Designing biodiverse arable production systems for the Netherlands by involving various stakeholders

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Received 7 December 2006; accepted 19 April 2007

Abstract

A study was done that aimed at designing biodiverse crop production systems for the Netherlands taking into account the views held by stakeholders in society. Biodiverse crop production systems contain different species and/or different genotypes within a species, leave room for other plants (both spontaneous and sown plant species) and enhance the associated biodiversity of microfauna, mesofauna and microflora. The study was carried out jointly by closely co-operating scientists in the fields of agronomy, environmental sciences and social sciences. To integrate the knowledge of specialists and stakeholders a stakeholder consultation was done consisting of a literature review analysing the Dutch policy on biodiversity, a workshop consulting intermediary institutes about their views on arable biodiversity, and an expert panel that not only monitored the design process but also regularly discussed the developments during a three-year field test of a highly diverse production system that meanwhile was designed. The results of the study were used to compare the design with other production systems. In addition, a list of indicators was compiled to test this design for system performance in terms of societal (people), ecological (planet) and economic (profit) aspects. Finally, through this study, choices in the design process were made explicit and research topics were identified to test performance of the resulting system.

Additional keywords: agro-ecosystem, biodiversity, diagnostic study, Kolb's Learning Cycle, low-input production, stakeholder consultation, sustainability indicators

Introduction

The Netherlands is one of the most densely populated countries in the world. At the moment about 60% of the Dutch land is used for agriculture. The Dutch agricultural sector is one of the world's largest exporters (by value) and is market leader for many agricultural products with a high added value. Dutch agricultural policy is currently being reviewed and revised (Anon., 2003).

At present, land is much in demand for other uses than traditional production agriculture. Open space is becoming increasingly scarce, as an ever-increasing part of the land is needed for housing, industry, infrastructure, recreational purposes and nature conservation. Society also demands soil-bound agriculture to become more environmentally friendly. To adapt to these changing circumstances, some farmers have diversified their activities: farmers are no longer merely focused on the production of food, feed or raw material, but also provide services related to tourism, nature conservation, preservation of national heritage, and green care. A recent study about the future of land use in the Netherlands illustrates that agriculture, nature conservation and recreation should be combined and integrated (Koomen *et al.*, 2005). Also earlier studies, carried out abroad, confirm the need to integrate agriculture and landscape ecological aspects (Gulinck, 1986; Giampietro, 1997).

Biodiverse crop production systems contain different species and/or different genotypes within a species, leave room for other plants (both spontaneous and sown plant species) and enhance the associated biodiversity of microfauna, mesofauna and microflora. The objective of this paper is to present a study that aimed at designing biodiverse production systems that integrate societal, ecological and economic goals. So far, very few such studies have been carried out (Van Mansvelt, 1997; Vereijken, 2002), which is partly due to the lack of science-based and politically acceptable indicators of biodiversity. The same is true for sustainability of agro-ecosystems. Von Wiren Lehr (2001) concluded that "there is a lack of ample sustainability indicators, especially of methods to deduce indicators for agriculture" and for "an adequate evaluation of agro-ecosystems". Our study could be called a 'diagnostic study' as it formed the basis on which sustainability indicators for biodiversity development in agriculture were identified. Diagnostic studies were originally designed to identify and articulate research problems in developing countries. Through active participation of farmers, options were evaluated and solutions selected that farmers could accept and adopt (Röling *et al.*, 2004). We carried out a 'diagnostic study' to make the pre-analytical choices underlying the design of biodiverse production systems for the Netherlands more explicit and to improve the design process. In this study we consulted different stakeholders to design biodiverse production systems that not only fit in the window of opportunities of Dutch farmers but that also comply with the wishes and demands of society as a whole.

Before describing and discussing the methodology and the results, we provide a short overview of relevant literature.

Overview of the literature

For a long time, agriculture has intensified its production systems. High external input agriculture demands standardization of production techniques, thus reducing or excluding variation within a cropping system. The high production level resulted in overexploitation of natural resources and in a decrease in biodiversity and variation. As a result agro-ecosystems became less and less sustainable (Almekinders *et al.*, 1995). Several concepts show that it is possible to develop agro-ecosystems that are less dependent on external inputs, particularly N fertilizer and biocides, by making better use of natural processes (Almekinders *et al.*, 1995). In this way, systems can be created or re-created with a high biodiversity. Diversity in arable plant communities can be achieved using species diversity and/or genetic diversity within species.

