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Eveline Stilma

Development of biodiverse production systems for the Netherlands

Proefschrift

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Abstract

Abstract

The Netherlands is a densely populated country in which space is becoming scarce. Space is needed for economical, ecological and societal goals. About 60% of the Dutch area is used for agriculture. Agriculture in the Netherlands has been managed intensively for a long time. High yields were obtained which, however, was associated with a decrease in agricultural diversity. Additionally, the agricultural landscape has changed after the re-allocation of land that was necessary for the intensification of agriculture. The effects on the environment and associated agricultural diversity are now becoming prominent. Flora and fauna species that used to thrive in former agricultural fields are becoming extinct. Therefore, production systems with different levels of biodiversity were designed in which aspects of ecology, economy and sociology were combined. Aim was to obtain ‘adequate’ yields and systems should leave room for development of associated diversity. Moreover, systems should be attractive and contribute to the landscape scenery. Eight kinds of production systems with different levels of diversity were designed. The design was improved after consultation of stakeholders who were related to agriculture. Systems were a spring rye or a mixture of 11 spring barley varieties each grown in monocrop, in mixed crop with pea and/or in a mixture with five sown wild flower species. Systems were grown continuously for three years on a sandy and a clay soil to allow associated diversity to develop. Harvested cereal seeds were used as sowing material for the subsequent crop. No fertilizers or chemical control measures were applied. The first year of the experiments were repeated in another year at two other locations. Indicators were chosen to obtain insight in the functionality of the systems. For ‘ sociology’, interviews were held about perception of the public of biodiverse production systems to assess whether systems would contribute to the landscape scenery. For ‘economy’, the quantity and quality of silage and grain yield were measured. For positive and negative associated ‘ecology’, the dynamics of several flora and fauna species were assessed. Allocation of Coleoptera diversity over time was measured within one growing season. Development of populations of soil nematodes were assessed over time. The development in number and species diversity of the associated plants and sown wild flowers were recorded. To obtain insight in the results a mathematical model was made to describe the relation between crop growth and recruitment and attrition of sown wild flowers. Additionally, soil fungal and bacteria diversity were assessed and the development in variety composition of the spring barley mixture over time was assessed. Results showed that high yields could be obtained especially in the first year of production. Associated diversity developed during the three years of production. Wild flowers in the mixtures were mostly perceived as beautiful. Performance of production systems depended on the year and the location. Pea in the mixtures enhanced silage yield, but especially in 2005. Yield was not significantly reduced by sown wild flowers. Wild flowers performed best at soils with high initial soil nitrogen. Coleoptera diversity was higher in mixtures with pea. Plant species composition had developed over time. The development differed between locations. Production systems with different levels of biodiversity affected the associated diversity differently at the locations because of a difference in yielding ability. System performance was analysed and options to improve the systems are given.

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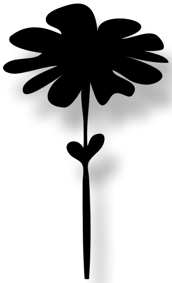

01 General introduction

Eveline S.C. Stilma

Agriculture in Europe

The Netherlands is a small and densely populated country (4.2 Mha, 16.4 million inhabitants) and space is needed for economical, social, and ecological goals (Table 1). In the Netherlands, 55% of the acreage is used for agriculture. In agriculture a 'green revolution' started around 1870 by the introduction of chemical fertilizers and pesticides, causing a steady yield increase per ha and per animal (Zanden, 1991). The highest productivity was achieved in Denmark, Britain, the Netherlands, Belgium and France. The continuous intensification was even more stimulated by the implementation of the Common Agricultural Policy (CAP) founded in the Treaty of Rome (1957). The CAP protected member states' economies through guaranteed prices for the farmers by storing surplus products, imposing levies on cheaper imports and granting export subsidies. Consequently, the most successful producers cashed the bulk of the subsidies. Highly intensive agriculture in the Netherlands attracted four times more subsidies than more extensive farmers in Spain and Portugal. The Netherlands obtained about € 700/ha whereas Spain and Portugal obtained about € 175/ha (Donald et al., 2002). As a result, in the mid-1980s only 25% of the EU (then EC) farmers produced 80% of total food needs (Rizov, 2005). High yields in intensive agriculture were achieved by using chemical fertilizers. Currently, high applications of nitrogen per ha are still common in arable crops (Table 2), but the trend towards ever increasing intensification has stopped as the impact on the environment has becoming increasingly evident (Giampietro, 1997; McLaughlin and Mineau, 1995; Stoate et al., 2001).

Table 1. Distribution of the Dutch land use in 2003

Acreage for	(ha)	(% of total)
Total Dutch land acreage	4,152,795	100
Traffic	114,268	3
Built-on	328,867	8
Semi-built on	50,615	1
Recreation	93,702	2
Agricultural land	2,304,074	55
Forest and open natural areas	484,090	12
Inland water	359,815	9
Sea	417,363	10

The use of fertilizers, pesticides and herbicides diminish the abundance of associated floral and faunal diversity. Also changes in tillage practices and crop management cause a shift in species diversity. Farmland birds are often used as indicators of biodiversity in agricultural areas as they are high in the food chain and feed on associated floral and faunal diversity in agricultural fields (Green et al., 2005). Farmland birds have been declining since 1990 in many European countries (Figure 1), which was related to higher yields by agricultural intensification as stimulated by the CAP (Donald et al., 2002). In the 20th century, the composition of the Dutch flora has changed (Tamis et al., 2005) and also in other European countries the number of plant species declined (Stoate et al., 2001; Sutcliffe and Kay, 2000). Some of the species that now become endangered are typical for agricultural production systems (Pyšek et al., 2005). However, a decline in diversity of plant species and in species of other kingdoms is not desirable. Biodiversity contributes to a rich natural environment that is needed as a source of raw material for animals and people (Díaz et al., 2006; Marshall et al., 2003). Therefore, policy was developed to protect biodiversity. The Dutch government signed together with 181 other countries the 'Convention on Biodiversity' (CBD) agreed upon in 1992 in Rio de Janeiro.

Changing attitudes towards biodiversity

Since 1992, the CAP has changed in two ways. First, the system of price support of agricultural products has changed into a policy of subsidies that distort prices and trade less. Second, the CAP is now stimulating multi-functionality in agriculture providing support for non-agricultural activities like agri-environment schemes (Râmniceanu and Ackrill, 2007). Also new regulations on environmental protection have been implemented in EU policy. Consequently, agricultural management practices are changing. Conventional production is becoming more environmentally friendly, e.g. precision agriculture techniques are starting to be used for a more precise application of fertilizers and crop protection agents. Fertilizers, herbicides or pesticides are applied only when and where they are required (Neményi et al., 2003; Stafford, 2000). Also organic agriculture has evolved, which obviates the use of synthetic fertilizers and pesticides and in which weeds are controlled by crop management (cover crops, crop variety selection) or mechanically (Bond and Grundy, 2001). Agri-environment schemes were introduced in which areas like field margins, wood edges and ponds are managed for biodiversity. Besides, through agriculture and agri-environment schemes, farmers increase their income by extending their services to recreation, health care, energy production (e.g. by wind mills) resulting in a multi-functional agriculture. On average, for each farm enterprise broadening activities contribute to 10% of the income (Râmniceanu and Ackrill, 2007; Schoorlemmer et al., 2006).

New approaches

The technology to manage farmland biodiversity can still be improved. Although agri-environment schemes did improve conditions for some species, (especially plant species) (Holland and Fahrig, 2000; Kleijn et al., 2006), it was also shown that agri-environment schemes were not very successful for other species (farmland birds) (Kleijn et al., 2001). A method to improve the management of farmland biodiversity is by applying an interdisciplinary approach (Van Mansvelt, 1997). Therefore, knowledge from different disciplines is required. Experts from farm ecology, farm economy and farm sociology should be asked for advice: biodiversity measures need to be manageable within a farm economy, enhance species diversity and, when possible, be an asset to the landscape. First should be described how each discipline could contribute to the management of farmland biodiversity. For example, Gulinck (1986) described parameters to identify landscape-ecological aspects. Kirchmann (2000) analysed agricultural quality components. Second, methodologies need to be developed to apply these quality parameters. For example, a simulation model was used to optimise sustainable production systems (Kropff et al., 2001). Jackson et al. (2007) analysed how measures for conserving agro-biodiversity in agricultural landscapes can be become sustainable and economically beneficial. To work out a methodology, cooperation between experts from different research groups needs to be set up. In this thesis an interdisciplinary approach was used to design production systems with different levels of biodiversity.

Project design and thesis lay-out

The project 'Design of Biodiverse Production Systems' was part of the research programme called 'Creating Space, System Innovations for Sustainable Food Production' (Scheppen van Ruimte, Systeeminnovaties voor Duurzame Voedselproductie (SvR)). In a small and densely populated country like the Netherlands, there is always a strong competition for land (space) between different functions, such as housing, industrial activities, agriculture, nature and recreation. The SvR programme aimed at creating space in the Netherlands through innovation of the food and feed production chain (Neeteson et al., 2003). Development of new technologies can only become successful when these new technologies are accepted and adopted in society. Therefore, another SvR project team was created that supported the 'technical' researchers during the design process called 'Research Guidance: de Rode Draad door Systeeminnovaties' (Research Guidance: Connecting System Innovations). The Research Guidance team was also involved in the stakeholder consultations and assisted us

Table 2. Amount of agricultural land, usage of fertilizers and pesticides and yield per ha for three common crops in 12 countries in Europe in 2000.

	Total agricultural land (ha)	Fertilizer use (kg N, K_2O and P_2O_5/ ha	Pesticide use (kg active gradient/ha)	Cereal yield (tonne/ha)	Sugar Beet yield (tonne/ha)	Potato yield (tonne/ha)
Austria	3,389,905	64	1.05	4.5	62	29
Czech Republic	4,279,900	77	0.00	4.2	46	21
Denmark	2,646,982	132	1.04	7.6	57	43
France	30,575,588	136	3.19	7.1	76	40
Ireland	4,418,423	136	0.48	9.5	57	34
Latvia	2,484,944	20	*	2.7	32	15
Netherlands	2,350,800	178	4.11	8.4	61	45
Poland	18,504,400	86	*	3.2	39	19
Slovakia	2,440,667	31	*	3.1	43	16
Slovenia	690,780	171	*	4.3	63	21
Sweden	3,298,000	86	0.50	6.0	*	30
United Kingdom	:	*	*	8.0	54	40

Source: Eurostats

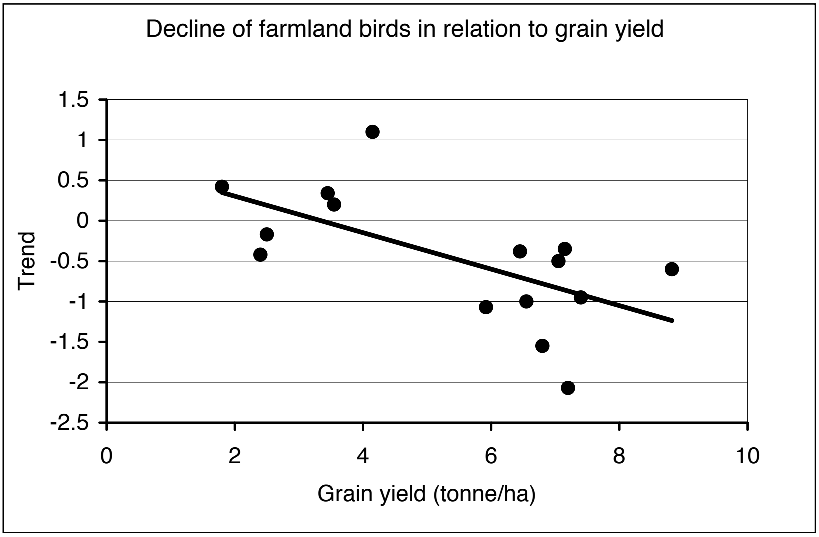

Figure 1. Mean trends of farmland birds (56 species) in the EU15 against wheat yield (the dots represent the 15 Member States)— http://apps.fao.org/faostat/default.jsp
The trend is explained in Birdlife International (2004)

during the study about the social implications of the design (Chapter 2,3) (Westerman et al., 2004).

We designed new kinds of production systems with different levels of biodiversity. The aims were high quality crops, which leave room for associated diversity and were, because of their attractiveness, an asset to the landscape. In our experiment the systems were designed and tested for aspects of ecology, economy and sociology. The methodology we used is not common. Mostly, experimental set-ups were focused on one aspect. Later on the results were integrated in review papers. In-depth analyses per discipline have been carried out for a long time in agricultural research. As reviewed in the previous paragraph, it is now becoming acknowledged that connections between disciplines have to be made in order to use the acquired knowledge in practice. This thesis describes the development of a methodology for multi-functional research and applied this methodology to test the developed production systems.

The content of the thesis is as follows. Chapter 2 describes the design process for production systems with different levels of biodiversity. It was described how an initial design was made based on a literature review. The initial design was then discussed with stakeholders that were involved in sustainable agricultural production, like farmers, representatives from nature conservation organizations, scientists, consultants from intermediary institutes and policy makers. After the discussions, the design was improved in order to facilitate application in society. Moreover, indicators were developed to test the design for system performance. These indicators were used to set up the experiments that are described in Chapters 3 – 10.

