually ingested via our meals (Smit et al., 2009). However, in the case of P, one should acknowledge that improved efficiency (i.e. an increase of the output/input ratio) will only buy time to work on more sustainable solutions, i.e. a complete recycling of P from societies back to agriculture. Recycling definitely becomes considerably easier the lower the throughput of P, so improving the use efficiency should be part of any solution although in the end an efficient use will not suffice on its own. As for the required recycling, we expect N and P fluxes between livestock farms (importing feed) and arable farms (producing forage and concentrates) to become fully restored by either reducing distances between both types of farms, or by reducing the (fresh) weight of the goods (feed, manure, meat, dairy) that these fluxes comprise. This development could take place on the medium run. A subsequent step will involve the recycling of N and P from industrial and urban waste water. The technology for the recovery of nutrients from these sources is already fully available. Full exploitation could reduce the need for mineral fertilizer substantially. Note, however, that sanitation systems are as yet non-existing in many parts of the world, making it a long term rather than a medium term product. The application of refinery techniques at the start of the pipe instead of the end, i.e. by refining whole crops instead of wastes, could be another avenue for the long run. It allows tapping the material flow along the route at the most efficient moments. Wageningen UR is an active player on each of the aforementioned fields at scales ranging from the individual animal, field and farm, to production chains, regions and the world as a whole.

5.6 Aspects underexposed

Previous sections in this chapter describe the main stream aspects of current nutrient-related research with emphasis on the work done within Wageningen UR. It is worth noting that some aspects receive too little attention. First, we are in need of more precise estimates of the minable P reserves in this world, as the reliability of United States Geological Survey data is questioned from time to time. Research efforts should also be stronger directed to the abatement of soil degradation, as a large quantity of P is lost to the environment via wind and water erosion (Smil, 2000). Consequently, eroded land may be abandoned permanently, requiring the reclamation of new areas that often need ample P supplementation before becoming productive at all. Generally, statistics on net land use do not reveal this turnover rate and its implications for P demands.

If recycling of P is to become a success, users of 'wastes' need to be sure that these fertilizer substitutes do not contain intolerable concentrations of heavy metals, medicine residues, hormones and pathogens. Research can contribute to the design and implementation of safe sanitation systems for both industrial and household wastes.

Expenses on technology needed for the best utilization of resources, including P, can probably only be justified in intensively managed production systems i.e. farms of a certain size and degree of specialization. Intensification, however, carries a price which is as yet not always internalized in the price of agricultural goods. Examples of these

Box 5.2 Sustainable Use of Phosphorus in the European Union

Being self-sufficient in terms of agricultural production does not necessarily mean self-sufficient in terms of the resources needed for that production. Recent surveys indicate that agriculture in the European Union strongly relies on net imports of phosphorus (P), mainly in the form of P rock and phosphoric acid (1.6 MT P per year) and feed (0.2 MT P per year). As fossil P reserves are finite recycling will become a must, if only to become less dependent on the few countries owning these diminishing reserves. The European Commission commissioned Wageningen University and Research Centre to investigate:

- *the remaining reserves of high, medium and low grade P rock and the anticipated P demand in view of the growing world population, changing dietary preferences and the production of biofuels and bioenergy.*
- *the environmental impact of P use on aquatic biodiversity, human health (radio activity), soil quality (heavy metals) and green house gas production.*
- *the scope for improving the use efficiency in mines, fertilizer industries, farms, food industries and municipalities.*
- *the institutional changes required for improvement of the use efficiency and, eventually, full recycling.*
  The work will be executed in 2010 by Wageningen University and Research Centre, in close cooperation with the Stockholm Environment Institute.

externalities are publicly funded expenses on research, education and control, gently taxed inputs (gas for heating glass houses, fuels for the transcontinental transport of products), expenses on the abatement of pollution and climate effects, and for the as yet unappreciated loss of animal welfare, farmland biodiversity and landscape qualities. Additional research could help to make these externalities more explicit and define more precisely which degree of intensification meets societal needs at the lowest costs. Whatever the outcome of the aforementioned analysis, a complete return to extensive production systems is not at all realistic if society is to address the needs of a growing population with its changing dietary preferences (Bindraban, 2009). We cannot deny, however, that there is a negative relationship between the product of the human population size and individual consumption profiles on the one hand, and the time remaining for a transition to a cyclic handling of particularly P. Research can again help to show the relationships between these buttons and make options explicit.

5.7 *Recommendations*

Sooner or later a full recycling of P will be needed. The urgency of the attending measures will be determined by the P reserves considered minable, the prevention of accumulation and losses, the size of the global population and its preferences in terms of food, feed, fibers and fuels, and our appreciation of biodiversity. Both food security and biodiversity require that nutrients are not dissipated but stay where they are needed, that is in the fields devoted to agricultural production. This does not only require drastic adjustments of the way we organize our agriculture, but also for adjustments of our society as a whole. A truly holistic view is needed to address this problem.

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6. Soil ecology for agricultural production and ecosystem services

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6.1 Summary

In this chapter, I distinguish between the soil ecology-related aspects of a 'seeds and breeds' approach to agriculture which focuses on higher yielding crops/livestock on the one hand, and, on the other hand, an 'environment' approach, which emphasizes ecosystem services, such as nutrient regulation, as pertinent to agricultural production. I sketch recent developments in trait-based ecology, offering prospects for new ways to design agroecosystems and, indeed, agricultural landscapes, in which soil ecology generates knowledge to make such systems eco-efficient and sustainable. I argue that public investment in soil ecology research is needed and more so in the 'environment' approach, because, contrary to the 'seeds and breeds' approach, it lacks substantial private funding. Such impulse should be aimed at creating the right conditions for soil ecology and, indeed, sustainable agriculture research, rather than at specific research subjects. Most needed are financial support for a network of Long-Term Ecological Research Sites (LTERs) across Europe and for long-term monitoring of soil biota and ecosystem functions/services in common combinations of soil type and land use. Hence, we need to adopt a long-term perspective of costs and benefits across agroecological zones to develop and value new technologies that are eco-efficient.

6.2 Introduction

In the special issue of Science, entitled "Soils - The Final Frontier" (Science 304, June 2004, pp. 1613-1637), a map is published entitled "Soil and Trouble". The articles in this special issue and the map nicely illustrate that we have neglected soil research and appropriate action and that the main incentive to revert that situation has seven negative connotations: erosion, desertification, compaction, sealing, pollution, salinization and nutrient depletion. In its proposed directive for soil protection, CEC (2006) adds organic matter decline as number eight and, in addition, calls for special attention to soil biodiversity, which is considered threatened. Agriculture has been associated with most of these problems as a result of land reclamation and overexploitation, and overuse of external inputs (artificial fertilizers, water, pesticides, fossil energy). The observation that the decline of major civilizations in history was associated with soil degradation (Hillel, 1991), which currently is still rampant (UNEP, 2009), adds to the sense of urgency that food security is at stake.

What knowledge can soil ecology contribute, now and in future, to ultimately better inform decisions aimed at resolving this gloomy situation? If ecology is the science of organisms, their mutual interactions and the interactions with the abiotic environment, then soil ecology is the science of the soil biota, their interactions and the interactions with abiotic soil constituents. Progress in understanding the interactions between agricultural management interventions and the capacity of the soil to respond, depends on insight into the functioning of the living soil as an integrated subsystem of the agroecosystem. In this context, a focus on the living soil is necessary, because, while the chemistry and physics of the soil system provide the context in which the biotic assemblages of soils operate, the unique and crucial feature of the biota is that it is adaptive to changes in environmental circumstances, driven by processes of natural selection, in ways that the abiotic soil is not (Kibblewhite et al., 2008).

In this chapter I will explore where we stand and what is needed to better understand and use this adaptive capacity and, hence, to turn soils from part of the problem into part of the solution in the search for an agriculture that both provides food security and conserves natural resources. To that end, I propose that, whereas the Science special issue is framed in terms of soil problems, it is more productive to think in terms of what the living soil contributes to ecosystem functioning and services.

Before doing so, we have to delineate what we mean by 'agriculture'. Broadly speaking, agriculture appears most prominently in two forms (Brussaard et al., 2010):

1. Intensive agriculture first and foremost emphasizes food production and is characterized as being relatively physical capital- (technology-) and financial capital-intensive.
2. Ecoagriculture emphasizes the interconnectedness of agriculture with society at large and the natural environment (Scherr and McNeely, 2008). It capitalizes on biodiversity and ecological processes for sustainable production and is associated with multiple commodity and non-commodity outputs, the latter exhibiting the characteristics of externalities or public goods, for which markets so far function poorly or are non-existent. It is characterized as being relatively human capital- (knowledge-) and social capital-intensive.

Both are natural capital-intensive, but with ecoagriculture relying more on renewable (internal) resources versus intensive agriculture relying more on non-renewable (external) resources. The dichotomy is not absolute. For example, subsistence agriculture, which is prevalent in poor regions of the world, not always fits well in the scheme and solutions advocated in either framework have to be handled with caution there. Yet, the two appearances of agriculture underlie the two most prominent visions on how to develop agriculture for food security, viz. those of the World Bank (2007) and the IAASTD (2009), respectively. The World Bank approach emphasizes 'seeds and breeds' research for breakthroughs towards higher yield potential and also advocates research and practices to close the yield gap between potential and realized production at the lowest possible environmental impact. In this approach, the most prominent criticism on ecoagriculture is that it requires much more land and may nonetheless not be able to feed the world. The IAASTD approach emphasizes 'environment' (and equity and food sovereignty, which are beyond the scope of this chapter) in addition to food production proper. In this approach, the most prominent criticism on intensive agriculture is that it externalizes many production costs and overly relies on non-renewable resources, such as fossil energy and phosphate fertilizer, which is considered unsustainable to the extent that in the long term it may not be able to feed the world, either.

I suggest that the largest improvements will be gained where both the 'seeds and breeds' and 'environment' aspects of agroecosystems receive due attention in research and practice. Hence, both will be considered in this chapter, inasmuch as soil ecology is concerned.

6.3 State of the art

The terms of reference for this chapter mention 'high-tech' and 'eco-efficient' agriculture. According to Wilkins (2008) eco-efficient farming should satisfy the following five key attributes: (i) it uses resources efficiently and makes the maximum use of renewable inputs, (ii) it is neither locally polluting nor does it transfer pollution to elsewhere, (iii) it provides a predictable output, (iv) it conserves functional biodiversity in relation to strengthening ecological processes, reducing greenhouse gas emission and pollution generally and limiting soil erosion, and (v) it is capable of responding rapidly to changes in the social, economic and physical environment. It is also crucial that eco-efficient farming satisfies economic criteria in relation to farm profitability. At first glance 'high-tech' may be associated with the 'seeds and breeds' approach in intensive agriculture and 'eco-efficient' with the 'environment' approach in ecoagriculture. However, this would be inappropriate, because the first approach is increasingly conscious of the environment, while the importance of human and social capital in the second approach implies a level of knowledge that equals high-tech in a non-material way. Moreover, the need to increase knowledge-intensity and technology has to be recognized in both approaches. These notions are woven into the remainder of this chapter.

The remaining key words in the terms of reference of this chapter on soil ecology are: carbon, nutrients, water, diseases and robustness[1]. Figure 6.1 provides a conceptual framework to address these issues in a context in which the soil 'problems' associated with agriculture are connected with sustainability. For this purpose, we have to delineate what we mean by 'sustainability' in agriculture. It encompasses the following principles, partly derived from Pretty (2008):

- Persistence: the capacity to continue to deliver desired outputs over long periods of time (human generations);

[1] Hence, I will not deal with soil contaminants, nor with the concept of soil health or soil quality.

- Resilience (robustness): the capacity to absorb, utilize or even benefit from perturbations (shocks and stresses), and so persist without qualitative changes in structure;
- Benevolence: the capacity to produce desired outputs (food, fiber, biofuel), while sustaining the functioning of ecosystem services and not causing depletion of natural capital (e.g., minerals, biodiversity, soil, clean water);
- Sustaina'g'ility: the ability ('agility') of agents to adapt and transform, in contrast to simply sustain the present conditions or system and meet needs in new ways (Jackson et el., 2010).
- Although the fourth principle is beyond the scope of this chapter, it is important because it puts the farmer in the driver's seat. It has to be considered whenever the knowledge presented in this chapter is put to practice.

From bottom to top, Figure 6.1 conveys the message that agroecosystem sustainability not only hinges on the production of biomass ('ecosystem good'), but also on 'regulating services' (MEA, 2005), such as water and nutrient regulation, both on-farm and to the benefit of society at large. These services are utilitarian outcomes of ecosystem processes, whose functioning depends on ecosystem structure. The drivers of ecosystem structure are partly natural and partly of human origin (including agricultural management practices in the top right of the Figure). In this Figure, the living soil is represented by 'soil biodiversity',

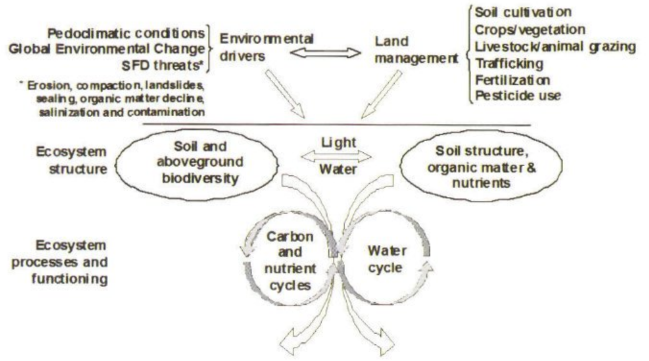

Figure 6.1. Conceptual diagram of drivers, state variables (ecosystem structure), ecosystem processes/functioning and ecosystem goods and services, determining agroecosystem sustainability. SFD= Soil Framework Directive as proposed in CEC (2006). Modified after Brussaard et al. (2007a)

interacting with the abiotic soil, represented here as soil structure, soil organic matter and soil nutrients.

Different ecosystem goods and services (Figure 6.2 left) are delivered by different ecosystem functions (Figure 6.2 middle left), which in aggregate (Figure 6.2 middle right) are associated with certain groups of the soil biota, which, therefore, are called 'functional assemblages' (Figure 6.2 right).

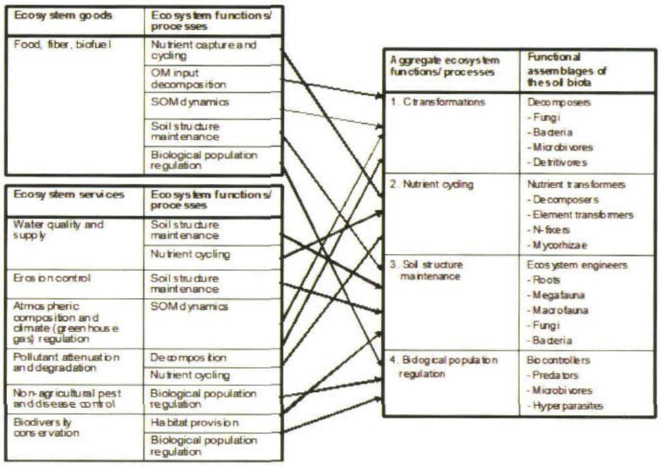

Figure 6.2. Relationships between the activities of the soil biological community and a range of ecosystem goods and services that society might expect from agricultural soils.

The effects of (changes in) environmental drivers and land management decisions on the sustainability of the system (Figure 6.1, top to bottom) are mediated by such functional assemblages. With very few exceptions, all functional assemblages in soil are ultimately driven by carbon, so carbon transfer with associated energy flows is the main integrating factor. This suggests that the flows and allocations of carbon between assemblages of organisms may provide information about their relationships to ecosystem functions (Figure 6.3).

Emphasizing carbon as the common currency refers to the fact that ecosystems are driven by two biological processes of overriding importance: photosynthesis (composition/ carbon fixation, primary and secondary production) and respiration (de-composition/ carbon dissipation). These processes occur largely aboveground and belowground, associated with plant growth and plant/animal death, respectively, which puts the aggregate ecosystem functions of Figure 2 into the perspective of Figure 6.3. Ultimately, the unifying process is biological population regulation (Figure 6.3 bottom left).

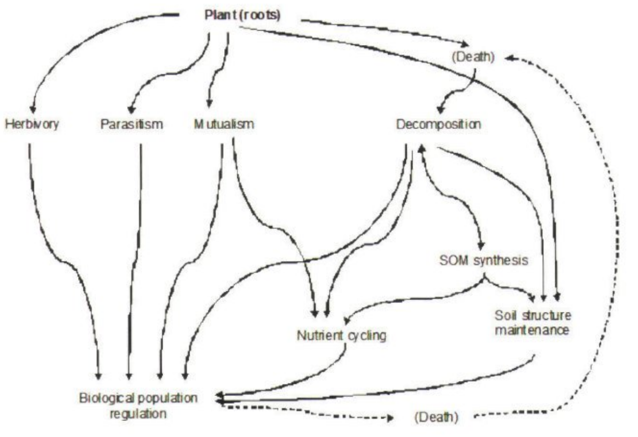

Figure 6.3. Interconnectedness between the major ecosystem functions of soil. The arrows represent two flows of energy from the plant to the major functions of the soil biota: either directly through the actions of roots, herbivory, parasitism and mutualistic symbiosis, or indirectly via heterotrophic carbon-transforming processes in the soil. Soil organic matter (SOM) synthesis is pictured as supported by energy flowing from the decomposition of plant residues and contributing energy in its turn directly (i.e. by virtue of its properties) to soil structure maintenance (and associated water movement) and indirectly, through its own decomposition, to nutrient cycling and biological population regulation. Modified after Kibblewhite et al. (2008).

These observations yield some clarity about the contributions from soil ecology in the 'seeds and breeds' and the 'environment' approaches, which are largely focused on the crop/plant and decomposition components of Figure 6.3, respectively. To elaborate this, I use the ecological hierarchy as a model of biological/ecological interactions from genome to ecosystem and vice versa (Figure 6.4).

In the 'seeds and breeds' approach, soil ecology research focuses on the levels from the bottom of the diagram up to, and including 'individual'. In the 'environment' approach soil ecology research focuses on the levels from the top down to, and including 'individual'. Hence, the approaches meet at the level of the individual plant/crop or (farm) animal, interacting with the biotic/abiotic environment. I recognize that 'individual' includes mutualistic symbionts, such as N-fixing bacteria and mycorrhizal fungi, which deserve more consideration at the interface between the 'seeds and breeds' and the 'environment' approach than can be given in the context of this chapter.

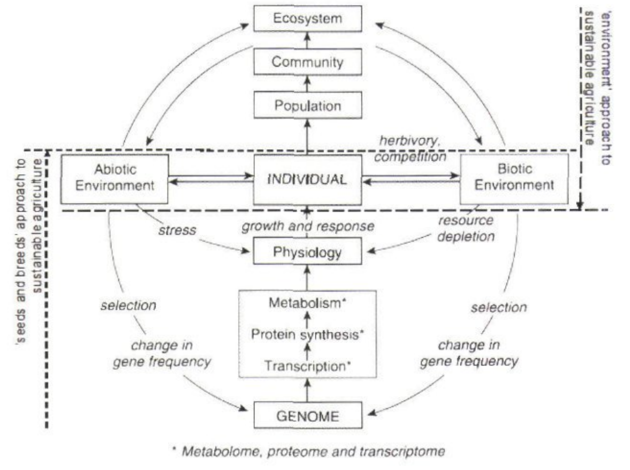

Figure 6.4. The ecological hierarchy with the levels spanned by the 'seeds and breeds' and the 'environment' approach, respectively. Modified after Fitter (2005).

Soil ecology in the 'seeds and breeds' approach

Scientific endeavors in the 'seeds and breeds' approach are aimed at increasing light, water and nutrient use efficiencies of plants, increasing feed conversion efficiencies of animals, and increasing disease and pest resistance of both, all contributing to increasing productivity, mostly using a genetic and genomics approach (Royal Society, 2009). Some of these efforts do not have an explicit soil-related component, but they may have soil-related effects, which need to be considered. For example, breeding for perenniality of annual crops and incorporating the C4 photosynthetic pathway into C3 plants (Hibberd et al., 2008) will affect the functioning of the soil in yet unknown ways. Such effects are self-evident if soil-related plant properties are specifically targeted, as is the case in incorporating the ability to fix atmospheric nitrogen into non-leguminous plants (Saikia and Jain, 2007) and in breeding for a certain root architecture (Lynch, 2007) and/or mycorrhizal responsiveness (Gao et al., 2008). Especially when the application of genetically modified crops is considered, effects on and feedback from the living soil require scrupulous investigation. Research to that end is largely funded under the ECOGENOMICS program, to which WUR researchers contribute extensively (http://www.ecogenomics.nl/).

The well-established term GxMxE interactions shows that it is widely recognized that results of genomics (G) research have to be validated under management (M) and environmental (E) conditions, which themselves can be subject to intentional change to better fit the new plant and animal properties. Vice versa, just as plant and animal breeding for higher productivity should be considered (more) in terms of compatibility with, and adaptation of the upper levels of Figure 6.4, so should recent developments in trait-based ecology guide plant- and animal-focused efforts at the lower levels of Figure 6.4 in terms of conservation of natural resources. This is a relatively new area of (applied) ecology and the subject of research in the 'environment' approach.

Soil ecology in the 'environment' approach

This approach recognizes that, in nature, sets of plant species commonly occur together ('plant community') and that they are predictably characterized by common sets of plant traits (Grime, 2006; Díaz et al, 2007; Green et al., 2008). In trait-based ecology (Webb et al., 2010), organisms are characterized in terms of their multiple biological attributes such as physiological, morphological or life-history traits. A trait is a well-defined property of organisms, usually measured at the individual level and used comparatively across species. The conceptual foundation consists of trait distributions (initially derived from the pool of possible traits of individual organisms - see upper level in Figure 6.5) and performance filters (i.e. environmental filters eliminating traits with inadequate local fitness - see middle level in Figure 6.5), resulting in associated community composition and ecosystem functioning (see lower level in Figure 6.5). This framework can be used to analyze the dependence of the functioning of existing agroecosystems on the existence of traits and trait filters, using a procedure developed by Díaz et al. (2007). We suggest that, as trait-based ecology theory develops towards projection of performance filters across environmental gradients to make predictions, it can be applied and further developed to (re-)design agroecosystems at the landscape scale in ways that are conducive to wild biodiversity and to the use of as yet un-/underutilized crops/varieties and livestock/breeds that enhance food security, as well as to environmental health and social well-being.

Although herbivory and climate-related factors aboveground certainly play an important role in structuring plant communities, the mechanisms behind observed patterns reside to a large extent belowground. The productivity filter that the pool of traits, represented in a pool of plant species, is 'sieved' through (Figure 6.5), is largely a soil fertility filter. The potential plant community composition is subsequently determined by a disturbance filter (Figure 6.5).
Likewise, soil communities are selected by environmental filters that determine the playing ground for the expression of genes (Figure 6.6).

Hence, trait-based processes structure plant and soil communities in terms of fitness (growth, reproduction, survival), performance (interactions with other species and the environment) and information (genome size and content, mutation rate). In agroecosystems, both filters are to a large extent imposed by agricultural management, which, in no small measure, is soil management (Figure 6.1, top right corner). The challenge to soil ecology in the 'environment' approach is, hence, to better understand the sorting of traits in natural communities (comprising both plants, animals and microbes) and apply those in agriculture.

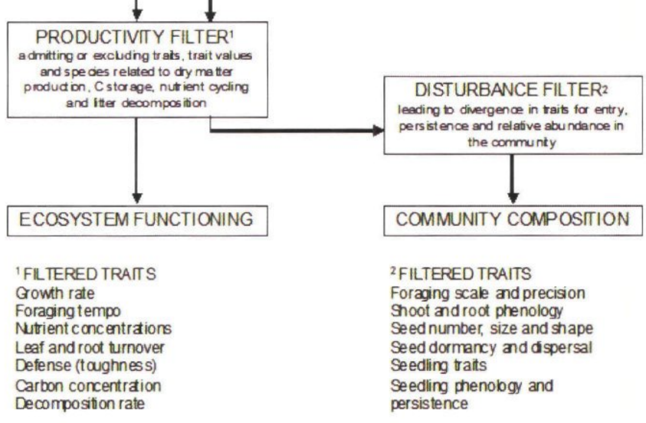

Figure 6.5. Environmental filters of plant functional traits, which may be used in the (re)design of agricultural landscapes. After Grime (2006).

As we have seen in Figure 6.1, regulating ecosystem services are important for the production and sustainability of agriculture. In the 'environment' approach of soil ecology, ecosystem services take central stage (Figure 6.2 left).
We already noted that carbon is the common currency in the ecosystem, which, in the case of the soil, is carbon in

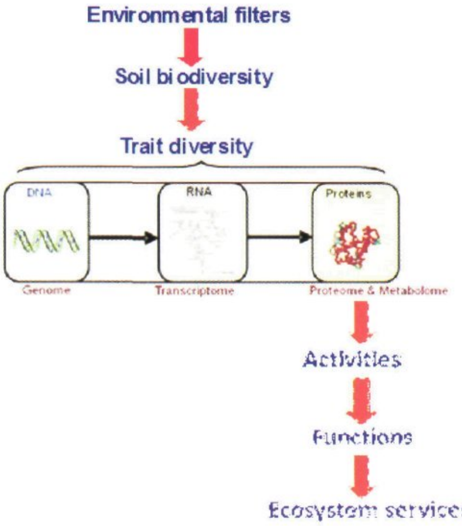

Figure 6.6. Environmental filters determining trait diversity and gene expression underlying ecological functions and ecosystem services. Modified from Figure of unknown source.

the dissipative pathway. Hence, it makes sense to view the quantities and quality of organic matter as indicative for the state of the soil (shaded boxes in Figure 6.7).

It is tempting to think that, just as crop and livestock management have impacts on the living soil and associated soil ecosystem services, vice versa living plant and organic matter-induced manipulations of the soil biota will in turn affect crop and livestock performance and ecosystem services. Is there such role for the soil biota? Broadly speaking, there are two views. One plays down the role of soil ecology; I will call this the soil biogeochemistry view. The other one highlights the role of soil ecology; I will call this *the soil biology view.*

The *soil biogeochemistry* view emphasizes the apparent consistency in microbial communities and soil organic matter dynamics across widely different ecosystems, in large part driven by constraints over the physiology and metabolic activity of soil communities and the effects of physical-chemical processes in soils on organic matter stabilization (Fierer et al., 2009). Considering plant nitrogen availability and land management impact at local scales, however, Schimel and Bennett (2004) posed the following questions:

1. How are biotic processes, such as depolymerization, mineralization, microbial uptake, and root uptake linked?
2. How important are physical and spatial processes occurring at the microsite scale in regulating macroscale characteristics of ecosystem N cycling?
3. How important are roots and mycorrhizae in creating high-N or low-N microsites and in mediating the biochemical/biological processes and their linkages?

Clearly, soil organisms are important, but do we need to know which ones and what they do? As regards the aggregate ecosystem function 'C transformation' in Figure 6.2, the soil biogeochemistry view implies not (Fierer et al., 2009), while in regards of 'nutrient cycling' a 'no' seems inappropriate (Schimel and Bennett, 2004).

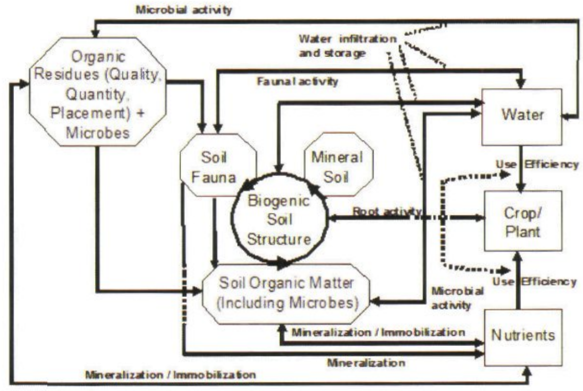

Figure 6.7. Conceptual diagram showing that organic additions and soil organic matter (shaded) are indicative for the state of the soil, affecting (interactions between) soil organisms, soil structure and the carbon, water and nutrient cycles, which in turn affect plant water and nutrient use efficiencies and, hence, plant performance. For reasons of simplicity boxes and arrows of feed-forward from crop/plant to animals and feed-back from organic plant residues and manure are omitted. Modified after Brussaard et al. (2007a).