Genetic diversity is important for the functioning of semi-natural agro-ecosystems (Maxted *et al.*, 2002). Often – but not by definition – genetically diverse populations are more stable (Booth & Grime, 2003) and are better able to withstand a variety of pests and diseases (Finckh *et al.*, 2000) than genetically poor populations. This is particularly true for pests and diseases with a narrow host range and for pathogens with a high specificity (Finckh *et al.*, 2000). Non-specific fungal pathogens show a smaller response to genetic diversity (Jeger *et al.*, 1981a, b).

In tropical areas, a long tradition of mixed cropping systems already exists. Mixed cropping is often superior to monocropping, because the former shows better disease control, better use of available labour, and better monetary income than monocropping (e.g. Norman, 1974). Moreover, it allows better coping with variable rainfall than monocropping (Norman, 1974).

Research in temperate regions also shows that species diversity, as in mixed cropping, can contribute to stability in agro-ecosystems. Stability may be improved by better weed suppression resulting from differences in crop architecture, and some diseases may be suppressed by host diversification (Kropff & Walter, 2000; Butts *et al.*, 2003; Hooks & Johnson, 2003; Hauggaard-Nielsen & Jensen, 2004).

Mixed cropping can control wind erosion and improve water infiltration (McLaughlin & Mineau, 1995). Especially in legume–cereal mixtures it was found that under low-input conditions individual crop yields can be higher with mixed cropping than with monocropping, because of an increase in resource use efficiency resulting from niche differentiation. When legumes are a component of the mixture, an increased nitrogen use efficiency of the whole mixture will also play an important role (McLaughlin & Mineau, 1995; Van Ruijven & Berendse, 2003).

Associated plant diversity is a special case of biodiversity. Weed abundance in itself does not create a yield advantage, as weeds can cause great losses in crop yield (Kropff & Walter, 2000). Yet, the presence of some wild plant species can be desirable for various reasons. Wild plants may attract useful organisms (Comba *et al.*, 1999; Carreck & Williams, 2002), thereby increasing biodiversity and contributing to the stability of the agro-ecosystem (Altieri, 1999). Current production practices have reduced the abundance of many plant species: many former weeds on arable land have been put on the list of endangered plant species (the so-called Red List species). By creating more diversity in production systems, the ecological environment in which these species thrive can be re-created so that these species can perform their ecological function in the resource management of the agro-ecosystem (Marshall & Moonen, 2002). Abundance of wild flowers can, if rightly used, contribute to the "enrichment of the landscape" (Van Elsen, 2000).

Methodology

This 'diagnostic study' started with a preliminary design that met most of the ecological objectives – as reviewed in the section above – of a low-external-input arable production system, but economic or societal goals were not taken into account. To also add these objectives a multidisciplinary team was composed that comprised scientists in the fields of agronomy, environmental sciences and social sciences. After the initial design, the further design process and the diagnostic study consisted of three additional steps.

1. The social scientists supplied methods to structure the mental process of the agronomist, the first author of this paper. This is called Research Guidance (Verstegen *et al.*, 2000; Smit *et al.*, 2006). The structure of the design process and methods used – a major outcome of this first step – are outlined in Figure 1 on the analogy of a Research Guidance pathway. Kolb's Learning Cycle (Kolb, 1984) was followed to set up the design, using information from literature, and to complete it, using information from stakeholders and society. During the different steps of the Research Guidance pathway, methods such as Mind mapping (Plsek, 1997) and Funnel analysis (Smit *et al.*, 2006) were used (Figure 1).
2. A stakeholder consultation was carried out to integrate the knowledge of specialists from different disciplines and stakeholders from various Dutch organizations. This stakeholder consultation consisted of three parts: (1) a literature review by the agronomist to analyse the Dutch policy on biodiversity in agriculture, (2) a one-day workshop at which the views were analysed of intermediary institutes that convert policy and research themes into practical advice at farm level, and (3) consultation of an expert panel to improve the working structure, the research methods and the focus of the design. The expert panel met twice a year for 4 years. The workshop attendants and the expert panel consisted of relevant stakeholders (Table 1) including persons, groups and institutions with interests in the project (Anon., 1995). The last column in Table 1 shows the parts of the stakeholder consultation to which the stakeholders contributed.
3. The improvement of the initial design of the biodiverse production systems through an iterative process of creating, implementing and validating ideas and making explicit the pre-analytical choices. The comments made by stakeholders during the stakeholder consultation were used for a comparison of the biodiverse production systems with other systems of sustainable production and arable biodiversity in the Netherlands and for compiling a list of indicators to test the performance of this system.