In Figure 2, the experimental set up of the experiments is shown. The biodiverse production systems consisted of a genetically rich cereal (11 spring barley varieties or spring rye (cross pollinator)) as a monocrop or cropped in a mixture with either a semi-leafless pea or with five introduced wild flower species, or both, resulting in eight different crop mixtures. Systems were grown at two locations in 2004, a sandy and a clay soil. At these locations, the defined production systems were continuously grown for three successive years. Therefore, harvested cereal seeds were used as sowing material for the next year, wild flowers were sown only in the first year and pea was purchased and sown every year. Fertilizers were not applied and pest, weed or disease control measures were not taken. In 2005, the experiment was repeated for one year at two other locations, also a sandy and

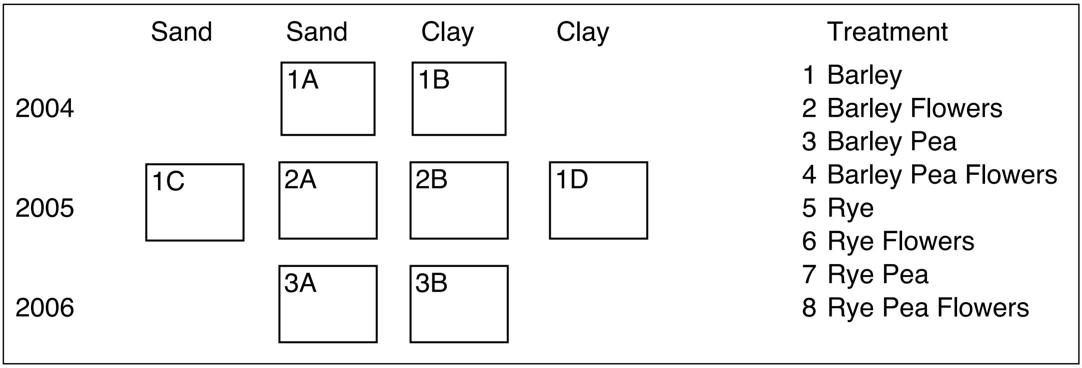

Figure 2. A scheme of the system development experiments (block 1,2,3 A and 1,2,3 B) and the repetition experiments (block 1C,1D) at four locations in different years.
Each block represents a field of 1 ha. At each field a randomized block design placed with 32 plots (8 treatments (Table 1) and 4 replications). The numbers represent the years after the start of the experiment. The letters in the blocks are used to name the locations.

a clay soil. A detailed description of the material and methods is provided in Chapter 4.

To test performance in society an indicator was defined: the extent to which biodiverse production systems contributed to the landscape scenery, as described in Chapter 3. Therefore, respondents with different backgrounds related to nature and agriculture were interviewed. They were asked to express their opinion about fields as part of the landscape in the countryside and these were compared with current production systems.

In Chapter 4 it is described how biodiverse production systems performed based on ‘economy’. Therefore, the amount and quality of silage and grain yield were assessed. Yield assessments were conducted at all locations (Figure 2). Application in society is easier if system yields are at an acceptable level.

Chapters 5 – 10 describe floral and faunal biodiversity development. To describe the mechanisms underlying the attrition and recruitment of sown wild flowers under a growing crop canopy within one season a simulation model was developed; it is described in Chapter 5. In Chapter 6, the development of populations of the sown wild flower species and the spontaneously occurring plant sprecies was monitored for three years in a row in the continuous cropping systems (Fig. 2, locations 1 ABC and 2ABC). Differences in species composition between locations and between treatments, and recruitment of new species over time were analysed. The effects of biodiverse production systems on faunal diversity were also assessed. It was assessed whether biodiverse production production systems were attractive for associated insects. In Chapter 7, the number and diversity of Coleoptera were measured continuously throughout the season within one year (Fig. 2, locations 3, 4). Nematodes were expected to cause a threat to crop production in the continuous cropping systems. In Chapter 8, the rate of reproduction of plant-parasitic nematodes and the combined beneficial nematodes species were analysed over years in the system development experiments to analyse system performance against pests and diseases (locations 1,2,3 A and 1,2,3 B). Besides development of the associated diversity, we were also interested whether the crop could adjust to the environment. Chapter 9, a short note, describes the effect of development in genetic variation in barley. Biodiversity development above-ground was likely to have had an effect on biodiversity below-ground. Chapter 10, another short note, describes the relation between above- and below-ground diversity based on soil bacteria and fungi diversity after three years of continuous production.

In the general discussion (Chapter 11), results of the different studies are integrated.

Part one

Sociology (People)

1

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

Eveline S.C. Stilma, Ben Vosman, Hein Korevaar, Marijn.M. Poel-Van Rijswijk, Albert B. Smit and Paul C. Struik

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 (Anonymous, 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 (Giampietro, 1997; Gulinck, 1986). 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 and 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; Jeger et al., 1981b).

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 (Butts et al., 2003; Hauggaard-Nielsen and Jensen, 2004; Hooks and Johnson, 2003; Kropff and Walter, 2000). Mixed cropping can control wind erosion and improve water infiltration (McLaughlin and 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 and Mineau, 1995; Van Ruijven and 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 and Walter, 2000). Yet, the presence of some wild plant species can be desirable for various reasons. Wild plants may attract useful organisms (Carreck and Williams, 2002; Comba et al., 1999), 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 Designing biodiverse arable production systems for the Netherlands species can perform their ecological function in the resource management of the agro-ecosystem (Marshall and 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 (Smit et al., 2006; Verstegen et al., 2000). 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).

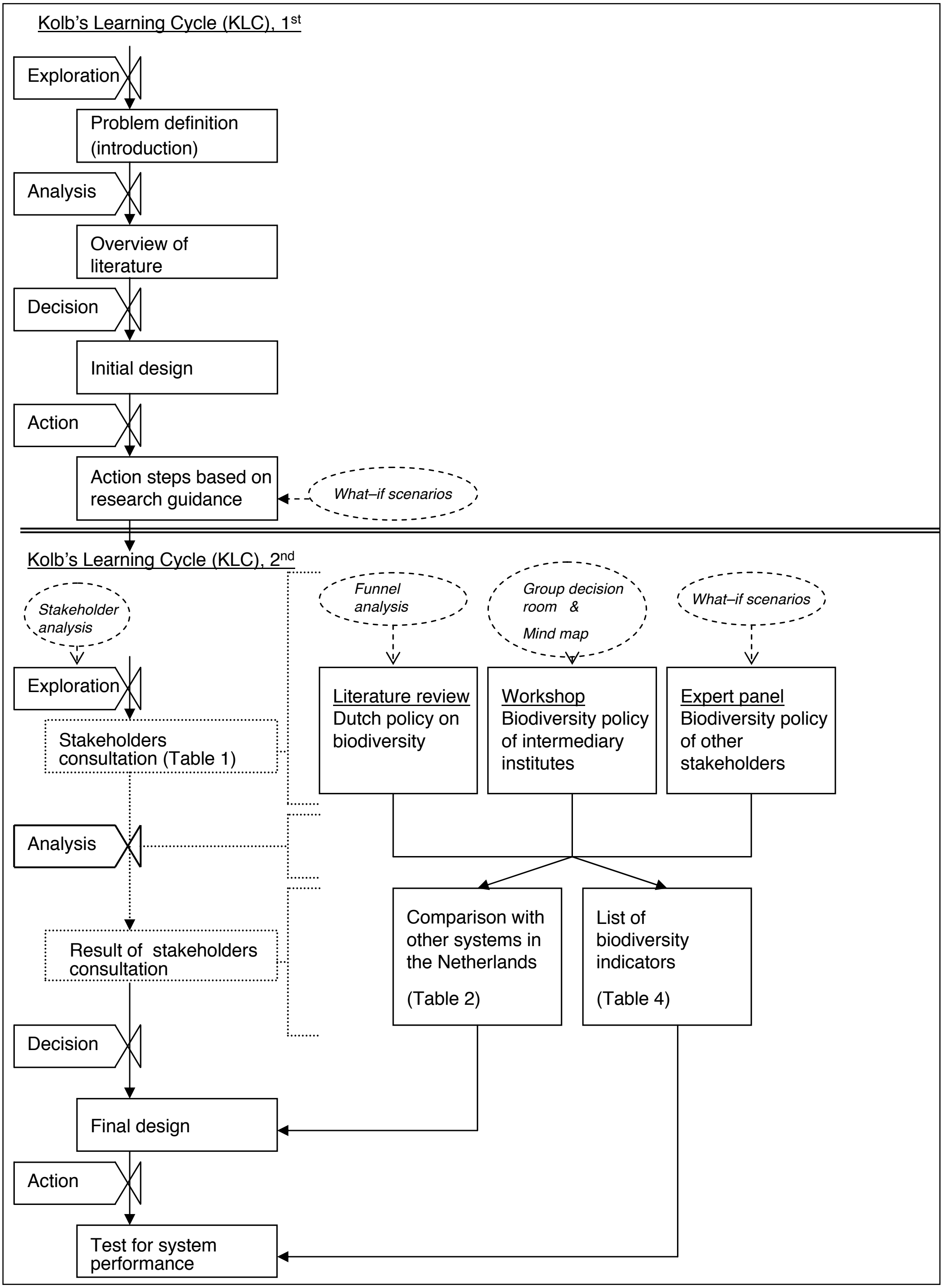

Figure 1. Structure of the design process and methods used for designing biodiverse production systems. References about tools used: Kolb (1984) for Kolb's Learning Cycle; Smit et al. (2006) for What–if scenarios; Eiff (2000) for Group Decision Room; Plesk (1997) for Mind map; Aarts (2000) for Stakeholder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

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 (Anonymous, 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 (S*ecale cereale*)) and pea (*Pisum sativum*). The cereal 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

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

	Interests	Wishes	Means	Contribution to
Primary stakeholders				
Farmers	Maintain quantity and quality of prodution to make living	Subsidy for biodiversity management.	Croppingsystem	Expert panel
		Easy applicable	Field margins	Workshop
			Agri-environment schemes	
Nature conservation agents	Increase natural values	Extension of biodiversity outside EHS1 areas	Agreements with farmers	Expert panel
	Maintain natural areas	Alternation of spring and winter cereals to maintain winter annuals	Private fields	Workshop
			Research that allies society	
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. LNV1	Comply with international agreements (e.g. Rio de Janeiro 1992)	Maintain and increase biodiversity	Laws	Workshop LNV1
		Decrease herbicide use	Convenants	
		Increase recreation	Subsidy	
Regional authorities	Comply with national agreements	Attractive country side	Regional planning	No contribution
		Development of agricultural area	Area planning	
			Protection and planning of species	
Intermediary institutes: e.g. LBI,CLM,DLV1	Intermediaries between policy and end users	Improve agricultural practises	Research extension	Workshop CLM1
Research: e.g. universities, PRI1	Explain ecosystem functioning	Increase biodiversity	Research	Analysis of Dutch policy: LEI1
				Workshop
				Expert panel (Professors of Crop Science an Nature Conservation; Crop analist)
Farmer organisations: e.g. LTO, AKK (chain partners)	Represent farmers in the Netherlands	Maintain agricultural practices at a high standard	Network	Workshop (LTO, AKK1)
			Membership fees	
Nature organizations: e.g. KNNV1	Represent ecologists in the Netherlands	Maintain nature in the Netherlands	Network	No contribution
			Membership fees	

[1]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.

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 (Díaz et al., 2006). Farming is the greatest threat to biodiversity on the planet (Altieri et al., 1987; Green et al., 2005; Tilman et al., 2001). 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 (Van Duinhoven et al., 2002). It describes agrobiodiversity as (Anonymous, 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 (Anonymous, 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 (Anonymous, 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

Table 2. Dutch production systems compared for biodiversity aspects.

Production system	Production	Ecology[1]	Care for the environment	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.

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 and 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 (Anonymous, 1991), (2) systems related to the Protection Plan Arable Plants ('Beschermingsplan Akkerplanten'; Anon., 2000) (Anonymous, 2000) , and (3) systems related to agri-environment schemes (Anonymous, 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).

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 (Tørresen 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 (Anonymous, 2003). Cereals enhance fodder quality by their 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).

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

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 (Anonymous, 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.

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 (Finckh and 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 and 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 and 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

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 veining1 in the agricultural landscape
	Subsidies for ecological farming

[1]To enhance the abundance and spread of natural enemies of crop epests and diseases.

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.

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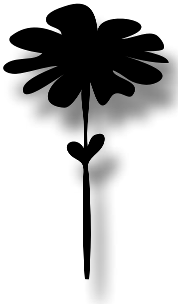

03 Perception of biodiversity in arable production systems in the Netherlands

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Arable production systems in the Netherlands are normally designed with solely a production function. The Netherlands is a small and densily populated country that requires a well-planned management of the landscape. In order to create space in the Netherlands, we designed arable production systems with production, ecological and societal functions. Systems differing in level of biodiversity were tested in a long-term field experiment for their production and ecological functionality. This article, however, encompasses their societal function, which is achieved if biodiverse production systems make the landscape more attractive than current systems. During the field experiment, pictures were taken when the crops flowered. These pictures were used to assess how different levels of biodiversity in the systems were perceived as an element of the Dutch landscape using the qualitative dialogue method. Pictures of existing, contrasting arable production systems in the Netherlands were included as a reference; e.g. forage maize crops, tulip fields and biodiverse field margins. Each of the 30 respondents had the possibility to express his feelings and to explain underlying thoughts while ranking and classifying the pictures. Most respondents appreciated the presence of wild flowers, but the farmers among them were hesitating as they feared yield loss. Barley was preferred above rye. Pea was not appreciated much but when present it was appreciated more in a mixture with rye than with barley. Respondents affiliated to nature or agriculture appreciated biodiversity in fields more than respondents who were not engaged.