The soil biology view has a different background. Whereas ecosystem ecologists (largely representing the soil biogeochemistry view) have not routinely used community-based models, which in turn are based on individual-level behavior in understanding population phenomena, community ecologists often use population dynamic models in explaining community structure. This separation between ecologists has long hampered our understanding of what linkages exist between biodiversity – which is a function of population and community ecology – and ecosystem processes and, hence, what the effects of changes in species or functional groups of soil organisms are on ecosystem processes and associated ecosystem services (Fitter, 2005). Population and community ecologists (largely representing the soil biology view) provide accumulating evidence that soil biodiversity (in terms of functional assemblages and composition) does matter for all aggregate ecosystem functions of Figure 6.2. This is expressed by Figure 6.8 for:

- decomposers, affecting soil metabolic activity and nutrient cycling (Heemsbergen et al., 2004; de Vries et al., 2006, 2007; Postma-Blaauw et al., 2006, 2010)
- nutrient transformers, such as nitrogen fixing bacteria (Giller, 2001) and mycorrhizal fungi (Cardoso and Kuyper, 2006)
- ecosystem engineers, such as earthworms and plant roots, modifying soil structure, the soil as a habitat for other soil organisms and plants (Brussaard 2007a, Pulleman, 2005a,b) and the greenhouse balance of the soil (Rhiziya et al., 2007; Giannopoulos et al., 2010)
- biocontrollers of soil-borne diseases, (e.g., Garbeva et al., 2004; Raaijmakers et al., 2009) and root herbivores affecting plant performance (Bezemer et al., 2005; Piskiewicz et al., 2008)

Yet, the relationships between soil biodiversity and ecosystem processes and services are not straightforward, because of widespread redundancy of function among soil organisms, due to the multifunctionality of ecosystems (Hector and Bagchi, 2007) and, in particular, due to the various spatial and time scales at which soil (biological) processes take place and interact as a result of which momentary observations at any spatial scale and point in time are difficult to interpret (Ettema

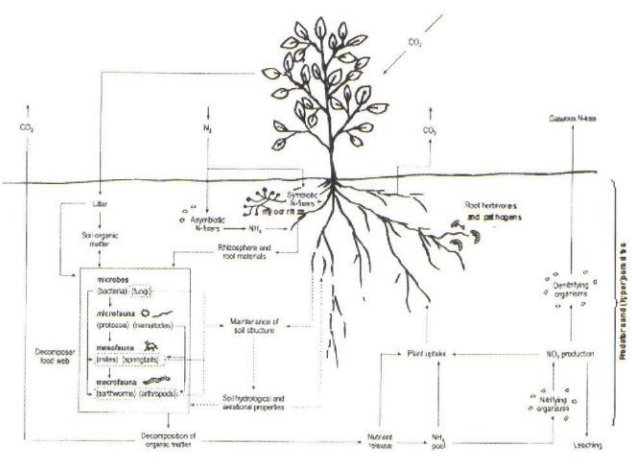

Figure 6.8. Depiction of the significance of functional assemblages of the soil biota for ecosystem processes. Modified after Wardle et al. (1999).

and Wardle, 2002, Brussaard et al., 2007a). Modeling has proved useful in understanding relations between biodiversity and ecosystem functioning. Modeling-assisted analysis of real food webs shows that trophic interactions among all soil organisms affect ecosystem stability (de Ruiter et al., 1995). Moreover, after alterations in the composition or relative abundances of species as a result of environmental changes or variability, web structure, i.e. the place of species showing their interactions with other species, may quickly stabilize (de Ruiter et al., 2005). This result confirms that, within broad limits, the soil biota confers self- organizing properties on the soil, as suggested before from observations by Young and Crawford (2004), thereby making it relatively robust. The trophic position of species in such dynamic food webs may influence the risk of loss of that species, whereby species at higher trophic levels tend to have larger effects on ecosystem processes (de Ruiter et al., 2005), which was concluded earlier from experimental evidence by Wardle (1995). Such insight is critical to our understanding of community resistance and resilience to environmental change and disturbance and holds promise for answering fundamental questions related to the partitioning of carbon and nutrients during decomposition among the various functional assemblages and associated ecosystem processes and services in soil. Some of these questions are (Kibblewhite et al., 2008): How might the allocation of soil carbon among the various functional assemblages regulate functional outputs?

- What quantities and qualities of organic matter are needed to support soil system performance?
- How do the forms and flows of soil carbon to and between different functional assemblages of soil organisms exert control over the physical condition of the soil habitat?

It appears that these questions require model-assisted research with a scope beyond the environment-driven soil biogeochemistry or trophic interactions-driven soil biology models we have available so far, because the required models should not just be related to (the persistence of) organic matter transformations that result in certain levels of carbon and nutrient cycling (aggregate functions 1 and 2 in Figure 6.2), but also to the partitioning of energy to soil structure maintenance and biological population regulation (aggregate functions 3 and 4 in Figure 6.2), as well as to defining thresholds beyond which the soil ecosystem moves to a new (and usually undesirable) stability domain (Solé and Bascompte, 2006). In other words, there is a need for soil food web modeling of element turnover to develop into interaction web modeling of the whole suite of ecological processes, including the living plant.

Such models will remain to be carbon-driven, because, as we have seen earlier, all functional assemblages in soil are ultimately driven by carbon. In natural systems, the various productivity (i.e. soil fertility) and disturbance filters of Figure 6.5 have been important selection forces resulting in the energetics of metabolism and the nutrient stoichiometry[2] of both plants and microbes and, indeed, the whole food web. Fierer et al. (2009) emphasize that the latter are rather fixed in soil across widely different ecosystems due to physiological constraints. As a result, organic matter passing through the soil food web, undergoes predictable transformations that reduce variations in chemical structure, which is also due in part to the effects of physical and chemical processes and their effects on organic matter stabilization (Fierer et al., 2009). However, the very existence of numerous different natural communities suggests that, over evolutionary time scales, there has been 'room to maneuver' for both plants and microorganisms and, indeed, the whole food web, to not just respond to the soil fertility and disturbance filters of Figure 6.5, but to modulate them towards persistence of the aggregate functions of Figure 6.2, i.e. for sustainability of the ecosystem over ecological time scales. One driving force behind the partitioning of energy is modulation of plant mineral nutrient availability by the plant itself, in addition to modulation by the soil food web, ultimately matching the nutrient stoichiometry of the plant species in the community. Another driving force is enhanced plant systemic defense induced by beneficial microbes interacting with plant roots and there is evidence that the two reinforce each other (Phelan, 2009). Even organisms generally considered detrimental, such as soil-borne pathogens and root herbivores, may confer systemic defense against aboveground pathogens and pests (Bezemer and van Dam, 2005). Considering the aggregate soil functions of Figure 6.2, I propose that a third driving force is soil porosity and associated water-holding capacity as important determinants of plant growth, for which part of the organic matter is allocated to feed soil ecosystem engineers such as earthworms (Lavelle et al., 2001).

Practical implications

Interestingly, the fundamental questions listed under the bullets above, have also surfaced in recent years as practical questions, mostly framed as concern over the possible decrease of organic matter contents of agricultural soils worldwide (Dawson and Smith, 2007; Hanegraaf et al., 2009; Reijneveld et al., 2009). These questions have arisen, because farmers' options to bypass the natural functioning of the soil by external inputs, such as fertilizers, pesticides and water, at least in industrialized countries, have decreased due to environmental regulations. All these inputs are energy-intensive and becoming more and more expensive. Concomitantly, the direct costs of fossil fuel to operate farm machinery have risen sharply, which is one of the reasons for the current interest in conservation tillage. Hence, the need to significantly reduce levels of external inputs to the soil is widespread. The relevance of this quest for the post-fossil carbon economy needs no further explanation.

Rather than from a high-input starting point, the questions are also pertinent from a low-input starting point, which is prevalent in countries where external inputs are not available and/or affordable to the farmers, i.e. in many developing countries. Under such conditions, agriculture has resulted in soil fertility decline, especially in Sub-Saharan Africa, where soil fertility is inherently low in the first place. External inputs should not be excluded, wherever the natural conditions are too poor to allow acceptable yield levels (Vanlauwe and Giller, 2006). However, such inputs should be a necessary supplement to the reinforcement of natural processes by applying trait-based ecology in (re)design and optimization of the management of agricultural and non-productive landscape components, so as to avoid any disadvantages of external inputs the developed world is just trying to repair. Hence, the quest for measures and means to work with nature is global.

The living plant, organic matter-derived plant residues and manure are the carbon sources partitioned to the functional

[2] Nutrient stoichiometry is the ratio of nutrients that has to be available for optimal plant or microbe nutrition. This ratio differs between species.

assemblages (Figure 6.8) in soil that in agriculture exert the (soil) ecosystem functions of Figure 6.2. Analogy with natural systems suggests that diversification and a judicious choice of crops, both in terms of rotation/ intercropping/ relay cropping and animals in livestock husbandry, and crops and animals in mixed farming, holds promise to optimize the functions and services of Figure 6.2 and make agricultural production systems robust and adaptable to changing climate variability and environmental risks. In this context, 'judicious' hinges on the outcome of research for options to choose crops/varieties and livestock/breeds and to choose the amounts and qualities of organic matter entering the soil, so as to optimize the match between the provision of agricultural goods and ecosystem services at the desired productivity level in a way that generations of farmers can thrive in agricultural landscapes. That the current soil food web models already show the importance of trophic interactions in conferring self-regulation on natural communities, holds promise for further development of these models to include the biological interactions and the interactions between biological and chemical and physical processes underlying the ecosystem functions and services of Figure 6.2. Such models would be an important tool in developing an integrated understanding of these interactions and, hence, in the development of sustainable agroecosystems based on the manipulation and optimization of soil processes. The entry points through which the outcomes of soil ecology

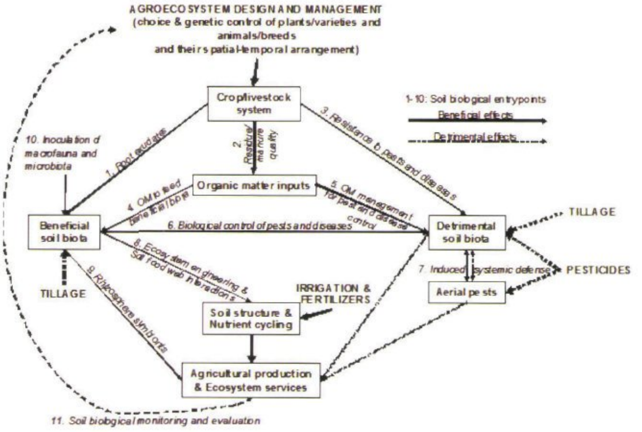

Figure 6.9. The potential entry points (1-10) for biological management of crop/livestock systems, organic matter inputs and soil organisms, aimed at sustainable agricultural production and ecosystem services, and feedback to agroecosystem design and management using montoring and evaluation (11). OM= organic matter. Modified after Brussaard et al. (2007b).

research (will) influence agricultural practices (Figure 6.9) will be increasingly better used, as advances in soil ecology inform us of further options for eco-efficient and sustainable agriculture. Examples of recent 'Wageningen' research for each of those entry points are given in Annex 1.

6.4 Research directions and short- and medium term-products

With fundamental soil ecology and agricultural practice basically asking the same questions, the further prospects for mutual reinforcement should be good. The more agriculture moves into the direction of conservation agriculture, i.e. agriculture characterized by minimal soil disturbance, keeping the soil continuously covered by mulching/cropping and applying crop rotations and diversification (Hobbs et al., 2008), the more similar will the ecological processes in agriculture be to those in non-productive ('natural') elements of the landscape and the better the prospect will be of applying ecological knowledge on natural ecosystems in agriculture. The prospects are even brighter when we put both in a landscape perspective. A landscape is characterized by both agricultural crop and livestock diversity and wild (be it planned or unplanned) biodiversity in a certain spatial configuration. Landscape composition and configuration determine to what extent agriculture benefits from biodiversity and the associated ecosystem services, e.g. by providing (habitat for) natural enemies of pests (Tscharntke et al., 2005) and, vice versa, to what extent agriculture can be improved to do less damage and, indeed, contribute to biodiversity and ecosystem services by, e.g., reducing nutrient losses or provision of habitat for farm birds. Regarding the soil, it is even conceivable that field margins be managed to increase beneficial soil organisms such as earthworms (Smith et al., 2008) to the effect that they (re)colonize agricultural fields, exerting beneficial functions such as soil structure maintenance. With the need to halt the alarming rate of biodiversity decline and the equally appalling hunger and malnutrition of approximately 1 billion people on the planet, the prospect of reconciling biodiversity conservation and food security should be vigorously pursued (Brussaard et al, 2010).

6.5 Aspects underexposed and recommendations

There is no doubt that most of the proponents of both the 'seeds and breeds' and the 'environment' approach are genuinely dedicated to the cause of increasing food security and reducing the negative impacts of agriculture on the environment and both deserve support, especially in combination. However, as this chapter is (also) meant to guide government funding in research, it is noteworthy that the 'seeds and breeds' approach favors return on private investment in research by industry in the relatively short term and, as a consequence, the corresponding research is relatively strongly represented and well-funded. In contrast, the 'environment' approach largely lacks private investment research incentives, the corresponding research falls short of public funds and, hence, progress is relatively slow. Soil ecology has important knowledge to contribute in either approach, but requires more support to make substantial progress in the 'environment' approach. This calls for re-allocation of financial means that support unsustainable practices, towards enhancement of research and practices that maintain the provision of both agricultural products and ecosystem services in agricultural landscapes.

However, the research mentioned above has to be tested and inspired by agricultural practices. Therefore, long-term monitoring of soil biodiversity (i.e. functional assemblages of the soil biota) in common combinations of soil type and land use is pivotal. Monitoring and evaluation (mentioned as activity # 11 in Figure 6.9) at a reasonable number of farms, representing the relevant combinations of soil type and land use offers the best opportunities. Such a monitoring network already exists in The Netherlands. It has proven to generate novel results for science (Mulder, 2006) and practice (Rutgers et al., 2009). As its value cannot be overestimated, funding just has to be secured.

One of the challenges of the research mentioned in Figure 6.9 and annex 1 is to ensure synergy between the various efforts. To develop unifying principles and models and to test them, as much of the research as possible has to be concentrated on common research sites, where we can assess how different soils under different climatic conditions respond to treatments. To that end we need sites under long-term continuous management where research can be done by the rules of the game, recognizing soil spatial and temporal variability (e.g., Wall et al., 2008). A set of Long Term Ecological Research Sites (so-called LTERs) across Europe serves that purpose best and is cost-effective. Therefore, existing efforts (http://www.lter-europe.net/) to achieve that deserve financial support.

Funding these sites and monitoring efforts for a long period of time may seem unattractive in terms of output in the short term. However, the knowledge needed for sustainability in agriculture cannot be acquired, unless we adopt a perspective of costs and benefits across space and time to develop and value technologies that are eco-efficient.

6.6 Conclusions

Soil ecology can contribute to increasing food security in both a 'seeds and breeds' and an 'environment' approach to sustainable agriculture. Recent developments in trait-based ecology offer prospects for new ways to design agroecosystems and, indeed, agricultural landscapes. Soil ecological knowledge may generate options to make such systems eco-efficient by manipulation of carbon partitioning among functional assemblages of the soil biota towards the robustness and adaptability of ecosystem functions and services. Modeling-assisted research of ecological interactions in the soil-plant system will foster these developments, but requires long-term data. Investments are needed in a network of long-term ecological research sites in Europe and the maintenance of a soil biological monitoring network in The Netherlands to cost-effectively create the necessary conditions for the required research resulting in practical applications in the medium term.

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Annex 6.1 Wageningen UR research aimed at soil biological management of agro-ecosystems for enhanced sustainability.

Below is listed a selection of Wageningen research that is ultimately aimed at measures to make agroecosystem design and management sustainable through each of the entry points of Figure 6.9. Annotations emphasize the main results.

Entry point 1: Root exudates

Nunes da Rocha, U., van Overbeek, L.S. and van Elsas, J.D., 2009, Exploration of hitherto uncultured bacteria from the rhizosphere. FEMS Microbiology Ecology 69: 313-328.

- Hitherto uncultured bacteria of two new bacterial groups (Acidobacteria and Verrucomicrobia) are explored for their contributions to plant growth promotion.

Nunes da Rocha, U., Dini Andreote, F., de Azevedo, J.L., van Elsas, J.D. and van Overbeek, L.S., 2009, Cultivation of hitherto-uncultured bacteria belonging to the Verrucomicrobia subdivision 1 from the potato (Solanum tuberosum L.) rhizosphere. Journal of Soils and Sediments (in press).

- The relationships of two hitherto uncultured bacteria (Acidobacteria and Verrucomicrobia) to root exudates are described. This information extends our understanding of 'rhizosphere functioning'.

Entry point 2: Residue/manure quality

Birkhofer, K., Bezemer, T.M., Bloem, J., Bonkowski, M., Christensen, S., Ekelund, F., Fließbach, A., Hedlund, K., Mikola, J., Robin, C., Mäder, P., Setälä, H., Tatin-Froux, F., van der Putten, W.H. and Scheu, S., 2008. Improving internal nutrient cycling and conservation biological control through long-term organic farming. Soil Biology and Biochemistry 40: 2297-2308.

- Soil communities in organic farming systems are more complex compared to conventional systems. This leads to improved soil quality and nutrient cycling, and increased control of aboveground pests.

van Vliet, P.C.J., Reijs, J. W., Bloem, J., Dijkstra, J. and de Goede, R.G.M. 2007. Effects of cow diet on the microbial community and organic matter and nitrogen content of feces. Journal of Dairy Science 90: 5146–5158.

- Diet composition affects chemical composition and microbial biomass of dairy cow manure. These changes affect the nutrient use efficiency of the manure.

Entry point 3: Resistance to pests and diseases

Scholten, O.E., van Heusden, A.W., Khrustaleva, L.I., Burger, K., Mank, R., Antonise, R., Harrewijn, J., van Haecke, W., Oost, E.H., Peters, R.J. and Kik, C. 2007. The long and winding road leading to the successful introgression of downy mildew resistance into onion
Euphytica 156:345 - 353.

- With the help of early isogenic lines four AFLP® markers closely linked to the resistance gene were identified, which can be used for marker-aided selection. The introduction of downy mildew resistance caused by Peronospora destructor into onion is a significant step forward in the development of environmentally-friendly onion cultivars.

Galván, G.A., Koning-Boucoiran, C.F.S., Koopman, W.J.H., Burger-Meijer, K., Gonzáles, P.H., Waalwijk, C., Kik, C. and Scholten, O.E. 2008. Genetic variation among Fusarium isolates from onion, and resistance to Fusarium basal rot in related Allium species. European Journal of Plant Pathology 121: 499 - 512.

- Describes selection among varieties for differences in resistance or tolerance to soil related to an important soil-borne disease, which is an important step towards developing resistant varieties.

Entry point 4: Organic matter to feed beneficial biota

de Vries, F.T., Hoffland, E., van Eekeren, N., Brussaard, L. and Bloem, J., 2006. Fungal/bacterial ratios in grasslands with contrasting management. Soil Biology and Biochemistry 38: 2092-2103.

- Reduced fertilization results in more fungal biomass (decomposers as well as mycorrhizal fungi). Soils with more fungal biomass show better nutrient retention and lower nitrogen losses, while grass production is maintained despite lower nitrogen inputs.

Postma-Blaauw, M.B., de Goede, R.G.M., Bloem, J., Faber, J.H. and Brussaard, L. 2010. Soil biota community structure and abundance under agricultural intensification and extensification. Ecology 91: 460–473.

- Agricultural intensification exerts strongest effects on species-poor (usually larger-sized) soil biota groups, thus supporting the hypothesis that biodiversity has an "insurance" function. Altered soil biota abundances and functional group composition under agricultural intensification are likely to affect the functioning of the agroecosystem.

Entry point 5: Organic matter management for pest and disease control

van Diepeningen, A.D., de Vos, O.J., Korthals, G.W. and van Bruggen, A.H.C. 2006. Effects of organic versus conventional management on chemical and biological parameters in agricultural soils.
Applied Soil Ecology 31:120-135.

- Organic management results in higher numbers of bacteria of different trophic groups, higher species richness of bacteria and nematodes, lower levels of nitrate and total soluble nitrogen and more resilience to a drying–rewetting disturbance in the soil. However, soil type has a much stronger effect on the soil characteristics than management type.

Termorshuizen, A. J., van Rijn, E., van der Gaag, D. J., Alabouvette, C., Chen, Y., Lagerlöf, J., Malandrakis, A. A., Paplomatas, E. J., Rämert, B., Ryckeboer, J., Steinberg, C., and Zmora-Nahum, S., 2006. Suppressiveness of 18 composts against 7 pathosystems: Variability in pathogen response. Soil Biology and Biochemistry 38:2461-2477.

- Composts have generally a positive effect on disease suppression, but exceptions occur. These are pathosystem- and compost-dependent.

Entry point 6: Biological control of pests and diseases

Postma, J., Schilder, M.T., Bloem, J. and van Leeuwen-Haagsma, W.K. 2008. Soil suppressiveness and functional diversity of the soil microflora in organic farming systems. Soil Biology and Biochemistry 40: 2394-2406.

- Differences in soil suppressiveness are described between fields of 10 organic farms for two economically important soil-borne diseases. A major finding is the correlation between presence of antagonistic Lysobacter species and suppression of Rhizoctonia solani AG2.

Lendzemo, V.W., Kuyper, Th.W., Kropff, M.J. and van Ast, A. 2005. Field inoculation with arbuscular mycorrhizal fungi reduces Striga hermonthica performance on cereal crops and has the potential to contribute to integrated Striga management. Field Crops Research 91: 51-61.

- Arbuscular mycorrhizal fungi can suppress the major parasite Striga in cereal cropping systems in Africa and have the potential to increase cereal yields due to enhanced phosphorus use efficiency.

Entry point 7: Induced systemic defense

Bezemer, T.M., de Deyn, G.B., Bossinga, T.M., van Dam, N.M., Harvey, J.A. and van der Putten, W.H. 2005. Soil community composition drives aboveground plant-herbivore-parasitoid interactions. Ecology Letters 8: 652-661.

- Soil organisms suppress populations of an aboveground pest (aphids) and enhance the performance of the natural enemy of the pest via changes in plant quality.

Soler, R., Harvey, J.A., Bezemer, T.M. and Stuefer, J.F. 2008. Plants as green phone: Novel insights into plant-mediated communication between below- and aboveground insects. Plant Signaling and Behavior 3: 511-614.

- Root and shoot feeding insects that feed on the same host-plants can communicate through induced changes in plant volatiles, allowing them to avoid feeding and thus competing for the same plants.

Entry point 8: Ecosystem engineering & Soil food web interactions

Van Eekeren, N., van Liere, D., de Vries, F., Rutgers, M., de Goede, R.G.M. and Brussaard, L., 2009. A mixture of grass and clover combines the positive effects of both plant species on selected soil biota. Applied Soil Ecology 42: 254-263.

- When clover is introduced in grassland to reduce the reliance on inorganic fertilizer, a mixture of grass and clover maintains the positive impact of grass roots on soil structure and increases the supply of nutrients via the soil food web. Thus, a grass-clover mixture combines the agronomic benefits of the two plant types.

Giannopoulos, G., Pulleman, M.M. and van Groenigen, J.W. 2010. Interactions between residue placement and earthworm

ecological strategy affect aggregate turnover and N2O dynamics in agricultural soil. Soil Biology and Biochemistry 42: 618-625.

- Intricate relations between earthworm belonging to different functional group affect the soil greenhouse gas balance, including N2O emissions.

Entry point 9: Rhizosphere symbionts

Cardoso, I.M. and Kuyper, Th.W., 2006. Mycorrhizas and tropical soil fertility. Agriculture, Ecosystems and Environment 116: 72-84.

- Summarizes knowledge on the multifunctional roles of mycorrhizal symbioses in tropical (low-input) agricultural systems and emphasizes the role of good soil management.

Gao, X., Kuyper, Th.W., Zhang, F., Zou C. and Hoffland, E. 2008. How does aerobic rice take up zinc from low-zinc soil? Mechanisms, tradeoffs, and implications for breeding. In: G.S. Banuelos & Z.-Q. Lin (Eds), Development and uses of biofortified agricultural products. CRC Press, Boca Raton, USA, 153-170.

- Revisits breeding for enhanced nutrient use efficiency for both high-input and low-input agricultural systems and the potential tradeoffs that have to be faced by the different mechanisms through which improved water and nutrient use efficiency can be achieved.

Entry point 10: Inoculation of macrofauna and microbiota is not (yet) an active field of research at Wageningen.

Entry point 11. Soil biological monitoring and evaluation

Rutgers, M., Schouten, A. J., Bloem, J., van Eekeren, N., de Goede, R.G.M., Jagers op Akkerhuis, G. A. J. M., van der Wal, A., Mulder, C., Brussaard, L. and Breure, A. M. 2009. Biological measurements in a nationwide soil monitoring network. European Journal of Soil Science 60: 820–832.

- Describes the Dutch national soil monitoring network of biomass, abundances and taxonomic diversity of an array of soil organisms and the Biological Indicator of Soil Quality, derived from 10 years of measurements to support policy frameworks for improving sustainable land management.

Van Eekeren, N., Bommelé, L., Bloem, J., Rutgers, M., de Goede, R.G.M., Reheul, D. and Brussaard, L. 2008. Soil biological quality after 36 years of ley-arable cropping, permanent grassland and permanent arable cropping. Applied Soil Ecology 40: 432-446.

- Ley-arable crop rotations are intermediate to permanent grassland and continuous arable land in terms of functioning of the soil biota (e.g., N mineralization). Permanent grassland is preferable wherever possible. For maize cultivation, a ley-arable crop rotation is preferable to continuous arable land, if not practiced at the expense of permanent grassland at farm level.

7. Systems Design in Metropolitan agriculture

Author: P.J.A.M. Smeets

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7.1 Introduction

This chapter describes the Wageningen UR research and its potential on system design. This research area contributes to significant increases in eco-efficient and highly productive agriculture by designing new agroproduction systems (on different scale levels) in co-operation with stakeholders. These systems are especially designed to operate in situations with competing claims on available resources and have the ambition to realize multitargeted production. Such design processes result in broadly based developments that can set the agenda for subsystem innovations. In order to achieve its goal to "explore the potential of nature to improve the quality of life" Wageningen UR follows an interdisciplinary approach combining natural and social sciences and humanities while keeping an eye on economic feasibility. System design methodology can be applied on different scale levels, from the genoom level to farm, chain and regional level, of which examples will be given in this chapter. This approach can offer solutions in any competing claims situation (urban, rural, peri-urban) but is especially useful in situations with high claims intensity as for example in the Dutch context of metropolitan agriculture.

Metropolitan agriculture

The world is urbanising. Already now half of all human beings live in cities. In a few decades the urban share will approach three quarters of what then are 9 billion people (Figure 7.1). Cities are where the world's economic growth is centred. The Northwest European lowlands are a frontrunner in urbanisation since the 14th century (Wallerstein, 1974) but the massive growth of metropoles in our times is taking place in Asia. The result is an explosive growth of the urban middle class with an increasing purchasing power. They have their own home, advanced means of transportation, their children at better schools, proper health care, and their jobs secured. They eat well and dress well, have time for sports,

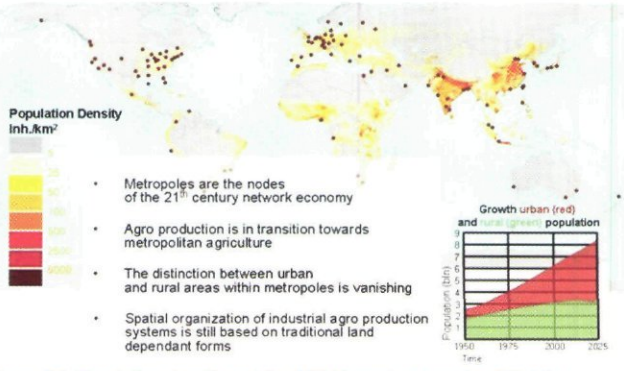

Figure 7.1. Population density and the 100 biggest metropoles (Stichting Onderzoek Wereldvoedselvoorziening van de Vrije Universiteit Amsterdam, 2009). The graph shows the expected growth of the world population and the rural and urban share of it. The transition towards more urban life will also greatly affect the worlds rural areas.

amusement, culture, take holidays abroad. They work hard to improve their position, and enjoy the rightful proceeds of their hard work with great gusto.

Purchasing power growth revolutionises consumption patterns, food consumption no less then other sectors. For food, the difference is not so much in the quantities, but first of all in the quality. Urban middle class workers need fewer calories from staple food as rice, wheat, potatoes. They consume much more fruit and vegetables and meat and fish and drink milk products, fruit juices, soft drinks, beer, wine and spirits. They do not accept health hazards and demand perfect freshness and excellent taste. Their food must be easy to purchase and prepare, and must be according to the latest fashion.

These changes in pattern and quality generate much more added value in the whole food chain than the traditional system based on non-processed staple foods, traded by middle men. While volumes of food do not change much, the value keeps increasing. So the general growth of the total purchasing power of the middle class will certainly also manifest itself in the food sector. And in the same way as middle class development is an urban phenomenon in general, the major part of this explosive growth in purchasing power with regard to food will concentrate in urban areas too.

The development of Metropolitan Agriculture (Smeets, 2009) in Northwestern Europe shows that as a response to the changes in food demand, a transition to highly productive, land independent agriculture is taking place, large parts of which are embedded in the fabric of the metropole itself. The development started in Flanders and The Netherlands in the 15th and 16th century (Wallerstein, 1980) and was boosted at the end of the 19th century (Bieleman, 1992) and after the second world war. Greenhouses, intensive livestock and dairy farms are the modern expressions of metropolitan agriculture and they are inside the metropoles or in the green space surrounding it. What cannot be produced in these metropoles themselves (fodder, concentrates, staple foods), is being supplemented by imports, while products particularly suited to the area, and hence abundantly available, are exported in return. In this way megacities establish another global network of agro-food chains that are integrated in the urban structure, from primary production of an enormous variety of food stuffs, via all kinds of processing activities, to trade and distribution. All along this chain added value is created, the more so when the highest standards of quality and market responsiveness are attained in each link. Metropolitan agriculture can be defined as the system of agroproduction with the ambition of being able to satisfy the changing and competing demands of the urbanised population on a sustainable basis through new and intelligent connections inherent to the network society (between producers, sectors, raw materials, energy flows and waste flows, between stakeholders and between their value systems).