Initial design

The preliminary design of possible biodiverse arable production systems by the agronomist consisted of low-input farming of mixtures of a cereal (either spring barley (*Hordeum vulgare*) or spring rye (*Secale cereale*)) and pea (*Pisum sativum*). The cereal

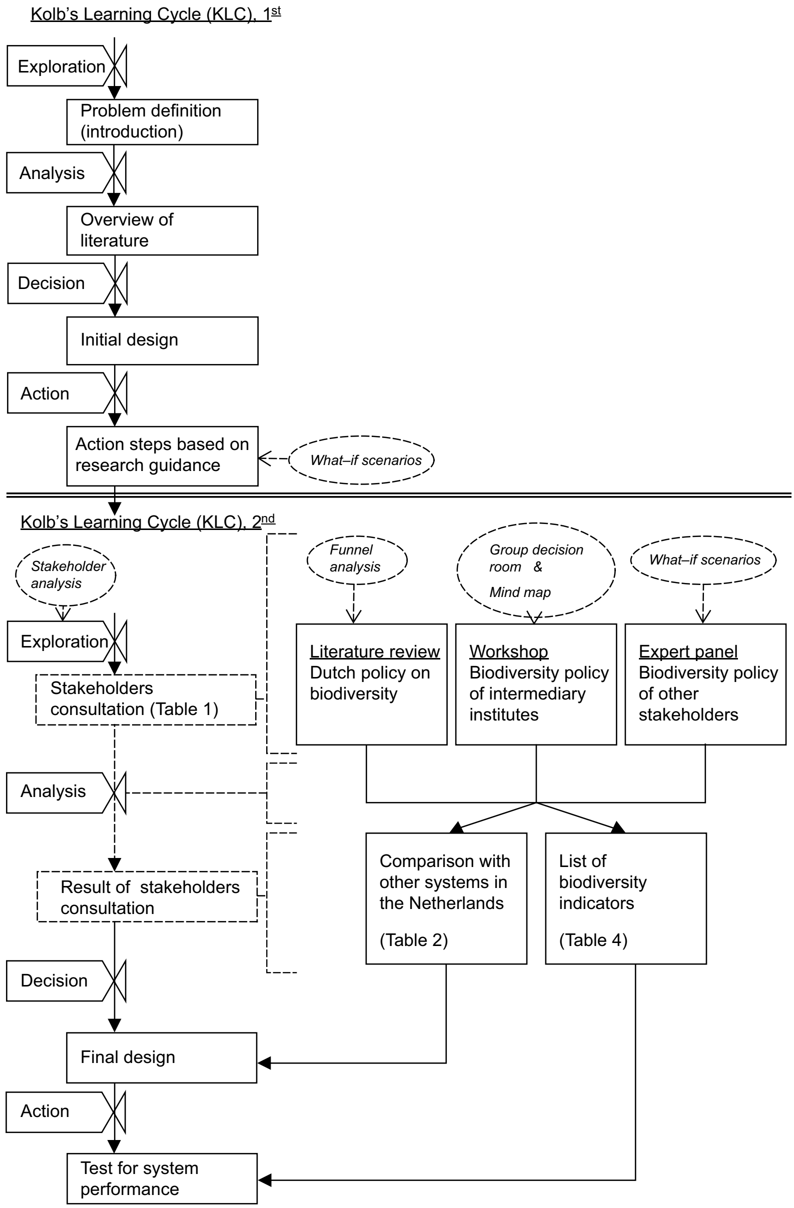

Figure 1. Structure of the design process and methods used for designing biodiverse production systems. References about tools used: Kolb (1984) for Kolb's Learning Cycle; Smit *et al.* (2006) for What–if scenarios; Eiff (2000) for Group Decision Room; Plesk (1997) for Mind map; Aarts (2000) for Stakeholder Analysis; Smit *et al.* (2006) for Funnel Analysis.

Table 1. Primary and secondary stakeholder analysis of biodiversity in agriculture in the Netherlands.