Additional keywords: landscape ecology, diversity, qualitative research, stakeholder

Introduction

The Netherlands is a small and densely populated country that requires a well-planned management of the landscape. The identity of the Dutch rural landscape has changed from a traditionally formed small scale landscape to a nameless high productive large scale landscape as a consequence of globalization and economic change. Inhabitants, however, are closely related to the aesthetics of their near surroundings e.g. during leisure activities. The importance of human well-being related to the management of the rural landscape is increasingly being acknowledged (Pedroli et al., 2007)

Landscape preferences have a personal bias and are influenced by earlier experiences and education (Nassauer, 1995). For example, people appreciate the fields of their home-town more than fields elsewhere (Goossen and Boer, 2006; Penning-Rowsell, 1982). Consequently, the elderly are more likely to prefer agricultural landscapes and are more focused on natural elements than the youth, because growing up in an agricultural or natural environment was more common in the past than nowadays. Similarly, first generation non-western immigrants do not particularly like a typically Dutch landscape as their preference for certain landscapes originates from their country of origin (Buijs and Vries, 2005; Kaplan and Talbot, 1988; Somers et al., 2004). Preference for a certain type of environment can also be formed through the function that a person assigns to that type. For example, farmers consider the landscape as an area for production, while others perceive the landscape as an area characterized by natural vegetation and flowers (Buijs et al., 2006). A farmer would prefer a field that is expected to give high yields; others prefer a field for different reasons, for example based on canopy structure, diversity and/or colours, smells, and motions (Chenoweth and Gobster, 1990). Knowledge and education can affect preferences for specific landscape elements (Van den Berg and Koole, 2006). For example, people with a well-developed taxonomic knowledge are more interested in biodiverse meadows than people without such knowledge (Lindemann-Matthies and Bose, 2007).

Studies about landscape preferences are numerous, but studies about preferences for types of agricultural fields are scarce. Biodiverse production systems were designed with production, ecological and societal functions (Stilma et al., 2007). This article encompasses a societal function that is achieved when production systems are made more biodiverse and as such make the landscape more attractive than current production systems and thus would enhance the recreational value. We investigated whether biodiverse production systems are appreciated as part of the landscape and whether background experiences in nature/agriculture are a factor through which appreciation is formed.

Materials and methods

Pictures

Pictures of eight different biodiverse production systems were made during flowering of the crops (digital versions of these pictures are available upon request). The eight biodiverse production systems were combinations of spring barley (*Hordeum vulgare*) or spring rye (*Secale cereale*) with or without semi-leafless pea (*Pisum sativum*) and with or without a mixture of the following 5 wild flowers species: *Papaver rhoeas, Centaurea cyanus, Chrysanthemum segetum, Misopates orontium, Matricaria recutita* (sandy soil)/*Tripleurospermum perforata* (clay soil). In addition, pictures were taken from conventional maize and tulip fields and of colourful field margins. Each field was represented by two pictures, a close-up from 0.5 m distance of the field margin and one from a distance of about 5 meters.

Respondents

In total 30 respondents were interviewed (Table 1). The group of respondents was a random sample of people living in the Netherlands covering the characteristics listed in Table 1. Within this group a subgroup of 12 stakeholders was selected based on their engagement in the agricultural sector. More specifically, these

Table 1. Description of the respondents in the survey.

Variable	Full group	Stakeholder group (province of Brabant) [1]	Variable	Full group	Stakeholder group (province of Brabant)
Age			Gender		
20–30	7	0	Male	13	8
30–40	5	2	Female	17	4
40–50	7	4	Education level		
>50	11	6	BSc-	15	9
			BSc+	15	3
Total	30	12		30	12

[1]This group is part of the full group.

stakeholders were selected from one region in the Netherlands, 'De Kempen', in the province of Noord-Brabant to exclude differences in stakeholders between regions. Five types of stakeholders were interviewed: farmers, other inhabitants, camp site visitors, administrators and civil servants in landscape management. Each type of stakeholder was represented by two respondents, except for the farmers who were four in total (with different degrees of interest in biodiversity in agricultural fields).

Questionnaires

We used the qualitative dialogue method that provides interviewees the opportunity to express their rationales for their behaviour and choices in full detail (Hoepfl 1997; Marshall 1989). All respondents were interviewed individually. The questionnaire was divided into two parts. The first part consisted of closed and open questions to assess the attitude of the respondent towards nature and agriculture (Table 2). Mentality was based on a 10 min test on internet (www.motivaction.nl, Motivaction International bv, Amsterdam), producing additional information about life style and attitude. The second part involved questions about pictures of fields with different levels of biodiversity and current production systems. During the interview the respondent was stimulated to share his feelings and thoughts with the interviewer. These remarks were analysed and included in the text.

Ranking of pictures

During the interviews, the respondents were invited to rank pictures of fields from 'the most beautiful' to 'the least beautiful'. Such an invitation took place in three rounds: I) rank the eight production systems based on first impression; II) rank the eight production systems after the respondent had received information about the ecological value of cereal, pea and wild flower mixtures; and III) rank the eight production systems when a field margin with flowers, a flowering tulip field and a maize field were added to the picture gallery.

Underlying thoughts for perception of systems

Answers to open and closed questions were analysed. Per question, groups of respondents were formed with similar answers. The answers to questions under E (Table 2) were analysed as being one question; the answers to questions F,

Table 2. Summary of the questions in the questionnaire.

Introductory questions:
Name, age, place of residence, occupation, education and mentality score.
Closed questions:
A) From 1 to 5, how much are you involved in i) nature, ii) agriculture.
B) From 1 to 5, how much are you interested in arable fields in i) place of residence, ii) place of holiday.
C) Are you a member of environmental and/or agricultural organizations? If yes, which ones?
D) Are you a subscriber to one or more environmental and/or agricultural journals? If yes, which ones?
E) Do you normally hike or cycle i) to work, ii) in your holidays, iii) free time, iv) other?
Open questions:
F) 'What is your vision on nature'?
G) 'What is your vision on agriculture'?
H) 'Have you ever been on a farm, and how did you experience farm life?'
I) 'Have you ever grown your own vegetables, and what were your experiences?
J) 'What is your image of a perfect arable field in the perfect landscape?'

G, J (Table 2) were analysed individually. The results of the mentality test were also used to form groups. Such groupings were only reported in the text if the answers resulted in clear patterns. Such patterns were related to the ranking orders of the pictures and analysed to find out whether background information and earlier experiences were a reason for respondents to differentiate between field types.

Results

Perception of biodiverse fields

The rankings by the respondents are summarized per field type in Figure 1. The respondents highly appreciated the barley monocrop. Frequently given reasons were: the opportunity to overlook the crop and watch the landscape as a whole, colour, beauty of the ears, and association with a wind-blown crop. Some respondents appreciated rye monocrop. Reasons were the straight stalks and elegance of the stems. Other respondents did not like the rye monocrop, because: a) ´The tall stems block the view´; and b) ´Tall stems are boring´. Pea in barley was perceived as less attractive than monocrop barley. The most frequently given reason was the "messiness" of the barley-pea field. The respondents who did appreciate pea in barley stated that pea made the system look more "wild" or "natural". Pea in rye did not change the attractiveness of the rye crop for some of the respondents. However, some others liked pea in rye better than the rye monocrop. A third group preferred rye monocrop above a mixture with pea, since they found that there was no clear difference between the two systems or that pea in rye looked messier than a rye monocrop. If respondents did appreciate pea in rye then they stated that pea in rye looked more natural and increased the variation.

Wild flowers enhanced the attractiveness of all systems for most respondents. The reasons were: colourfulness, natural look, diverse look, youth memories with similar crop systems. Only few respondents disapproved of the wild flowers; the reasons given were the association with weeds or with stinging insects.

Effect of knowledge about biodiversity

More than half of the respondents did not change the sequence of the photographs after receiving information about the usefulness of biodiversity. In general, this information was not new to them.

Therefore, they had already given fields with either pea or wild flowers or both a relatively high ranking. The others concluded that biodiversity is more important than personal preference and re-ranked the pictures. All of these respondents re-ranked them in such a way that fields with pea and wild flowers received the highest rank. Subsequently, most respondents gave the fields with wild flowers a higher rank than the fields with pea. The remaining respondents were indifferent in their choice between peas or wild flowers; only one respondent gave a higher rank to pea.

Perception of current systems

Overall, field margins were valued very much (Figure 2). Remarks were made about the beauty: 'beautiful flowers/colourful' or sometimes 'they are messy'. Remarks were made about the function: 'good for the environment/biodiversity' and 'a natural look'. Or 'unprofitable for the farmer' and 'fatal for crop production'. Remarks were made about field margins as part of the landscape: 'low', 'leaving the landscape open', 'they fit in with the rest of the Dutch landscape', and 'reminds me of old landscapes'.

The appreciation of tulips varied largely between respondents. They scored the tulip fields either as very unattractive, very attractive or were 'indifferent'. Respondents mixed positive and negative remarks based on the beauty and/or the function of tulips. However, their remarks were not always consistent with the rank they gave the tulip field: if beauty was considered most important they were given a high ranking; if production method was considered most important they were given a low ranking. Remarks describing the beauty were the colourfulness of the large fields. Negative remarks dealt with the production method: 'too structured', 'too cultivated', 'too large fields', 'too monotonous', 'unnatural production', 'only temporary'. Some respondents disliked tulips because they were not part of their personal current landscapes.

Maize was given either high, moderate or (often) low ranks. Respondents had different types of associations with maize based on aesthetics, earlier experiences, their place of residence or the function of maize. Remarks were made about the height: 'the height is fascinating' or 'blocks the view' or 'maize is boring'. Maize was beautiful to some respondents because it had been part of their landscape for many years. However, one respondent disapproved maize for the same reason. Production oriented remarks

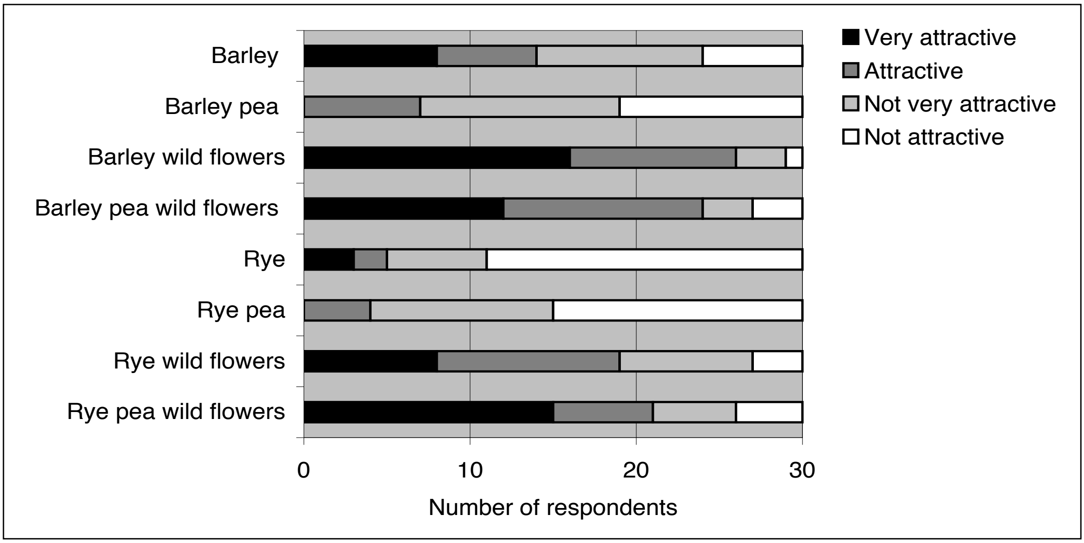

Figure 1. Attractiveness of eight production systems, differing in level of biodiversity, based on ranking of the pictures by 30 respondents.

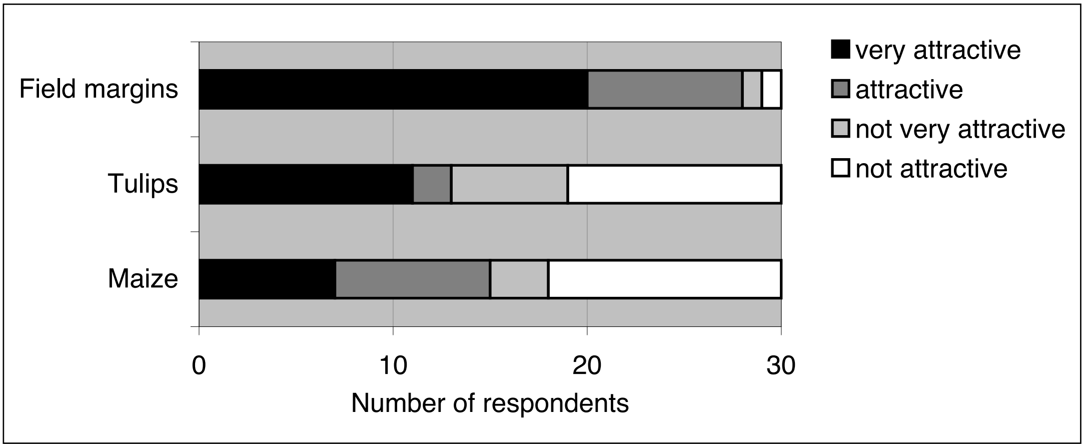

Figure 2. Attractiveness of three current systems expressed through ranking of the pictures by 30 respondents.

were: 'nice for a highly economic crop yield'. Or negatively, some respondents missed biodiversity in maize. Remarks based on memories were for example: 'a family member used to grow maize', or 'the opportunity to walk through the crop and to eat the corn'. Some respondents took notice of the grass field next to the maize crop. Different functions were attributed to the grass field. Maize which is nicely and neatly arranged next to a grass field gives either positive or negative evaluations, e.g.: 'the grass crop can use the surplus nitrogen from the maize field'or 'the diverse picture is appealing, in combination with grass and the ditch'.