The most important limitation in western society for the further development of metropolitan agriculture is the societal debate on industrial agriculture. Sloterdijk, 2006) describes this as the inhibitive context of modern metropoles in the western world, where *"every impulse is stifled by reactions, often before they have been really able to develop. Everything that wants to move forward, that looks into the distance, that wants to build, is, long before the first project has been started, reflected in protest, objections, counter proposals, swan songs – most reform proposals could be realised with a twentieth of the energy applied to their reformulation, watering down and temporary postponement (....) Governments are these days groups of people who are specialised in appearing to be able to energetically improve a country within this inhibitive context."*

This inhibitive context is to a large extent fed by the resistance inherent to the development of modern agriculture in western society. The distrust from society towards modern agriculture is also due to earlier and partly still existing bad performance of agriculture in environmental issues and climate change (Anon., 2008). And also a majority of European farmers faces the end of their existence as a farmer. They and the organisations by whom they are represented often oppose ongoing scale increase (Denktank varkenshouderij, 1998). The inhibitative context is a barrier that must be overcome by the implementation and thus in the systems design towards sustainable development of agriculture. As willl be discussed further on in this chapter, this implicates that this design process must also include these aspects, that are in the domain of politics, social sciences and psychology.
The need for showcases, that can act as examples for the necessary development of metropolitan agriculture worldwide and the inhibitive context in Northwestern Europe within which they need to be developed, motivate the KENGi-approach (i.e. Knowledge Institutes, Entrepreneurs, NGO's and Governmental organisations that together make system-innovations): only with the political support of all relevant stakeholders, these system innovations can materialize. The design of the stakeholder participation process therefore becomes as important as the technical design of the innovation (Van Mansfeld and Smeets, 2009; Verkaik, 1998).

7.2 Research Directions: Wageningen UR and Metropolitan Agriculture

Figure 7.2 presented by Rabbinge and Slingerland (2008) depicts the object of the Wageningen UR research, that embroadens a wide arrange of interactions between natural and social sciences. Moreover, when turning scientific inventions into innovations in society, also aspects of humanities play an important role, such as design-theory, communication sciences, history, psychology and philosophy. The Wageningen UR scientific approach can therefore be characterised as interdisciplinary and in its co-operation and participatory practice with other stakeholders as transdisciplinary (Tress et al., 2004).

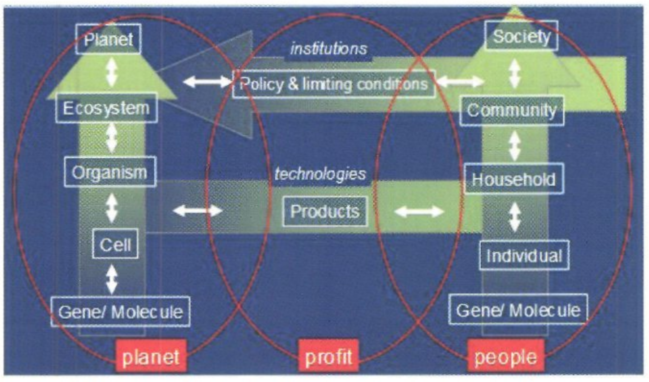

Figure 7.2. The goal of Wageningen UR to "explore the potential of nature to improve the quality of life" is elaborated by an interdisciplinary approach combining natural and social sciences and humanities.

System design towards sustainable development is based on a transdisciplinary approach, in which co-operation between science and stakeholders in society is essential. The aim of the work of Wageningen UR on metropolitan agriculture is to generate these system innovations in different places around the world. Research by design or co-design (De Jonge, 2009) is applied as a form of engineering with regional designs as the end-products, where scientific research may take the form of feasibility and suitability studies, as well as process evaluations concerned with the generation of greater generic knowledge. The research is interdisciplinary; it covers both the natural and the social sciences, while also taking account of aesthetics, cultural history and communication. The design produced in co-design is not only aimed at technological systems but also at the generation of inventions and interventions, leading ultimately to the system innovations required for agriculture to link up with the new challenges of globalisation and the network society. Since this consistently involves practical spatial planning situations in which scientific knowledge is in an ongoing process of iteration with the practical know-how of the various participants in the concrete projects, it comes down to transdisciplinarity in practice.

Examples of systems design on different scale level.

Within this broad framework of regional planning, the introduction of innovations on other scale levels is very attractive. In the following section examples will be given on the level of molecules, greenhouse, stables and integrated agroparks, that all show these characteristics of co-design with KENGi-partners in a metropolitan context, in which the inibitive context plays an important role.

Molecule and cell level: Cis-genesis in apple

In 1998 the Dutch government formulated the ambition to reduce the use of pesticides with 95% in 2010. The Dutch pip fruit chain is one of the biggest users of pesticides and for the biggest single crop, apples, applescabies is the most important disease. The consumption of Dutch apples is significantly decreasing. Its price is high partly because of strict environmental regulations but also the taste of Dutch fruit is decreasing in competitiveness. The development of new apple strains, using traditional growing techniques, would take at least 20 years; which is far too long, given global competition. The development of new apple strains can be speeded up to 5 years by using the innovative 'cisgenesis' technique in which genes of wild apple species that generate resistance against the disease, are combined with the genes of the existing species. This in contrast to transgenesis where genes of different species are combined. The cis-genetic design aimes at reduction of the environmental burden but can also be applied for generating new and different tastes.

However the question is whether and how the difference between cis-genesis and transgenesis would contribute to a better social acceptance of apples of which production, due to their lower phytosanitary vulnerability would need less pesticides. The design aiming at this innovation therefore not only needed to aim at the technical invention of cis-genesis but also needed to address and influence a discussion in society about the acceptance of this technology. This discussion partly takes place in the domain of politics where new regulations need to be implemented that allow cis-genesis to be applied in the fruit sector. But it is also in the public domain where consumer organisations and other NGO's oppose the introduction of genetic modification in food (Transforum, 2010b).

Different players in the Dutch fruit sector founded a joint innovation company "Innovafruit" to deal with the demand for more and more swift innovations. Innovafruit joined with researchers of Wageningen UR in 2004 and started a project "Healthy Pip Fruit Chain", that aimes at the systems innovation of introducing the cis-genesis in the development of new competitive apple varieties. In doing so this systems design project combined efforts in three directions: (i) the technological invention of introducing genes from wild apple varieties that generate resistance against apple scabies into existing commercial varieties; (ii) a discussion with the Dutch government and EU-legislators to get cis-genesis excluded from the heavy and very strict regime regarding introduction of genetically modified crops (Schouten et al., 2006, Schouten and Krens, 2006, Commissie Genetische Modificatie, 2006); (iii) consumer research to the perception of genetic modification in general.

General characteristics of system innnovations also apply to this specific project: allthough the technology of cis-genesis, applied to the design of new apple varieties is complex, this hardware problem is relatively easy to solve in comparison with orgware issues (change of regulation) and software issues (change of consumer perception).

Product and field level: Innovative greenhouses
Dutch greenhouse horticulture owes its leading international position to ongoing knowledge development. However, it is also responsible for approximately 10% of total natural gas consumption in the Netherlands. The future of this sector would be more sustainable if its dependency on fossil fuel could be reduced and the use of it could be made much more efficient. From 2000 onwards researchers at Wageningen UR and inovative growers joined hands to develop new inventions to realise this ambittion. One basic idea was to use a completely closed greenhouse and store the heat surplus during summer through a heat exchanger in an aquifer and to do the same with cold surplus in wintertime. Subsequently, the surplus heat can be used in wintertime to heat the greenhouse while the surplus cold can be used to cool during summer months (Figure 7 3). By doing so the greenhouse can minimise open air ventilation during summer and this adds significantly to the efficiency of CO_2 application for stimulating growth and of biological pest control. And moreover: In dutch climatic circumstances the greenhouse creates a surplus of heat on a yearly basis (de Zwart et al., 2007). At the moment this concept of heat and cold storage in aquifers is being successfully applied by a number of growers in The Netherlands (Anon., 2009).

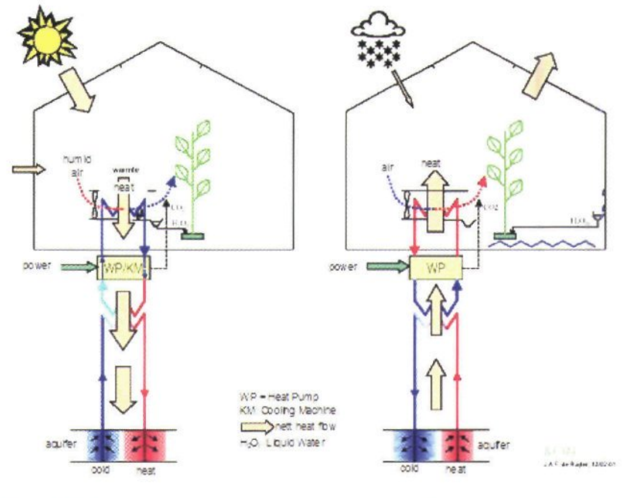

Figure 7.3. Principle of heat and cold storage in aquifers below greenhouses.

Another innovation that is being applied on a fairly large scale by greenhouse growers is the combination of crop production and power production by a small scaled power generator on natural gas in a greenhouse (Figure 7.4). The main purpose of the power production is not the power but the clean carbon dioxide that comes as a by-product, but that is used within the greenhouse to stimulate the growth of the crop.
The other by-product of power production: heat, can be used during cold periods for heating of the greenhouse. In many cases the power is used for assimilation lightning of the crop during dark periods but deliverance to the grid is as least as attractive. Since CO_2 and heat both can be stored for longer time the grower can choose to produce and deliver power to the grid at the moments when the price he gets is at the highest. This results in a high price for the produced power but also in a very efficient and flexible power production without the waste products (heat and CO_2) that come with traditional power production in large scale power plants (Knies and Raaphorst, 2005).

For the knowledge management concerning innovations in energy-efficient greenhouse production the project 'SynErgy' has been set up (Transforum, 2010c). By joining forces, innovators are encouraged to share knowledge and early adopters are induced to follow. A learning network has therefore been set up of innovative growers and researchers. Synergy has created a learning network of growers, greenhouse constructors and knowledge workers, who are

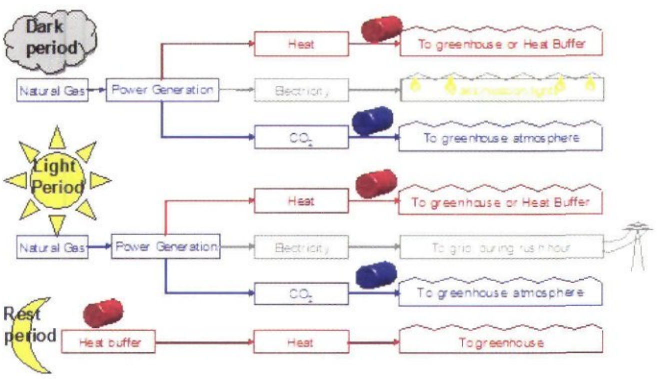

Figure 7.4. Greenhouse and power production. Combination of greenhouse and small scale powerproduction can be made very efficient during different periods of light intensity throughout the year.

at the forefront of energy-efficient greenhouses. The network is now evolving into a Community of Practice (Wenger and Snyder, 2000). New knowledge about energy savings in the greenhouse horticulture sector is being developed and distributed at a high pace and in a demand-driven way. The Community of Practice has formulated several research projects that focus on different aspects of crop production systems in closed greenhouses. All these efforts have generated enthusiasm among early adopters among the growers towards investing in closed greenhouse systems (Bakker et al., 2009).

Product and building (and chain) level: Integrated broiler system

As part of the agropark project New Mixed Company, an integrated broiler production and processing facility has been assigned by Kuipers Kip. It is a system innovation in many aspects, if compared to the existing poultry producers (Figure 7.5).

In contrast to traditional broiler producers, this facility will integrate egg-production, breeding, broiler growing, slaughtering and processing on one location and in doing so it strongly reduces transportation between these chain elements. But most importantly, a much larger part of the added value in the whole chain, specifically the financial margin of slaughtering and processing, will be kept by the grower/processor. To make slaughtering profitable a minimum delivery of 2000 broilers per hour during at least 8 hrs/day is necessary. Given a growing period of 7 weeks, this results in a minimum scale of 1 million broiler places in primary production.

The broiler production stable will be completely closed with biological air washers that eliminate ammonia, smell and fine dust before emission. This reduces the environmental burden of the primary production but also greatly improves the air condition inside the stable, leading to more healthy broilers.

The growing of broilers takes place on a conveyor belt. At the end of their growing period this conveyor belt is switched on and transports the broilers direct to the in-house slaughter, taking out the gathering and transport of broilers, that is seen as the worst aspect of broiler production with regards to animal welfare.

In the system design the broiler manure together was projected to be processed in a co-digester to produce biogas and turn that into power, CO_2 and heat. The CO_2 was projected to be delivered to a nearby greenhouse complex, while the heat and power were to be used inside the New Mixed Farm Agropark (see also Figure 7.8) (Broeze et al., 2006).

The hardware plans for the New Mixed Farm have been presented in 2004 for the first time. In many evaluations it has proven to contribute substantially to sustainable development of agriculture (Kool et al., 2008). Since 2004, the entrepreneurs have been trying to aquire all the licences

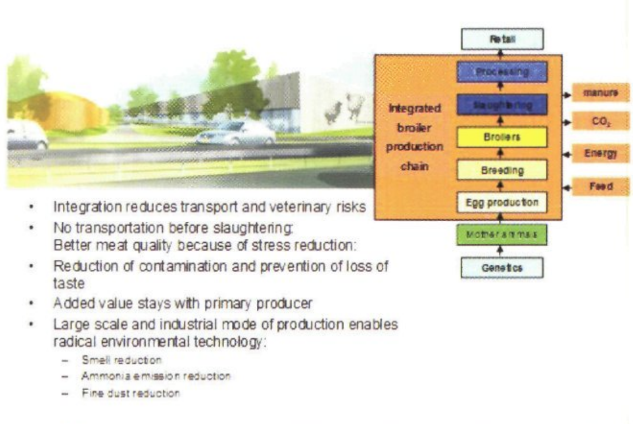

Figure 7.5. Integrated poultry chain of Kuipers Kip as part of New Mixed Farm Agropark.

and permits they would need to construct this farm. However, the concept of New Mixed Farm has become the subject to the national debate on the future of intensive livestock farming It was heavily opposed by local citizens that expressed great concerns about the expected inconveniences (smell, heavy traffic, fine dust) A number of environmental and animal welfare organisations used this case in their national campaign against the further development of industrial livestock farming. Despite these protests the local government decided to approve the project, that is now being implemented. (Hoes et al., 2008; Smeets, 2009).

Product and building level: Cow garden

The Dutch dairy industry is under pressure from the possible abrogation of European support measures. At the same time, society has set high standards for animal welfare, product quality and quality of production. Farmers seek to provide working conditions that meet these current standards. This calls for new production systems that meet these challenges and demands while also enabling profitable operation.

The 'Dairy Adventure' project experiments with new concepts of enterprises in order to determine the required scale and intensity of production in order to ensure the industry's viability. These concepts are being elaborated around central themes such as stable design, pasture systems, slurry processing, landscape management and the creation of added value. The focus is not only on the technical aspects but also on the co-operation models and on the development path that existing family farms can follow. The project also aims at developing and stimulating new competences farmers need in order to balance society's demands with an operating profit, and at the social and policy conditions, that are required to turn businesses of this type and scale into a success. (Transforum, 2010a). One of the outcomes of the Dairy Adventure project is the Cow Garden design (van Kasteren, 2009: Figure 7.6)

In order to further explore solutions that meet the growing concerns in society on animal welfare in livestock husbandry, the designers changed the perspective for stable design to that of the cow. How would a stable look like if it were designed completely from a cow's perspective? This resulted

Figure 7.6. Animation pictures of the cow garden design, an innovative cow stable concept aiming at maximal animal welfare.

in a series of terms of reference to be taken as a starting point for the design:

The resulting design is a synthesis between a greenhouse and a traditional cow stable of which a first pilot version is now being build by a farmer, with support of the Ministry of Agriculture, Nature and Food Quality and several organisations that stimulate innovations in the dairy sector.

Ecosystem and regional level: Agroparks in Intelligent Agrologistic Networks

Agriculture and logistics are very closely connected within metropolitan agriculture. An 'intelligent agro-logistic network' (Figure 7.7) is composed of a number of agroproduction chains, that are connected through logistical operations and flows of knowledge and information. Typical components of the network are, at one end of the chain, production regions, centred on 'rural transformation centres', then at the other end 'consolidation centres' directly servicing metropolitan or export markets, and in between 'agroparks' forming the linking pin between the two. In consolidation centres products, both raw and processed, coming from the rural environment or from specialised agroparks, are combined with import flows, if necessary be processed further, and then recombined and distributed. Perfect freshness and compliance with the highest quality standards are the key issues for operation. For that purpose consolidation centres need to be close to the metropoles. Rural transformation centres work as collection

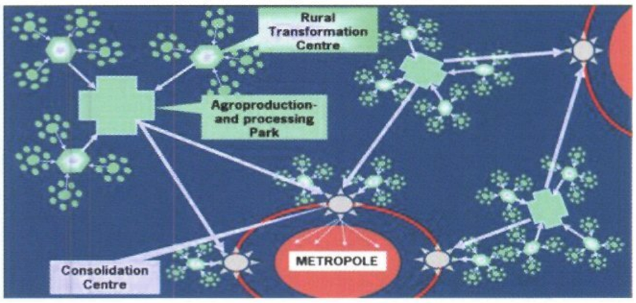

Figure 7.7. An agrologisic network serving the needs of a metropole and consisting of consolidation centres, agroparks and rural transformation centres.

Figure 7.9. Planning and implementation of Agroparks in the Netherlands

points from where primary products are transferred to other parts of the network. Rural transformation centres are the nodes where the inputs for the whole network can be sourced and where trading facilities will be located. They will also be the contact centres for contract farming and for training and education of farmers.

Of all the elements of the network, agroparks are the most innovative, linking supply and demand flows in entirely new ways. An agropark is a spatial cluster of high-productive plant and animal production and processing units in industrial mode combined with the input of high levels of knowledge and technology. The cycles of water, minerals and gases are skilfully closed and the use of fossil energy is minimised, particularly by the processing of various flows of residual- and byproducts. An agropark may therefore be seen as the application of industrial ecology in the agrosector (Figure 7.8). What is not available from the primary production areas around the rural transformation centres, will either be supplemented by concentrating import flows on the agropark, or intensive, high-tech production within the agropark itself. The third component of the agropark are its trading and distribution functions. These are closely related to the agropark's central point from which all information flows are directed, for the whole intelligent agro-logistic network of the metropolitan region.

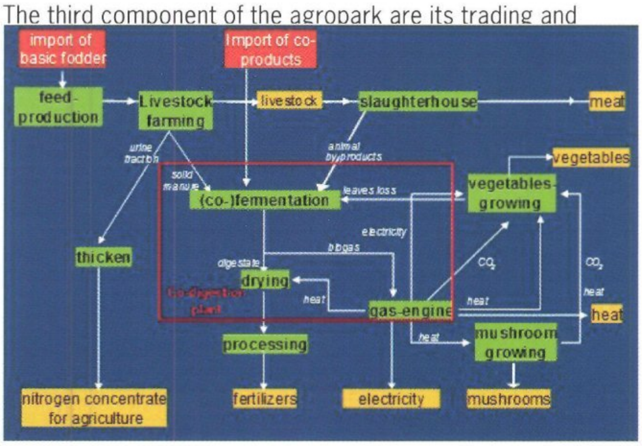

Figure 7.8. Industrial ecology in an agropark with greenhouse and mushroom production and animal husbandry.

The co-design activities of Wageningen UR on agroparks started in 2000 when a first design (Deltapark De Wilt et al., 2000) was launched to start a societal discussion on the pros and cons of this approach. Smeets (2009) gives an overview of a number of designs that have been produced and the research that came with it. Some of these designs have already been implemented (Biopark Terneuzen (Boekema et al., 2008), WAZ-Holland Park in China (Smeets et al., 2004)) while others are under construction (IFFCO Greenport Nellore in India (Smeets et al., in prep.)). In several regions of the Netherlands spatially concentrated agricultural activities are implementing elements of industrial ecology, inspired by the insights that have been produced in this co-design (Agropark Bergerden in Huissen, Agriport A7 in Wieringermeer).

Figure 7.9 shows the existing agroparks, the locations of agroparks in planning and other sites with high potential. Around these projects a large KENGi-network has been established, that from 2002 until 2006 has been actively supported by the Platform on Agrologistics, a co-operation between the Dutch ministries of Agriculture and Transport (Kranendonk et al., 2006).

7.3 Contribution to high-technological and eco-efficient agriculture:

Apart from the extended specialised natural sciences aspects that form the large knowledge base of the above presented designs, there are three overarching theories that are key for the research-by-design or co-design that is characteristic for all mentioned examples.

Resource Use Efficiency

The first of these is the resource use efficiency theory (De Wit, 1992). An agropark is primarily concerned with production and the processing of plant and animal products and with the efficient management of the residual and by products of these processes. The resource use efficiency theory in its basic form holds that the amount of nutrients needed increases with increasing yield level when expressed per hectare, but decreases with increasing yield level when expressed per unit yield. That means that the efficiency of the agroproduction process in a chain increases the greater the yield per hectare. It also increases with the level of integration: the number of controlled factors as well as their intensity. The theory was originally formulated and illustrated for single crop fields. It has also been applied to integrated systems of plant and animal production. In the report "Ground for Choices" (Wetenschappelijke Raad voor het Regeringsbeleid, 1992) the theory was successfully applied in formulating land use strategies for the European Union.

The innovative greenhouse concepts and the integrated broiler chain concept, that have been discussed in the section before are a striking example of the application of the Resource Use Efficiency theory.
By expanding the greenhouse with heat and cold storage in the aquifer below the greenhouse, the precondition for the use of sunlight for heating and of winter low temperatures for summer cooling is being created. But the system is only productive if the greenhouse is closed, which only makes sense for high productive systems (de Zwart et al., 2007)
By changing the character of power supply from an external input to an internal produced asset, the growers are able to catch the benefits of what is waste in the classical power production: heat and CO_2, and then turn it into a major cost reduction (Knies and Raaphorst, 2005)
The integration of different chain elements in broiler production, needed in order to keep a larger part of the total added value in the chain, is only possible on the basis of a large scale primary production facility. But it also strongly reduces transportation costs and it enables the industrial application of air washers and they again add to the productivity of the whole (Kool et al., 2008).

The Resource Use Efficiency theory clearly has not been the starting point for the design of the Cow Garden. This stable design maximises not on an integrated set of preconditions but favours one in particular: animal welfare. It is to be expected that the application in practice of the concept will be governed much more by a more integrated set of preconditions.

The analysis of seven agropark projects carried out by Smeets (2009) shows the theory also to be applicable for agroparks. Clustering results in transport reduction. Waste processing reduces costs and produces energy. Reduction of emissions, efficient use of water, energy and raw materials reduce the environmental impact. Added to these profit and planet aspects of sustainable development there is the improvement of animal comfort and improvement of labour conditions. Moreover the theory also encourages the high productive use of space for agriculture in metropolitan areas. The reverse conclusion is that within the metropole low productive agriculture should be prohibited. Applied to the resource knowledge, the theory is a plea for maximising the input of the explicit and tacit knowledge of different stakeholders resulting in transdisciplinarity.

Landscape theory

The second theory concerns the three-dimensional landscape as formulated by Jacobs, 2006) . A landscape is at the same time matterscape, powerscape and mindscape. Landscape is a concept in natural sciences, social sciences and humanities (Figure 7.10).

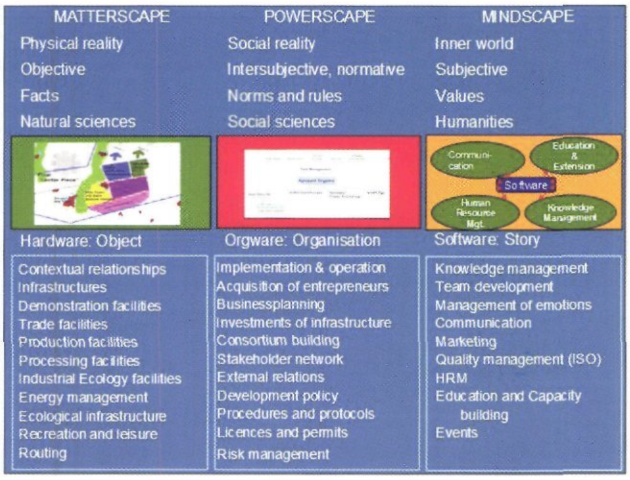

Figure 7.10. Design aspects of the three dimensions of landscape: the matterscape dimension is hardware design, the powerscape dimension is orgware design, the mindscape dimension is software design.

Even the discussion in society on genetic modification is partly taking place on the level of the landscape. Although the technology intervenes on the level of genes and molecules, citizens fear its effects partly on the landscape level. They are affraid that modified species spread in an uncontrolled way and mix up with local species. The fears are clearly mindscape and mix up with regulatory aspects in powerscape.

Greenhouses and cow stables are important elements in metropolitan landscapes. Where ever they are being planned or are enlarged, they are heavily discussed (Gies et al., 2007)

The Intelligent Agrologistic Network (IAN) is functioning on the level of the global network society but also on the level of the landscape where it connects Rural Transformation Centres, agroparks and Consolidation Centres in a region. The design of an IAN on this landscape level should take the three dimensions of the landscape in full account. The first dimension is that of natural sciences with aspects such as soil, water and vegetation, the crops, livestock and the physical infrastructure (the matterscape). The second dimension is that of the social sciences and it covers the balance of power between people and groups in the region and the related economic aspects (the powerscape). The third dimension is that of subjective aspects such as aesthetics, history and communication forming part of the humanities (the mindscape). In terms of the theory of the three-dimensional landscape an IAN is regarded as a landscape in which matterscape, powerscape and mindscape each play an important role and must be specifically designed.

An important finding of Smeets, 2009), in his analysis of seven agropark design projects, is that in these design processes the attention of the designers tends to be focussed on the hardware aspects. But it is in the domain of orgware, where the decisive discussions are taking place on the implementation of these designs. The software aspect is in many cases determining the critical path of implementation: training and educating the people that are needed to operate a greenhouse, a modern cow stable or an agropark takes more time than building them.

Process theory

The third theory concerns the design process itself. What conditions must the design of a complex system innovation like an agropark satisfy for it to be a realistic prospect in present-day society? Verkaik, 1998) states that a system innovation is impossible to reach without the co-ordinated effort of all so called KENGi-partners. They have to co-operate in order to reach that complex objective. What are the steps from invention to implementation? De Jonge, 2009) introduced the concept of Co-Design as working method executed by experts who (on the basis of extensive expertise in transdisciplinary design situations) are able to deal with the uncertainties that come with system innovations. They work in an iterative mode, using scenarios and other advanced design techniques. The basic characteristic of a co-design process is its openness. The dialogue with the other KENGi-stakeholders takes place in a 'free space', where participants have an open mind, allowing them to seize opportunities outside the 'dialogue space' as they come by.

Quantitative potential

The application of Resource Use Efficiency Theory on European land use (Wetenschappelijke Raad voor het Regeringsbeleid, 1992), showed that in Europe agricultural productivity can still be significantly improved by intensifying agriculture and performing agriculture in the most productive

regions. This would hold even more for the relative inefficient agriculture in countries like China and India.
Ex ante evaluations of agropark projects show significant cost reductions (with transport reduction and reduction of fossil fuel use as most important single factors) and large contributions to other aspects of sustainable development (reduction of environmental emissions, of space use, increase of employment and improvement of quality of labour) (Smeets, 2009)

The most important contribution from Landscape Theory on the hardware aspect is a strong improvement of the spatial organisation of agroproduction. Fourty agroparks of 1000 ha in the Netherlands would be able to fully take over all production of intensive livestock, dairy production and greenhouse production. This would not only reduce the direct and indirect space use of these sectors but also improve the quality of space in large parts of the metropolitan green space that would no longer suffer from smell, emissions of ammonia and fine dust and of the heavy traffic that the current spatial organisation brings.
From the orgware perspective of landscape theory a strong plea can be derived to design the masterplanning as well as the implemenation of systems-innovations as an open innovation process in which all future stakeholders participate from the beginning. If professionally organised the extra time investment in the early development stages of this participatory process will be more than compensated with the speed in procedures later on. The same holds for the software development

Application of Co Design Process theory combined with careful monitoring and evaluation will greatly improve the learning attitude of the partners involved and strengthen their ability to generate ongoing system innovations

Limitations

To summarize: The strong improvement of resource use efficiency that can be reached is the most important contribution of metropolitan agriculture. System design processes are necessary methodological steps to realise the innovations in products, in production modes, in chains and in networks, adapted to this context. Furthermore in western countries an important improvement can be expected of the spatial re-organisation of industrial agriculture in these densely populated areas, where space is scarce. In emerging market countries as well as developing countries metropolitan agriculture will be able to meet the demands of the growing middle class in terms of more diverse and better quality food. It will generate a large flow of added value and will generate employment for the rural poor who migrate to these metropoles.

7.4 Short and medium term products

The most important result that Wageningen UR and the entrepreneurs and governmental organisations will deliver on metropolitan agriculture in the coming four years are proofs of practice. In different countries around the world Intelligent Agrologistic Networks are being designed and implemented and get connected. They will not only be system innovations that greatly contribute to sustainable development in practice but because of their strong performance in terms of immanent control and transparency they will act as a research base for continuous improvement and innovation of this practice (continuous co-design). The network will also be the practice where education institutes, that are already involved in these designs, will educate students for the jobs that are provided in the network, from farm factory floor workers to the top management. For this knowledge management system aiming at R&D and education, the foundation TransForum, established by the Dutch government to promote sustainable development of agriculture, has established a worldwide network, called the innoversity on metropolitan agriculture.