	Interests	Wishes	Means	Contribution to
Primary stakeholders				
Farmers	Maintain quantity and quality of production to make a living.	Subsidy for biodiversity management. Easily applicable.	Cropping system Field margins Agri-environment Agri-schemes	Expert panel Workshop
Nature conservation agents	Increase natural values. Maintain natural areas.	Extension of biodiversity outside EHS[1] areas. Alternation of spring and winter cereals to maintain winter annuals. Research that allies society.	Agreements with farmers. Private fields	Expert panel Workshop
People that use the countryside for leasure activities	Beautiful landscape	Beautiful landscape	None	(Workshop was cancelled last minute)
Secondary stakeholders				
Representatives of national authorities: e.g. LNV[1]	Comply with international agreements (e.g. Rio de Janeiro 1992).	Maintain and increase biodiversity. Decrease herbicide use. Increase recreation.	Laws Convenants Subsidy	Workshop LNV[1]
Regional authorities	Comply with national agreements.	Attractive country side. Development of agricultural area.	Regional planning. Area planning. Protection and planning of species.	No contribution
Intermediary institutes: e.g. LBI, CLM, DLV[1]	Intermediaries between policy and end users.	Improve agricultural practices.	Research Extension	Workshop CLM[1]

Table 1. (Cont'd).

	Interests	Wishes	Means	Contribution to
Secondary stakeholders				
Research: e.g. universities, PRI[I]	Explain ecosystem functioning.	Increase biodiversity	Research	Analysis of Dutch policy: LEI[I]. Workshop Expert panel (Professors of Crop Science and Nature Conservation; Crop analist).
Farmer organizations: e.g. LTO, AKK (chain partners)	Represent farmers in the Netherlands.	Maintain agricultural practices at a high standard.	Network Membership fees	Workshop (LTO[I], AKK[I])
Nature organizations: e.g. KNNV[I]	Represent ecologists in the Netherlands.	Maintain nature in the Netherlands.	Network Membership fees	No contribution

[I] EHS = Ecological Main Structure; LNV = Ministry of Agriculture, Nature and Food Quality; LBI = Louis Bolk Institute (organic agriculture); CLM = Centre for Agriculture and Environment (research and advice); DLV = Agricultural Extension Service; PRI = Plant Research International; LEI = Agricultural Economics Research Institute; LTO = Organization of Employers in the Agricultural Sector; AKK = Foundation of Agro-chain Knowledge; KNNV = Royal Dutch Organization for Natural History.

component would be genetically diverse by mixing different cultivars (barley) or by cross pollination (rye). Associated plant diversity could be enhanced by refraining from chemical weed control (spontaneous wild plants) or by sowing wild flowers. The presence of several crops and of wild plants would then affect the population dynamics of soil-borne flora and fauna as well as population dynamics of other micro-, meso- and macro-organisms, such as nematodes, air-borne fungi, insects, Carabid beetles and butterflies. Crops could be used for whole-crop harvesting or for grain production. The system level of the initial design was the arable field. Therefore no other elements, such as natural or semi-natural landscape elements (like hedges, ponds, semi-natural grasslands) were included in the design. We also did not consider the entire cropping plan of a farm or a long-term crop rotation.

Action steps based on the Research Guidance

The preliminary design described a production system with a potentially high biodiversity. Based on the research guidance the design was further developed and tested against the views of stakeholders. Stakeholders, who were identified and selected based on the first steps in Kolb's Learning Cycle, had several questions about the system, like how to evaluate this system for successful performance? Is it economically viable? Is it accepted as being 'natural'? Is there an added value for recreation? This step resulted in a more advanced design but also created awareness that knowledge about views on biodiverse production systems from society and farmers was lacking. Therefore a further consultation of stakeholders was carried out.

Stakeholder consultation

As indicated under Methodology, the stakeholder consultation consisted of three steps: a literature review, a workshop, and consultation of an expert panel.

Literature review on Dutch policy on biodiversity

The Dutch government strives for biodiversity management based on its commitment to the international policy on biodiversity. Together with 181 other countries it signed the 'Convention on Biodiversity' (CBD) agreed upon in Rio de Janeiro in 1992 and now has to implement the agreement. In the CBD, biodiversity was defined as: "*The variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems*".

Conservation of biodiversity is important because loss of biodiversity threatens human well-being. Humans need basic materials for a satisfactory life. Biodiversity is the starting point for security in the face of environmental change, because its effects on the ecosystem processes lie at the basis of vital life support systems (Diaz *et al.*, 2006). Farming is the greatest threat to biodiversity on the planet (Altieri *et al.*, 1987; Tilman *et al.*, 2001; Green *et al.*, 2005). Nevertheless, especially for farming we need biodiversity, e.g. as a basic resource for breeding varieties with new characteristics, for the production of new crops to meet future food, feed and energy demands (Frankel *et al.*, 1995) as well as for medicine development (Dalton, 2004).