Vision on nature

The respondents were classified into four groups based on their vision on nature. The first group was the group 'nature is everything green or growing'. Half of the respondents explained their vision on nature literally by stating the phrase 'everything that grows or has the green (plants) or blue (water) colour'. The rest of this group described vision on nature comparable to 'everything', as they included agriculture, trees in the large city, bees, etc. Half of the respondents of the group 'everything' particularly mentioned certain types of agricultural fields ('fruit trees', 'pastures', 'green fields') when they described their vision on nature. Only one respondent also mentioned 'human beings'.

The second group (´nature in reservations´) was a group of respondents that limited their vision on nature to specific areas in the Netherlands. They looked at nature as areas to go for recreation. Such areas had to be outside town. Examples were given like 'forest of the National Nature Conservation Organisation, 'de Utrechtse Heuvelrug', sea and beaches, pools, heather land and sand dunes.

The respondents of the third group ('value for flora/fauna') argued from a biodiversity point of view, starting from a high-grade habitat for flora/fauna. For them, it was not a problem if these areas were managed by human beings.

Respondents in the fourth group ('primeval nature') mentioned that nature involves areas that are independent of human intervention or areas without a function for human beings.

Perfect landscape

All respondents found 'a perfect field fitting in a perfect landscape' ideal based on their experience. The majority of the respondents described landscapes with variation in landscape elements. Landscape elements mentioned were trees or hedgerows, field margins, ponds or ditches, pastures with cows or horses, small lanes, farms, and /or houses. Some of the respondents mentioned that fields in the landscape should look natural or biodiverse. Other respondents stated that landscape elements had "to fit in" with the rest of the landscape.

When we focus at field level, three groups of preferences could be distinguished. One group liked large colourful fields of either/ or tulip, hyacinth, sunflower or grape. Another group preferred fields of maize, barley or pasture. Both groups were focussed on a high agricultural production. They appreciated fields with low weed pressure, without ditches and with a good water management system. The third and last group appreciated traditional biodiverse arable fields with cornflowers most.

Mentality

The mentality scores from progressive to conservative were equally divided among the respondents for the full group. In the stakeholders group, most of the respondents had a 'progressive' mentality type.

Stakeholders group

The stakeholder group differed from the full group as they commented on pictures from fields they knew from experience. Half of the respondents in the stakeholder group had a strict vision on nature. In the whole group there were only few respondents with that vision. Only one stakeholder had changed the ranking order after receiving information on the value biodiversity. The rest already knew the benefits and had used that information while ranking the pictures. The farmers based their judgement of fields on productivity. Some farmers saw the benefits of wild flowers because they had co-operated in programmes to stimulate nature conservation through field margins. Nevertheless, they hesitated to grow wild flowers within the fields. The other stakeholders were all in favour of such flowers. They gave high preference to stimulating biodiversity and they loved a colourful countryside. The pictures of current landscapes were seen as representatives of their daily landscapes. Therefore, they appreciated maize fields and field margins more than tulip fields. Their appreciation was based on stimulating biodiversity in their own environment. Field margins were part of their landscape and good for biodiversity, maize was part of their landscape and not good for biodiversity and tulips was neither of both. Contrary to the full group, none of the stakeholders were looking for a park type landscape in the pictures.

All the stakeholders with a 'progressive' mentality type were in favour of field margins and wild flowers.

Influence of background information on preference

Respondents who had a strict vision of nature ('primeval nature' or 'value for flora/fauna') and respondents who preferred 'a various landscape' were also very much in favour of wild flowers, field margins and pea (Figure 3). They disliked tulip and maize fields. Respondents with a broader vision on nature had more diverse preferences for particular systems. Respondents who were in favour of 'tulip/ hyacinth or sunflower fields' liked the colours in field margins and wild flowers, but also liked the neatness and structure of the tulip and maize fields. Respondents who liked 'fields of maize and barley' were production oriented. They liked the colours in field margins because they did not harm production and they liked the productivity of maize.

Respondents with a more progressive mentality type were more in favour of wild flowers in mixtures and field margins than of fields of tulips and maize compared to respondents with a more conservative mentality type who appreciated all the systems equally.

Discussion

In this study, the respondents were asked to rank the pictures for beauty. The rankings differed amongst respondents. Apparently, there is not a common sense of what is beautiful and what not or less. Therefore, it will be impossible to create a landscape that suits everybody. When spatial planners or farmers want to serve as many (groups of) stakeholders as possible, it could be wise to create different sub-landscapes answering the needs of the different groups. However, knowledge about nature/agriculture appeared to be decisive for appreciation of

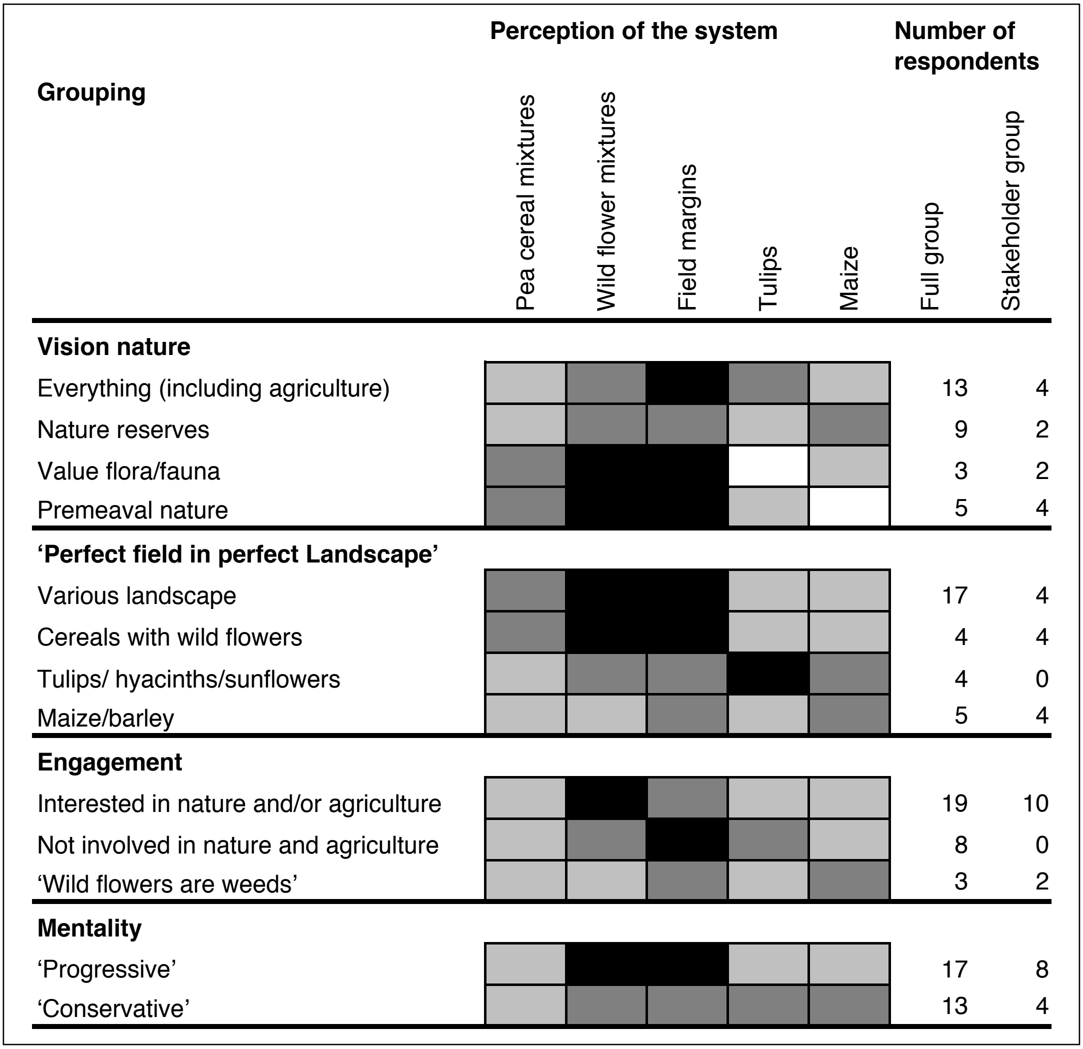

Figure 3. Perception of pea in cereal, wild flowers and current systems after grouping into vision on nature, preference for landscape, engagement in nature/agriculture, or mentality, based on the ranking of pictures by 30 respondents.

biodiversity in arable fields. Communication with all stakeholders in the region studied about the function of biodiverse production systems could help to increase the appreciation for biodiversity in arable fields in that region. Such an intervention should therefore stimulate a stronger focus on biodiversity in local planning processes, improving the public support for biodiverse production systems.

Although there is a large variation in perception, the respondents generally preferred barley above rye, pea in rye above pea in barley, and presence of wild flowers above absence of flowers. The combination of cereals and peas is a favourable system from a nutritional point of view, especially in organic farming, where a lack of local protein supply urges imports of protein from non-local organic sources. Therefore, from an organic farmers' point of view, pea would be a helpful species in the system, making it more profitable than an organic monocrop cereal system (Smit et al., 2006). Therefore, organic farmers have to face the challenge to make cereal-pea systems more attractive in the perception of their non-farming fellow citizens.

The positive perception of wild flowers by many respondents adds to the ecological reason to include these in the system, meaning that such wild flowers may host natural enemies of plague insects. This concept of functional biodiversity is a subject of research (e.g.Westerman et al., 2004) in which the distance between plague insects and natural enemies turns out to be a critical success factor. A favourable invasion of natural enemies as far as to the centre of the field may be better facilitated by host plants throughout the whole system (wild flowers spread over the full field) than by biodiverse field margins alone. However, this concept has not yet been fully optimised, meaning that practically feasible solutions for growing host plant species in cereal-pea systems are still to be developed in further detail (Altieri, 1999).

The preference of the respondents for barley above rye contrasts the historical system in the sandy areas of the Netherlands, where monocrop rye was widely grown up to the seventies and eighties of the 20th century, when the higher yielding silage maize took over (Bieleman, 1992). Many respondents prefer rye above silage maize, because rye is shorter than maize. The landscape in many sandy regions has dramatically changed due to this conversion to silage maize, and a large number of respondents would gladly see the old system re-established.

Concluding, the system preferred by most respondents would be a cereal-wild flower system, whereas organic farmers would find a combination with pea more attractive from a nutritional and therefore profit point of view. Leaving pea out of the system would make it surely less profitable than conventional cereal growing, at least in an organic system. A challenge would be to improve the perceptional aspects of a cereal-pea-wild flower system. Again, a means to improve the perceptional aspects is giving inhabitants information about the usefulness of biodiversity. We found that after information was given about biodiversity in arable systems, respondents appreciated biodiversity of wild flowers and pea much higher. This result coheres with earlier research where knowledge about nature/agriculture resulted in a higher appreciation of biodiversity in production systems (Lindemann-Matthies and Bose, 2007). If inhabitants are getting used to biodiversity in systems, they are likely to appreciate such systems higher. We found that appreciation of wild flowers, barley, rye, maize and tulips were related to earlier experiences and knowledge of nature/agriculture. However, pea in a mixture with cereal was not recognised, since that system has not yet been applied widely. Alternatively, a cereal-wild flower system could become more profitable through a public-private co-operation as already applied by nature conservation organisations ('Natuurmonumenten'). Such a co-operation could be helpful to compensate for the high costs of the wild flower seed in all systems with additional perceptional value for the public (Reinhard and Silvis, 2007; Smit et al., 2006).

For specific spatial planning projects including agricultural functions, the small-sized qualitative approach as described in this paper should be completed with a larger-scale quantitative study, meaning that a large number of stakeholder-respondents in that specific area would receive a questionnaire, in which they can rank different biodiverse production systems. The results from this qualitative study can be used to assess the most optimal combination of pictures in the quantitative study. The qualitative study was intended to get insight in the full range of perception patterns and the visions and explanations behind them. A more quantitative study is mainly focussed on the numbers of respondents and their preferences for different systems, facilitating the decision making process in e.g. spatial planning projects. In this qualitative study, it is therefore important to describe the mechanisms behind the perception patterns observed.

In the first place, the respondents' vision on nature appears to be rather decisive for their preferences. Wild flowers in arable fields and in field margins are predominantly preferred by respondents with a strict vision on nature (groups 1 and 2). These groups are in favour of a system including pea, but dislike fields with tulips or maize (Figure 3). Respondents who were able to define a strict vision on nature, had probably based their vision on previous knowledge about nature. Therefore, they could also appreciate pea higher than respondents with a less defined vision on nature as they could imagine a possible function of pea to the mixture. Other respondents with a less strict vision on nature are also in favour of wild flowers but not of pea. Furthermore, they are not always against tulip or maize fields.

In the second place, there are different visions on a 'perfect field in a perfect landscape' among respondents. More than half of the respondents is in favour of a various landscape, in which systems with pea and wild flowers are welcome, but tulip and maize are not acceptable (Figure 3). There also respondents who find a less various landscape with cereals with flowers perfect, also not accepting fields with tulip and maize. This gives a quite different picture. Two other pictures, a system with tulips, hyacinths and/or sunflowers and a system with monocrop maize/barley are also quite different, e.g. accepting maize as part of the landscape. Although the landscape in the Netherlands has changed to a more monotonous landscape since the re-allocation of land since the 1920s (Bieleman, 1992), most people still appreciate a various landscape above a monotonous landscape (Nassauer, 1995). Biodiverse production systems are suitable for small scale farming as part of a various landscape which was appreciated highest by most respondents.