7.5 Aspects underexposed

A large part of the funding for the research of Wageninge UR is coming from the Dutch Ministry of Agriculture, Nature and Food Quality. No wonder that the research agenda is dominated by the issues that are dominating the societal debate in the Netherlands. The cow garden design is a typical example of an answer to this discussion, expressing the emphasis on animal welfare in the debate on the future of animal husbandry. Worldwide, Dutch agriculture is regarded as a frontrunner on many aspects (Ministerie Landbouw Natuur en Voedselkwaliteit, 2004; Porter, 2001) and there are high expectations on the potential of knowledge export, not only for Wageningen UR but for the whole transdisciplinary network, including the entrepreneurs and the government, that knows how to innovate the regime in which modern food production can take shape.

It would therefore be wise to broaden the research agenda with a number of global issues such as hot and humid climates, robust systems that can operate in less clean environments, systems that address massive water shortages and societies where hightech logistics and infrastructure are not yet in place. But not only matterscape of The Netherlands is different and sometimes quite unique. There are powerscape differences that matter too: The strong emphasis that animal welfare gets in Northwestern Europa was already mentioned. In some parts of the world animal welfare is not such an issue and investments in it are not understood nor supported. In these cases it helps if direct benefits of animal comfort on productivity can be emphasised (Leenstra et al., 2007). On the other hand, in India, a cow is regarded as holy in Hindustan religion and this demands for specific solutions with regard to cow replacement and treating of calves. Another example of a totally different powerscape is the public debate and government attitude towards genetic modification. It will be very difficult for Wageningen UR to keep its place as a global frontrunner regarding this aspect, if the European regime is taken as the reference in the long term.

Despite the mentioned attention for training and education, great care should also be taken that this aspect is not becoming the Achilles heel of metropolitan agriculture. There is a general tendency to focus on the hardware aspects of metropolitan agriculture (stables, greenhouses, industrial ecology, infrastructure) and to get stuck in the orgware of it (investors, organisation structure, who has the power?). When finally the agropark opens, there may not be enough trained staff available to deal with the complexity of it. Hence training and education are essential.

7.6 Recommendations

Dutch agricultural enterprises (especially primary producers but also many processors) who are willing to participate are typically small or medium sized. They deserve more support to take the risk of developing metropolitan agriculture worldwide not only from government but also from research institutes. When they succeed in exporting the innovations to countries like India and China, they contribute significantly in showing the innovative power of the industry behind them (greenhouse and stable constructors, ICT developers, large scale processing industry, logistical enterprises) and to the most innovative sector of Dutch economy as a whole. Moreover, The Netherlands as a worldwide leading country in agriculture and Wageningen UR as its leading knowledge institute should put more emphasis on the establishment of showcases. It is not wise to only take the Dutch policy debate as the one and only benchmark, given the international context in which the sector as a whole and the knowledge institutes that belong to it, operate.

A more effective innovation infrastructure might also need a different orgware: in its report on innovation in the Netherlands, the scientific council of the government points to the need of so called "third spaces" (Wetenschappelijke Raad voor het Regeringsbeleid, 2008; Wissema, 2009). These are virtual or physical organisations aiming at interactions between university and enterprises that are partly connected and partly are preserved from universities and enterprises to protect exploration against too big commercial pressure and at the same time to protect exploitation against the unstoppable preference of researchers to continue exploration. A third space often is needed to enable the interdisciplinary and transdisciplinary research and innovation that the disciplinary organised universities are unable to generate themselves.

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8. Robust and resilient agriculture

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8.1 Introduction

Technological approaches, mainly driven by population growth and globalization, have dominated agricultural development over the last half century. The resulting improved varieties and production technologies delivered both good and bad results, and not necessarily to the same regions or people. Rachel Carson's book Silent Spring (1962) was amongst the first to draw attention to the devastating effect of pesticides on the environment, particularly on birds. Subsequent studies demonstrated the negative effects of nutrient surpluses associated with agricultural input use on water quality, soil and flora (Vitousek, 1997). The 1972 UN Stockholm Conference on the Human Environment was a landmark in which the concept of sustainable development was argued to present a way to address the environment-versus-development dilemma.

In agricultural systems, typically, decisions and activities at the lower scales interact with and affect the biophysical environment (Figure 8-1). For example field level activities such as land clearing and fertilizer application can have an impact on the environment through erosion and nutrient leaching. The impacts, however, are not necessarily confined to the field level but could impact higher levels for example via pollution of aquifers or emissions of greenhouse gasses contributing to global warming. Similarly, higher-scale effects, such as changes in temperature and precipitation regime, have an impact on options for agriculture at the lower scales. The various scales in the biophysical environment are clearly nested.

Policies at higher scales aim at creating incentives for lower-scale decision makers to achieve policy goals such as food security, sustainable production, biodiversity, and/or a reduction of greenhouse gas emissions (Figure 8-1). The farm and farm household are positioned at a crucial intersection. It is at this level that demand and supply meet and decisions are made about production methods that affect the biophysical environment. Here, the socio-economic domain and the biophysical domain interact directly. Decisions at household scale feed into higher scales, for example revenues from agriculture contribute to the regional economy, and reductions in greenhouse gas emissions at field and farm level contribute to the mitigation of global climate change. Often, the higher-scale effects draw attention (signaling) from governmental and non-governmental organizations and lead to the formulation of policies aimed at influencing decision-making at lower-scales (Figure 8.1) (Verhagen et al, 2007).

Sustainable agriculture will need to take into account the socio-economic and biophysical environment, acknowledging scale and process linkages and accepting that agriculture is not limited to the primary production of tradable commodities but also delivers several non-market goods and services. Operationalising the sustainability concept for agriculture is therefore location and context-specific.

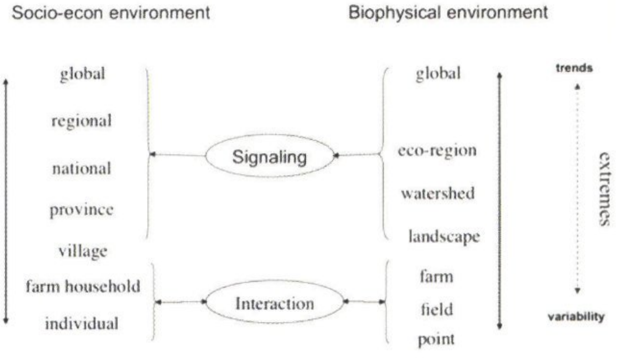

Figure 8 1. Biophysical and socio-economic interactions and signaling at different scale levels. (Verhagen et al. 2007) .

A complicating factor is that agricultural systems face natural variability (e.g. weather, price fluctuations), trends (e.g. global warming, loss of soil fertility, energy, political and market developments) and have to deal with extreme events (flash floods, storms, hail, pest and diseases outbreaks, heat waves) (Figure 8-1). Changes in these factors may cause temporary loss of production performance and economic return, increases in waste, pollution or residues, and deterioration of animal welfare and health. These changes may even result in social unrest or changes in public perception towards agriculture.

Sustainable agriculture should be able to manage short-term variability and deal with long-term trends enabling the development of robust agricultural systems. The objective of this paper is to discuss the role of robust and resilient agriculture for maintaining sustainability in the face of variation and trends.

Securing a stable performance for the provision of food and raw material within the inherent variable production environment is part of the challenge for agriculture. It may not require a totally different approach of looking at farming systems, but it does call for another way of dealing with the production environment in the design of the production system. How to deal with changes in variability and extreme events in a sustainable manner is a critical challenge for the future of agriculture.

To be sustainable, agriculture must display a dynamic response to changing ecological and socioeconomic conditions. Farming systems that deliver high and stable production levels and have the ability to deal with shocks and surprise are therefore part of the answer. In agriculture, resilience is a component of sustainability (Fresco & Kroonenberg, 1992). It is the ability of a system to absorb changes and restore production levels after a disturbing event.

8.2 Coping with change and variability

Reacting to changing environmental and socio-political conditions is not new to agriculture. In fact agriculture is formed by the interaction between these environments, on the one hand reacting to societal needs on the other hand operating within a dynamic biophysical setting.

The conventional approach in the Netherlands is to stabilize high productivity levels by keeping any disturbances away from animals and crops as much as possible, for example through killing bacteria with antibiotics and pesticide use. This approach focuses on improving the resistance of the agricultural system. Scale-enlargement enabled the protection of increasing herds and land holdings against different threats and stresses. This has lead amongst others, to beef, veal, pig and poultry production systems with high concentrations of animals per farm, low labor requirements, a high level of automation and protective environments. Similarly, crop production systems are characterized by uniform and large-scale cultivation with high efficiencies and outputs and high reliance on agro-chemicals.

Box 8.1: In livestock production systems (LPS), the predominant strategy to maintain functionality is to control variation in the production environment, by controlling internal system conditions and keeping away disturbances and perturbations. Although this has proven to be a successful approach, the drawbacks and constraints of completely relying on this approach, such as infectious animal diseases, overburdening of animals, loss of biodiversity and a lack of public support, are accumulating. It highlights the need to reconsider the design of LPS from the perspective of maintaining the system's functionality in a dynamic environment.

LPS are complex systems with natural, technical and social sub-systems. Robustness refers to the way in which systems are able to function when external conditions change beyond the range of conditions for which the system was designed. These changes in environment are referred to as perturbations and disturbances in system theory.

Robustness involves two aspects, resistance and flexibility. A system with a highly controlled environment has become resistant to certain perturbations, if the system does not need to respond to the perturbation to avert its impact. Therefore, an optimal performance strategy can be used for this situation. This involves 1) uniformity and homogeneity, 2) efficiency and 3) enlarging of scale in the design of the system to obtain an optimal performance.

However, no environment can totally be controlled. Failure to comply with protocols, technical failure and new unforeseen perturbations, such as upcoming unknown diseases or weather changes, may pose a threat to future performance of the LPS. Hence, a more risk-averse strategy for LPS is to reduce the consequences in the presence of the causes; it minimizes the impact of external systems conditions on the performance of the system. The latter will require the system to change its mode of operation in a flexible way and tends towards a robust performance strategy. This strategy can be regarded as the flexibility of the system. The rate of 1) diversity and heterogeneity, 2) redundancy and 3) a modular design determine the ability to handle and to adapt to new circumstances. (Adapted from Van der Veen et al., 2009)

In animal production systems endemic infectious diseases are a serious problem, because of the high concentration of animals and the constant influx of unchallenged animals. An outbreak of an infectious disease therefore often has long-term consequences for the profitability, because of higher mortality, higher veterinary costs and lower productivity. Avoiding outbreaks of disease has become a very critical issue in animal farming. Given current production systems, there is little farmers can do but to increase biosecurity, and veterinarians advise accordingly. It is now common in animal production to restrict the number of visitors to the farm to the minimum, to have shower facilities or provide visitors with boots and overalls, to restrict intake of animals and clean and disinfect pens regularly. Similar protective measures can also be observed in seedling and cutting nurseries and other high-value greenhouse production systems. This increases the cost of production substantially, but within the given system it is cost-effective (ten Napel et al, 2006).

Ten Napel et al (2006), looking at farming systems in the Netherlands, advocate that a stable and reasonable income should be the preconditions in designing production systems, while financial income should no longer be the only optimization criterion. The design of production systems and processes needs to be optimized for stable performance in the normal bandwidth of sources of variation. This approach focuses on developing the flexibility of the system.

Farmers in political and environmental unstable production environments have developed a range of livelihood strategies to cope with the inherent variability of the system and to increase food security (Dietz et al., 2004). Farmers in relative stable, biophysical and or political and socio-economic, production environments developed via specialization and spatial concentration (Vereijken & Hermans, 2010).

Diversification is believed to contribute to production and income stability in less stabile production environments. Whether income diversification in farming systems is a better strategy compared to specialization is controversial. Brons (2005) indicates that diversification, besides its functionality for mitigating income risks, is also a structural consequence of poverty. Therefore, income diversification itself is an insufficient strategy to alleviate poverty, and additional attention should be given to the institutions and technologies of the different livelihood components. Others (Ellis 2000; Niehof 2004) argue that diversity in farming activities may increase income stability and reduce income risks of resource-poor households. If large fluctuations in costs and revenues are not controlled at a higher system level (e.g. via subsidies), the best strategy for maintaining a reasonable income is diversification. If the structure at a higher system level absorbs large fluctuations, then specialization has the potential to offer a much higher income. Similarly, if large fluctuations and extremes are not controlled at a higher system level, specialization may not be the best option.

Box 8.2: In an explorative study on nutrient cycling and the production capability of farm household systems Rufino et al. (2009) looked at nitrogen flows in crop-livestock systems in Africa. The farm households were studied using indicators on size, activity and cycling, and the organisation and diversity of the nitrogen flows were compared with system productivity and food self-sufficiency.
The results revealed that productivity was positively related to network size, its organization and nitrogen cycling, but utilization efficiencies were different across sites in relation to soil nitrogen stock and the importance of livestock for nitrogen flows. Greater size of the nitrogen flow network and its organization led to increased productivity and food self-sufficiency, reducing dependency on external inputs which may increase the adaptability and reliability of small-holder crop-livestock systems. (from: Rufino et al 2009)

Redundancy or the trade-off between deliberate overcapacity and reduction in risk is a common strategy in biological systems (Kitano, 2004). Examples in agricultural are storage facilities allowing to sell at a better price, the ability to erect temporary accommodation for pigs to cope with a temporary transport ban or paying an insurance fee for covering the financial risk associated with natural variation.

Diversification of farming systems contributes to income stability and efficient use of resources only if farm activities are effectively integrated. The integration of crop and

livestock activities is perhaps the clearest example, but also when off-farm income is reinvested in the farm is an example of integration. Diverse and integrated farm household systems enable the realization of complementarities between different activities and may improve resource use efficiencies (Rufino et al., 2008). Integration of activities, however, takes some of the benefits of diversification away, as integration reduces the possibility to shift between activities.
In line with economic and ecological studies, Rufino et al (2008; 2009) used network analysis to assess and evaluate the economic and environmental performance of mixed farm household systems in Ethiopia, China and Honduras.

Complementary to diversification is modularity i.e. when systems can be broken down into a number of components that can be mixed and combined. Scale enlargement generally increases cost efficiencies, but also increases the magnitude of damage if something goes wrong. So a larger number of smaller groups of cows would be more robust than a single large group. By separating components, modular design also allows for buffering the negative impact of a disturbance. An example is the three-site pig production system that is frequently used in North America (Harris, 2000), which separates weaned pigs from finisher pigs and breeding sows.

Although robustness at one system level does not imply robustness at a higher system level, it is a good starting point for a robust design to use robust components (Jen, 2003). This also applies to agricultural systems. For example, animals are generally quite capable to identify the most comfortable location in their environment, so the environment can be made more robust by providing a range of micro-environments. Improving the robustness of animals and plants through genetic selection is beneficial, provided that the production environment allows the expression of the adaptation (Ten Napel et al., 2009)

Even for existing production systems, it is possible to further improve the robustness of the technical aspects of the system. In industrial engineering, an approach has been developed for making existing designs, prototypes or systems in operation more robust by identifying the combination of settings of any aspect that can be conFigured in an existing prototype or system that yields the least impact of common disturbances (Phadke, 1989). This approach has not been applied yet to agriculture, but could provide entry points for finding the most optimal solution in a specific context.

In relation to climate change it seems that gradual change favors regions in North Western Europe with a strong agro-business complex, partly because these systems benefit from increasing temperature and CO_2 levels and partly because these regions have the infrastructure and resources to adapt (Hermans et al., 2008). Extreme events like floods, droughts, storms, hail and changes in pest and diseases, however, have the potential to cause serious damage to infrastructure and destroy entire harvests.

The Northern provinces in the Netherlands, i.e. Groningen, Friesland, Drenthe and Flevoland together with the farmers' organization Land- en Tuinbouw Organisatie Nederland, the private sector and Wageningen UR are working on the adaptation agenda for agriculture to climate change. The first question addressed related to the competitiveness of Dutch arable farming (potato and wheat) and the dairy sector (grassland) in a European context taking into account climate change and changes in markets (Hermans et al., 2008). The results indicate that gradual climate change is not a critical bottleneck for the future of agriculture in the region, in fact given the already strong position and the relative benign impacts of climate change the region has a relative advantage compared to other European regions.

The potential effects of extreme climatic events and surprises related to pest and diseases could however be more important for the future of agriculture. In a first step to assess the impacts of extreme events on crop production (Schaap et al, in prep) developed an agro-climate calendar in which, based on literature, model studies and expert judgment, crop and tillage specific critical climate factors, periods and associated thresholds were identified. The change in frequency of occurrence of these critical periods and thresholds based on the historic data records (1976 – 2005) for a representative meteorological station and for the future climate (2026-2055) provides insight in possible changes in risks. For example heat waves during the growing season can prompt early growth. In potato this is currently already a problem but with global warming the frequency, depending on the scenario, will double or triple. In interactive adaptation ateliers with farmers adaptation measures (e.g. irrigation, broader ridges, isolation material) are discussed and evaluated.

In Ethiopia Wageningen UR scientists in the policy-supporting project on climate change are implementing a similar approach. Here a two-track approach is being worked out. The first track is to enhance capacities of policy makers needed to formulate and implement effective, responsive and realistic adaptation and mitigation activities integrated in their policy domains. This concerns the ability of researchers to access and provide knowledge to set the policy agenda, and it involves the ability within the policy system to respond based on evidence and societal needs and put in place policies and mobilize resource for implementation. The interaction between policy makers, stakeholders and scientist is needed to arrive at well feasible action plans. The second track relates to the design of a scientific framework to the support policy decisions (Verburg et al., 2010). This track is currently being implemented in two cases studies. The first relates the impact of climate change on coffee production and quality. The vulnerability of different coffee productions systems (forest coffee, shade trees, mono culture) to climate change will be studied, and potential carbon benefits will be quantified. The second case study will focus on horticulture in the Central Rift Valley; here the vulnerability of vegetable production to changes in temperature, water and pest and diseases will be addressed.

8.3 *Concluding remarks*

The need to provide food and raw material to an increasing population with changing demands is clear, and so is the responsibility of agriculture towards the environment. A robustly sustainable agriculture, able to cope with dynamic environmental and economic conditions, requires a re-design at multiple levels of the agro-production chains. This should be a pro-active integrative approach in which agriculture takes responsibility and is part of the solution. Examples from the Netherlands and Ethiopia in which researchers, local stakeholders and policymakers are cooperating in addressing the future role and functions of agriculture in changing environments may provide the basis for new arrangements for agriculture.

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9. Towards a sustainable biobased economy

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9.1 Introduction

In the biobased economy biomass is not only used for food and animal feed, but also for the production of chemicals, materials, fuels, power and heat[3]. This concept is not new, biomass has always been used to a certain extent for these applications: wood is used as timber, or to produce heat in a stove, and power in a biomass electricity plant. However, within the scope of the biobased economy a significant part of the products that are now made from mineral resources, oil, gas and coal, will also be produced from biomass.

Drivers for the development of the biobased economy are depletion of fossil resources, climate change mitigation and energy security. Crop based production, including aquatic biomass production, is the only way to fixate CO_2 in a sustainable manner and at a sufficiently large scale. To increase sustainability of crop based production, and to concomitantly increase its economic profitability, scientific breakthroughs are required in two fields: A) maximize production per unit of input: land, water, nutrients and energy; B) maximize economic value per unit of biomass by production of high value molecules for biobased applications.

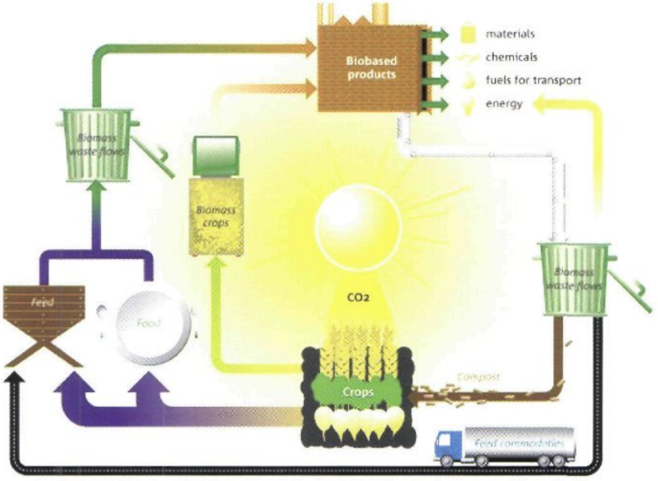

Figure 9.1. Concept of the biobased economy (LNV 2007).

[3] More general information on the biobased economy is collected on the website: www.groenegrondstoffen.nl.

Increase of crop productivity is realized by summoning numerous crop traits, including improved efficiency of photosynthesis (addressed in the research program Towards Bio-Solar Cells, which is coordinated by Wageningen UR and will start in 2010) or by exploiting new organisms with higher solar energy conversion efficiencies, such as algae. The main challenge in the second field is to realize the production of high value molecules that can be supplied by the agrosector and can match the feedstock needs of the chemical industry. Such molecules must be supplied in sufficient quantities, must be of adequate quality and chemical functionality, and must be produced at a competitive cost price. (Annevelink et al 2009)

The demand for renewable raw materials by energy and chemical industry sectors will increase the demand for biomass, which implies larger pressure on limiting resources such as arable land, nutrients and water, and will inevitably compete with food production (see: chapter 10 "competing claims"). Consequently it is essential to use the biomass as efficiently as possible, by using whole plant concepts, and also using rest products from the various biomass based production chains as feedstock for biobased products. (see Figure 9.1) (Bennet and Annevelink 2009). Two components are critical to achieve a successful and sustainable use of biomass:

1. Efficient production of high quality biomass, which comprise a high total yield per input unit, high level of valuable compounds, excellent processability;
2. Biorefinery of biomass, implying separating total biomass in a variety of components, which are then converted into a spectrum of products.

Just as is the case with a chemical refinery complex, a biorefinery can be profitable when all biomass components can be converted into marketable products. IEA has developed a definition of biorefinery which is presented in Box 9.1.

Box 9.1: Definition Biorefinery

Biorefinery is the sustainable processing of biomass into a spectrum of marketable products and energy (IEA Bioenergy Task 42 on Biorefineries) This definition includes the key words:

- *Biorefinery: concepts, facilities, processes, cluster of industries*
- *Sustainable: maximising economics, minimising environmental aspects, fossil fuel replacement, socio-economic aspects taken into account*
- *Processing: upstream processing, transformation, fractionation, thermo-chemical and/or biochemical conversion, extraction, separation, downstream processing*
- *Biomass: crops, organic residues, agro-residues, forest residues, wood, aquatic biomass*
- *Spectrum: more than one*
- *Marketable: a market (acceptable volumes & prices) already exists or is expected to be developed in the near future*
- *Products: both intermediates and final products, i.e. food, feed, materials, and chemicals*
- *Energy: fuels, power, heat*

Within the concept of a biobased economy, biobased raw materials are inherently meant to substitute fossil sources. It is of critical importance that the biobased products have a better environmental performance than their fossil counterparts. Furthermore, to ensure market acceptance of the biobased products, their quality performance should be at least equal compared to the present products, at an acceptable price.

Industry claims that the biotechnological processes which are applied in many biorefinery processes might lead to a cheaper product, since they can be performed at lower temperatures and generate less waste and therefore are more sustainable than the petrochemical processes. But also the price of sugar or starch/sugar and in the future lignocellulose is more reliable on the longer term that the price of mineral oil, which gives a solid base for the development of a biobased economy. (Blaauw et al. 2008)

Whereas the biorefinery concept focuses on separating the biomass in components, in some cases a more basic approach can be taken, using more simple technology like mechanical conversions to convert side streams from conventional commodity or food production into valuable materials. This is also of interest for developing countries, where waste streams from biomass production like coconut husk, can be converted into board material, which turns it from a serious environmental problem, into a valuable material. (van Dam et al. 2006, van Dam et al. 2007)

9.2 Research directions

The biobased economy presents a broad and ambitious transition. Although for many technological concepts within the biobased economy the proof of principle is given, still much research and development is needed, in order to turn the concepts in sustainable an economically viable products. In the area of biomass production research and development is necessary on crop choice and crop optimisation, productionparameters and collection of biomass, and closing of the nutrient and carbon cycles at farm level. In the area of application of the biomass research and development is necessary on biorefinery and conversion technology, the development of a wide range of applications of the biomass in biobased products, and on the economics of a biobased economy. Many of these research directions are presently taken up by Wageningen UR.

Sustainable farms in the biobased economy

Farms are the starting point of (dedicated) biomass production, specializing on livestock or arable production or combining both in one agricultural system. Crop residues and waste streams from food production are traditionally used as animal feeds, nutrient source or soil improvement. Typical examples for western European countries are the use of waste products from breweries and potato or sugar beet processing industries as feed or, the use of straw or other primary crop residues as a soil carbon source. On the other hand biobased non-food and non-feed production can induce a new type of, or an increasing amount of existing, side streams that can be used on farm level for feed or as nutrient and carbon source (Smeets 2009).

In general the use of crop residues or waste streams for the production of biobased materials, chemicals, fuels, heat or power will change the existing nutrient and carbon flows on farm level and beyond, to a new balance situation. Animal

nutrition and crop nutrient supply are part of the traditional expertise of Wageningen UR.
On the other hand the biobased economy can offer farmers possibilities for the production of non-traditional types of biomass such as aquatic biomass (i.e. duckweed (Lemna) or algae) or more added value to their traditional crops. Algae for instance can be produced using the CO_2 from co-digestion as input.

Logistics and markets

Organising the logistics chains is an important aspect of the biobased economy. The change in logistic chain and scale of operation will influence the possibilities of both the traditional use of side streams and the production of higher added value products by farmers. The scale of operation and the logistics of biomass collection are parameters that impact both the economic viability and the environmental sustainability of biobased chains. Wageningen UR has developed modelling tools for the arrangement of sustainable chains (Velazques-Marti and Annevelink 2009). Also the economics of production chains are being modelled, and the influence of the development of new biobased chains on agricultural markets is studied (Meeusen 2010).

Biomass production

As stated above, within a biobased economy, crop choice might come out differently than in an agricultural system that produces mainly for food. Crops could be bred to produce not only edible parts, for instance the grains, but also a significant portion of other biomass like lignocellulose to be used for the production of for instance chemicals.
Two approaches might be taken, either produce the high value-added component directly in the plant, or produce the high value-added component via chemistry or biochemistry (fermentation) from the "standard" components in the biomass, carbohydrates, lignin, oil or proteins.
Two recent USA studies by NREL (NREL 2004, NREL 2007) identified several chemical building blocks that could be produced from biomass components (carbohydrates or lignins). A recent report (Beilen et al 2007) identified three European crops as production platform for chemical building blocks (CBB): tobacco, Miscanthus and sugar beet. Since in the Netherlands sugarbeet is already subjected to relatively modern biorefining (including logistics) and has a very high yield potential, a logical next step would be to develop a sustainable production chain for combined production of chemical building blocks and bio-ethanol (or bioethylene) using sugar beet as production platform (Figure 9.2)

Another option under study is the production of algae, which can be cultivated in areas not suited for arable production or in maritime areas, and requires only suitable strains, nutrients and sunlight and fresh or salt water. Wageningen UR has many ongoing activities in the field of algae[4]. Wageningen UR is presently setting up Algae-PARC, a research facility on pilot scale to assist the scaling up of algae production for the production of biofuels (biodiesel) and biobased chemicals. Algae contain a relatively high percentage of fatty acids, which can be used for the production of fuels or chemicals (Mooibroek et al. 2008).

[4]See for a selection of projects: http://www.algae.wur.nl/UK/projects/

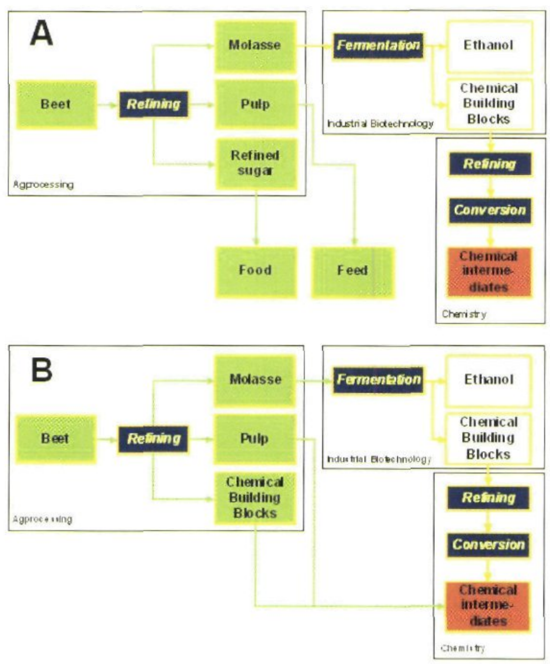

Figure 9.2. Existing production concept for food, feed, energy and CBB from beet biomass (A) and new production concept for combined production of chemical building blocks and bio-energy.

Another option is the development of an industrial platform for sustainable production of algal hydrocarbons. The work will deliver tools and technologies needed for the establishment of a new industry sector: Industrial Biotechnology with algae for the manufacture of new biopolymers, chemicals and biofuels. Hydrocarbons are selected as target compounds because they are an excellent feedstock for these large volume, medium value products.

Biorefinery

The collected biomass will be processed in a biorefinery. A biorefinery process comprises of a number of steps.