The Dutch government focuses on biodiversity management in both natural and agricultural areas (Duinhoven *et al.*, 2002). It describes agrobiodiversity as (Anon., 2003):

- Diversity in genetic resources (species, varieties, breeds, micro-organisms) that are used for the actual production of food, fodder, fibre, fuel and pharmaceuticals.
- Diversity in non-harvested species that support production (functional biodiversity; soil micro-organisms, predators, pollinators). This group also includes the organisms that, for instance, improve soil fertility and soil structure or suppress pests and diseases.
- Diversity at ecosystem level. This includes diversity in the wider environment that

supports agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems and the diversity in plants and animals that are not part of the agro-ecosystem but make use of it, such as meadow birds and wild plants (associated biodiversity).

The Dutch government has an agri-environmental scheme for landscape- and nature management on farmland that includes subsidy agreements between state and farmer (Subsidieregeling Agrarisch Natuurbeheer). Enhancement of biodiversity is a major aim of these agreements. However, it should be mentioned that the biodiversity policy in the Netherlands is still under debate. The policy landscape in the Netherlands with regards to biodiversity is very dynamic as there are conflicting views. Some policy makers opt to combine commodity production by agriculture with 'green and blue services' by farmers. This is also the dominant view within the EU, where the subsidizing of farming based on support of agricultural production alone is shifted to direct income support based on production of integrated ecosystem services (Anon., 2005). However, the opposite view of maintaining agriculture as a high-tech industry on a restricted area, with minimal impact on the environment, while at the same time buying as much agricultural land as possible for nature conservation, is also present. Designing and evaluating biodiverse production systems is therefore very topical (e.g. Rossing *et al.*, 2007).

Workshop on biodiversity policy of intermediary institutes

Stakeholders from intermediary organizations in the Netherlands looked upon biodiverse production systems as part of landscape development. Their view is based on Dutch regional policy, which in turn is based on the historical background of an area (Anon., 1999). In the past, sandy soil areas were organized differently from clay soil areas, resulting in differences in landscape structure. Compared with the open landscape on clay soils, the sandy soils tended to have more landscape elements, such as hedges and tree rows. Each area had a characteristic species composition that depended on the soil type and on the farming system prevailing in the area. Many of the wild plant species that used to grow in these ancient, mostly cereal production systems are now threatened by current production practices. The authors decided to include both spontaneous and associated plant species in the design of the biodiverse production systems.

At production level, stakeholders added the following points. Biodiverse production systems can be managed using current technology. For example, mycorrhizas may be added to the soil or enhanced by agronomic practices to stimulate plant growth and plant health (Douds & Millner, 1999). Modern technology like Global Position Systems (GPS) can be used for precision application of nitrogen. Release of natural enemies can be used to control pests. The use of current technologies is best put into practice if stakeholders in an area join up to develop landscapes with improved natural pest control. Furthermore, biodiverse production systems are economically embedded in the community. They will be affordable partly because of yield and partly because of other functions they fulfil, like their value for recreation (by tourist taxes) or in biodiversity conservation (subsidies within the framework of agri-environment schemes).

Consultation of expert panel to assess biodiversity policy of other stakeholders

Members of the expert panel compared biodiverse production systems with other types of production systems in the Netherlands. Biodiverse production systems could best be compared with the following three systems: (1) organic agriculture (Anon., 1991), (2) systems related to the Protection Plan Arable Plants ('Beschermingsplan Akkerplanten'; Anon., 2000), and (3) systems related to agri-environment schemes (Anon., 1998).

During the design process, participants in the expert panel advised the agronomist the following on the prerequisites of the biodiverse system. First, a biodiverse production system needs to be profitable to farmers and must fit in the landscape. So the agronomist should clearly define the starting situation and from there predict the possible result achievable during the development process of the system. Since the validation experiment had to be carried out within the framework of a PhD programme, for practical reasons the time horizon of the development process was 3 years. The aim should be a system in which changes in yield, soil fertility, and abundance of wild (sown and spontaneous) plants could all be taken into account. Stakeholders agreed that the success of system performance would have to be measured on the basis of parameters related to economic and ecological evaluation criteria as well as societal aspects of the final design. Systems will develop differently depending on e.g. location, soil type and soil nitrogen level. Rich soils may generate lower diversity (Stevens *et al.*, 2004) although higher yields are to be expected. So it was necessary to carry out the experiment on soil types with a different level of soil fertility. Secondly, consistency in agronomic crop husbandry practices is essential to make clear the trends over the years. Thirdly, it can be expected that seeds from wild flowers do not germinate in the second year because they were placed in deeper soil layers when the soil was ploughed after the first year. Consequently, it would be logical to sow wild flowers in the first two years of the experiment. In our analysis the population ecology of sown wild plants could be assessed only if these species were sown once, i.e., in the first year of the experiment. Fourthly, during the design process the agronomist should make a clear distinction between activities related to analysis and those to synthesis. The agronomist should also focus on key-indicators to be able to handle a multi-disciplinary experiment. This means that first the production system should be set up and next the system should be analysed. Furthermore, the emphasis should be on ecological goals and then the societal and economic impact should be investigated. Eventually, the agronomist should integrate the results obtained from the ecological, economic and sociological investigations.