In the third place, the respondents' engagement in nature and/or agriculture plays a role. Those who are, find wild flowers in fields or field margins very attractive and tulips and maize unattractive (Figure 3). However, there is a group with engagement in agriculture who look at wild flowers as weeds; this group is naturally not in favour of systems with wild flowers. They find tulip and maize fields acceptable. This group of respondents judged fields based on their function. Wild flowers are good for biodiversity, and tulips and maize are not. To attribute a function to a field and accordingly judge a field based on the level that function is fulfilled is a means to decide whether to give preference to a field or not (Buijs et al., 2006). The group 'not involved in nature and agriculture' seems to appreciate all systems as long as pea is not included. They did not attribute a function to the field and liked the fields based on aesthetics only. Therefore, their appreciations to different types of systems were diverse.

In the fourth place, mentality can be regarded as an explaining factor for preferences. Both in 'De Kempen' as in the full group, more progressive respondents are more in favour of systems with wild flowers than more conservative respondents. More conservative respondents are more in favour of tulips and/or maize than more progressive respondents, who generally dislike such fields.

Summarising, in local spatial planning projects, firstly it is important to take into account the characteristics of the population. A relatively progressive population with a stricter vision on nature will be in favour of a various landscape including fields or field margins with wild flowers and pea. A more urban population with little involvement in nature and/or agriculture will be less critical about the landscape, but will not be in favour of systems including pea. A more conservative group will be in favour of more traditional systems with tulips and/or maize/barley. In most cases, spatial planners will have their own vision of what is 'good' and 'beautiful' for a population, maybe even taking the population characteristics into account. However, the political colour as a measure of mentality/progressiveness may not be sufficient to predict which system and landscape the population will prefer. A relatively conservative population with a strong involvement with nature and agriculture may be in favour of a system with rye and flowers, since they grew up in such an environment. The findings from other studies about the relevance of the environment in which people grow up is therefore confirmed by the results of this study. Secondly, inhabitants judge fields based on their functions. Information about biodiversity can increase the appreciation for diversity in fields. Thirdly, respondents appreciate diversity in diverse small scale landscapes. Biodiverse production systems fit in such landscapes. This also implies that a quantitative study on system and landscape preferences may be very worthwhile as relevant input in the spatial planning process.

Acknowledgements
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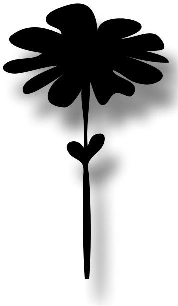
Part two

Economy (Profit)

2



04 Crop yield and quality in bio-diverse production systems designed for the Netherlands

Eveline S.C. Stilma, Hein Korevaar, Ben Vosman, and Paul C. Struik

Production systems were designed for the Netherlands with little pressure on the environment, increased biodiversity and a profitable yield. A genetically diverse cereal crop (cross-pollinating spring rye or a mixture of eleven self-fertilising spring barley varieties) was grown either as a monocrop or together with pea. These monocrops and cereal-pea mixtures were grown in association with or without sown wild flowers, on a sandy soil and on a clay soil, under conventional tillage. Production systems were monitored for aspects of biodiversity, landscape aesthetics and yield. In this article, silage yield and quality as well as cereal grain yield and quality were assessed during three years. The first-year experiments were replicated one year later at two other locations to assess year and location effects on the establishment of the cropping system. Silage yield and quality were relatively high in the first year, especially on nutrient-rich soils. On fertile soils, barley performed better than rye because it combined a high yield of good quality with low competitiveness with pea and sown wild flowers. On poor soils, however, rye yielded more silage than barley, albeit of a lower quality. Pea was a good companion crop, especially in combination with barley on poor soils, resulting in a strong increase of silage quantity and quality. High yields of good quality were obtained and production costs were low because there were no external inputs. Yields can be improved by proper choice of crop composition but successful production also depends on site characteristics.

Keywords: biomass, silage, cereal grains, pea, *Pisum sativum*, spring rye, *Secale cereale*, spring barley, *Hordeum vulgare,* no input, farmland conservation, arable biodiversity

Introduction

Conventional agricultural production systems are intensively managed and artificial fertilizers and pesticides are widely used. Although intensive management resulted in high economic outputs, the environment paid the price (Schröder et al., 2003; Stephens et al., 2003). Harmful quantities of nitrogen and phosphorus are emitted into the environment by intensive agricultural practices (Tilman et al., 2002). Plant species that particularly depend on agricultural systems are declining as result of intensive herbicide use (Altieri et al., 1987; Tilman et al., 2001b). Some plant species associated with low-input arable farming are even becoming extinct (Sutcliffe and Kay, 2000). The effects of human intervention on biodiversity are becoming increasingly prominent (Díaz et al., 2006) and it is increasingly being acknowledged that environment and biodiversity need to be treated with care. However, agricultural production systems with enhanced biodiversity and care for the environment are possible. Systems with a diversity of crops, associated plants and animals can show higher and more stable crop yields than less diverse systems, especially at low levels of external inputs (Almekinders et al., 1995; Altieri, 1999; Brussaard et al., 2007; Tilman et al., 2001a). For many species combinations, the combined intercrop yield is higher than any of the sole crop yields (Mead and Willey, 1980). A well-known example of a diverse crop combination with high yields on poor soils is a mixture of cereals and legumes. The intercropping advantage of such a mixture is mainly achieved by nitrogen fixation by the legume and a high nitrogen use efficiency of the combined crop (Stern, 1993). Other advantageous aspects are improved interception of solar radiation, water use efficiency and a lower incidence of insect pests and diseases. Overall, intercrop systems appear to give more sustainable productivity than sole crops (Fukai, 1993).

Resilience against diseases can also be increased by using genotype mixtures (Finckh et al., 2000). The risk of crop failure after infestation by a disease is smaller when only part of the genotype mixture is sensitive to the disease. In grassland communities a genetically rich plant community was found to be more stable over time than a genetically poor community (Booth

Experiment	1	2	3	4
Co-ordinates	N 51°,59'	N 51°,57'	N 51°,59'	N 51°,57'
	E 5°,39'	E 5°,38'	E 5°,39'	E 5°,38'
Starting year of experiments	2004	2004	2005	2005
Soil type	Sand	Clay	Sand	Clay
Preceding crop	Phaselia	Sugar beet	Winter wheat	Spring barley
Nitrogen level prior to the experiment				
NO_3-N (mg/l extract)	0.8	2.3	4.9	2.9
NH_4-N (mg/l extract)	<.05	<.05	0.6	<.05
Available supply (N kg/ha)	8	28	66	35
Recommendation (N kg/ha)	110	110	110	110
Deficit (N kg/ha)	102	82	44	75
Nitrogen level after three years				
Last year NO_3-N	1.6	2.2		
Available supply (N kg/ha)	10	14		

Table 1. Site and soil characteristics of the locations used for the four experiments.

and Grime, 2003; Finckh et al., 2000; Jeger, 2000).

Crop mixtures are especially common in low external input cropping systems in the (sub)tropics. However, in the Netherlands, biodiverse arable systems – although common in the past – have become rare (Bieleman, 1992). Intercropping has almost completely disappeared and farmers are largely controlling associated biodiversity within crop fields. The surviving associated biodiversity mainly survived on field margins and small areas outside the agricultural fields. Agri-environment schemes are stimulating further development of associated biodiversity (Tscharntke et al., 2007). Although positive effects were recorded (Holland and Fahrig, 2000), effectivity has also been subject of debate (Kleijn and Sutherland, 2003). Success of biodiversity management could also be achieved by preserving biodiversity within the field itself: in a comparison between conventional and organic farms, biodiversity was higher on the organic farms due to higher within-field biodiversity (Gibson et al., 2007; Hole et al., 2005). For a long time weeds and (pest) insects have been controlled in agricultural fields to obtain maximum economic results. Biodiversity within agricultural fields does not necessarily result in unprofitable production as profit can be achieved by savings on labour and control measures (Omer et al., 2007). Moreover, biodiversity, if rightly used, contributes to sustainability (Altieri, 1999; Smithson and Lenne, 1996). Production systems should therefore be especially designed to obtain profitable yields while maintaining within-field biodiversity (Albrecht, 2003).

We designed production systems with different levels of biodiversity for the Netherlands that could yield a profitable, high-quality crop, produced in an environmentally friendly way and providing a habitat for wild plants and animals. Details on the design process are described by Stilma et al. (2007). The biodiverse production systems consisted of a mixture of a cereal and a legume (pea) to enhance yielding ability under low-input conditions. It was assumed that yield stability was enhanced by mixing cereal varieties (barley) with different characteristics or by using a cross pollinator (rye). Spring barley is a common crop in the Netherlands with high fodder quality. Rye used to be grown on poor sandy soils and is able to reach high yields even under low fertilizer input. Barley is already grown in mixture with pea to improve yield and to enhance the protein content in the fodder (Waldo and Jorgensen, 1981). Rye-pea mixtures are not common and were tested in this experiment. We used a semi-leafless pea variety as it is less competitive to the cereal than normal pea. Wild flowers were introduced to enhance associated biodiversity. These flowers used to be common in cereal fields in the Netherlands but nowadays some have become endangered species. We expect that the wild flowers will enhance insect diversity (Clough et al., 2007) and the aesthetic value of the fields (Van Elsen, 2000). These biodiverse production systems were maintained for three subsequent years to allow the systems and the associated diversity to develop. Development of associated diversity is reported elsewhere.

This paper focuses on quantity and quality of silage and of grain yield of the various production systems. We address the following questions: How does the yielding ability of the different mixtures develop over time on different soils and locations? Do the two cereals behave differently? Is there an effect of including the pea component into the system? How does the biomass of associated plant flora develop?

Materials and methods

Sites

Two three-year field experiments were conducted at the experimental farm of Wageningen University and Research Centre, the Netherlands, in 2004, 2005 and 2006, one on a sandy soil and one on clay soil, here referred to as the 'system development experiments'. In 2005, experiments were duplicated for one year on the same experimental farm, once on a sandy soil and once on a clay soil to assess whether establishment of the systems was reproducible. These experiments are referred to as the 'duplicate experiments'. Details on location, soil

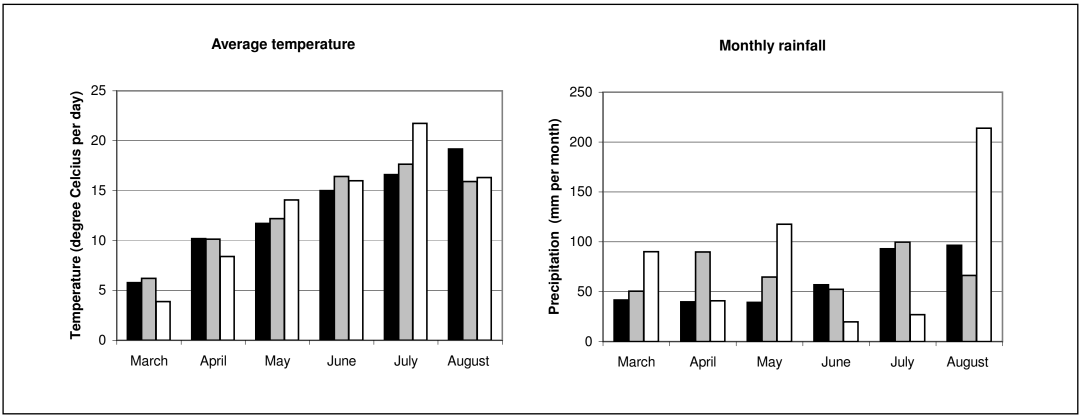


Figure 1. Monthly weather data in Wageningen, the Netherlands in 2004 (black bars), 2005 (grey bars) and 2006 (white bars), from Meteorological Station Wageningen

type, preceding crop and nitrogen level are listed in Table 1. Soil samples for N and NO_3 analysis were taken from all plots at the end of the growing season in 2006 at a depth of 0–15 and 15–30 cm. Samples per treatment for each soil were pooled before soil analysis. Soil samples were analysed by a certified laboratory (Bedrijfslaboratorium voor grond en gewasonderzoek, Oosterbeek, the Netherlands). Weather data were obtained from the official Meteorological Station Wageningen and are summarised in Figure 1. Fields had been conventionally managed prior to the experiment. During the experimental years soils were ploughed to a depth of 17 cm.

Crops and wild flowers

The cereal component consisted of a spring barley (*Hordeum vulgare*) mixture of eleven varieties (Apex, Aramir, Class, Extract, Jersey, Madonna, Orthega, Pasadena, Prestige, 'Reggae', and 'Saloon') and one spring rye variety (*Secale cereale* cv. 'Sorom'). Each cereal was monocropped or intercropped with semi-leafless pea (*Pisum sativum* cv. 'Integra') and/or five sown indigenous wild flower species (*Centaurea cyanus*, *Chrysanthemum segetum, Misopathes orontium, Papaver rhoeas.* In addition, *Matricaria recutita* on the sandy soil plus *Tripleurospermum maritimum* on the clay soil was sown. Wild flowers were obtained from Biodivers b.v., Reeuwijk, the Netherlands. The nomenclature used is according to Van der Meijden (1996) and common names are cornflower, common poppy, corn marigold, weasel's snout, scented mayweed and sea mayweed, respectively, according to Stace (1997). The different combinations resulted in eight treatments (Table 2). The seeds of the cereals, pea and wild flowers were not chemically treated before sowing.