The first step, the pre-treatment is needed to separate the biomass into the various components. In some cases this is established technology originating from food industry, however for other biomass streams this still poses a challenge and processes need to be optimised further. This is especially relevant for the separation of the high value-added components that can be produced in the plant. These need to be isolated as pure as possible and with high output. Also challenging is the separation of lignocellulosic streams, the unedible parts of crops.
Various options are available, like pressing, critical CO_2 extraction and other. And for lignocellulose separation possibilities like for instance steam explosion (which is commercially used), alkalic pretreatment, acidic pre-treatment and other are explored. The choice for the pretreatment step is relevant for the whole system, since different pretreatment methods lead to different composition of the various streams.

Next, the separated biomass that cannot be used as such can be broken down to smaller building blocks, usually performed by enzymes through enzymatic hydrolysis. In the case of lignocellulose the building blocks are for instance fermentable sugars (C5 and C6 sugars). The building blocks thus ideally are platform chemicals, from which a variety of chemical products and polymers can be produced.

In the third step the building blocks are transformed in the desired products. This can be done by a (biochemical) fermentation step, but in some cases also (normal) chemical transformations can be applied.

Major challenges lie in the optimisation of the processes, in terms of efficiency, energy demand and selectivity.

Wageningen UR cooperates in a large number of biorefinery projects with other knowledge institutes and industry, aiming at the production of among others bio-ethanol, biohydrogen, biobutanol, lactic acid, natural rubbers and a wide variety of other building blocks (chemicals)[5]. Many of these building blocks contain two functional groups, which makes them suited for the production of (polymer) materials. Focus in most of these projects lies on all three steps of the biomass conversion: optimising pretreatment via different routes, enzymatic conversion, and fermentation or normal chemistry for the production of building blocks. The Catch-Bio consortium in which Wageningen UR participates for instance focuses on catalyst development for chemical conversions of biomass, the B-Basic consortium focuses more on biochemical conversions.

[5] Wageningen contributes to a large number of projects: ao Biosynergy (www.biosymergy.eu), EOS Biobutanol, EOS bioethanol, EOS N-ergy (see also www.biorefinery.nl), EU-pearls (www.eu-pearls.eu), lignovalue (www.lignovalue.eu).

Product development

The production of chemical building blocks is the first step towards development of intermediary and end products. The building blocks need to find their way into viable applications in the market. Necessary for this is the development of materials, polymers and other products. Wageningen UR cooperates with a large number of companies either in Public Private Partnership (PPP)-constructions or in bilateral co-operations on the development of products. Examples are starch plastics for packaging, Polylactic acid (PLA) (compostable) plastic products for horticultural applications, packaging or for insulation foams. In principle, once the building blocks are converted into plastics or other materials, one might find biobased materials throughout the whole society. (Bolck 2009)
Recently the BPM program has started, a cooperation of Wageningen UR with 6 Dutch knowledge institutes and 40 companies, which focuses on the development of performance materials (mainly plastics) from biomass, which can compete with a wide range of fossil based plastics in

terms of properties and price.
In cooperation with the Dutch Polymer Institute Wageningen UR also is active in the development of new chemical processes for the production of building blocks for high temperature resistant polymers. These processes are generally not based on biochemistry or fermentation processes but require chemical processes, with for instance carbohydrates as feedstock.
Next to the development of biobased chemicals and plastics, Wageningen UR is also active in the development of natural fibre reinforced materials for car parts, building applications, and other. Fibres under study are amongst other flax, hemp, kenaf and jute for composite materials with either fossil based plastics or biobased plastics as matrix material, and also the all cocosfibre based composites, cocoboard, which uses ingredients already present in the fibres to obtain board material by hot pressing, without addition of a binder.

9.3 State-of-the-art

Use of biomass for non-food, non-feed applications is not new. Wood for timber, fibres for textiles, oils for paints, and soap, cellulose for polymers (acetate and viscose) and starch for glues are just a few examples.

This indicates that there has always been agricultural production for non-food/non-feed applications. Usually the present flour mills or potato starch factories are essentially biorefineries, which produce mainly for food, but also for non-food markets. In the case of potato starch, the non-food market volume is significant, and might be one third of the starch production.

However, the recent increased Research and Development effort into developing crops and the biorefinery concept and new non-food applications for biomass, has led to new knowledge and also to new products which have already been introduced into the market.

Biomass production

Wageningen UR is very active in the development of the production of high value-added molecules in plants (Koops et al 2010). Two molecules are selected for direct production in sugar beet, lysine, which can act as a building block for nylon-6, and itaconic acid, which can serve as building block of acrylate based polymers.
Production of itaconic acid up to 2% of dry weight and production of lysine up to 2% of dry weight was realized in potato (2009). Patents on genes and concepts for overproduction of these molecules in crop plants are gained or in preparation (and therefore not yet published). (Koops 2009)

Wageningen UR is involved in various pilot scale projects on the production of algae for fuels and chemicals, and also cooperates with companies that already produce and market from algae, aiming at optimization of production and product development of new products from algae. Key enabling technologies for establishing industrial biotechnology with algae (and other feedstock) are fermentation science, metabolic pathway engineering, innovative downstream processing (DSP) and bio- or chemocatalytic process design. A key technology in the successful application of metabolic engineering is the availability of a well annotated genome and quantitative tools or genome-scale metabolic models that permit manipulation of the genome. Apart from fermentation science and DSP, none of the enabling tools are addressed in Wageningen UR. The first step is genome sequencing of hydrocarbon producing algae and comparative genome analyses from three different algal strains.

Methane fermentation (anaerobic digestion) producing biogas is a non-discriminatory type of biomass conversion into a general energy carrier (methane). Methane can be directly burned for lightning, cooking or heating, can be used for the production of electricity and heat using a combined heat and power (CHP) unit. It can also be fed into a natural gas grid or used as a biofuel for transportation in virtually all types of Otto or Diesel engines. It is implemented in all continents at different scales, from traditional low-tech small scale

Box 9.2: Anaerobic digestion

Installation for anaerobic digestion of biomass, including animals waste, on farm level are often treated as a black box. Farmers first attention is driven to either crop production or livestock keeping and the AD-installation is assumed to run autonomously. However, this is not the case and results in sub-optimal digestion processess and non or too little economic revenues. To realise an increase in economic results knowledge about the response in gas production to changes in feedstock is needed. The use of dynamic linear models (DLM), a Bayesian method for on-line analysis of time series, can provide this knowledge. Experiences in (concentrate feeding) of dairy cows shows that this technique is successful (Andre et al, 2009) and (Bleumer et al, 2009). Use of this technique on an AD installation is in the test phase and shows good results at a full scale AD installation on an dairy research farm of Wageningen UR Livestock Research.

household units in China and India to recent large scale high tech industrial units in western countries (i.e.Germany). By replacing fossil based energy sources anaerobic digestion contributes to a lower carbon dioxide emission. When also animal manures are used an extra greenhouse gas emission reduction is achieved by preventing methane emission for these manures (van Dooren 2009). Anaerobic digestion as a part of the biorefinery concept can contribute to a energy balanced production process by converting the non-usable rest products to energy. Wageningen UR expertise and contribution in this field ranges from fundamental research and modeling of anaerobic processes to applied knowledge on anaerobic treatment of wastewater and animal slurries.

Biorefinery and process technology

Biofuels have entered the market some years ago. At this moment the biofuels are mainly produced by the so-called first generation technology, based on well established fermentation of carbohydrates or transesterification of natural oils. Second generation biofuels are slowly entering the market and are expected to grow in the coming years. Wageningen UR is strongly involved in the further optimization of these processes. The feasibility to produce for instance bioethanol from straw, or biohydrogen from watery rest products has been shown and these processes are presently developed, focusing on higher yield and shorter reaction times. (Maas et al 2008), Panagiotopulos et al 2009, Panagiotopoulos et al 2009 (2)). Applications for lignin are presently being developed (Gosselink en al 2008, Gosselink et al 2010).

Wageningen UR has extensive research on the development of new and better enzymes. Recent developments have led to micro-organisms that are more efficient in converting biomass into products, thus reducing the production costs. These developments do not only focus on the production of biofuels but also on the (co-) production of chemicals from the same feedstock. (Maas et al 2008 (2).

Glycerol, the side stream of the biodiesel production from natural oils is now used as feedstock within the chemical industry and new production plants were recently constructed for the production of chemicals that were previously made from a fossil feedstocks (van Haveren and Heeres 2007). New applications for natural oils and the development of more benign reaction conditions is a focus within Wageningen UR, which resulted amongst others in the concept of a environmentally friendly alkyd paint, with good properties. Also a recent development from Wageningen UR is the production of Calendula oil for use in environmentally benign paint systems (developed in the Carmina project.

Product development

Especially in the field of bioplastics, there are many recent developments, where new plastics, such as polylactic acid (PLA) polyhydroxyalkanoates (PHA) and starch plastics were introduced recently.

Recently R&D institutes and the chemical industry have entered a new direction, where, based on the sugar platform, building blocks for polymers are produced by biorefinery and subsequent fermentation (Haveren et al 2007, Sanders et al 2007, Scott et al 2007, Scott et al 2010). The aforementioned PLA is a product from this development, but the building blocks are also used to replace a part of the present fossil building blocks in a number of materials. A product from this development is for instance Polyethyleneterephthalate (PET of the PET bottle) which is partly renewable (Sablong et al 2008). As mentioned above Wageningen UR has already contributed to these developments by developing new building blocks for bioplastics, and for plasticisers (Molenveld 2006), and also by product development for different bioplastics.[6] (Molenveld and Schennink 2009, van der Sluis and Schennink 2009)

6 More information of 4 research directions in this field can be found on: Lignovalue http://www.youtube.com/watch?v=GUW-flb4BDM EU-Pearls http://www.youtube.com/watch?v=ovlXsnKpDEs Bio-Pur http://www.youtube.com/watch?v=5FF7w88vnfM Algicoat http://www.youtube.com/watch?v=bU7xwBDLFKI

Natural fiber reinforced composites are commercially used in a variety of applications like car parts. The development of the all coconut fibre boards has led to the construction of a pilot production plant in the Philippines, and construction of a full-scale plant is presently under study.

9.4 Contribution to high-technological and eco-efficient agriculture

For decades the European agribusiness has suffered from low profits, overproduction and a negative image (large environmental impact, subsidy dependent). However, new societal drivers may revitalize European agriculture by turning arable farming land into an essential supplier of chemical feedstocks and energy. Major leaps forward in crop quality, crop yield and bioprocessing are needed to improve the economic viability and sustainability of crop based chemicals production.

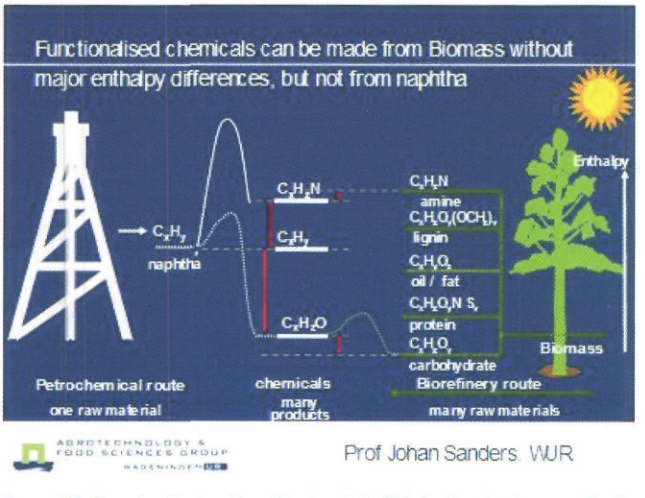

Figure 9.3. By using the functionality already built-in by the plant, energy for the production of functionalized molecules can be saved (source Johan Sanders, VPPS Wageningen UR).

A very important basic aspect of the biobased economy is that by using the functionality already built-in in the biomass, one can save a lot of energy for the production of chemicals (Figure 9.3). In the chemical industry building-in of for instance oxygen or nitrogen groups are very energy intensive processes. By using biomass these steps can be omitted and agriculture can thus help to make the chemical industry less energy intensive.

Producing chemical building blocks directly in plants gives agriculture the possibility to gain more added value in the production. Lysine and itaconic acid are now produced by industrial fermentation, using plant sugars as feedstock carbon. Direct production of these molecules in sugar crops, followed by refining according to Figure 9.2 will provide environmental and economic benefits, such as lower cost of production and lower capital investments.

The research on development of high value added chemical building blocks (CBB) will provide an example for an integrated high-tech approach towards achieving a new value chain, where values for the different uses will be stacked. The development of CBB/energy beets coincides with the significant reductions in sugar beet cultivation and significant reduction in profitability for the farmers as a consequence of the latest EU sugar reforms (2006). At the EU level the crop acreage for sugar production will be reduced by approx. 0.5-1 Mha due to the sugar reforms. Accordingly, there will be plenty of redundant processing plant capacity.
The proposed dual purpose non-food beet will contain high value-added chemical building blocks plus fermentable sugars for energy and other chemical building blocks with

Box 9.3: Production itaconic acid by starch potatoes
Itaconic acid is a building block chemical for high value polymers. Researchers of Plant Research International succeeded to genetically modify starch potato plants in such a way that they produce, in combination with starch, also itaconic acid to a high level. Production of chemicals by plants does not only deliver green chemicals for chemistry, but also ensures a direct, cheap and optimal usage of biomass.
http://www.youtube.com/watch?v=G4RN5fl8pWg

Box 9.4: Biofoam from bioplastic
Wageningen UR has supported Synbra Technologies, a Dutch based polymer producer, in the development of biobased and biodegradable expandable bead foams (Biofoam), a product that can replace polystyrene foam (piepschuim). At Wageningen UR PLA formulations were developed that can be foamed and moulded into products of 30 g/l, which leads to products with a high insulating value. Furthermore Wageningen UR has constructed the outlines of the process (foaming agent, processing temperatures) for the production of Biofoam.

a more simple structure, like furanics from the C5 sugars, and ethanol, succinic acid, lactic acid or others from the C6 sugars. This beet may easily lead to full compensation of the acreage loss. On top of that another 1.0 Mha of set-aside land could be used. Growing CBB beets on 2.0 Mha, preferably partly under control of Dutch industry, would be sufficient to replace 10% of gasoline by bio-ethanol, and to cover 15% of the chemical feedstock consumption for polymer production in Europe. Markets would easily absorb these quantities of CBB and fuel.

Concerning the introduction of algae, there are a number of criteria for the successful realization of this concept. Firstly, for an industrial production concept with algae to be competitive with microbes, or even crop plants, it is necessary to take full advantage of the typical microalgal strengths. The advantage of microalgae over microorganisms and plants is their very high photosynthetic productivity, and the ability to convert the larger part of their biomass into useful compounds: oils, hydrocarbons, specific algal carbohydrates and protein. Moreover, industrial production with algae provides an opportunity to capture substantial amounts of industrial CO_2 from other industry sectors. Large scale algal production thus complies with the European ambition to mitigate CO_2 emission. Biorefinery with subsequent industrial biotechnology transformations with algae may further contribute to raw material independency, in particular sustainable production of fuels and chemicals to substitute for fossil petrochemical products. And lastly, algae can grow in areas that are not suited for crop based agriculture. This aspect allows production of bio-energy and biobased chemical feedstocks, without competing with food production for limited resources such as land and fresh water.

In a well established biobased economy biomass is used efficiently for a wide range of applications. This implies also that value is added to side streams that were previously considered as waste. This is important in the Netherlands but it might be even more important in developing countries, where waste from agricultural production can pose a serious environmental problem. The all coconut fibre board materials are an example of this concept. Previously the fibres were considered as waste and burned. These kind of developments both diminish the waste problem and at the same time produce products to replace timber, so it diminishes the demand for wood, decreasing deforestation.

In most cases however the introduction of biorefinery concepts is a complex step and can have many effects on existing crop rotation, waste streams, animal feeding, nutrient balances, soil carbon content etc. These effects can range from regional to international level. Technology can contribute to the challenge of introducing these concepts and at the same time increase the eco-efficiency by closing nutrient and carbon cycles.

9.5 Short and medium term products

CBB producing sugar beet prototypes can be expected for the further development of biorefining procedures and conversion of CBB in chemical intermediates and end products (e.g. polymers).
As enzymes are optimised further, a wider range of 2nd generation biofuels (for instance also biobutanol), new biochemicals and new bioplastics, are expected to be developed in the coming years.
New building blocks will lead to the development of new bioplastics, but the development of a new polymer material generally takes approximately 10 years.

Material development will also lead to further optimisation of the properties of existing bioplastics which makes them suitable for a wider range of applications. An example of this is the development of a foaming process for PLA plastics by Wageningen UR. Synbra, a Dutch polystyrene foam producer is constructing a plant in the Netherlands to produce this biodegradable isolation foam.

Research on algae is expected to extend the range of products that is presently produced from algae (at this moment mainly feed and food ingredients). Focus lies presently on the development of fatty acids for biofuels, paints or bioplastics. Interest in the development of applications for algal proteins is rising. Spin off from the algal research could furthermore be the development of optimized algal strains, which will serve as production platforms for specific hydrocarbons. These strains will produce different hydrocarbon monomers and other raw materials for the manufacture of biopolymers, bulk chemicals, lubricants, fuels and fine chemicals. Also new metabolic concepts for hydrocarbon production, protocols for manufacture of new biomaterials or useful molecules are foreseen.

9.6 Aspects underexposed

Although there are many activities ongoing, these are mostly more or less isolated developments. Approaches focussing on integrating the whole system are scarce.
Especially the link between agriculture and the (chemical) industry needs to be strengthened and an integrated vision needs to be developed together with all industrial and societal stakeholders.
Many industrial developments are presently focused on the sugar platform, using sugar, starch or cellulose as feedstock to produce the desired chemicals by subsequent fermentation. The perspective to realize a high production level of specific chemical feedstocks by plants is still relatively underexposed. The viability of in planta production of CBB depends on the generation of substantial yields without a deleterious impact on the host. Plants must be capable of accumulation a selected compound to up to 10% of the crop dry weight (2% of fresh weight), which is still 5 times higher than currently realized. The fundamental work include the identification of bottlenecks in the pathways leading to these molecules, the identification of membrane bound carrier proteins, and to target the carrier proteins to the tonoplast to mediate the active accumulation of these molecules in the vacuole. To ensure industrial use of CBB, the agro-processor, in close interaction with the end user and technology providers, needs to develop procedures for extraction, and purification of these molecules from sugar beet (or other crop) process streams.

Because of high productivity, and the possibility of raw material production beyond areas suitable for arable production, development of concepts for large scale industrial production with algae need further consideration. The first step into this direction is taken by a small number of players worldwide, amongst which Wageningen UR. To take full advantage of the unique algal production capability, controlled input of nutrients is essential. However this do not fit well with production in open connection to the environment. Since biobased production is inherently large scale, concepts for cheap, large scale, contained production of biobased raw materials with algae is urgently needed.

Another aspect that needs more attention is the development of robust biorefinery processes that are capable of handling a mixed biomass input and can deliver well defined output. Many mixed biomass streams are presently used to produce energy, which is a relatively low value application, both in terms of economics are well as in terms of sustainability. Better refinery processes in combination with new better logistics can increase the sustainability of biomass applications.

9.7 Recommendations

For the biobased economy to develop into a sustainable system it is of importance to pay attention to effects of the new use of biomass or biomass components on crop rotation, nutrient and carbon cycles and energy consumption, in combination with the environmental effects that the further processing of the biomass in the biorefinery and further on into products has. It is essential to approach the whole production system, from production of the crops/ biomass sources in conjunction with the separation processes in the biorefinery and the following chemical conversion processes, including valuation of the rest products and waste streams a whole. This is not an easy task, since it also requires the connection of researchers and stakeholders of very different professional backgrounds. Nevertheless producing and processing biomass (growing crops or using waste or side streams) for food, feed or any other purpose should be approached as a whole. Wageningen UR is one of the few players that is able to connect chemistry and agriculture.

Wageningen UR is presently setting up its future research agenda around six research and development directions, which will be managed in connection with each other in order to maintain the integral approach:

- Dedicated crops for BbE
- Land-use and resource management
- Biobased chemicals
- Biobased materials
- Biofuels and energy
- Sustainable chain development

Which these six focus area's Wageningen UR covers a large part of the research field.

In order to develop the biobased economy in the Netherlands, cooperation between knowledge institutions, academia, industry and SMEs is essential (Bos et al 2008). Furthermore, industry from different sectors, agri-food, chemistry, energy and logistics needs to join forces in order to build production chains from biomass production to end products.
The government therefore needs to strengthen the cooperation between the various players, for instance by supporting PPP initiatives. Development of sustainable technology is a key success factor for the development of the biobased economy. Next to technology societal issues and research questions on sustainable production and consumption need to be addressed. Furthermore, building public awareness on the alternatives for fossil resources can help support the introduction of sustainable biobased products.

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10. Competing Claims on Natural Resources

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10.1 Introduction

The earth has limited natural resources whereas the claims on these resources are multiple and increasing. This may lead to scarcity, competition and conflict. An increasing world population accompanied by an increase in demand for food and water and an income-dependent demand for meat and energy, gold and diamonds, leads to increasing claims on natural resources. Population growth also puts pressure on social systems. Both the increase in population and globalization make decision making and policy about access to, and use and protection of natural resources rather complex as increasingly more parties are involved.

To deal responsibly and carefully with competing claims knowledge is needed about the resources, their potential uses, mechanisms of access, and the multitude of parties that represent historic, present and future claims. It is important to realize that parties are not neutral nor mainly aiming for the public interest or safeguarding public goods, but rather serving their own private interests using different forms of power and persuasion.

Decision-making regarding access to and use of natural resources is complex because claims are made and negotiated simultaneously at different hierarchical levels. Policies will be translated in concrete activities at specific locations whereas in turn local activities based on local claims can influence processes and developments at higher levels. Furthermore there is a tension between short term and long term objectives. Finally there is tradeoff between the economic and ecological system. The economic system includes markets, investments, prices, costs and benefits as ruling principles related to the exploitation of resources. The ecological system has a certain, though restricted, resilience based in regulation through internal feed-back relations, in response to exploitation, but might flip into undesired states as a result of "overexploitation' or other types of disturbances (Scheffer et al, 2001).

For sustainable solutions regarding competing claims on natural resources attention has to be given to effects on and trade off between the three sustainability domains (people, planet, profit), locations (spatial scales) and short and long term (temporal scales). Sustainability implies that the resource base should at least not decrease in quantity or quality in the future. Research is needed to develop new technologies and new production systems to increase absolute production and production efficiency, by decreasing the use of inputs, materials and spillover effects to the environment. In the people domain the diversity of actors, the distribution between costs and benefits over these actors, equity issues and power relations require attention. Research is needed in societal processes and institutions fostering more equitable distribution and reducing exclusion, hunger and violence. Knowledge and competencies in negotiation processes, participative policy and decision making, creation of social support and mobilization of both private sector and civil society for public goods is crucial to further social stability and to prevent that competing claims end in conflict and war.

Key question of this chapter is what can Wageningen UR science contribute to sustainably resolving competing claims? In the current Competing Claims on Natural Resources research programs of Wageningen UR natural resources are explicitly connected to agencies that claim the resources hence both natural and social sciences are needed and preferably integrated to solve competition over resources, either avoiding or solving conflict.

A typical research domain for the natural sciences of Wageningen UR is to assess the quantity and quality of the natural resources, their spatial-temporal dynamics and the past, current and future claims on them in scenario studies. Ongoing research in new technological opportunities and system design will decrease competing claims by simultaneously satisfying previously mutually exclusive and thereby conflicting demands. Such technological opportunities and designs aim to increase natural resource use efficiency and productivity through developing non-excluding alternative uses (e.g. bio-refinary, whole plant concept, multiple land use) and reduce environmental costs by closing nutrient, water and material cycles (e.g. agro-production parks). Research ranges from incremental improvements (higher efficiency of existing systems and technologies) to research aiming at system changes and transitions (e.g. bio-based economy). Such research will provide new alternatives to be included in the scenarios.

The social sciences in Wageningen UR aim at contributions to solve competing claims by doing research on stakeholders, their historic, present and future claims, interests, rights, duties and power, and the meaning of natural resources and claims in a social context. Specific research attention is geared to negotiation processes going beyond compromises, acknowledging the outcomes of win-loose solutions needing explicit compensation for the losers, but especially aiming at integrated and synergetic outcomes satisfying different claimants at the same time. Social science research provides insight in policies, economic processes and in the institutional settings at different scale levels where claims are expressed and agreements, policy and laws are devised and implemented.

10.2 Research directions

The research is focused on developing an integrated approach to identify, analyse, explore and contribute to resolving competing claims on natural resources designing social, technical or socio-technical options for more sustainable and equitable resource use. The essence of the approach is captured in two Figures (Giller et al, 2008). In the domain of resolving competing claims we need to be aware of the different scale effects and their interconnections. Figure 10.1 deconstructs the myth that local problems are created at local level and can be solved by local solutions alone. Insight in the larger political, economical and ecological context is crucial for understanding the driving forces leading to local problems and these higher scale levels need often be included in their solution. Figure 10.1 also intends to show that international polices tend to have large influence on local processes (bold arrows) but are only weakly informed by them (dotted arrows). Yet accumulation of local actions and individual decisions can have large influences on global processes and collective goods. Think of the interaction between international nature conservation agreements such as peace parks initiatives leading to collective resettlement of individuals depriving them from their natural resource base in a particular locality or on the other side individual decisions to buy and drive a car above certain income levels, collectively undermining the effect of global climate change policies. The research challenge is to connect the different scales while integrating biophysical, economic and social-cultural aspects, capturing the spatial-temporal dynamics of resources, their use and users.

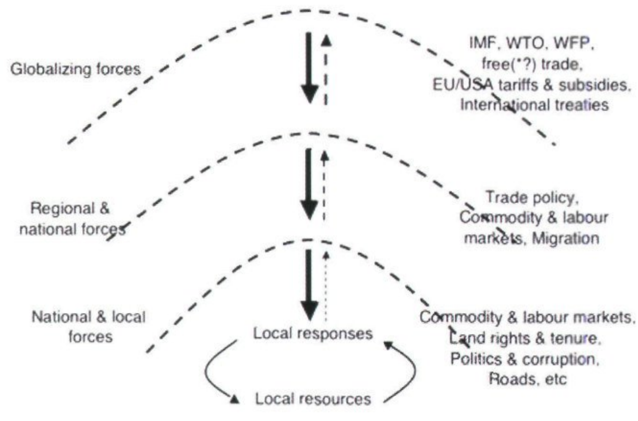

Figure 10.1. Multi-scale drivers of competing claims on natural resources (Giller et al, 2008).

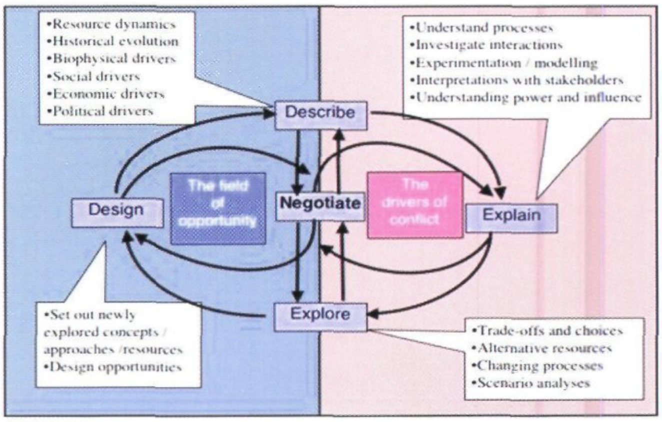

Figure 10.2. Phases of resolving competing claims.

To work on resolving competing claims we distinguish four phases (Figure 10.2): to describe, explain, explore, design (Giller et al, 2008).

Negotiation is placed central in Figure 10.2 as in each of the phases interaction with the relevant stakeholders (claimants) is crucial and knowledge as well as potential solutions will be generated in negotiation with them.

In summary we aim to develop analytical tools to increase the understanding of competing claims and their driving forces and to develop solutions that fulfill different claims simultaneously instead of favoring one claim(ant) over the other. More sustainable resource use and more equity in this use are the two central aims of the approach. The four mentioned phases and the relevant research questions that fit each phase are given below. Wageningen UR is conducting research on each of these research questions but not necessarily in interaction or as part of a generic approach to deal with competing claims issues.

***A** Describe (Inventory)*

A1 To use natural science methodology to describe the availability of natural resources (water, soil, and all organisms that grow on/in them: forest, crops, fish, etc) and their spatial-temporal dynamics in particular locations.

A2 To use social science methodology to make an inventory of the relevant claimants, their history, claims, discourses, interest, technical economic and political powers, their alliances, institutional environment and their way to understand the dynamics of resource competition.

A3 To identify and quantify the competition for resource use that results from the mismatch between resource availability and claims at different levels.

***B** Explain (Increase understanding)*

B1 To research the underlying socio-economic and agro-ecological processes that drive and shape resource use and competition.

B2 To research the different scales and levels at which the mentioned processes occur with particular attention for the interactions between these processes across scales.

B3 To quantify the effects of different resource uses.

B4 To increase the technology base for higher yield, higher resource use efficiency and new processing techniques satisfying more demands from the same resources.

B5 To research new forms of institutions, agreements, laws, platforms etc. facilitating more equitable negotiations over resource access and use and compliance to agreed outcomes.

***C** Explore (The uncertain future)*

C1 To develop scenarios about the resource base and its dynamics; including past, current and future availability and potential production of natural resources in relation to past, current and potential future demands for food, energy, biodiversity, etc.