Analysis of stakeholder consultation

Final design

The stakeholder consultation was used to compare our design with other systems of sustainable production and (arable) biodiversity in the Netherlands (Table 2).

Table 2. Dutch production systems compared for biodiversity aspects.

Production system	Production	Ecology[1]	Care for the environment[2]	Landscape
Conventional agriculture	+++ [3]	–	–	–/+
Organic agriculture	++	++	+++	+
Protection plan for arable weeds	–	+++	+++	+
Field margins (agri-environmental schemes)	++	++	+	++
Biodiverse cropping system	++/+	++	+++	++

[1] Diversity of animals and plants.

[2] Use of pesticides and inorganic fertilizers.

[3] – = not important; + = of little importance; ++ = important; +++ = very important.

During the stakeholder consultation we experienced that comparing our biodiverse systems with other systems that aim to increase plant biodiversity cannot be done without considering differences in interpretation between different stakeholders. For example, the term 'nature' is differently interpreted by stakeholders with a background in either agriculture (e.g. farmers) or in ecology (e.g. members of nature conservation organizations). Ecologists focus on the presence of biodiversity and rare species in different habitats, whereas agronomists focus on crop production and look at nature from a management point of view. If a system is designed for combining production and nature conservation functions, the design must comply with these two perceptions. This means that biodiversity in the system is not only managed by sowing wild species into the crop, but also by allowing the system to develop in such a way that indigenous species can establish and persist.

Among the systems we compared, several were characterized by a large diversity of plant species. In some of them the plant species included several crops, several varieties of the cereal crop, but also variation in associated and functional diversity. Wild plant species are also preserved in the Protection Plan Arable Weeds. However, in that plan production systems are maintained for many years in a row with the only objective to protect the wild plants. Our production systems were only studied for a few years and we also strove for other goals than protecting wild plants, like a certain level of production. Consequently, the number of preserved wild species will be lower than in the Protection Plan Arable Weeds. We aimed at a number of plant species comparable with what is attainable in field margins. The biodiverse production systems encompass the entire field, not only the field margins. Contrary to currently prevailing production systems, biodiverse production systems are designed to fit in the landscape. For this aspect, the biodiverse systems tested in our study can best be compared with field margins. Biodiverse production systems are not designed for maximum economic crop yield but for achievable production levels given the ecological and societal restrictions imposed on the system. Biodiverse production systems are therefore better comparable with organic agriculture but with larger ecological and societal restrictions. Such production systems do not exist yet.

The stakeholder consultation elucidated certain aspects of the design that needed reconsideration. The most important one was soil tillage. In semi-natural production systems no-tillage is most common (Titi, 2003). However, after consultation with soil scientists it was concluded that no-tillage practices are only manageable once soil life has significantly been improved. During that transition process weed populations will change drastically (Torresen *et al.*, 2003), and yield reductions due to physical soil problems will occur (Kuht *et al.*, 2001). These effects may interact with other experimental factors, with the risk of obtaining useless results. Soil scientists suggested starting the experiment on already stabilized fields, but such fields were not available. So soil tillage was carried out according to current practice in the Netherlands, i.e., ploughing to a depth of 17 cm. Other aspects that needed consideration included weed infestation (both in terms of numbers and species), amount and quality of the harvest, marketability of the product and consequently farm income, development of pests and diseases and acceptance of the production system by farmers and society at large.

Experiment, pre-analytical choices and design of the biodiverse production systems