Experimental design and crop husbandry

Each experiment was laid out in a randomized block design with four blocks and eight treatments. Individual plot size was 180 m^2, with 3 m between plots. In the first year, cereal monocrops (with or without wild flowers) were sown at recommended sowing densities (Anonymous, 2004) of 114 (barley) or 89 (rye) kg/ha. Cereal-pea mixtures (with or without wild flowers) were sown at half the sowing densities recommended for the sole crops, i.e. 57,
44 and 173 kg/ha for barley, rye and pea, respectively. Wild flowers were sown at densities recommended by the producer (Biodivers b.v., Reeuwijk, the Netherlands) resulting in approximately 80–175 viable seeds m^{-2} for *P. rhoeas* and 50–80 viable seeds m^{-2} for *C. cyanus, C. segetum, M. orontium,* and *T. maritimum* and *M. recutita.* In the system development experiments, the cereal grain harvested in one year was used as seed in the following year. For pea new seed was purchased each year. Wild

flowers were sown only in the first year of the experiment. Barley, rye and pea sowing densities in the second and third year were based on 1000-grain weight and germination percentage of the harvested grain, allowing a number of germinated seeds 10% above the sowing density in the first year to compensate for soil fertility decline. Plots were located at exactly the same place as in the preceding years. Cereals and pea were sown mechanically; wild flowers were mixed with silver sand and were sown by hand one day after the crops were sown. No fertilizers were applied and pests, diseases or weeds were not controlled. Seeds of the 2006 barley-pea-wild flower mixture on the sandy soil were contaminated with rye seeds during harvesting in 2005. The 2006 yield data of this treatment were therefore assessed by counting the number of barley and rye stems and recalculating the barley yield on the basis of true yield and the ratio between barley stem numbers and rye stem numbers.

Silage harvest and quality assessment

In each plot 1 m^2 was harvested at the soft dough stage of the cereal grain. Electric hedge trimmers were used to cut the crop on this area 5 cm above soil level. All biomass was put in plastic bags for transport to the lab for processing. Fresh weights were determined for the whole sample and for subsamples consisting of cereals, pea, sown wild flowers and spontaneously occurring plants. Subsamples were dried at 70 °C for 36 h. Harvest dates are given in Table 3.

Dried matter was analysed using the Weende analysis. Quality parameters included dry matter content (DM), crude protein (CP), crude fibre (CF), crude ash (CA), and starch. Digestibility of the organic matter (DOM) was assessed according to Tilley and Terry (1963).

Cereal grain harvest

Grains were harvested from an area of about 12 m × 1.5 m with a combine harvester (harvest dates are given in Table 3); the exact size of the harvested part of the plot was measured. Grains were dried for storage in a drying chamber at 20–25 ºC. After drying, grains were cleaned for associated plant seeds and fractioned into cereals and pea. Cereal and pea seeds were weighed. Thousand grain weight (TGW) and germination percentage of cereal grains were determined using standard procedures as described by (ISTA, 1999).

Table 2. Eight crop mixtures and abbreviations.

	Treatment	Abbreviation
1	Barley	B
2	Barley Flowers	BF
3	Barley Pea	BP
4	Barley Pea Flowers	BPF
5	Rye	R
6	Rye Flowers	RF
7	Rye Pea	RP
8	Rye Pea Flowers	RPF

Data analysis

The repeated measurements analysis of variance method (Genstat 9th edition) was used to analyse data of the system development experiments. Means per treatment per location per year were calculated and significant differences among means were assessed using the least significance difference (lsd) method for 1) total silage yield, biomass of pea, sown wild flowers and spontaneously occurring plants, 2) biomass of cereal grains, and 3) TGW and germination percentage of cereal grains. General analysis of variance was used for the duplicate experiments and the first year of the development experiment. To save costs on silage quality analysis, duplicates were pooled before analysis. To allow statistical analysis of treatment effects on silage quality, analysis was calculated by a ‘location + treatment’ effect with general analysis of variance. N and NO_3 soil content data at the end of the growing season in 2006 were analysed with general analysis of variance for differences between barley versus rye treatments, cereal-pea mixtures versus monocrops, and sown wild flowers versus no wild flowers.

Eight treatment combinations were used in the experiments (Table 2). Effects of certain treatments were sometimes small. Treatment combinations were, therefore, grouped and are

Table 3. Sowing dates and silage and grain harvest dates with accumulated degree days (˚Cd) at the different locations.

	Sowing date	Silage harvest	Tsum (˚Cd)	Grain harvest	Tsum (˚Cd)
Sandy soil 2004	20 April	28 July	1402	6 September	2161
Sandy soil 2005	30 March	12 July	1397	17 August	1984
Sandy soil 2006	6 April	18 July	1496	7 August	1924
Clay soil 2004	19 April	28 July	1411	6 September	2170
Clay soil 2005	6 April	13 July	1337	18 August	1926
Clay soil 2006	23 March	18 July	1630	7 August	2058
Sandy soil (2) 2005	30 March	11 July	1376	17 August	1984
Clay soil (2) 2005	13 April	13 July	1263	18 August	1852

as such described in the results section. The following terms were used. Barley treatments (B+BF+BP+BPF) versus rye treatments (R+RF+RP+RPF), monocrops (B+BF+R+RF) versus cereal-pea mixtures (BF+BPF+RP+RPF). Barley monocrop treatments (B+BF), rye monocrop treatments (R+RF), barley-pea treatments (BP+BPF), and rye-pea treatments (RP+RPF). Treatments with wild flowers (BF+RF+RP+RPF) versus treatments without wild flowers (B+R+BP+RP).

Results

Weather and soil

Average temperature and rainfall in 2004 and 2005 were almost similar except for higher rainfall in April and May in 2005 than in 2004 (Figure 1). The year 2006 was different from the first two years: a colder spring, higher rainfall in May and August and lower rainfall in June/July.

The average N and NO_3-N contents at the two locations are presented in Table 1. There were no main treatment effects on soil N and NO_3-N content at the end of the 2006 growing season (data not shown).

Silage biomass

Total yield

In the first year of production, total yield was different per location, per treatment and there was a significant location × treatment interaction (Figure 2; Table 4). Barley monocrop treatments gave extremely poor yields on onesandy soil in 2004, but performed better at the other three locations. On the sandy soils pea biomass yield was significantly higher in association with barley than with rye; this was not the case on clay.

In the system development experiment on the sandy soil, average total yield of all treatments was highest in the first year and lower in the second and third year. In the first year all treatments had the same total yield except barley monocrop treatments that had a lower total yield than the other treatments. In the second year, barley monocrop treatments again showed the lowest total yield. Cereal-pea mixtures yielded more than cereal monocrops. The barley-pea treatments yielded over 50% more than barley monocrop treatments (Figure 2). The proportion of pea in the total yield was higher when cropped with barley than with rye. Rye monocrop treatments yielded more than barley monocrop treatments. Rye-pea treatments and barley-pea treatments had the same total yield in the second year. In the third year, rye treatments yielded more than barley treatments. Monocrops and cereal-pea mixtures gave the same yield in the third year despite the fact that pea biomass was extremely low.

On clay soil, average total yield of all treatments was highest in the first year and lower in the second and third year. In the first year total

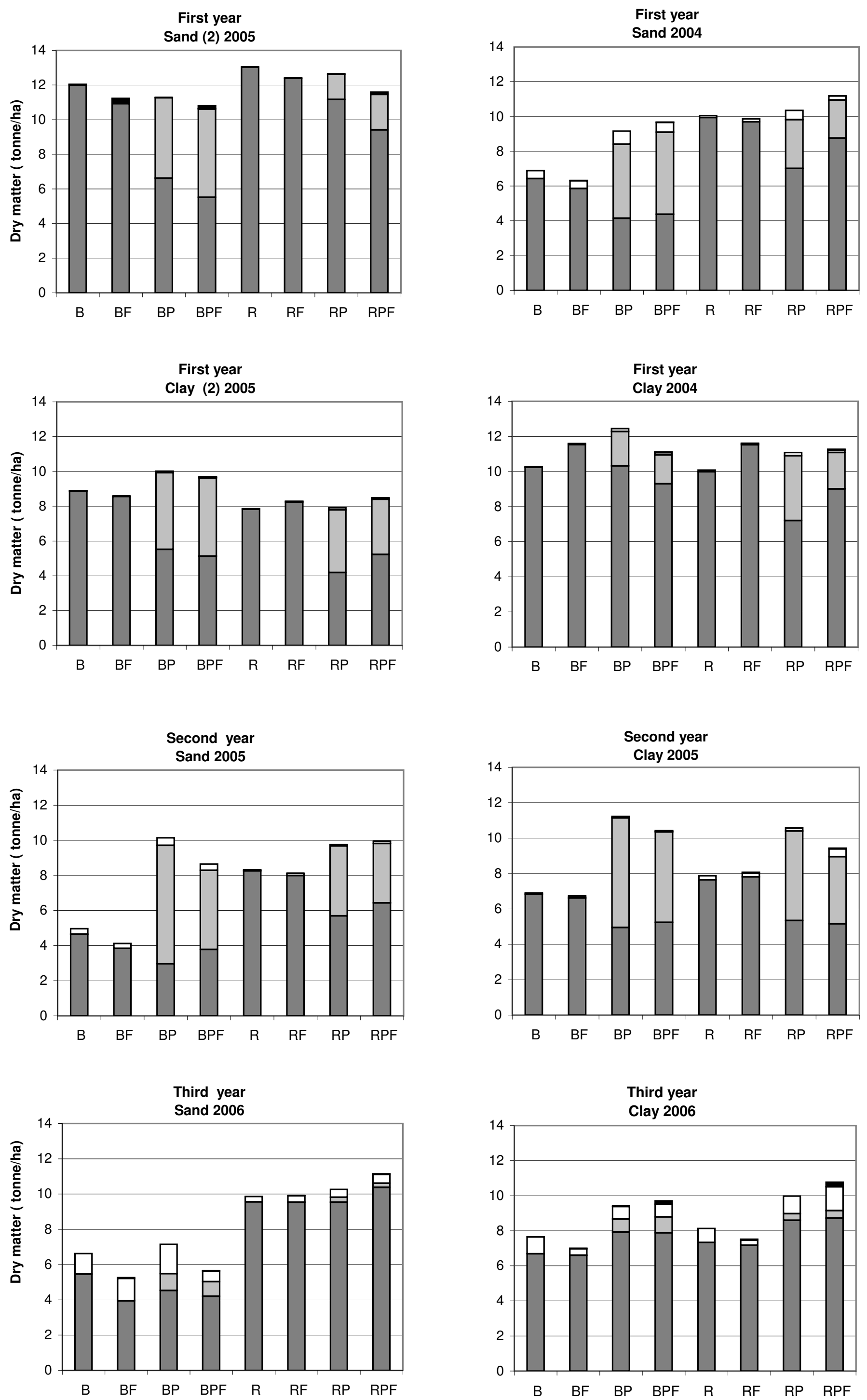


Figure 2. Amount of silage yield from biodiverse production systems in Wageningen, the Netherlands. Cereal = dark grey, pea = light grey, spontaneously occurring plants = white, and sown wild flowers = black. Each figure displays the eight treatments at one location. For statistics see Table 4, for treatment codes Table 2.

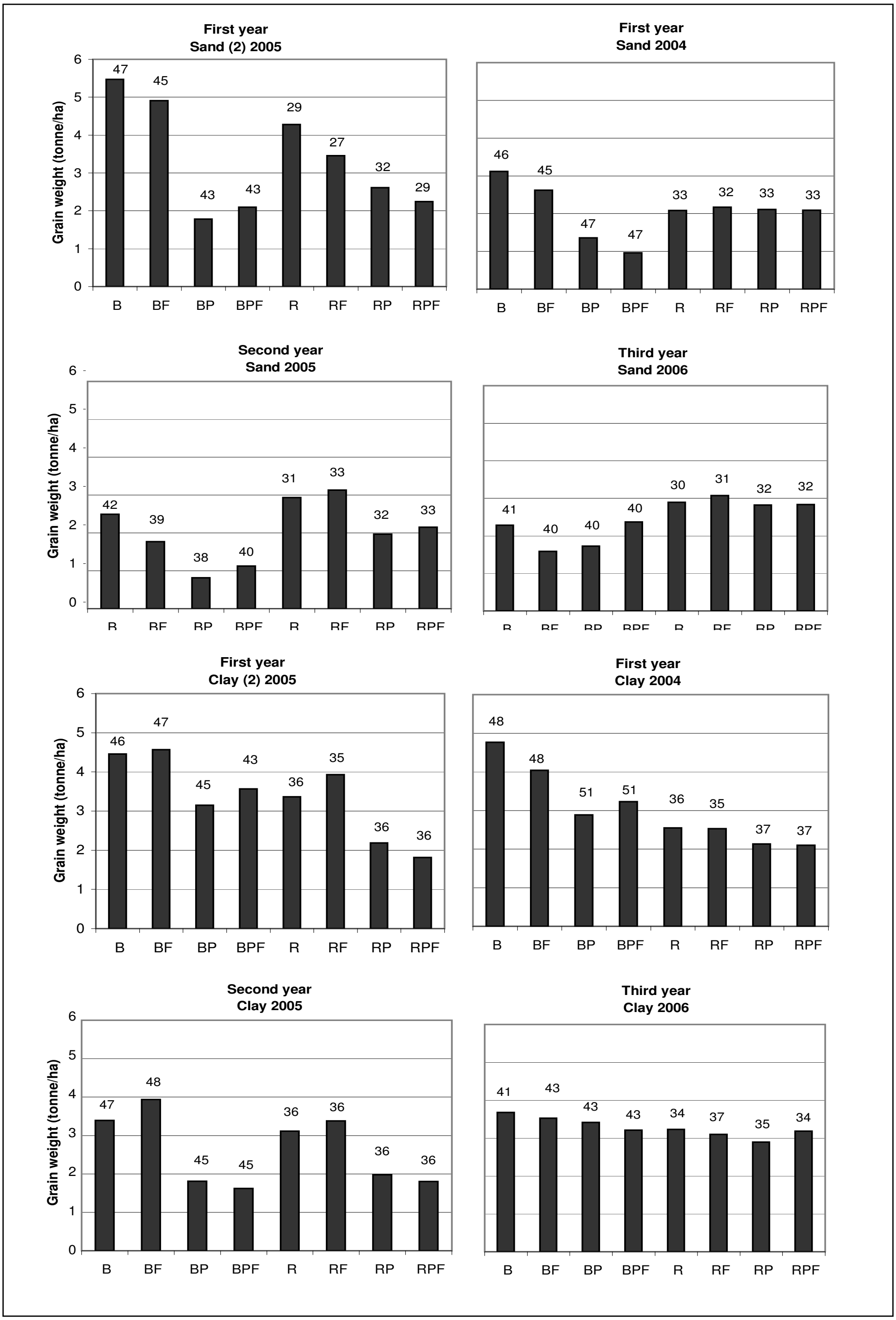


Figure 3. Cereal grain yield (column) and thousand grain weight (numbers in grammes/1000 seeds) from biodiverse production systems in Wageningen, the Netherlands. For statistics see Table 4. For treatment codes see Table 2.

yield was the same for all treatments. Pea biomass was higher in association with rye than with barley. In the second year, total yield was higher in cereal-pea mixtures than in cereal monocrops. Unlike the first year, pea biomass in the second year was lower in association with rye than with barley. Pea biomass was lower in treatments with sown wild flowers than in treatments without wild flowers. In the third year, total yield was higher in the mixtures than in monocrops. Total yields of rye and barley treatments were virtually the same. In the third year pea biomass was very low whereas biomass yield was higher in cereal-pea mixtures than in monocrops.