C2 To develop scenarios that provide insight in trade offs and complementarities in an uncertain future.

C3 To develop knowledge about and skills in participation in integrated negotiations leading to an increase in solution space.

C4 To identify ecological, ethnological, social, economic, institutional and political obstacles that might be encountered in the process of realizing possible options.

C4 To improve scenarios with potential alternative technologies (B4) and institutions (B5) allowing multiple claims to be satisfied at the same time either by more efficient resource use or by new processing technologies or by new resource use agreements.

***D** Design (a desirable future)*

D1 To provide technical, social or techno-social solutions to resolve competing claims.

D2 To develop solutions that fulfill different claims simultaneously instead of favoring one claim(ant) over the other.

D3 To provide solutions to support action to actually resolve resource conflicts.

D4 To improve existing or build new institutions capable of dealing with integrative negotiations and a variety of claimants.

D5 To design new forms of agreements, models of cooperation that lead to more equitable and sustainable management of natural resources.

10.3 State-of-the-art

The domain of Competing Claims on Natural Resources is particularly new in its attempt to provide an integrated approach (see Section 2). Therefore we will mention here the state of the art in a few key research domains: natural resource dynamics; natural resource use(rs); integrated assessment approaches. We introduce here the analytical tools and research approaches needed for the "describe and explain" phase although integrated assessments and scenario studies focus on the explore phase.

Competing claims occur on terrestrial and marine resources. As LNV has also commissioned a study on water issues we have omitted Wageningen UR research on this domain in this document.

Natural resource dynamics

To describe spatial-temporal natural resource dynamics Wageningen UR has a number of groups that are specialised in two large research areas. One type is focusing on understanding the underlying mechanism of interaction between flora and fauna in nature conservation areas (Resource Ecology group) or the effect of different management regimes by people on specific resources for instance in the domain of forestry (Forestry and Nature conservation group). Another type is doing research on resources focusing on land use. They conduct large scale land cover studies distinguishing between cropland, forest, pasture, urban areas, deserts or bare soil based in aerial photographs, satellite images and remote sensing techniques combined with ground truthing (Land Dynamics group). Typical types of information resulting from these methods are vegetation cover (and land use class), soil quality and standing biomass and their development over time. Appropriate combinations of methods can be used in global, continental, national, regional, and even local scale. Methods to assess quality of the biomass through remote sensing techniques are in development.

Land cover and land use are not identical. Land cover focuses on landscape level and can only assess the outcome of management, for instance in terms of biomass. Within each class of land cover, management can be very diverse even leading to similar (biomass) outcomes and this can not be assessed with the same methods. Hence Wageningen UR provides more in depth research on land use by forestry groups and by farming systems research groups (Plant Production Systems group and Animal Production Systems group). Here the research automatically gets a social dimension as people decide on access rules, use and management practices. Geographical Information System (GIS) technology is used to support spatially explicit land cover and land use studies. In the context of competing claims participatory GIS approaches (ALTERRA) are available to involve current and potential resource users in the inventory of resources and their users. A very important issue is how to combine information from different scales. Aggregating farms does not connect one to one with what happens at a regional level where for instance a watershed has its own dynamics and management needs. Also, farms cannot just be added up in area but farm managers show different behavior and interact for instance through markets which makes adding up of farms problematic in the socio-economic domain as well. Scaling down from satellite image-based land cover units to local level leads to discovery of high heterogeneity within land cover classes established at higher scale levels. Hence, a combination of perspectives using different tools is required to provide knowledge to understand processes at different scales and across scales. The choices of tools and scale depend on the research question or problem definition.

Natural resource use(rs)

The inventory of the spatial-temporal dynamic of resource use(r)s is highly complex. Analysis of time series of aerial photographs and satellite images may reveal land occupation patterns but only distinguish broad categories and do not tell by whom they were occupied. The social sciences study historical literature, archives and maps that may reveal official boundaries between territories and registered landownership. However land use is subject to many unwritten rules of access and use that is the research domain of Rural Sociology and Law groups that can investigate localities where competition on natural resources takes or will potentially take place.

These informal rules interact with formal laws and policies leading to legal pluralism and strategies of stakeholders to deal with that. An inventory of past and current claimants requires research on different scale levels, connecting formal and unwritten policies, laws, rules, international and local agreements. Institutional economics (Development Economics group and LEI) is a field of science that explicitly addresses temporal variations in institutions ranging from slowly changing norms and values in society to daily price setting. An economic approach towards dealing with competing claims is pricing all goods and services, including ecosystem services and costs of pollution or so-called negative externalities (Environmental Economics group). Although a very useful element of the equation, as a stand-alone approach this economic approach may favor those with purchasing power over those that have not and not necessarily guarantee public goods to all or in the future.
The Forest and Nature Conservation Policy group focuses on environmental diplomacy and the Public Administration and Policy group focus on multilevel governance, both aiming to address decision-making at different levels. Although an important contribution to the multi-scale issue, policy decisions need to be multi-domain as well to address the complexity of Competing Claims issues. In the explorative phase agent based modeling (Communication and Innovation Sciences; Logistics, Decision and Information Sciences) is available as a tool to increase insights in potential stakeholder behavior and results. The recently launched Centre for Development and Innovation (CDI) within the social sciences group of Wageningen UR has particular competencies in facilitation of stakeholder and negotiation processes mainly at local but occasionally also at national or international level. Within Wageningen UR connecting such competencies and experiences with theory especially through linkages between CDI and the Communication and Innovation group (Leeuwis, 2000), working on similar issues will increase knowledge about such processes and their contribution to solving resource competition.

Integrated assessment and modeling

A number of frameworks and tools have been developed to try to simultaneously assess the different impacts of technological developments, policies and decision-making. At farm scale so-called bio-economic farm models have been developed that assist in assessing consequences of alternative farm management and design and possible farm responses to changes in policies (Janssen and Van Ittersum, 2007). These models allow to reveal tradeoffs or synergies between environmental and economic goals and underpin the quantification of the effects of policies and changes in farm management and lay-out. The Plant Science groups (PRI and Plant Production Systems) tend to lead such modeling exercises including expertise from economic and animal sciences groups, such as Business Economics, Development Economics and Animal Production Systems groups.
The environmental science groups (in particular Land Dynamics group and ALTERRA) have large expertise with spatially explicit models at landscape level also apt to deal with a number of tradeoffs between different domains at landscape level (Stoorvogel et al, 2004). The environmental sciences group is also actively involved in the climate change models underpinning global scale scenario studies used by IPCC (Environmental Systems Analysis and ALTERRA) exploring potential effects of climate change policies.
The social science groups have large expertise in modeling both the process of global trade and Common Agricultural Policy (GTAP and CAPRI by LEI, for instance) and at smaller scale on behavior of farmers or other stakeholders in agent-based modeling (CIS and LDI).

Essentially most of these models originate from one scientific discipline and draw theory and expertise from other disciplines - these are examples of at least partially integrated approaches. One step further is to aim for an integrated assessment using an interdisciplinary modeling framework. A recent large international initiative that explicitly conducted research in this field is SEAMLESS (EU Framework Programme 6). Integrated assessment frameworks and tools are relevant in the Explain and Explore stage as they can provide insights in trade-offs resulting from a variety of policy or technology choices. The final choices will be based in negotiation about the desirability of the results weighing gains in one domain against losses in another.

SEAMLESS

European agriculture and rural areas face rapid changes in response to agreements to liberalize international trade, the introduction of novel agro-technologies, changing societal demand towards food and rural areas, and climate change. The challenges in responding to these driving forces are not framed in terms of competing claims but rather framed as a challenge to devise policies underpinning sustainable development (SD). Assessing the strengths and weaknesses of new policies and innovations on all aspects of sustainability prior to their introduction, i.e., ex-ante impact assessment, is considered vital in policy development for SD. As SD includes many domains a framework allowing for an integrated assessment of policy impacts at different scale levels seems appropriate. The demand for such assessment came from European policy as since 2003 impact assessment is mandatory for all regulatory proposals and negotiation guidelines for international agreements included in the European Commission's Work Programme. With European funding and in collaboration with other European partners Wageningen UR (Van Ittersum et al, 2008) has led an interdisciplinary program aiming to develop a System for Environmental and Agricultural Modeling (SEAMLESS). The programme developed a computerized and integrated framework (SEAMLESS-IF) to compare alternative agricultural and environmental policy options.

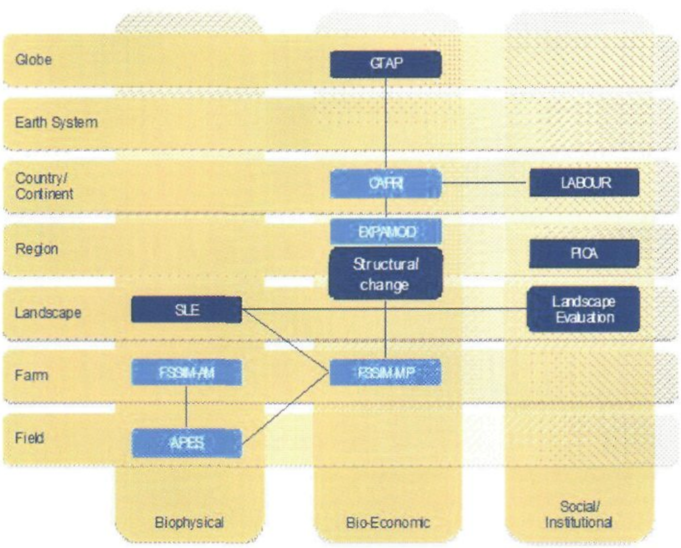

Figure 10.3. the SEAMLESS-IF framework consisting of connected models at different scale levels in the biophysical, bio-economic and social-institutional domain.

SEAMLESS-IF uses linkage of quantitative models, an integrated European database and a set of indicators to assess the impact on society of proposed policies. Bio-economic farm modeling (Janssen and Van Ittersum, 2007) forms an important cornerstone of the methodology, but is complemented with biophysical simulation models and economic models capturing supply and demand relationships. Jointly the models are able to cover relevant processes at field, farm, regional and international level.

For any policy that needs to be assessed the integrated framework follows a three phase workflow: (1) A pre-modeling phase consisting of a narrative part where the problem is stated, scenarios to be explored are described and relevant indicators are chosen. (2) A modeling phase where the chain of models suitable for analyzing the problem is selected and applied, and rules for scaling of model outputs are chosen. (3) A post-modeling phase focusing on visualization, presentation and export of results.

The framework has been developed around two case studies, one to assess impacts of the 2003 CAP reform and the nitrate directive in the Midi-Pyrenees region in France and one to assess effects of WTO trade liberalization proposals and in particular the reduction of international barriers to trade on European agriculture, consumers of agricultural goods and the income from agricultural tariffs. SEAMLESS-IF facilitates the process of assessing key indicators that characterize interactions between agricultural systems, natural and human resources, and society. The different model components enable assessment from European to field scale. In ongoing new projects the framework is further tested and applied, whereas a European Network of Excellence (LIAISE – led by ALTERRA) is focusing on the use of these type of tools in policy assessment.

10.4 *Contribution to high-technological and eco-efficient agriculture*

The approach on Competing Claims on Natural Resources is needed to assess where and when high-technological and eco-efficient agriculture is a feasible part of the solution.

The approach is suitable for any type of country and its unit of analysis can range from local to global level, in fact its strength lies in its multi-scale capability. High-technological and eco-efficient agriculture options need to be considered in the range of options for future development and hence to be included in qualitative or quantitative studies, integrated assessments and scenario studies. This type of agriculture reduces potential environmental externalities whereas the increased yield per ha and per unit input leads to lower claims on land, water and nutrients and therefore this type of agriculture is in itself an example of an integrated solution reducing claims on natural resources. Where this type of agriculture leads to different outlets for different components of produced biomass the claims on natural resources can be further decreased. In return the research on Competing Claims on Natural Resource can generate innovative ideas for high-technological and eco-efficient agricultural production systems as outcomes of integrative negotiations (Carnevale, 2006). Examples of solutions to increase the resource base are for instance biorefinary that came to the fore when exploring the biobased economy. Biorefinary allows produced biomass to be split into different valuable components hence one hectare can deliver both food, feed and chemicals instead of needing one hectare for each of them so we go from exclusive to integrated outcomes. Similarly agroproduction parks reduce ecological problems from different sectors of the economy by cleverly using each others waste products in a productive way. Hence instead of spending money on environmental friendly technologies the environmental problems (such as manure excesses) are turned into production opportunities (biogas production or substrate for mushroom cultivation). Such solutions only come to the fore and are only economically viable when competing claims are explicit, stakeholders interests are combined and needs arise for integrated solutions and when institutions change to facilitate or accommodate them. For agro-production parks integrated environmental assessment procedures need to be developed integrating those for agriculture, industrial land use and urbanization in one system.

10.5 Short and medium term products

In the Wageningen UR funded INREF program "Competing Claims on Natural Resources: Overcoming Mismatches in Resource Use through a Multi-Scale Perspective (Giller et al, 2005)" an integrated approach is tested and further developed consisting of the four mentioned phases, paying attention to negotiation and to driving forces at different spatial-temporal and political scale levels. Fifteen science groups from Wageningen UR and many international partners from research institutes in the countries where the research is conducted are included in the program. Research is conducted by PhD students and, based on the results and experiences encountered during this program, staff is challenged to further develop the methodology. The program focus is on solving local competing claims in Zimbabwe, South Africa and Mozambique in the vicinity of a proposed transfrontier nature conservation area (Peace park). The program works together with the University of Zimbabwe and Eduardo Mondlane University of Mozambique and the AHEAD (Animal and Human health for the Environment And Development: www.wcs-ahead.org) program but also with local park authorities and private biofuel companies and NGOs either pursuing nature conservation agendas or development agendas. The choice for three countries is motivated by the aim to test the robustness of the methodology in different contexts. The article by Giller et al (2008) was a first conceptual output and research-based results are expected end 2011.

The question of robustness in different socio-economic, natural resource and policy contexts is further addressed by conducting a similar program in Brazil, including other scientists from Wageningen UR and for which the results will be available end 2012. A first analytical paper on multi-scale drivers of competing claims in the sugarcane area will be available early 2010. Four PhD students work on issues of deforestation, land degradation and "forced" migration, resulting from competing claims between meat, wood, sugarcane, soy production and nature in rainforest and savanna, each of them driven by a combination of

Brazilian policies on land tenure, bioenergy and economic development, by European demands for soy and bio-energy and global claims for nature as voiced by international NGO's.

Robustness related to different dominant or new driving forces in specific locations is tested within the "Competing Claims-Competing models" project (an international consortium of scientific partners) on biofuel investments in Mozambique, as part of the Wageningen UR-DGIS partnership program. In this project MSc students from different study programs carry out research that aims to support Mozambican and Dutch policy development on biofuels. During the project outputs are immediately shared with Mozambican government, industry and civil society and feed into the formulation of a governmental policy for sustainability criteria regarding biomass for bioenergy production in Mozambique. This way a particular interface between science and policy is tested on its contribution to avoiding natural resource conflicts. The more aggregated results will be available early 2011. Within the Wageningen UR-DGIS partnership program three more projects are conducted: one on competing claims in forest areas in Ghana (Consortium led by CDI and Forest and Nature Conservation group) where a variety of stakeholder processes and policy instruments are evaluated that might assist in solving them; one dealing with claims on water in the Incomati river basin in South Africa (consortium led by LEI) mainly focusing on building a model quantifying water use; and one in Ethiopia (consortium led by PRI) on Improving livelihoods and resource management in the Central Rift Valley of Ethiopia where water of a lake is claimed for many uses. These three programs will also deliver their aggregated results early 2011.
The proposed competing claims approach by Giller et al. (2008) is also used in the Dutch context for instance in Almere (Visser et al, 2009) where urban development, nature conservation, climate change mitigation (room for water), agriculture and recreation compete for space. Results of this approach become annually available as part of the strategic research program of Wageningen UR (KB-programs). The approach is also applied to highlight how scientific knowledge was mobilized in the competing claims context of the poldering of De Noordwaard area in The Netherlands.
The "room for the river" approach implemented by the Dutch government in De Noordwaard affected a variety of stakeholders each of them using specific scientific results to substantiate its claims in the negotiation process. Timing of scientific input appeared to have large influence on its impact on policy. The results have already been published (Schut et al,).

Box 10.1: Scenarios in the explore phase
In Almere the following functions needed to be accommodated in an area that was to small for the sum of them: building of houses for citizens of Amsterdam, ecological corridor, storage of water in times of high tides, agriculture, leisure. In a multi-stakeholder process four scenarios were developed to explore different futures. The two most contrasting ones were: the Mondriaan landscape, consisting of large square fields of different highly productive seasonal crops in attractive colors, combined with large luxury apartment stores with in-house cinema, fitness centre etc. where single people or couples live that do not work in the region, have a global orientation and therefore do not have much time or interest to interact with the landscape other than enjoying viewing it. Water storage is in a separate zone with houses floating on water, whereas the nature corridor is set aside. A second scenario, Arcadian landscape, representing the romantic view on the past, meandering rivers, water storage through seasonal flooding of riversides, corridors intertwined with farmers fields, environmental friendly production only, restoration of cultural heritage sites, housing scattered in the landscape following the landscape features, many people spending daytime in the area enjoying being connected to the landscape through buying regional produce on-farm, outdoor education and tourism activities, home gardening, care farms, etc.

When focusing on Dutch or European cases we can state that KB programs are dealing with Competing Claims issues and can potentially benefit from and contribute to the current Competing Claims approach. Landscape use and planning processes are for instance in the core of KB and deal in essence with Competing Claims on land and water. Similarly, the KB research on the biobased economy, hosts the potential to increase competition for resources following from the claims for renewable energy whereas biorefinery for instance might decrease this competition. In the KB program on

Box 10.2: Negotiations leading to an integrative solution
In Mozambique seven villages need to be resettled because their homesteads, crop and grazing lands have been classified as national park by the Mozambican government as a result of an international agreement on the establishment of a transboundary peace park together with Kruger National Park, South Africa. They are resettled outside the park boundaries on land belonging to existing villages. As compensation for their lost land the park authorities negotiated on their behalf with the existing villages resulting in new crop land and a place to build their new houses. The houses were build for them, they received a water well and their land would be ploughed, all funded by an external project. In the meantime the Mozambican government gave a sugarcane company the right to start a 25.000 ha sugarcane plantation in exactly the same land. The settling villages had to move up to other land again and the amount of grazing land for both hosting and resettled villages became very small. The hosting villages complained as no compensation was foreseen for them. In a trilateral negotiation: park authorities-sugarcane company and villagers they came to the agreement that the sugarcane company would compensate the hosting villages for their lost crop land, and that the grazing cattle would get residues of sugar production as feed to compensate for loss of pasture. Villagers were also promised priority when the sugarcane plantation would need employees.

Sustainable Agriculture new technologies are developed fitting into phase B4 and C4 whereas the KB program on Transition focuses on new institutions both potentially contributing to solving competing claims issues. For 2010 these four strategic research programs have formulated an overarching Competing Claims project including the daily coordinator of the current Competing Claims programmes (Plant Production Systems group) to explore options that might lead to the formulation of new research questions or new applications aiming to further improve the current Competing Claims approach. Within the KB program on Transition Processes, several groups of Wageningen UR have also joined forces with the daily coordinator of the currently running Competing Claims programmes (PPS), not to develop research questions, but to add value to the competencies and experiences of CDI by building up more theory on the role of power in stakeholder processes and negotiations, the design of effective institutions and other governance issues related to competing claims. They focus on cases in developing countries. First results become available end 2010.

Processes in the biophysical world and governance systems often operate at spatial and temporal scales which are only partially overlapping. This results in mismatches between policy and science as information is often not available at the specific scale levels of decision-making whereas in return policies lead to unintended outcomes at different levels. The Scaling and governance program (one of the 6 strategic themes of Wageningen UR as defined in its strategic plan) jointly funded by Wageningen UR and the KB program on arranging the green and blue open spaces aims to develop methodology to address scales and levels in the biophysical world and policy domain in an integrated way. Three position papers have been produced (Buizer et al, 2010; Termeer et al, 2010; Veldkamp et al 2010) to outline the research domain and research agenda for this topic. In November 2010 an international conference will be organised to discuss the first results and to position them in the international progress in this field. More robust experiment-based results are expected in 4 years time when the PhD studies will have delivered their results. Yet four years seem too short to invest in this important research domain.

SEAMLESS has proven to work for specific policy questions and impact indicators. The continuous development of the framework after the lifetime of the project is ensured by the SEAMLESS Association, established in March 2009. The SEAMLESS association will maintain, document and update the models and the integrated framework. The association will also foster new applications. Applications of SEAMLESS-IF to scenarios with higher prices of agricultural commodities and climate change adaptation are ongoing in 2009-2011. New and continued research is anticipated on specific components to improve landscape and regional assessments and modeling of structural change. The different components of SEAMLESS such as the bio-economic models might be more or less easily adapted to be useful in many more contexts, supporting the explain and explore phase, leading to medium term results. This is presently being investigated for some developing countries in another EU funded project (LUPIS) and in a

Box 10.3: Application and outcomes of SEAMLESS integrated assessment

The framework has been used to assess impacts of the 2003 CAP reform and the nitrate directive in the Midi-Pyrenees region in France and to assess effects of WTO trade liberalization proposals and in particular the reduction of international barriers to trade on European agriculture, consumers of agricultural goods and the income from agricultural tariffs. Using SEAMLESS-IF the analysis from the SEAMCAP module indicated that in all scenarios agricultural income declined, whereas consumers' welfare increased with a decrease in tariffs. In all cases, the loss in agricultural income and tariff revenues was compensated by increasing consumer's welfare, so that the total welfare in the agricultural sector increased. Regional differences were determined by the mix of production activities. Meat prices declined most strongly in all scenarios, leading to a stronger decline in agricultural income in meat producing regions. The FSSIM model allowed to assess the biophysical impacts at regional level, showing that alongside the income decline nitrate leaching and soil erosion increased, whereas pesticide use declined.

WOTRO funded bioenergy project in Mozambique and Brazil. The other chapters of this report show that numerous results will be generated in the short, medium and long term that can feed into explore and design phases of our approach increasing space for resolving competing claims on natural resources either increasing the resource base and its products or providing resources users more attractive alternatives. Increasing the resource base by marine production systems, increasing resource efficiency by multiple use of biomass through bio-refinery or by closing cycles through agro-production parks, multiple land use e.g. urban agriculture on roofs of houses or recreation in industrial area are a number of very promising and underexploited options. The other chapters also elaborate on some of the modeling tools.

10.6 Aspects underexposed

So far many scientists approach competing claims only from a quantitative analytical way: calculating future demand and supply, under a limited number of restrictions. Koning et al (2007; 2009) provide an overview of Wageningen UR conducted scenario studies exploring future food security, their assumptions and their limitations. Certainly this type of research is very important as we need to know what the resource base is in terms of land, water, nutrients, minerals, biodiversity and to what extent it might suffice to fulfill the aggregated demands for food, feed and fuel without its ecological sinks being corroded in an irreversible way. However, in this chapter we redefined the Competing Claims approach as much more, by including a peoples perspective, the resource use and its users and the institutions associated with that use. This enriched approach leads to the definition of at least 5 underexposed aspects:

1. There is a need for solutions that can simultaneously fulfill a number of claims and compensate potential losers. So far, the quantitative scenarios are based on single land use, either forest, grazing or agriculture, and also single products, either food, feed or fuel. In future much more attention should be given to multifunctional land use and systems producing multiple outputs. This means also that processing should become part of the studies as for instance bio-refinery allows to yield food, fuel, feed, biomaterials, fine and bulk chemicals from a specific biomass produced. These new aspects of scenario studies reflect inclusion of opportunities with an emphasis on production and consumption of goods that directly aim to satisfy human needs and are therefore mainly part of the economic system.

2. In the domain of natural resources both supply and demand vary in space and time and sustainable use at global level will therefore highly depend on knowledge at lower levels. How to translate or connect aggregate quantitative models at global level to local level and vice versa has not been adequately explored and hence the relevance of many approaches is limited to the scale level and the geographic area for which they have been developed. This aspect of linkages between scales, and applicability of developed methodology in other parts of the world needs much more attention.

3. Tools are generally developed for a specific purpose and context. Their applicability and re-use to different or new problems often remains limited, whereas poten-

tially this could be very efficient and enhance timeliness of science-based information. SEAMLESS aims at developing generic models that can be linked and re-used for a range of purposes in European context. The precise contribution of this approach and the tools to Competing Claims issues and methodology in the Netherlands, Europe and developing countries needs to be further explored. Fig. 1 and 2 advocate a less formal integration of tools and methods in each of the four phases (describe, explain, explore, design). More in general, the transferability and the degree of conceptual and technical integration of methods and tools to achieve on the one hand proper integration and formalization and on the other hand sufficient flexibility, remains an issue of further investigation.

4. As mentioned before, claims are put forward by claimants and some claimants are more powerful than others. The tension between private interests and public goods, between short term versus long term costs and benefits and between different locations leads to a complex process with the chance that the most powerful claimants will have their claims awarded potentially at the expense of public goods and weaker parties in society. This point is linked to the former point as best options emerging from aggregated quantitative analysis not necessarily lead to best options at lower scale levels. Therefore it is urgently needed to understand access to and use of natural resources from a people perspective, including processes of power and negotiation, aiming for equity, sustainable resource use and safeguarding public goods such as clean air and biodiversity. This problem plays simultaneously at different levels and in several policy domains (agriculture, energy, forest and nature conservation, etc). There is therefore need for research on multilevel governance across domains, facilitation of stakeholder participation and negotiation within but especially across levels introducing issues such as representation and coordination, and the development and testing of a variety of institutions and policy instruments.

5. Finally scientists and policy makers need to address the role of science in policy making. The current debate about global climate change shows that knowledge alone is not sufficient to favor strong policies leading to effective and sufficient action. Policy decisions are made on many other arguments including power relations. How to make science more effective for the safeguarding and sustainable exploitation of public goods? How to provide timely convincing data to base policy on and how to provide scientific feedback about policy impact to contribute to the policy process as a learning process rather than a static process based in once-decided laws and regulations. How can science contribute to go from internationally common means-based to goal-oriented policies. The Scaling and governance programme, the INREF funded Competing Claims program (Giller et al, 2008) and more recently the EU funded LIAISE network of Excellence programme all aim to investigating this issue.

10.7 Recommendations

Section 6 described five aspects which require specific research: 1. serving multiple purposes and producing multiple outputs; 2. linkages between processes at different spatial and temporal scales; 3. integration and transferability of tools and methods; 4. private interests and public goods and especially the institutions to deal with cross scale and cross domain negotiations; 5. the role of science-based information in policy making. It is recommended to stimulate research in each of them.

1. Scenario studies enriched with the mentioned aspects to explore the biophysical boundaries providing the space and constraints of policy decision making, are urgently needed and need frequent revisiting. Aspects include promising technologies from the other chapters of this report (such as biorefinary, agroproduction parks), serving multiple purposes and producing multiple outputs, thereby increasing the resource base and its use.

2. It is recommended to further develop research on connections between scale levels to provide insight in effects of global processes and national and international policy at lower scale levels and also impact of lower scale level processes and activities for global processes and policies.

3. SEAMLESS is one way to assess the effect of European policy at lower scale levels. It is currently developed for Europe where extensive data bases to support such a modeling framework are available. Application of the approach has so far been limited to assessing a small number of currently important policy questions. More generally, over the past decade Wageningen UR has been developing a range of models and databases. Their maintenance, re-use and applicability to new domains remain limited, whereas potentially this could be very beneficial for reasons of efficiency and timeliness of delivering science-based information to address issues of competing claims. Initiatives such as a Modeling platform (initiated through the graduate school Production Ecology and Resource Conservation) and SEAMLESS Association should be supported.

4. The complexity of Competing Claims issues requires new ways forward in research for instance on sustainable development diplomacy, addressing the combined effects of agricultural, environmental and energy policies rather than focussing on each policy in isolation. The multilevel and across-level aspects of governance require explicit attention (see point 1). Not just the availability but rather the distribution (equity) aspects and dynamics of natural resources and their products need to be addressed. Research in the domains of economic, technical and political power and negotiation should be intensified and in particular the design or creation of new institutions capable to facilitate negotiation on competing claims issues should urgently be explored.

5. Research on Scaling and Governance should be extended to continue conceptual and practical work on scaling methods in the biophysical and governance domain (point 2, 3 and 4) and in the connection between those and on enhancing the science-policy interface.

Dutch policy makers at different scale levels could benefit from the outcome of the above mentioned types of research. Decentralized bodies such as province or municipalities need to negotiate at local levels with different claimants of Dutch resources. On behalf of the Netherlands, Dutch government needs to negotiate with claimants of global resources in international arenas such as EU, UN, WTO, but also roundtables and special meetings about biodiversity or climate change.

Research can provide policy makers with both new and realistic "negotiation space" that will avoid crossing "irreversible" ecological boundaries and creating socially unacceptable inequalities, increase the quality of the negotiations, lead to more realistic outcomes and increasing the development of effective policies. Research on highly technological and eco-efficient options can provide society with solutions satisfying multiple claims at the same time which is one way to decrease or resolve resource competition. To achieve these goals research should on the one hand be free to do research that might or might not have future implications (climate change was "discovered' and put on the agenda due to scientific research that no one commissioned) and that might come up with profitable results that no policy maker ever dreamt of asking for (e.g. internet based flower auctions; energy providing greenhouses). Curiosity-driven research should be stimulated. On the other hand research should be conducted at the interface between research and policy to allow timely delivery of desired scientific input in negotiation processes, realising that negotiation is not about scientific insights alone. This implies responsibilities on the side of policy and science.