As a result of the iterative design process, a 3-year field experiment was carried out on two sites (one with a sandy soil, one with a clay soil) near Wageningen, The Netherlands (51°58' N, 5°38' E). External inputs were limited (no fertilizer, no chemical control of weeds, pests and diseases) but high inter- and intraspecific diversity was enhanced. The first year of this field experiment was repeated on a sandy site and a clay site. These experiments were the main activity of a PhD programme carried out by the agronomist. Eight different plant associations were composed consisting of a cereal (spring barley or spring rye), pea and indigenous (sown) wild plant species. The eight associations were: a genotypically diverse cereal crop in sole stand (barley or rye), a mixture of pea and a genotypically diverse cereal (barley or rye), a mixture of a genotypically diverse cereal (barley or rye) with (sown) wild plants, a mixture of a genotypically diverse cereal (barley or rye) with pea and (sown) wild plants (Table 3). These associations were chosen for the following reasons. Rye used to be grown in the Netherlands on poor soils with an intrinsically high biodiversity. At present, rye is mainly grown on poor soils to conserve plant species that are close to being extinct, the so-called arable land conservation areas. Rye was also chosen because it is a cross-pollinating species contrary to most other cereals, which are self-pollinators. This characteristic was important because we wanted to assess the changes in allele frequencies in the genotypically diverse rye. Barley, which is a self-pollinator, was chosen because in the Netherlands barley–pea mixtures have been introduced in organic agriculture as a new protein rich, economically profitable crop combination to replace grass or forage maize (Anon., 2003). Cereals enhance fodder quality by their

Table 3. The plant and crop associations tested in the experiment.

1.	11 spring barley varieties
2.	11 spring barley varieties with pea
3.	11 spring barley varieties with wild plant species
4.	11 spring barley varieties with pea and wild plant species
5.	Spring rye
6.	Spring rye with pea
7.	Spring rye with wild plant species
8.	Spring rye with pea and wild plant species

high starch content. Pea improves the fodder quality by its high protein content. A semi-leafless type of pea was chosen as it is not a strong competitor for light. Spring cereals were used because pea is a spring crop and both crops need to be sown simultaneously to obtain positive interaction. Indigenous wild plant species commonly associated with cereal stands were used because they are adapted to growing in association with a cereal crop. They have pretty and large flowers that not only attract flying insects but are also highly appreciated by people.

The experiment was carried out on a sandy soil and a clay soil to assess soil type effects. The harvested grain was used as seed for the next two years to allow selection to occur. The following wild flora species were re-introduced by sowing in the first year of the experiment: *Papaver rhoeas*, *Centaurea cyanus*, *Chrysanthemum segetum*, and *Misopathes orontium*. In addition, *Matricaria recutita* (sandy soil) or *Tripleurospermum maritimum* (clay soil) was sown. (The nomenclature is according to Van Der Meijden , 1996.)

Test of system performance

The stakeholder consultation was also used to make a list of indicators to test the design for system performance at different levels (Table 4). Indicators were grouped by the categories people, planet and profit. It was not possible to extensively investigate all indicators that are listed in Table 4. Only indicators were chosen that were representative of the performance of the system as a whole. Why indicators were chosen per group is argued below. Note that profitability is used both under People and Profit, for the reason that profitability proved to be essential for farmers in their evaluation of the acceptability of the systems.

The first group concerns ‘People’. People’s well-being is enhanced if the countryside is well managed (Anon., 2004). If biodiversity is high, people can enjoy a diverse countryside with plants, insects and animals like birds, rabbits, and hares. The amenity of biodiverse production systems was evaluated using questionnaires to analyse whether people like these fields more than conventional fields. To obtain information on the level of acceptance of biodiverse production systems, people from different groups in society were consulted, including farmers, policy makers, tourists and citizens.

Table 4. Possible indicators to test for system performance of biodiverse arable production systems based on the sustainability parameters People, Planet, and Profit. Indicators that are investigated are underlined.

Sustainability parameters	Indicators for system performance
People	Image of farmer
	Farm tradition
	Perception of fields
	Landscape tradition
	Appreciation towards environmental agriculture / environmental care
Planet	Development of cereal variety composition (genetic diversity)
	Development of weeds and introduced wild plant species (plant biodiversity)
	Aboveground functional diversity of pests (aphids, thrips, etc.), diseases (fungi, viruses, bacteria), natural enemies (e.g. ladybeetles), pollinators, other organisms
	Below-ground functional diversity (nematodes, fungi, viruses, bacteria, arthropods, other organisms)
	Associated biodiversity, including Carabid ground beetles, flying insects, birds, mice, special associated plants
	Soil organic matter
	Soil nutrients
Profit	Production costs
	Profit
	Processing techniques
	Implementation costs, e.g. in rotation (consequences of other crops grown)
	Machinery purchase
	Education costs farmer
	Community resources through tourist taxes for beautiful landscape
	Subsidies for biodiversity enhancement
	Subsidies for green-blue veining[I] in the agricultural landscape
	Subsidies for ecological farming

[I] To enhance the abundance and spread of natural enemies of crop pests and diseases.