Sown wild flowers

In the first year of production, sown wild flower biomass was the same in all treatments. An outlier was observed in the duplicate experiment on sandy soil where the sown wild flower biomass in the barley + flowers treatment was very much higher (0.26 tonne/ha) and much higher in barley pea flowers (0.16 tonne/ha) than in the other treatments and other locations (average 0.032 tonne/ha). Averaged over the years in the system development experiment on clay soil, sown wild flower biomass was higher in treatments with pea than in treatments without pea.

Spontaneously occurring plants

In the first year of production, spontaneously occurring plant biomass was much higher on sandy soil in the development experiment (0.49 tonne/ha) than on the other locations (average 0.055 tonne/ha) due to abundance of *Chenopodium album*. At this site, spontaneously occurring plant biomass was higher in barley treatments (0.55 tonne/ha) than in rye treatments (0.26 tonne/ha) and higher in cereal-pea mixtures (0.52 tonne/ha) than in monocrops (0.30 tonne/ha). On clay soil in the first year of the development experiment, spontaneously occurring plant biomass was higher in cereal-pea mixtures (0.16 tonne/ha) than in cereal monocrops (0.055 tonne/ha). Spontaneously occurring plant biomass did not differ between treatments in the duplicate experiments.

Although there were differences between treatments in the system development experiment on sandy soil in the first year, spontaneously occurring plant biomass was the same in all treatments in the second year. In the third year spontaneously occurring plant biomass was higher in barley treatments than in rye treatments. On clay soil, in the first two years there were no differences between treatments. In the last year, the number of spontaneously occurring plants was significantly different between the treatments, but without a clear pattern.

Cereal grain yield

Cereal grain yield was different per location, per treatment and showed a location × treatment interaction (Figure 3; Table 4). In the first year of production, grain yield was higher in barley than in rye and higher in barley monocrops than in barley-pea mixtures.

In the first year of the system development experiment on sandy soil, barley monocrop treatments had the highest cereal grain yield, intermediate yields for rye treatments, and the lowest cereal grain yield for barley-pea. In the second year, the barley treatments had a lower grain yield than the rye treatments and cereal-pea mixtures had a lower grain yield than monocrops. In the third year there were no differences between cereal-pea mixtures and monocrops. All rye treatments had a higher grain yield than the barley treatments.

In the first year of the system development experiment on clay soil, barley monocrop treatments had the highest grain yield, barley pea treatments a lower grain weight, and rye treatments the lowest grain yield. In the second year, grain yield was higher in monocrops than in cereal-pea treatments. In the third year, there was no difference in grain yield between treatments.

Silage quality

In the system development experiment crude ash, DOM and starch were lower whereas dry matter content and crude fibre were higher on sandy soil than on clay soil. Crude protein content was the same on both soils. Protein content was highest in 2005 at all four locations. Silage quality was the same for the two locations in the duplicate

	Total silage (tonne/ha)			Pea (tonne/ha)			Spontaneously occurring plants (tonne/ha)		
First year	df	F	lsd	df	F	lsd	df	F	lsd
Location	3	***	0.92	3	ns	1.21	3	***	0.06
Treatment	7	*	0.80	3	***	0.71	7	***	0.09
Location x Treatment	21	***	1.71	9	***	1.66	21	***	0.18
Development sandy soil									
Treatment	7	***	0.55	3	**	0.61	7	***	0.12
Time	2	***	1.27	2	***	1.00	2	***	0.25
Time x Treatment	14	**	1.78	6	*	1.33	14	***	0.38
Development clay soil									
Treatment	7	***	0.60	3	ns	0.65	7	ns	0.23
Time	2	***	0.99	2	***	0.96	2	***	0.36
Time x Treatment	14	**	1.67	6	*	1.37	14	ns	0.65

	Sown wild flowers (tonne/ha)			Cereal grain (tonne/ha)			TGW (gramme/1000grains)		
First year	df	F	lsd	df	F	lsd	df	F	lsd
Location	3	*	0.07	3	***	0.34	3	***	0.94
Treatment	3	*	0.04	7	***	0.48	7	***	1.33
Location x Treatment	9	**	0.10	21	***	0.96	21	***	2.66
Development sandy soil									
Treatment	3	ns	0.02	7	***	0.21	7	***	0.93
Time	2	ns	0.02	2	**	0.53	2	***	2.14
Time x Treatment	6	ns	0.04	14	***	0.71	14	***	3.02
Development clay soil									
Treatment	3	ns	0.11	7	***	0.35	7	***	1.08
Time	2	ns	0.08	2	**	0.43	2	***	1.67
Time x Treatment	6	ns	0.19	14	**	0.91	14	**	3.00

	Germination percentage (%)		
First year	df	F	lsd
Location	3	*	2.37
Treatment	7	***	3.35
Location x Treatment	21	*	6.70
Development sandy soil			
Treatment	7	ns	1.73
Time	2	***	4.53
Time x Treatment	14	**	5.97
Development clay soil			
Treatment	7	ns	2.09
Time	2	***	5.48
Time x Treatment	14	ns	7.27

Table 4. Results of statistical analysis of silage yield and the biomass of the components pea, spontaneously occurring plants and sown wild flowers. Also displayed are the analysis of cereal grains, the corresponding thousand grain weight (TGW) and germination percentage. First year' are the locations sandy soil 2004, clay soil 2004, sandy soil (2) 2005, clay soil (2) 2005. Analysed with analysis of variance. Development sandy soil' is the location sandy soil in 2004, 2005 and 2006. 'Development clay soil' is the location clay soil in 2004, 2005 and 2006. Analysed with analysis of variance, repeated measures. Displayed in the table are the degrees of freedom (df), F probability (F) and the least significant difference (lsd) at 5 % confidence. ns = not significant.

experiments in 2005 (Table 5).

Silage quality differed per crop type. Barley treatments had lower dry matter and crude fibre contents, and higher crude protein, crude ash, DOM and starch contents than rye treatments. Mixtures had a higher crude protein content and a higher crude ash content than monocrops. Barley-pea treatments also had a higher crude fibre content than barley monocrop treatments.

Grain and yield quality

Thousand grain weight (TGW) was significantly different between locations (Figure 3; Table 4). TGW was always higher in barley treatments than in rye treatments. When the treatments were averaged over the locations in the first year, TGW was higher in rye-pea treatments than in rye monocrop treatments. Differences in TGW values between barley monocrop treatments and barley-pea treatments in the system development experiments depended on the year: TGW was higher in barley monocrop treatments than in barley-pea treatments in 2004 but lower in 2005. On the sandy soil, barley TGW decreased after the first year, rye TGW decreased after the second year. On the clay soil, barley TGW decreased every year, rye TGW remained constant. Pea TGW showed no trend over time.

Germination percentage (GP) was 85% on sandy soil in 2004, which was significantly lower than on the other three first-year locations with an average GP of 88%. GP was significantly higher in the barley monocrop treatments (92%) than in the other treatments (85%). In the system development experiments, the GP of cereal grains significantly increased each year on both soils. In the first year on sandy soil, GP was higher in barley than in rye. In the second and third year GP was similar for barley and rye. On clay soil, there was no trend for treatments over time (data not shown).

Discussion

Yielding ability

Production systems with different levels of biodiversity were designed. No fertilizers were used or chemical crop protection measures taken. Associated flora and fauna were allowed to develop freely. Results show that silage yields of all systems were high, especially in the first year of growth, except for barley monocrop treatments on sandy soil in 2004. Preceding crops on these soils were managed conventionally and the initial amount of nitrogen in the soil was still high. However, a fallow crop had been grown on the sandy soil in 2004 which had lowered soil nitrogen availability; this may explain poor growth of barley on that soil (Figure 2; Table 1). Rye was less sensitive to the low nitrogen level and performed better than barley. The amount of silage biomass in cereal treatments decreased over time in the system development experiments; this effect diminished (for the duration of this experiment) if pea was included in the systems (see discussion below). The amount of biomass of spontaneously occurring plants and wild flowers remained below 9%, except for barley monocrop treatments in the system development experiment on the sandy soil.

Despite the location effects, yield loss due to pests and diseases did not occur. Reliable yield is more important in low-input systems than high yield potential (Lammerts van Bueren et al., 2002). The use of genetic crop mixtures in our experiments may have contritubed to reliable yields. Genetic mixtures are known to be more resilient to disturbances than a one-variety crop (Booth and Grime, 2003; Finckh et al., 2000). Moreover, most of the varieties used were modern crops that were bred for high resistance against diseases (Anonymous, 2004).

Effect of pea

In our experiments, pea mixed with barley increased total silage yield on the sites where barley monocrop treatments performed poorly (Figure 2). This was also the case for rye treatments although rye seems to suppress pea slightly more than barley. These results confirmed our original hypothesis that the addition of a legume would increase total silage yield. Pea was used in combination with barley or rye in view of the expected yield advantage

Table 5. Silage quality averaged per location and averaged per treatment. DOM = digestible organic matter. Different letters denote significant differences between treatments per column. For treatment codes see Table 2.

Location	Dry matter g/kg		Crude protein g/kg		Crude fibre g/kg		Crude ash g/kg		DOM %		Starch g/kg	
Sandy soil 2004	930	c	55	a	311	e	43	ab	55	a	157	a
Sandy soil 2005	918	a	79	b	287	cde	42	ab	62	c	223	b
Sandy soil 2006	922	b	56	a	303	de	40	a	61	b	237	bc
Clay soil 2004	922	b	73	b	226	a	56	d	69	d	311	d
Clay soil 2005	916	a	78	b	258	b	51	cd	64	c	234	b
Clay soil 2006	916	a	55	a	279	bcd	47	bc	62	c	283	cd
Sandy soil (2) 2005	921	b	82	b	298	cde	49	c	58	ab	193	ab
Clay soil (2) 2005	916	a	76	b	273	bc	50	c	63	c	203	ab
Treatment												
B	917	a	60	ab	229	a	47	c	67	c	308	c
BF	916	a	66	bc	225	a	50	cd	67	c	287	bc
BP	918	a	92	d	270	b	54	de	66	c	266	bc
BPF	916	a	91	d	260	b	55	e	66	c	245	b
R	925	c	50	a	322	c	39	a	54	a	175	a
RF	923	bc	51	a	306	c	41	ab	56	ab	178	a
RP	922	bc	72	c	317	c	45	b	58	b	192	a
RPF	921	b	72	c	306	c	46	c	58	b	190	a

of cereal-legume mixtures under poor growing conditions (Dapaah et al., 2003; Ghosh et al., 2007; Mead and Willey, 1980). Pea was also expected to enhance fodder quality, especially because of its high protein content (Crosse et al., 1998; Waldo and Jorgensen, 1981). Results show that this indeed was the case. Crude protein concentration of the silage was highest in the pea-containing treatments. The silage quality of pea depends on the morphological stage of pea at harvest (Borreani et al., 2007; Cavallarin et al., 2006). In a mixture, setting the optimal harvest time can be difficult because the maturation date of the species may differ (Weik et al., 2002). Each year the crop was harvested at the soft-dough stage of the cereal seeds. This coincided with pea maturity in 2005. In the other years, pea matured earlier and this resulted in poorer silage quality due to a decline in protein content at maturation (Borreani et al., 2007). The positive effect of pea in our experiment was most evident in 2005 (Figure 2; Table 4). Pea biomass was higher than in the other years.

In the last year (2006), pea biomass was low. Pea is sensitive to nematodes (Anonymous, 2007), which may become a greater problem after a period of continuous cropping. The nematode population in the soil was measured and it was concluded that it was unlikely that plant pathogenic nematodes were the sole cause of the large yield reduction in our experiments (Stilma et al., submitted). Average temperature and rainfall in 2006 were different from those in the two preceding years. A combination of a cold spring, drought in June and July and extreme rainfall in August are more likely causes of the low pea yield in 2006.