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11. Innovation processes towards eco-efficient agricultural production. Search for manageability

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11.1 Introduction

At the frontiers of natural and technical sciences new knowledge and technologies are produced which bear promise for further enhancing production processes and solving societal problems. Notably ICT, micro systems, nanotechnology and genomics are expected to continue to contribute to innovations that will affect not only agriculture but society at large. In the agricultural domain various areas are expected to benefit from these technological developments: production and use of energy and biomass; robotizing of labour; precision production per small unit of area, per plant or animal; aquaculture; meat replacers; logistics and increased efficiency in the supply chain; abatement of emissions and improvements in animal and human health (Cuhls, 2006; Leenstra and Van der Peet, 2009).

Innovations in the mentioned fields could lead to improvements in yields comparable with those achieved during the green revolution. In an inventory on possible future yields of farmed species, Sylvester-Bradley et al. (2006) state that by applying new technologies the production of wheat could double to 20 t/ha, the reproduction rate per cow could increase 60% and feed conversion rates for beef cattle with 50%. Such increases in production efficiency would save large areas of land for other uses than agricultural production. In a similar way the green revolution saved worldwide a third of the area that otherwise would have been needed to produce the same amount of agricultural produce (Borlaug, 2000).

However, from the green revolution experience we also gained the insight that new technologies directed at improved production efficiencies may affect eco-systems, climate, animal welfare, health, depletion of resources and socio-cultural stability. This is inherent to innovation processes, which generally tend to largely neglect emerging risks that become visible only when a technology is applied on a large scale and over a long period of time (Beck et al, 1994).

These insights gained from technological innovation at large and not just from agriculture, have led to the development of theories on alternative ways of knowledge production with an emphasis on involving stakeholders, like Mode II Science (Gibbons et al, 1994) and Post Normal Science (Funtowicz and Ravetz, 1993). These theories see a role for science in producing not only "scientifically reliable knowledge but also societal robust knowledge". Science should also reduce uncertainties in trying to solve complex societal problems which lack a structured problem definition as is the case in sustainability related problems.

The process of invention ("the initial idea of a new solution"), which may be based on a scientific breakthrough, to innovation ("a new combination of technology, culture and organization that works in practice") is however a tedious, knotty and only partially understood process. Evaluations of projects that aimed to realize innovations, show that most projects fail. This implies that innovations are generally recognized only in hindsight and that all efforts that never produced innovations tend to be overlooked. Thinking in terms of "invention to innovation" and "overlooking" efforts that never became an innovation seems to be strongly associated with the traditional linear innovation model, which describes innovation as a process from basic research to applied research to development to diffusion and which increasingly is abandoned.

Godin (2006), in a historic analysis, depicts this linear model as a "rhetorical entity" that is notably useful because the steps correspond with the different domains of knowledge production and administrative resource allocation towards these domains (university, institutes for applied research and commercial enterprises, respectively). In other words, this model does not describe the process of (technological) innovations, but institutional divisions.

Alternative innovation models have been developed with an evolutionary and adaptive view on the innovation process and emphasize importance of interfaces, interactions and non-linearity. This concerns the interactions between the individual level of the novelty (or the entrepreneur) and the existing technological regime as in the Multi-Level Perspective (Geels et al, 2002) and between governments, industry and universities in the Triple Helix Model (Leydesdorff, 2006).

Eco-efficiency, eco-effectiveness and sustainability

The challenge of innovations for an eco-efficient agriculture adds to the complexity of innovation processes. Eco-efficiency is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution. In their "Cradle to Cradle" approach McDonough and Braungart (2002) add an interesting twist by differentiating between eco-efficiency and eco-effectiveness. The latter refers to ways of production which support eco-systems as contrasted to exploit eco-systems. Key elements in the Cradle to Cradle approach are the recycling of nutrients to places in eco-systems were they are needed and support the intended (production) processes. This applies for organic materials that should be reused in e.g. agricultural production as well as for technical materials that should be recycled in technical production. This differentiates recycling as being in either the techno-sphere and bio-sphere. Another important feature of the Cradle to Cradle approach is avoiding the diffusion of toxic-materials in the bio-sphere by using only non-toxic materials in products.

However, both eco-efficiency and eco-effectiveness focus on ecology only and neglect economic and socio-cultural aspects. If these are also taken in account, sustainability seems to be a more appropriate term than eco-efficiency. Although sustainability, like eco-efficiency, lacks a clear definition, a common and essential characteristic is that other aspects than production efficiency are taken in account. Troughout this paper we shall therefore use the term "sustainability".

Innovation literature suggests that leaps in sustainability-performance of technological systems cannot be attained by merely replacing certain parts by more efficient technology, while leaving the basic structure of the system intact. For this, a system innovation is needed, that essentially comprises structural changes in technology and social and institutional organization (cf. Elzen et al, 2004, Loorbach, 2007). A whole field of scientific research is emerging around the theme of governing system innovations (Grin et al, 2010). In this perspective the traditional picture of an innovation as the succesful material realization of an invention is possibly even detrimental if used as the guiding principle for innovation towards sustainability, since such an approach would easily produce lock-ins in a technological trajectory that makes the system even more resilient towards more radical changes that address multiple undesired side effects at the same time.

Taken together, it should be concluded that the realisation of the assumed potential of a (technical) invention is paved with uncertainties of different kinds. These include uncertainties about manageability of the innovation process, uncertainties whether innovation will perform favorably in comparison to existing technology, and uncertainties how the innovation will compare to other new emerging innovations. In addition, the (normative) goal of contributing to sustainable development adds at least two major uncertainties, which are both associated with long term effects. Firstly, the uncertainty of envisaging in advance which innovations will contribute to sustainable development and secondly, whether innovations when when applied on a large scale and over extended periods of time will produce new risks.

In the following paragraphs we will sketch the changing roles of government, industry and knowledge institutes associated with creation of knowledge based economy in combination with sustainable development. Finally, we will zoom in on specific approaches in knowledge institutes to perform these projects.

11.2 Changing role of government in innovation systems

From the beginning of the 20th century, nation-states have increasingly maintained research institutes to support activities of national interests. These systems have been described as "national systems of innovation" (e.g. Lundvall 1992). In the Netherlands, this applied also to agriculture, where the Ministry of Agriculture was responsible for professional and academic E(ducation), E(xtension) and R(esearch). This EER-triplet (OVO in Dutch) focused on improving production efficiency by a linear view on innovation. Many of the technologies applied today stem from this period in the second half of the 20th century.

Research systems were restructured from the early 1980's for various reasons, including doubts on efficiency of knowledge transfer, rising financial costs for the government to sustain the rapidly expanding research areas together with a more general shift in policy ideology towards a market orientation (Boden et al. 2004). Most visible in west European countries is the privatization of research institutes and promotion of the entrepreneurial university. This was accompanied with a shift in the idea of a linear model of innovation (R&D) towards an evolutionary view on innovation (Leeuwis et al. 2008).

Another landmark is the Lisbon Summit in 2000. Here the EU formulated an agenda directed at improving and exploiting the EU knowledge base to maintain economic growth. Innovations based on scientific progress, often referred to as the knowledge based economy, are considered to be key to achieve this goal. The Lisbon Summit subsequent actions of the EU illustrate the change in thinking about the knowledge system: from R&D to innovation.

Knowledge institutions

Within the domain of Wageningen University and Research centre (WUR), the ideas about the Third Generation University (Rabbinge and Slingerland, 2009) and about lower scale organized interactions (e.g. Food valley[7]; Immuno valley[8], and Dairy valley) could be seen as examples of emerging new innovation systems to support the knowledge based economy. Thus, the interfaces between science, industry and government are shaped by their interactions and includes sponsoring knowledge production by public finances. The government can also use systemic innovation instruments, which can manage interfaces, construct and organize innovation systems, provide a platform for learning and experimenting, provide infrastructure for strategic intelligence, stimulate demand articulation, strategy and vision development (Smits and Kuhlmann, 2004; Van Mierlo et al , 2010).

Within the research programs financed by LNV[9], WUR research programs adapted at least part of the functions of such systemic innovation instruments. This applies notably for the program Sustainable Production and Transition (2004-2009). This program crosscut several research groups such as the Animal Sciences Group, the Plant Sciences Group, and the Agricultural Economics Research Institute at Wageningen University. With a predominant focus on primary agriculture, it combined vision development, action research and reflection on these processes (see Box 1). Innovatienetwerk Groene Ruimte en Agrocluster was one of the instruments that the government implemented to strengthen the research and innovation climate. The government, NGOs, the private sector and knowledge institutes developed knowledge agenda, and prepared for implementation (see also Grin en Van Staveren, 2007) with an emphasis on development of visions. Transforum Agro and Groen, an innovation program for agriculture and green spaces was another systemic innovation instrument (Veldkamp et al., 2008).

Entrepreneurs/industry

From the entrepreneurial point of view, improved competiveness is the goal of innovation. Sustainability (c.q. eco-efficiency) is not a prime driver unless there is a market for "green" innovations. However, governments and non governmental organisations stress the need to combine commercial activities with maintaining and improving eco-system services given the challenges of climate change, biodiversity and pollution combined with the expected increase in global population, Thus, market opportunities could arise out of changed preferences of customers or be created by governmental regulations (e.g. by production rights, tax facilities etc.).

[7]See www.foodvalley.nl [8]See www.immunovalley.nl [9]Ministry of Agriculture, Nature and Food Quality

Though innovation is seen as main driver to improve competiveness, only few innovation projects started by companies lead to market products. Fortuin en Omta (2009) analysed factors that contribute to a successful innovation in Dutch agri-food and technology based companies. In their Wageningen Innovation Assessment Tool (WIAT) 5 sets of criteria are distinguished which contribute to performance of innovation project (see Table 11.1). Notably, when discussing the results of ex ante assessment, WIAT proved to be a poweful tool to improve industrial innovation projects.

Table 11.1. Sets of criteria in the Wageningen Innovation Assessment Tool to assess individual innovation projects perfomed by agri-food indusrtry (From: Fortuin and Omta, 2009).

Central factor	Assessment criteria
Company	Project-company fit Project resources
Project team	Team communication
Product	Product superiority Product aspects
Market	Competition Market volume Institutional environment
Time	Project planning Product specifications Future performance

11.3 New configurations and interacting roles of business, knowledge and government

A main challenge for sustainable agricultural production is combining innovation processes by industry and entrepreneurs with (radically) improved sustainability. The role of the government in this combination is to shape conditions that at one hand support interaction between industry and knowledge institutes and on the other to stimulate innovations that will improve sustainability. This requires new models of national (and regional) innovation systems that are characterized by networks of government, industry, and knowledge production. The Triple Helix theory is based on these temporary interactions of government, industry and knowledge institutes and provides an analytical framework for knowledge generation and economic growth through innovation. The Triple Helix theory explains that knowledge in itself becomes a production factor in addition to the classical production factors capital, labour and natural resources (Leydesdorff, 2006).

As to the sustainabilty challenge, innovation literature suggests that improvement in sustainability cannot be attained by merely replacing certain parts of the technological system by more efficient technology, while leaving the basic structure of the system intact. For this, a system innovation is needed, that essentially comprises of structural changes in both technology as well as social and institutional organisation (cf. Elzen et al 2004; Loorbach 2007). To attain system innovations, new configurations between enterprises, knowledge institutes and governments are required. In order to realise system innovations for sustainable development, the boundaries between enterprises, knowledge institutes and governments become more diffuse: enterprises have to take part in knowledge creation and the governance of societal change, governments have to actively participate in innovation processes, and knowledge institutes have to produce results in a much more engaged fashion as suggested by Mode II approaches to knowledge production (Gibbons et al, 1994).), linking political and societal issues to the market and society. For the three of them this will lead to tensions regarding their traditional role and the expectations of others (Grin et al, 2010).

11.4 The knowledge worker: design of innovations projects aiming for sustainability

Several schools of thought that have developed over the last decades, focus on innovations projects that aim to improve sustainability. Most prominent in the Netherlands are Transition Management (Rotmans, 2003) and the related approach on System Innovations (Grin et al, 2010). Both focus on the governance and manageability of transitions towards sustainability. Both also develop overarching theories and concepts to understand transitions that have occurred, and build an interventionist approach to 'manage' the emergence of desired transitions (e.g. Elzen et al 2004, Elzen and Wieczorek, 2005). Geels et al. (2002) introduce a multilevel perspective on transitions from one system (i.c. socio-technical regime) to another. They distinguish three conceptual levels: a "niche" level in which radical novelties emerge, a "regime" level that refers to cognitive rules shared in social networks related to the existing system, and a "landscape" level that refers to exogenous developments.

Parallel to the development of these theories, governmental bodies have adopted the idea of governing transitions and facilitating system innovations, and have commisioned a range of projects that aim to improve sustainablity. The theories and concepts inform and inspire knowledge workers to design projects meant to improve sustainability in a certain context (i.e. "doing system innovation"). Such projects face challenges on translating theories into project design, including how and which stakeholders should be involved, how the sustainability goal should be formulated and how results should become embedded in the regime.

The struggles of designing and implementing outcome-oriented projects have led to an emerging set of approaches that guide the design of such projects. Because of the diversity of activities, including vision formulation, stakeholder approaches and interdisciplinarity, such approaches tend to incorporate and amalgamate various theoretical sources (cf. De Grip et al, 2005).
For the agricultural domain, WUR has executed several of such projects, and consequently assumed the role as change agent contributing to an explictly normative change. Progress within WUR has been published by Poppe et al. (2009).

Such projects have also led to a range of approaches that try to systematise this new role of change agent and to formulate prescriptions on how to design and perform innovation projects. Examples include Sustainable Technology Development (Weaver et al, 2000), Reflexive Interactive Design (Bos et al. 2009) and Transdisciplinary Science (Hirsch-Hadorn et al, 2008). Further experimention with these approaches is needed to achieve concrete results in progress for sustainability and provide cases for theoretical advancement. Below we will briefly discuss these three approaches.

Sustainable Technology Development (STD)

STD was a Dutch interdepartmental governmental program in the 1990s with a main focus on development of sustainable technology as the core driver for long term structural societal change (Weaver et al 2000, Smits and Kuhlmann, 2004). STD focused on the development and implementation of new technology to reduce the existing environmental pollution and to neutralize the long term (> 40 years) environmental effects of an increasing global population with an increased living standard. To achieve this technologies fulfilling basic human needs (e.g. nutrition, housing, transportation) must become a factor 20 improved efficiency (i.e. the use of energy, space and raw materials) in comparison to days technologies. In STD it was recognised that can not be achieved by technology alone, but will require structural (societal and technological) change. The STD developed visions of desirable futures by interacting with stakeholders. Visions were subsequently translated to short term actions by a process of step by step reasoning. This comprised of going backwards from the future vision to intermediate milestones and determing the short term actions to be taken in the present. This process has become known as backcasting (Quist, 2007). For a more elaborate description of the STD approach see Weaver et al. (2000).

The approach has given guidance to knowledge workers responsible for executing STD-projects. For many knowledge workers in The Netherlands this was their first experience with interdisciplinary and interactive research focusing on sustainability. Experimentation with the STD approach was also extended to agriculture and land use. Significant projects included the Profetas program on substitution of meat by plant based alternatives (Aiking et al., 2006). Profetas focused on a transition to a more vegetarian western consumption pattern. It took development of protein foods based on green peas as an example and included technological, market and

Function	Main activities in program VPT	References
Managing interfaces	Focus on primary production. Interface management concerned governments, NGO's, farmers and representative organisations and supply chain actors. Special attention was given to interaction with agricultural education.	Wijnands and Vogelezang (2009) Visser et al (2009)
Constructing innovations systems	Innovation systems constructed or supported included: Networking in the livestock production sector (in Dutch: Netwerken in de Veehouderij), Knowledge on the field (in Dutch: Kennis op de akker), Cultivate with perspective (in Dutch:Telen met toekomst), innovaton for multifunctional farming (In Dutch: Waarde Werken), Innovation agenda's livestock production, Dairy academy (In Dutch: Melkveeacademie)	Wielinga and Vrolijk (2009); Vogelezang et al (2009); Klerkx and Leeuwis (2008)
Platform for learning and experimentation	Developments in future exploration, action research, monitoring and evaluation, system analyses and reflection on these processes were exchanged in the periodic meeting of projectleaders. New insights and experinces were published in the quarterly magazine Syscope (see **www. syscope.wur.nl**)	Mierlo and Elzen (2010, forth coming); Wielinga and Vrolijk (2009)
Demand articulation	Based on learning experiences and in interaction with sector and ministry	
Strategy development	Strategy development took place in interaction with the Ministry and included translating experiences in new governmental policy instruments (e.g. Networking in the livestock production sector, SBIR Sustainable animal housing).	SBIR: **www.agentschap.nl** Networking: www.minlnv.nl\ dienstregelingen.
Vision development	Vision development according to DTO and RID approaches became starting point for projects.	Wolf et al (2006);Bos and Groot Koerkamp (2009)

Box 11.1 The program Sustainable Production and Transition as a systemic innovation instrument in hindsight
Dutch Minstry of Agriculture commisioned in de period 2004-2009 the program Sustainable Production and Transition (in Dutch: Verduurzaming Productie and Transitie -VPT) to Wageningen UR. The focus of the program was on primary production and included livestock production, arable farming, horticulture and greenhouse production. The research teams included notably knowledge workers of Wageningen UR Livestock Research, Applied Plant Research (PPO), and Agricultural Economics Research Institute in cooperation with Wageningen University. During the course of the program additional activities evolved that focused on exchange of experiences and attaining new conceptual knowledge. In hind sight functions of systemic innovation instruments recognised by Smits and Kuhlmann (2004) were fulfilled. The following table gives for different functions examples (not exhaustive) of activities. Information on projects mentioned is available on www.kennisonline.wur.nl

societal aspects in their research. The project on sustainable land use (De Boer and Kwak, 2003) foused on developent of multifunctional land use in an area of 20 000 ha in the vicinity of the Winterswijk and combined farming activities with water conservation, upgrading of agricultural byproducts and living and recreation. In livestock production (Spoelstra et al., 2002), the STD approach was used to develop visions of future livestock systems. Examples included green care farming with animals and animal welfare based piggeries.

Reflexive Interactive Design (RID)

Reflexive Interactive Design (RID or RIO in Dutch) builds on the ideas of STD. Because of its development in the livestock sector, RID has mainly focused on livestock production units with designs taking the form of new integrated technologies in animal husbandry systems.

Central in RID is design, both as a noun and as a verb. Design as a noun refers to the description and visual representation of a sustainable entity. Design as a verb refers to the activities in the design process, which is based on principles of structured design (Siers, 2006) as well as interaction with stakeholders. The design process starts with formulating basic needs of key actors in the system. In the livestock production application, this concerned notably needs of animals, of farmers, of citizens and of the environment. Needs of animals and the environment were largely based on existing knowledge in ethology and environmental disciplines. Needs of farmers and citizens were based on interviews.

The results are combined in a list of requirements for the production system under consideration, which forms the basis for a series of design workshops with stakeholders. During and after the design process, efforts are made to connect the design to concrete activities to start "real world" projects in which part of the visions will be realized as a starting point for learning about the practical usefulness of the new entity. Examples include Loving and keeping hens (Groot Koerkamp en Bos, 2008) and Cow Power (Bos et al.

2009). These projects formulated visions of farming systems for laying hens and dairy cows, respectively. Both projects have led to follow up activities of farmers and supply chain to realise parts of the design.

Transdisciplinary Science (TS)

Transdisciplinary science (TS) is very much a Swiss initiative (Hirsch-Hadorn et al, 2008). It builds on theories of action research, stakeholder participation and scientific analysis to "overcome the mismatch between knowledge production in academia and knowledge needed to solve societal problems". The normative goal is expressed as "the common good" which is formulated interactively in the project itself. TS distinguishes three interacting phases, all expressed in terms of knowledge production. First, production of system knowledge which refers to the phase in which complexity is reduced by exploring systems boundaries and positions of stakeholders. Second, the phase of formulating target knowledge or "the common good" as a result of structured interaction with stakeholders. And finally, the change knowledge phase which focuses on (in terms of TS) "how to bring results to fruition". TS was applied in the project Mediterrean grazing land management (see Hubert et al, 2008). This related to Mediterranean grazingland management issues, e.g. fire hazard control, biodiversity conservation and addressed the role that livestock farming systems can play. It included for instance, shephards' knowledge of grazing management and of herding practices

Project design of STD, RIO and TS

Projects aiming at sustainability are most often funded by government bodies or public funds. Within this type of projects, knowledge workers typically organise the innovation process including stakeholder involvement, the interactive formulation of future visions or the design in conjunction with analytical and reflective activities. Up till now, there is no commonly accepted name assigned to this type of research that aims to improve sustainability in interaction with stakeholders. Bos and Grin (2008) stress the active involvement of knowledge workers in process with stakeholders by the description "doing reflexive modernization". The various research strands, such as action research, transdisciplinary research, social learning or Mode II research, all emphasize interactive stakeholder participation and refer to part of the activities in STD, RID and TS. The approaches have in common that they try to formulate guidelines to design and carry out projects that aim to improve sustainability. They also all include the phases of (interactively) formulating a problem definition, formulating a vision and an approach of embedding and realisation.

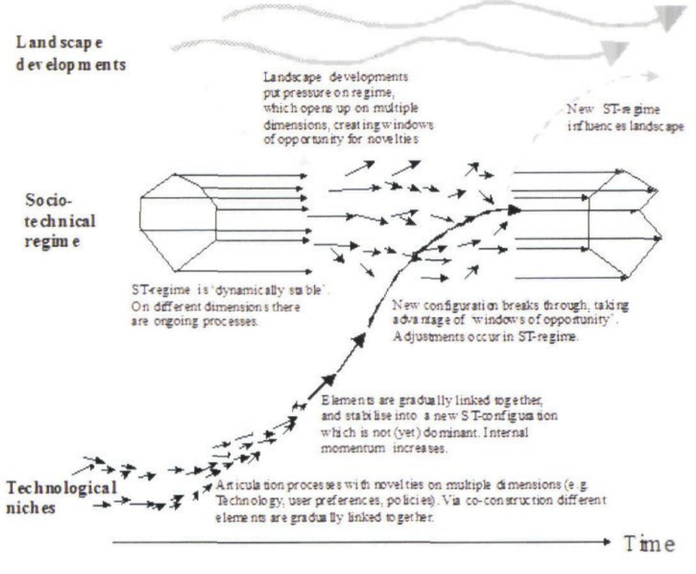
Of these, STD and RID have an explicit relationship with technology by focusing on technology development within the design process. However, neither has developed an explicit idea on including the possibilities of scientific breakthroughs and technical inventions inventions, for example by organising interactive design workshops with scientists or by patent search. The formulation of "visions of a desirable future", "design" or "common good" as it is called in STD, RID and ST respectively, has several functions in the process of innovation. The first function is to come to a formulation of a sustainable alternative for present practices. In the process of vision to innovation, visions serve additional functions like giving directions to short term actions, a certain distancing of oneself from today's preoccupations and achieving opening up and agreement among stakeholders about a future orientation. Smith et al (2005) distinguish the following functions of a vision building exercise:

- Mapping a 'possibility space': Visions identify a realm of plausible alternatives for conceiving of socio-technical functions and for the means of providing for them.
- A heuristic: Visions act as problem-defining tools by pointing to the technical, institutional and behavioural problems that need to be resolved.
- A stable frame for target-setting and monitoring progress: Visions stabilise technical and other innovative activities by serving as a common reference point for actors collaborating on its realisation.
- A metaphor for building actor-networks: Visions specify relevant actors (including and excluding), acting as symbols that bind together communities of interest and of practice.

- A narrative for focusing capital and other resources: Visions become an emblem that is employed in the marshalling of resources from outside an incipient regime's core membership (see also Rotmans, 2003; Loorbach 2007)

STD, RID and TS all stress the necessity of follow-up activities. For STD this includes technical research activities, but RID and TS emphasize learning from initiatives in a "real world" context. Despite the functions attributed to visions, the link between visions and implementation is rather weak for several reasons. Ownership in terms of budget, methodology etc. is initially in the hands of the projectteam of knowledge workers. By building networks, communication and specific approaches including back casting, (networks of) other actors can become interested in taking follow-up initiatives. Such initiatives will be confronted with uncertainties. To facilitate learning, the approach of Strategic Niche Management suggests creating temporarily a protection from the market for new initiatives (Schot and Geels, 2008). Such innovation niches could be created by e.g. subsidies, offering research support or lifting certain legal regulations. How can we use these initiatives to learn about possibilities for sustainable production? Such initiatives can be seen as learning experiments that contribute to the knowledge base by understanding barriers and chances for sustainable development. Thus, they are made part of the "portfolio of promises". This requires a process of monitoring of what goes on in terms of innovation and assess the relevance of the locally learned lessons within the broader portfolio (Elzen and Spoelstra, 2009).

Box 11.2 :The Multi Level Perspective



A central analytical frame work in system innovation is the Multi Level Perspective, which connects the rearrangement of socio technical regime, "the sector " at one side to apparently autonomous changes ("landscape level) and at the other to deliberate innovation initiatives and novelties aiming for sustainability ("niche level")

The so-called multi-level perspective (MLP) provides a dynamic view on innovation. The core of the MLP is that system innovations are shaped by interaction between three levels: the socio-technical landscape, the socio-technical regimes and niches. Socio-technical systems are located at the meso-level and are characterised as regimes to indicate a set of shared rules that guide and constrain the work of actors within a production and consumption system and the way technological systems are embedded in society. Engineering heuristics are aligned with rules of the selection environment

A novelty emerges in a local practice and becomes part of a niche when a network of actors is formed that share certain expectations about the future success of the novelty, and are willing to fund further development. The niche is formed against the background of the existing regime and landscape. Niches may emerge and develop partly in response to pressure and serious problems in an existing regime which can be either internal to the regime itself (such as animal welfare in industrial animal production) or come from the socio-technical landscape (e.g. the current pressure to curb CO_2 emissions which affects more than just the animal production sector). The further success of niche formation is on the one hand linked to processes within the niche (micro-level) and on the other hand to developments at the level of the existing regime (meso-level) and the sociotechnical landscape (macro-level). Supported by actors willing to invest in the new concept (industries, R&D organisations, government) and protected from competition at the market place, the technology is improved within the niche, broader networks are formed around it, and more is learned about technical directions for improvement and functions it may fulfill.

After some level of improvement of the technology, and after learning more about its potential, it may find its way in specific market applications, often typical segments that exploit new functional characteristics of the technology and focus less on cost structures (e.g. organic food).

11.5 Conclusions and recommendations

Despite the importance assigned to innovations for economic development in general and for sustainability in particular, no generally accepted theories on how to manage innovation processes have been developed. The question of manageability has not been answered yet.

This conclusion is relevant for knowledge workers who design and carry out a specific project, as well as for entrepreneurs and governments that shape the innovation environment. Against the background of a growing sense of urgency with respect to climate change, food production (security and safety) and animal welfare there is a felt need that the learning processes should be speeded up as well as better targetted and managed to contribute to the problems at hand.

Ways to formulate and design visions or designs of a sustainable production should be further developed. The approaches discussed could be developed by including recent scientific breakthroughs in the design process. A major point is the translation of visions to local short term entrepreneurial actions. Activities such as back casting, "demand tendering" and anchorage (Elzen, forthcoming) are useful, but should be more thoroughly investigated and developed.

Especially, experimentation to realise in the "real world" parts of the visions ("bottom up experiments") should be further developed. Up till now, visions have often elicited only few bottom up experiments. Ways to increase the number of these experiments and facilitation of learning processes need further development. Improving the design and monitoring of such experiments deserves attention because it will address issues such as the comparison of different new options; the comparison of the novelty to existing practice; barriers that need to be overcome; emergence of new risks; and potential contribution of the novelty to system change at the regime level.

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12. Synthesis

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Agnes van den Pol

12.1 Technology and implementation

The need for increasing agricultural productivity while reducing the claim on the natural resource base should be understood against the background of a growing world population, changing food habits, climate change, increased demand for biomass for fuel, an emerging biobased economy and the increased scarcity of natural resources. These developments urge agriculture to seek new development pathways, which was firmly underlined in the CSD-17 Shared Vision Statement.

Current agricultural productivity and eco-efficiency largeley differ across the world depending on local biophysical, socio-economic and political conditions, thus demanding different approaches and priorities (FAO, 2009). In post-industrial countries, environment and food safety merit most attention and thus eco-efficiency provides substantial challenges. In most developing countries, on the other hand, food security and livelihoods are pressing issues and increasing productivity is a more urgent objective than improved eco-efficiency.

The technological approaches presented in the previous chapters can contribute to improving the performance of agro-production systems, but each under specific (local) conditions. Technological inventions can only result in effective innovations in agriculture when they contribute to the relevant objectives and the interests of stakeholders involved and when they correspond with the available resource base, its claims and claimers and with the location-specific systems context and when proper processes guide the implementation process. Figure 12.1 tries to visualise the uncertain outcome of technology implementation when the socio-economic context is not considered. There is no such thing as a linear implementation process starting from technological inventions and ending up with innovations in practice. The need for technology and its appropriateness depend not only on local situations but also show strong interactions with drivers and contexts at higher hierarchical levels.