The second group, the 'Planet', was taken into account by enhancing biodiversity and ecosystem functioning compared with regular production systems. Species and genetic diversity of the main crops (barley and rye) were introduced as factors in the design.

Genetic development of the main crop was measured as it is an important factor for success of resistance against pests and diseases (Finck & Mundt, 1992). Changes in genetic composition of the cereal throughout the years were assessed. Pea was sown as companion crop, and its development and production and the diseases associated with its continuous cropping were monitored. Wild plant species were introduced in the design; changes in wild flower composition and associated plant species composition over the years were measured.

Functional and associated diversity consists of many types of organisms (Table 2). Nematodes were chosen as they are regularly used as indicators of biological soil condition (Bongers & Bongers, 1998; Yeates, 2003). Nematode populations also show rapid changes in response to the frequency of crops in the crop rotation and show much stronger changes than other soil organisms (Korthals, 2001). Finally, nematodes are very important as the returns of the crop are greatly affected by an increase in density of specific plant parasitic nematodes (Yeates & Bongers, 1999). Nematode problems occur especially with continuously grown peas. We therefore measured the changes in the nematode population over the years. We also did some measurements on soil-borne fungi and bacteria.

Carabid beetles were counted as they are representative of associated and in several cases functional biodiversity. These beetles are often used as an indicator of biodiversity in both natural ecosystems and production systems (Kromp, 1999). They are potentially important natural pest-control agents because of their predatory polyphagous diet (Kromp, 1999). As they are attracted to weed-rich fields (Hough-Goldstein *et al.*, 2004), differences between weed-rich and weed-poor production systems can be expected. Carabid beetles were recorded in a one-year experiment on both sandy and clay soils.

The third group was 'Profit'. Profit of biodiverse production systems is made by the production, the subsidies and possibly other resources such as payments for 'green services', in order of importance (Table 2). Profit from the production is the most important factor for success at the implementation stage. Additionally, options like biorefinery were investigated. Biorefinery means that the product harvested is processed to separate the components (starch, protein) that then may be sold as separate products. Based on the profit that can be made from biorefinery, the need for returns from other sources to make the system competitive were calculated.

Dutch farmers will have a hard time surviving when monetary income is only based on sales of products on international markets for agricultural commodities. Public support for their services is essential for their economic survival. It is still very unsure how in the future public funds will be used for paying small-scale agriculture for the production of ecosystem services.

Discussion

During the set up of the methodology the order of activities was considered crucial. Should stakeholders be consulted before or after the agronomist started with the design? We decided to consult the stakeholders before starting with the actual design process but after the initial design. Advantages were that the agronomist had an open mind towards comments from stakeholders. The agronomist would still have options to adjust the design of the system to create a better match with societal needs. During the process we also encountered disadvantages. Because the agronomist was not focused on a certain goal yet, it was not possible to select stakeholders or to ask the right questions. For example, some stakeholders we addressed had a particular interest in a specific type of system that already existed. Subsequently, we decided to start with an initial future-oriented design. During the process we experienced the advantages of this approach. By confronting stakeholders with a new kind of system, the discussion was more oriented towards implementation of the new system, which brought about new insights: stakeholders experienced new systems, and the scientist learned how to design a new system in such a way that it could be used.

The methodology developed in this study provides a guideline for the design of other production systems with a societal component. The main aim, in addition to designing an optimum agricultural production system, was to design for other aspects, like environmental care and fit into the Dutch landscape. To that end a list of sustainability indicators was compiled. The design was also tested in a field trial. Until now, mostly experiments were carried out or design models developed in which society aspects had already been included (Van Mansvelt, 1997; Vereijken, 2002). Our study is an example of using research guidance and stakeholder consultation for an actual design, and testing the design in a field trial. So this study is one step closer to finding answers to fill the gap between theory and practice in sustainable agro-ecosystems (Von Wiren Lehr, 2001).

Through this study it was possible to elucidate the most important pitfalls. Although the final design is not perfectly suited for every practical situation, this study made it possible to move forward towards a system that takes the views of a diverse group of stakeholders into account. The knowledge gained is a step forward to improve this and other production systems. The list of indicators to test for system performance summarized in Table 4 can be used for similar production systems. The method developed can also be used to design sustainable production systems that match a particular area. At the site of interest, stakeholders should be consulted and a new list of indicators should be made.

Future publications of the senior author based on this design will deal in detail with the results of the field experimentation, with elements of the stakeholder consultation, with the analysis of the biodiversity indicators and with the economic evaluation of the biodiverse systems.

Acknowledgements

The authors wish to thank the participants of the workshop and the members of the expert panel for their positive contributions.

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