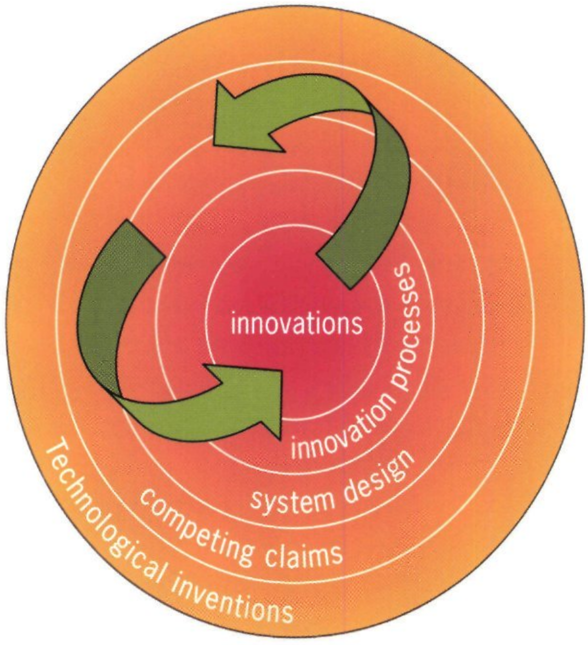

Figure 12.1. Invention and implementation of technology in interaction with competing claims, system design and innovation processes

Agricultural production systems and the value chains in which they operate are increasingly complex. Sustainability deals with interacting economic, ecological and social objectives and involves trade-offs among them. Supply chains must produce foods and feeds with high standards of safety, health and comfort. Spatial demands emerging from diverse land use functions are increasingly intertwined, stimulating multifunctional uses of land and forms of agriculture. Animal welfare and increasing problems with zoonosis have evoked high demands on and great concerns related to production processes. Climate change puts agriculture both on the side of causing the problem as well as on the side of providing solutions. Global and societal drivers make success factors of invention implementation increasingly pluriform and thus make the outcome uncertain. This can be illustrated by the case of GM technology of which the promise could not be cashed so far. The technology did not match consumer preferences and demand resulting in disappointing development of this concept.

Moreover, the urgency of the challenges ahead, the corresponding time frame together with the described societal drivers, require transitional changes (shifts) of current agroproduction systems next to incremental improvements of these systems. Transitional changes require new designs of complete systems building on renewed thinking or paradigm shifts. Increasing competing claims tensions, competing stakeholder interests and ethical discussions regarding new technologies, require system changes and transitions. Incremental improvements can be realised within present systems without changing the boundary of systems nor their relationships or the thinking that underlies them. This is likely to make incremental improvements less sensitive to societal discussions and more acceptable to the stakeholder arena. Transitions (or systems shifts) on the other hand, are more likely to raise more discussions as they imply profound changes, as was illustrated in chapter 7 on the agroparks concept.

Experiences with and scientific knowledge of competing claims, system design and innovation processes should to a high degree be leading in setting the technology research agenda. However, in this agenda, technological inventions remain the basis of technological innovations (see Figure 12.1).

12.2 Transitional pathways

The preceeding chapters have revealed interesting and promising technological developments within several domains. They present an overview of various technological approaches, their state of the art and their possible contribution to raising agricultural productivity while lowering the ecological foot print of agriculture substantially. The technological developments contribute to four transitional pathways:

- **a)** Stretching production potential
- **b)** Closing yield gaps
- **c)** Increased eco-efficiency
- **d)** Developing and adapting agroproduction systems in situations with competition for natural resources

Some of the preceding chapters describe basic technological domains like X-omics, plant and animal health, irrigation and water use, nutrient cycling and soil ecology, each with a selection of individual technologies. Their potential contribution to the aforementioned transitional pathways are summarised in Table 12.1.

The chapters on biobased economy and robust and resilient agriculture describe technological domains, combining basic technologies and integrating socio-economic aspects. The chapters on competing claims, system design and innovation processes start from a socio-economic context and call upon technologies to realise location specific goals. These sciences are not specifically directed at increasing production potential or at closing yield gaps.

12.3 Stretching production potential

Production potential can be defined as the maximum production that can be reached with a given crop or herd and variety under the prevailing physical environment (light, temperature, CO_2 level) under optimum availablility of water and nutrients and in the absence of pests and diseases (Van Ittersum and Rabbinge, 1997). This represents a theoretical production level. The maximum actual production level that can be reached on farm level using best practices (optimum fertilisation, optimum water supply, no pests and diseases) depends on prevailing management levels and socio-economic conditions. This yield could be presented as the best practice production level which is lower than the theoretical potential level. It depends on crop arrangements, design of animal husbandry systems, harvest or milking techniques, level of mechanisation, farm scale but also on costs and availability of inputs and functioning markets. Improved farm management techniques can increase the best practice production level, but cannot increase potential production level. To improve the latter, the genetic potential of animals and plants should be altered for given environments. The current X-omics technology has been boosted by next generation DNA sequencing that enables complete genomic information to be revealed at low costs. When X-omics

Table 12.1 Technology domains and their contributions to transitional pathways

Technology domain	Production potential	Decreasing yield gaps	Increasing eco-efficiency	Natural resource competition
X-omics (chapter 2)	• Developing crops and animals with increased yield potential • Epigenetics • Systems biology • Breeding by design	• Epigenetics • Resistance to plant and animal diseases	• Improving intestinal health of farm animals • Resistance to plant and animal diseases • Systems biology • Breeding by design	• Developing crops adapted to adverse or variable growing conditions • Deeper understanding of trade-offs between plant and animal characteristics • Breeding by design
Plant & Animal Health (chapter 3)		• IPM strategies • Population genetics of plant pathogens • Early detection and diagnosis of plant and animal diseases	• Precision farming and livestock management • Stress reduction of farm animals • Vaccination of farm animals • Knowlegde of disease epidemics • Seed technology • Early detection and diagnosis of diseases	• Using and stimulating natural resistance systems • Redesign of animal husbandry systems • Adapting soil cultivation practices • Management of soil organic matter
Irrigation and water use (chapter 4)		• Improving water holding capacity of the soil • Variable drainage depths • Water harvesting techniques	• Water re-use systems • Recirculation of drainage water • Irrigation decision rules based on sensor technology	• Improving rain use efficiency • Forecasting stochastic components of rainfall • Redesigned irrigation regimes • Saline agriculture systems • Water basin management systems • Remote sensing and seasonal climate predictions
Nutrient recycling (chapter 5)			• Dynamic feed systems • Nutrient saving techniques in application • Precision farming	• N and P recycling from urban waste • Developing safe sanitation systems
Soil ecology (chapter 6)		• Diversification of farming systems • Microbial plant growth promotion • Induced systemic defense	• Plant and beneficial microbe interactions • Increasing soil biodiversity	• Conservation agriculture • Natural resistance of soils • Organic matter management • Soil cultivation techniques to reduce N2O emissions
Systems design (chapter 7)			• Waste valorisation • Design of efficient agrofood chains • Energy management systems in greenhouses • Introducing industrial ecology in the agrosector	• Agropark design • Multifunctional agriculture • Co-design processes
Robust & resilient agriculture (chapter 8)			• Diversification • Modular design	• Multifactorial design processes • Adapting farming systems to changing environments
Biobased economy (chapter 9)			• Biorefinary technologies (pre-treatment, fermentation, separation)	• Processing crop residues (pyrolyses, gasification etc etc) • Algae breeding, production and processing techniques. • Biogas and biofuels production • Breeding crops with high value added chemical building blocks
Competing claims (chapter 10)				• Design integrative solutions • Design of analytical tools • Remote sensing techniques (monitoring of dynamics) • Participatory GIS technology • Integrated impact assessment tools • Interdisciplinary modelling • Scenario studies (multiscale interactions and trade-offs)
Innovation processes (chapter 11)				• STD and backcasting • Relexive interactive design • Transdisciplinary Science

technology is combined with marker technologies, breeding on demand becomes more realistic. Complex production traits can be more easily handled (Chapter 12) while genetic information can be increasingly coupled with phenotypic traits (Yin et al, 2004). It will be expected that X-omics technologies can not only result in higher productive varieties but can also produce varieties better adapted to diverse physical conditions.

For algae production (Chapter 9) and saline production systems, breeding techniques may have significant impacts on production levels as these potentials are largely untapped. The Wageningen UR initiative "Towards Biosolar Cells" is, amongst others, directed at increasing the photosynthetic efficiency of plants, but is also working on cellular and sub-cellular level to increase energy production with less competition with agricultural land (Figure 12.-2). To boost agricultural production in developing countries in for instance Africa, great effort is put on breeding varieties for African conditions (like AGRA's PASS program). Higher yielding varieties can be of value on mid to long term. However, whether the potential of better varieties will bear fruit depends on other limiting production factors that cause existing yield gaps like nutrient and water availability, knowledge level, access to affordable capital and the presence of functioning input-output markets to deal with these production factors

12.4 Closing yield gaps

From the definition of the potential production potential, it can be deduced that pest and disease management may cause yield gaps. As stated in Chapter 3, yield losses can be huge, accruing to 70%. Technologies to prevent or combat pest, weeds and disease infestations are developed on different scale levels from plant or animal level to the regional level. Traditionally, IPM strategies and resistance breeding are approved means in the continuous battle for plant and animal health. As stated before, because X-omics technology is leading to the concept of breeding by design and breeding within tighter time frames, more resistant varieties can be expected to evolve in the future. IPM strategies can be developed more sophistically as knowledge and insights in epidemiology and pest-plant or

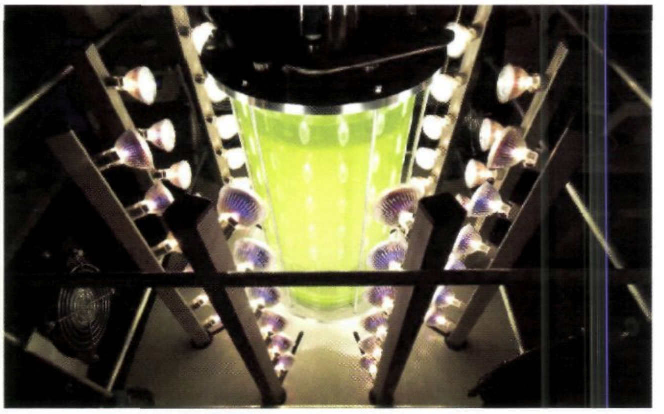

Figure 12.2. The initiative " Towards Biosolar Cells" holds promise for greater solar energy

pest-animal relationships increase. It must be stated at this point that the implementation of IPM strategies does not only depend on technological developments. For example, societal concerns about the environment are thought to have been greater driving forces to lower pesticide usage in recent decades in the Netherlands than technological developments.

A lurking problem in the pursuit of plant health is the rise of resistance to pesticides. More knowledge and insights are needed in population genetics of resistance genes, resulting in the development of measures to slow down or prevent resistance. In animal husbandry, antibiotic resistance of disease inducing bacteria is an increasing problem and solutions can be expected from the redesign of husbandry systems from control geared towards more robust and adaptive systems. On the plant and animal health level, much can be expected from early detection and diagnosis tools emanating from X-omics and bionanotechnologies. With these tools low levels of infestations can be detected not only for one but for a combination of several disease organisms (multiplex).

Besides plant and animal health improvements through breeding and crop protection, improved water availability can narrow yield gaps. Improving the water holding capacity of soils, varying depths of drainage and water harvesting techniques are expected to have positive effects in certain environments. The water holding capacity of the soil is partly related to the organic matter content as increase of this content will increase water holding capacity of the soil.

Yield gap analyses can reveal several soil related limiting factors. First, nutrient availability perfectly tuned to crop nutritional needs should be pursued. Soil texture, organic matter content, pH and other features determine nutrient availability and the processes that cause nutrient losses to the environment or fixation in the soil. Soil structure can be inadequate, resulting in suboptimal oxygen and water supply to plant roots. Finally, soil health is a complex phenomenon related to crop rotations and crop characteristics. Organic matter levels relate to soil disease suppressiveness but more knowledge is needed to reveal when and how and whether this mechanism can play a role in farm management.

The largest yield gaps exist in animal and plant productions systems in developing countries such as in Sub Saharan Africa. Inputs are usually low, as is soil fertility. Many technologies are available to boost African agroproduction (IAC, 2004) and the challenge lies in identifying the production factors that are the most constraining and thus determine yield responses to inputs, and in supplying affordable technologies together with adequate knowledge support. New technologies must fit in the context of existing farming systems and given the enormous variation in farming systems there will no one 'one fits all' technology. A range of options must be developed to match the demand even within the heterogenous farming systems in Africa (Giller et al., 2007). Yield increases are possible with higher inputs with simultaneous decrease of resource use efficiency. Whether yield gaps are indeed decreased, depends not on technology alone but also on availability of functioning input/ output markets conducive to apply best practices.

12.5 Increasing eco-efficiency

Both stretching production potential or decreasing yield gaps have consequences for eco-efficiency as the relationship between inputs and outputs is being affected. A higher yielding variety may require more nitrogen and the ratio between additional nitrogen and additional yield determines the outcome on the level of eco-efficiency expressed as amount of nitrogen per kg product. A higher yielding dairy cow may need additional input of concentrates. Decreasing the yield gap with an improved IPM strategy can result in higher yields with more pesticides per hectare and yet result in an increase of eco-efficiency expressed as the amount of pesticides per unit product. These examples illustrate the multifacetted aspect of eco-efficiency as described by Keating et al (2010). They also illustrate that increased eco-efficiency does not necessarily mean less inputs. This is underpinned by the resource use efficiency theory as described by De Wit (1992) in his eco-efficiency diagnosis framework, elaborated by Keating et al (2010) in their efficiency frontier and by Koning et al (2008) in their evolution of successive production systems.

The multi-facetted aspect of eco-efficiency becomes increasingly complex when economic and environmental aspects are included as suggested by Park et al (2010). The authors suggest that also economic or social circumstances influence farmers' decisions to move along the aforementioned efficiency frontier and may cause less food production when increasing input prices negatively influence gross margins. However, in situations where one input element is minimally used or available, increasing its use will improve the efficiency of other input elements.

The input element that needs to be supplied to take production to a higher level and thus contributing to closing the yield gap, can differ among neighbouring farmers. A simple example of tomato production in Tanzania showed that increasing fertilisation led to a higher yield for one farmer with corresponding increase of efficiency of land and water use, but did not lead to yield increase for another farmer resulting in decreased fertiliser use efficiency. The second farmer discovered that water availability was the minimum production factor on his farm which was located on slightly higher altitude. This simple example tells us that strategies to increase eco-efficiency should be matched to local conditions. A pluriform approach like this is also the basis of the success of implementation processes on farm level in the Netherlands within some of the networking projects in the Dutch research program on Sustainable Production and Transition as described in Chapter 11.

Generally, available technologies are the tools for farmers to increase their eco-efficiency. These technological tools and the context in which they can be applied, are well described in the preceeding chapters. The breeding-by-design concept can result in varieties that can produce more with the same or lower amounts of water or nutrients when their uptake efficiency is increased. Precision farming can apply input rates to individual animals or plants or targeted locations in a field. Andre et al (2010) have shown that their concept of dynamic feeding of dairy cows can increase the eco-efficiency expressed as feed per unit of milk production. For crop production, Zande et al (2009) showed that use of a sensispray concept saves 30-60% on haulm killing chemicals using a green leaf sensor (GreenSeeker: Figure 12-3). Also, in irrigation management, experiments have been done using sensors to direct water use and tune it to the need of sub-crop level (Pardossi et al, 2009). These examples show that the highly technological concept of precision farming can lead to an increase in eco-efficiency.

Other examples of technologies which increase the eco-efficiency are those that promote the health of animals without using profylactic antibiotics, such as X-omics technologies that discover the genetic basis of improved intestinal health. Also stress reduction of animals can be one of the interesting transition pathways to reach eco-efficiency, including optimal housing, ventilation and careful animal management (Chapter 3). In addition, Chapter 8 provides animal husbandry examples that illustrate the concept of robust and resilient agriculture. In the Netherlands, seed coating has shown the potential of improving eco-efficiency by using less pesticides without yield loss or even with increased yield (Ester et al, 1997 & 2003). This technology holds great promise for vegetable crops in Asia and Africa as well. An important technology to increase eco-efficiency lies in early detection and diagnosis technology, because it has the potential to control pests and diseases effectively in an early stage of population development, thus ensuring higher yields at lower pesticide inputs.

The preceeding chapters have not only shown new and promising technologies, but they have also shown that there is a need for knowledge and insight into mechanisms and

Figure 12.3. The sensispray concept in potato haulm leaf killing.

interactions, for instance with respect to phosphorus recycling concepts. Process technologies are available or can be developed to isolate phosphorus from urban waste materials, but this process has yet to be set in motion. However, a challenge lies with the relatively short time horizons of societal concern combined with delayed feed-back mechanisms, especially in the case of phosphorus: when urgency is imminent, is there still ample time to develop solutions?

The use of eco-efficiency promoting technologies such as those described in Chapters 2-6, 8 and 9 can -combined with other technologies- be effectively implemented according to the knowledge and insight described in chapter 7, 10 and 11. For instance, increasing the resource base by biorefinary and waste valorisation concepts developed in sytem design processes, is an interesting transition pathway. This is illustrated by the agroparks described in Chapter 7. Although concepts such as large agroparks may lead to societal concerns, they can contribute to increased eco-efficiency by increasing the use of waste streams. On a smaller scale, this can be achieved by several concepts shown in Figure 12.4. For instance, on farm level, feedstocks like forage maize and cattle slurry can be transformed into a number of products, including renewable energy, protein feed and chemicals. Upcoming technologies will reveal more opportunities to maximise biomass valorisation, for instance when lignocellulosic biomass can be used to produce feed, energy and biochemicals.

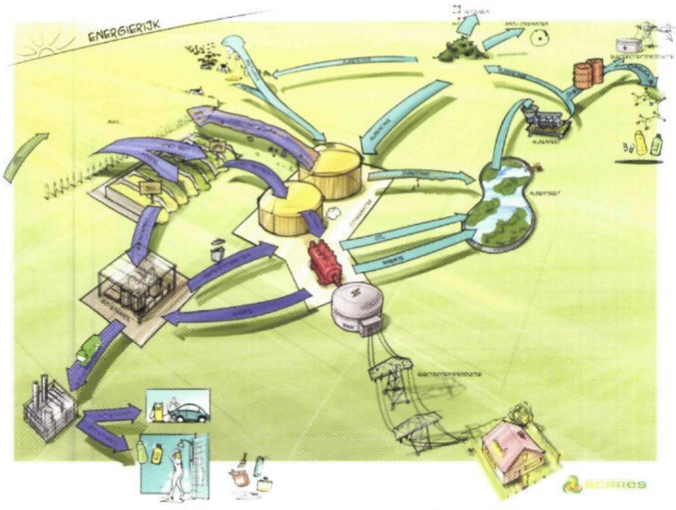

Figure 12.4. Farm scale biomass valorization concpt targeted at waste stream r-use and whole plant use

12.6 Developing and adapting agroproduction systems within natural resource competition

An important transition pathway to respond to the challenge of high production levels with high eco-efficiency (which are also acceptable to society and economically viable) is the development of agroproduction systems that harmonise different claims on the same natural resources as being used by agriculture. An explicit analysis of the resources, the claims and claiments is necessary. The systems need not only to fulfil current but also future needs. However the future is inherently uncertain therefore an exploration phase during which scenarios are developed can be very useful. These scenarios can inform stakeholder negotiations leading to decisions about desired designs. These are likely to lead to different outcomes for different locations and involving different scale levels. But in all cases, technologies, new designs and/or new institutional settings or a combination of both are necessary to realize solutions.

Science-based and computerized models constitute an important instrument to improve understanding of systems and to allow cheap experimentation with systems where physical experiments are not possible (e.g. at farm and regional level). Also, these tools can be used for ex-ante assessment of new design and technologies, i.e. what are pros and cons of new options in terms of economic, environmental or social objectives. In Chapter 10, the integrated modelling framework SEAMLESS is described as an example of such integrated assessment tool for multiple levels, i.e. from field, farm, regional and European level. Many other models can be helpful in a variety of set-ups. For example, Vos et al (2006) presented the WATERPAS instrument with which the influence of water regimes on dairy farms can be simulated and with which the influence of dairy management on surface and ground water quality can be assessed.

An illustration of a technology which serves water quality goals, water quantity concerns and farmers' interests revolves around the case of controlled drainage in grassland (Figure 12.5) in the Netherlands. On a national level, temporarily collecting water in rural areas is important in case of water supply excess to prevent flooding downstream. At the same time, on regional and national levels, concerns over water quality are widespread due to agricultural use of nutrients. Finally, farmers wish to decrease their expenses on fertilisers and would like to have a good water supply in summer. The concept of composite drainage could provide a technological answer to all these concerns. It allows farmers to increase water holding capacity

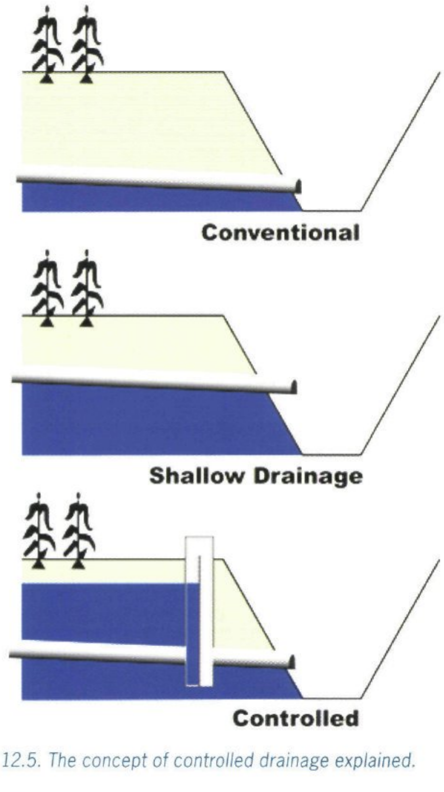

Figure 12.5. The concept of controlled drainage explained.

in summer and decrease phosphate applications whilst allowing for more water to be stored in winter in rural areas which leads to lower phosphate emissions to surface waters (van Bakel, 2003).

The above example illustrates the importance of embedding technologies within the stakeholder arena to serve different claimers and claims. Another illustrative example of the solutions technology can offer to competing claims is shown in Chapter 4 with the concept of "De Zilte Zoom". This concept introduces new crops and products in saline areas thus not fighting salinisation but trying to seize the opportunities at hand.

12.7 Global challenges and the contribution of technology

In paragraph 12.2 the contribution of technology to transition pathways has been summarized. In this paragraph we will look at the contribution of technologies from the perspectives of the global challenges: what significance can technologies have to meet these challenges?

Food security

Food security asks for food production increases. New plant varieties and animal breeds and therefore X-omics techniques (breeding by design) have great potential to contribute significantly to food production increases as they have done so in the past. However, these solutions have an intermediate-term horizon. In many countries, in any case developing countries, improved farm, animal and crop management techniques can help closing the yield gap on shorter notice. These can be existing techniques that can be modified and adapted to match local conditions based on local knowledge or new developing techniques like precision farming. Yield limiting factors, such as water and nutrient availability, need proper attention on the basis of the existing reservoir on production ecological knowledge and corresponding management options. Also, novelties in control of pests, diseases (animal, plants) and weeds can help closing the yield gap by reducing the impact of yield reducing factors. The corresponding management options are elucidated in Chapter 3. Addressing this potential calls for improvement of R&D infrastructures especially in developing countries (IAC, 2004).

Climate change

Climate change influences the biophysical agroproduction environment and thus has a large potential impact on these systems throughout the world (Morison & Morecroft, 2006). As a substantial contributor to greenhouse gas emissions, agroproduction needs to mitigate these emissions. System design can for instance be helpful to develop animal husbandry systems with less greenhouse gas emissions and a lower eco-footprint, supported by more balanced and precision feeding as well as advanced breeding and animal health (FAO, 2009). In plant production for food, feed and fuel, direct and indirect emissions of nitrous oxide can be decreased by adapted management techniques such as soil cultivation and nitrogen fertilisation. In animal production, emissions of methane can be decreased by influencing the diets of dairy cows and by manure management. Technical developments can also contribute to adaptation to climate change. The concept of resilient and robust agriculture (Chapter 8) sets a framework for adapting agroproduction systems as climate extremes are likely to become more frequent and pronounced. Depending on what can be expected locally, risk buffering production systems need to be developed and system design (Chapter 7) can be helpful. Furthermore, existing knowledge on animal and plant health techniques (Chapter 3), efficient irrigation systems and concepts to improve use of green water (Chapter 4) and nutrient recycling (Chapter 5) can be used to develop building blocks for these resilient production systems.

Phosphorus

Phosphorus is an essential nutrient for plant and animal growth and is non-renewable. Therefore, recycling techniques are necessary to make agroproduction systems sustainable. Smit et al (2009) have analysed existing resources and have visualised the phosphorus flows in global food production systems. In Chapter 5 it is concluded that recycling nutrients (and especially phosphorus) is needed. Innovativetechniques have to be applied to recycle phosphorus from urban and industrial waste. Also management techniques to increase phosphorus use efficiency in agriculture are needed as wel (e.g. precision techniques). Furthermore, whole plant use close to the source of biomass production can contribute to closing nutrient cycles (regional recycling: see Figure 12-4). Regions with a positive phosphorus balance need to design systems that will allow for a phosphorus neutral agroproduction.

Water

Globally, water scarcity is unevenly distributed, both in time and geographically. Technology to produce a higher water use efficiency needs to be adapted to time and space. Chapter 4 gives an overview of the available techniques. Water saving techniques and water re-use techniques are available or under development (re-use of industrial or urban waste water). Agroproduction systems with high water use efficiency are available for high value crops (vegetables and fruits – e.g. hydroponic systems). Seasonal weather predictions can help to plan agroproduction in order to improve the match between water supply and demand. Production planning in water catchment areas according to regional differences in water buffering capacities can also be used to match supply and demand. The concept of resilient agroproduction systems (Chapter 8) fits nicely into these techniques. In some areas salinisation threatens agriculture, but this situations can sometimes also be used to develop saline production systems based on system design (Figure 4-2).

MDG's

In recent years the contribution of agriculture in achieving the Millennium Development Goals (Worldbank, 2007; McIntyre et al, 2009) has been stressed. Thus, developing eco-efficient agroproduction is not only necessary from an ecological point of view but also from a developmental, economic and societal point of view. The techniques available or under development will not only benefit agriculture but the whole supply chain. To implement agroproduction techniques in accordance to the stakeholders interests, techniques as described in Chapter 11 could be used. Examples in the past (intensive livestock production, GMO's etc) have stressed the importance of stakeholder involvement in developing an agroproduction which is not only ecological sound but also acceptable to society under the precondition of economic feasibility.

Shared vision statement CSD-17, 2009:
"With sharing our vision we underlined our deeper appreciation of the centrality of agriculture to sustainable development: agriculture in the broad sense, including livestock raising, agro-forestry and mixed systems"

Biobased economy

The oil crises, rising oil prices and climate change through greenhouse gas emissions have increased the urgency to develop renewable energy sources, e.g. bio-energy. It is increasingly clear that whole plant use technologies have great promise (Chapter 9). There is a potential interaction between agroproduction and the biobased economy. Technologies can make it feasible to produce feed and energy from ligno-cellulosic biomass. High value plant proteins can be refined from biomass which can contribute to subsitution of animal proteins by plant proteins. Moreover, the biobased economy can play an essential role in recycling nutrients and especially phosphorus. The technologies that underpin the biobased economy can contribute to improved sustainability (DeWulf & Van Langenhove, 2006).

Competing claims

Global societal developments and concerns are interconnected both in time, geographical locations and between scale levels. Claims on natural resources are intensify as the size of the claims is growing. To make proper scenario analyses, stakeholders need to be involved and insight in trade-offs is necessary. Technologies will be used when win-win scenarios can be constructed (or win-loose scenarios with compensation – see Chapter 10). This sets competing claims analyses in the frontline of technological development.

12.8 To conclude

In line with Koning et al (2008), we think that our world can feed 9 billion people whilst allowing for a certain level of biomass to be used in the biobased economy. However, this will not happen without a significant investment, particularly if we wish to keep the eco-efficiency at an acceptable level. To do so, potential yields need to increase, yield gaps need to be narrowed and natural resources must be used more efficiently. The technologies combined with the concepts for the implementation and use of technologies as well as redesign of systems, as described in this report, will contribute to meeting the multiple challenges ahead. Technology and system design allows us to take the step to the next production and efficiency frontier and thus increase resource use efficiency. Biobased technologies and concepts for waste stream valorisation will broaden the resource base and thus contribute to higher production levels. Concepts drawn from system design, thorough analyses of competing claims situations and involvement of stakeholders, can all set the technology implementation agenda. Governance is indispensable in these transitional routes by contributing to the creation of an enabling environment.

The transition pathways described in paragraphs 12.2 to 12.4 coincide directly with one of the five development tracks as defined by the policy document written jointly by both the Ministries of Agriculture, Nature and Food Quality and the Ministry of Foreign Affairs (Development Cooperation) on Agriculture, Rural Entrepeneurship and Food Security. Yet, transition pathways as described in paragraphs 12.5 and 12.6 are just as applicable in the context of this document.

This study aimed to assess the contribution of Wageningen UR to developing and introducing technology and system design that aims to improve agroproduction systems. It has developed knowledge and insights into processes that lead to technological innovations, which involve multiple interactions and stakeholders. Wageningen UR will continue to contribute to solutions for the future challenges: increasing agricultural productivity while reducing the claim on the natural resource base, against the background of a growing world population, changing food habits, climate change, increased demand for biomass for fuel, an emerging biobased economy and the increased scarcity of natural resources.

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