Low pea biomass in 2006 increased total yield indirectly by an increase of cereal silage biomass and cereal grain weight. In the first two years, cereal silage biomass and grain biomass were lower in cereal-pea-mixtures than in cereal monocrop treatments because half the amount of cereal seeds was sown and pea growth was normal (Figure 2). In 2006, pea growth was poor and the cereal took advantage of the space and the surplus nitrogen accumulated in preceding years resulting from pea nitrogen fixation from the air by its symbionts (Hardarson, 1993). Cereals grown in lower densities produce more tillers than cereals grown at higher densities (Simmons et al., 1982). A higher nitrogen level increases the number of tillers per plant (Abeledo et al., 2004; Aspinall, 1961). As a result, rye and barley produced the same amount of cereal silage and cereal grain biomass in monocrops and intercrops in the third year. High yield of cereals grown in a rotation after a legume is common (Chalk, 1998; Papastylianou, 1990). This effect was only achieved as result of vigorous pea growth in 2005. In 2006, pea growth was poor resulting in the high nitrogen level in the soil not being maintained that year as was shown by the N and NO_3–N levels being the same for all treatments. A positive effect of pea on cereal is expected to be lower if the experiment would have been continued for another year.

Effect of sown wild flowers

Wild flowers are usually regarded as weeds causing yield loss and are thus unwanted in production systems. However, in our production systems sown wild flowers never contributed more than 2% to yield. Crop yield was statistically the same in mixtures with or without sown wild flowers. The proportion of spontaneously occurring plants was higher than that of sown wild flowers but still lower than 9% of the yield, except for the barley treatments on sandy soil in the system development experiment. Systems should be designed in which the spontaneously occurring plants and sown wild flower population are optimally managed. Methods to achieve this goal are being investigated (Storkey and Cussans, 2007).

The results of our experiments show that wild flowers should be sown several times. Numbers of wild flowers and spontaneously occurring plants were lower or the same in the second year compared to the first year. Seeds were ploughed into deeper soil layers the second year and returned to the seedbed level in the third year (Colbach et al., 2000; Marshall and Brain, 1999).

In the first year of the system development experiments, sown wild flower biomass was higher on clay than on sand. Subsequently, establishment of sown wild flowers over time was more successful on clay than on sand. The successful wild flower growth in the first year could have been caused by the higher initial amount of nitrogen in the clay soil than in the sandy soil. High nitrogen levels benefit the crop as well as the associated plants (Liebman and Altieri, 1988). This result was confirmed in the duplicate experiments, where the location with the highest initial amount of nitrogen and crop yield also showed the highest amount of wild flower biomass (Figure 2; Table 4).

Relation between spontaneously occurring plants and crop biomass

Pea-cereal mixtures were more conducive to vigorous growth of associated plants than cereal monocrops. Biomass of sown wild flowers and spontaneously occurring plants is higher in cereal-pea mixtures than in cereal monocrops (Park et al., 2002; Poggio, 2005; Santalla et al., 2001) probably because of lower soil nutrient competition in cereal-pea mixtures than in cereal monocrops (Hauggaard-Nielsen et al., 2003). This, however, is only valid at relatively low nutrient availability. At higher nitrogen availability associated plant biomass is reduced again because crop biomass is more enhanced than weed biomass, resulting in enhanced relative competition of the crop (Valenti and Wicks, 1992). Pea and associated plants were also found to be suppressed more in barley mixtures on more fertile soils than on low fertile soils.

Conclusion

These results show that if competitiveness of the crop is sufficient, an equilibrium can be obtained between high crop biomass and spontaneously occurring plants and sown wild flower biomass. A minimum level of nitrogen is required to obtain an adequate level of production. At low nitrogen levels, rye performed better than barley, although it produced lower silage quality. The effect of pea, however, depended on year, site and component crop. Pea biomass was affected by competition and pea survived better in barley than in rye. Pea performed better on poor soils because of reduced competition by the cereal. Pea in the mixture improved crop yield quantity and quality when weather conditions were favourable. Over time, the cereal benefited from the accumulated nitrogen stocked in the soil by the pea from previous years. Consequently, the positive effect of pea on the amount of silage in mixtures compared to cereal monocrops was strongest in the first two years and faded away in the third year. If systems are to be maintained for a longer period of time, pea should not be included in the mixture every year. Associated plant biomass was higher at low competition, as was shown under poor growth of barley on the poor sandy soil in 2004. Associated plant biomass was higher in cereal-pea mixtures than in cereal monocrops.

Acknowledgements
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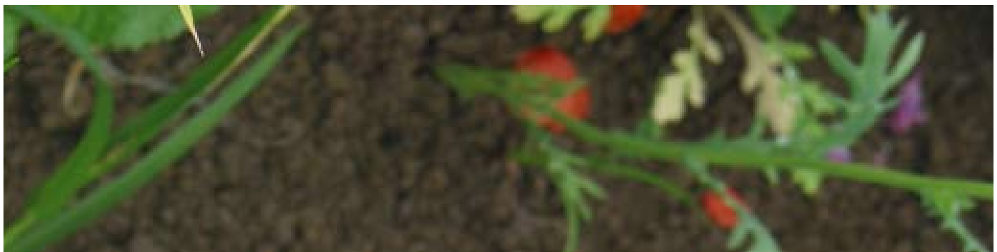
Part three



Ecology (Planet)

3

05 Recruitment and attrition of associated plants under a shading crop canopy; estimation and model selection

Eveline S.C. Stilma, Karel J. Keesman, Wopke van der Werf

The importance of maintaining a certain level of associated diversity within cropping systems is increasingly acknowledged. Here we study the population dynamics of annual plants ('weeds') within crop canopies within a season and introduce a minimal model to characterise the recruitment and attrition of annuals under the influence of a shading crop canopy. It is shown, based on first principles, that shading by the crop follows a logistic time course. The logistic light interception model is parameterized with light interception measurements in two single crops (barley and rye) and in mixtures of these species with peas. Population dynamics data were collected for four annual plant species: *Papaver rhoeas, Centaurea cyanus, Chrysanthemum segetum,* and *Misopates orontium*. The population dynamics model was identified using techniques for model selection and calibration, on the basis of experimental data collected on these four species in four crop systems, at two different sites in two years.

For three of the four annual plant species, a minimal model consisting of light-dependent recruitment in combination with a constant death rate, explained 75 to 96% of the variation in plant densities over the season. Model fit for *P. rhoeas* improved when a germination delay of 200 °Cd after sowing was included. Thus, a two parameter model gave satisfactory fits for three of the species, whereas a three-parameter model was needed for characterizing the population dynamics of *P. rhoeas.* The developed model has a simple yet biologically meaningful structure. The values of the parameters give a useful summary of the population dynamics of an annual plant population under the influence of the dynamic leaf cover of a shading crop.

Introduction

Conventional crop production systems aim at high yields by controlling pests, diseases and weeds and applying fertilizers. There is an increasing understanding that such production systems can have negative effects on the environment, e.g. leaching of nitrates and chemicals into the surface water. Furthermore, associated diversity of annual plants, invertebrates, small mammals and birds is often reduced (Anonymous, 2006). Reduced biodiversity may result in diminished resilience against outbreaks of pests, due to a reduction in number or species diversity of natural enemies (Altieri, 1999). Maintenance of biodiversity is a topic of worldwide concern (Díaz et al., 2006). Agri-environment schemes are in place in many countries to mitigate negative side effects of agriculture and to restore biodiversity by the use of field margins, ponds, woody edges and other non crop elements in the agricultural landscape (Donald and Evans, 2006). The effectiveness of such measures is questioned, however (Kleijn et al., 2006), and it has been suggested that an effective means to restore diversity would be to enhance it withín the cropped areas (Albrecht, 2003; Altieri, 1999).

In an earlier paper (Stilma et al., 2007), we describe an experimental approach towards the development of biodiverse production systems using intrinsic ecosystem processes such as competition, selection and invasion. Diversified production systems were initiated, using a seed mixture of eleven varieties of a cereal species, barley (*Hordeum vulgare*) or rye (*Secale cereale*), supplemented with semi-leafless pea (*Pisum sativum*). Associated diversity of plant and animal species (especially insects) was allowed to develop by natural processes. In addition, indigenous wild flower species were sown and the systems were managed without input of fertilizers or pesticides. The number of wild flowers per species was assessed over time, both within years and over years. The within year dynamics was characterized by an initial flush of germination, resulting in a peak density after which the number would gradually diminish for the rest of the season. Although it is well established that competing plants show self thinning (Silvertown and Charlesworth, 2001), the time course resulting from the combination of a flush of recruitment, followed by attrition is not well known. Knowledge about this time course is relevant for better understanding resource demands of associated plants throughout the season, and for assessing the role that these plants may play as a resource for insects, and other invertebrate and vertebrate organisms that use these plants as a resource.

The case of annual plants or weeds in a growing crop is special in the sense that the light environment changes rapidly, due to the development of crop leaf cover and canopy closure. As a result, the curve of recruitment and attrition of wild flowers over time did not follow a standard course that could be described with commonly available growth curves, most of which have an unbounded time course (exponential), an S-shape (logistic, Gompterz), or have no mechanistic interpretation (e.g. statistical probability distributions) (Brown and Rothery, 1993). To help interpret the observations, a simple mechanistic model was needed by which the population dynamics data of the annual plants could be summarized. The model should be simple, have few parameters to allow calibration of the model to the data, and the parameters should have a mechanistic interpretation to help provide insight into the dynamics of the system.

Many models have been developed for understanding plant population dynamics (e.g. (Bouman et al., 1996; Firbank and Watkinson, 1986; Freckleton and Watkinson, 1998; Jørnsgård et al., 1996; Kropff, 1988; Kropff and Spitters, 1991; Kropff et al., 1992; Liebman and Dyck, 1993; Rees and Long, 1992; Young and Evans, 1976). These models are based on detailed quantification of component processes within the plant life cycle. For the purpose of characterizing observed population trajectories with few parameters, these models contain too much detail and require too much data. Hence, none of these models would allow an accurate calibration to sparse data sets of annual plant counts. Thus, there are no simple models that could be used to characterize the recruitment and attrition of weeds under the influence of shading by a growing crop canopy.

Here we use a parameter-sparse, mechanistically based dynamic modelling strategy using a system identification framework to describe germination and attrition of weeds under a shading crop canopy. This approach is especially suited to the problem because biodiverse production systems are complex, the data sets are sparse, and prior knowledge of these systems is rather limited. System identification is an inductive modelling strategy that proposes alternative models on the basis of alternative hypotheses about system behaviour, fits these models to the data, and selects the 'best' model based on congruence with the data, model significance and parsimony, and mechanistic considerations (Ljung, 1987; Norton, 1986).

From prior knowledge, we know that the amount of light is an important factor for germination of plants (Holt, 1995), and for attrition of plants (Brainard et al., 2005). Growth of species becomes limited at low light intensities (Kleijn and van der Voort, 1997). We hypothesised that the effect of the crop on the plants could be captured by the amount of light penetrating through the canopy. A function for light penetration over time was therefore derived. Then, a set of alternative population dynamic models is proposed that describes the change in number of the annual plants as the balance between a germination process and a death process, both processes being influenced by the amount of available light. Subsequently, model selection is applied to find the simplest and most parameter sparse model that gives a good fit to the data. Thus, this study demonstrates the system identification concepts of model set specification, model selection and calibration to the modelling of an annual plant population in a diversified production system. The final objective of this work is to identify a simple and mechanistically based model for the recruitment and attrition of annual plants under a shading crop canopy.

Material and methods

Data collection

Observations were made in four field experiments. Each experiment included four cropping treatments: two monocrops, *viz.* spring barley (11 varieties of *Hordeum vulgare*: Pasadena,

Table 1. Sowing and counting dates in four experiments.

	Expt 1: De Born, 2004 (sand)		**Expt 2: Lawickse Allee, 2004 (clay)**	
	Date	**Tsum (˚Cd)**	**Date**	**Tsum (˚Cd)**
Sowing	April 20	0	April 19	0
Count 1	May 18-21	368	May 24-26	432
Count 2	June 7-11	633	June 15-16	741
Count 3	June 28-July 1	936	July 5-6	1036
Count 4	July 20-23	1296	July 26-27	1387
	Expt 3: Loesemer, 2005 (sand)		**Expt 4: Lawickse Allee, 2005 (clay)**	
	Date	**Tsum (˚Cd)**	**Date**	**Tsum (˚Cd)**
Sowing	March 30	0	April 13	0
Count 1	April 26	268	May 4	238
Count 2	May 17	486	May 25	461
Count 3	June 7	791	June 14	737
Count 4	July 26	1114	July 7	1170

Jersey, Prestige, Class, Madonna, Extract, Reggae, Orthega, Aramir, Apex and Saloon) and spring rye (*Secale cereale,* variety Sorom), and two intercrops, *viz.* mixtures of barley or rye with semi-leafless pea (*Pisum sativum,* Integra). Experiments 1 (2004) and 3 (2005) were conducted on sandy soil (N 51°, 59', E 5° 39'), while Experiments 2 (2004) and 4 (2005) were conducted on clay soil (N 51°, 57', E 5°, 38') near Wageningen, The Netherlands. No fertilizers or pesticides were applied in any of the experiments.

Each combination of cropping treatment and annual plant species was replicated four times in a randomized complete block design with plots of 180 m^2 (Stilma et al., submitted-a). Cereal monocrops were sown at the full recommended seed rates of 114 kg/ha for barley and 89 kg/ha for rye (Anonymous, 2004), while cereals in mixtures were sown at half the rate recommended for single crops. Peas were sown at 173 kg/ha, i.e. half the rate recommended for sole pea crops.

Four different wild flower species were sown in these cropping treatments: *Papaver rhoeas, Centaurea cyanus, Chrysanthemum segetum,* and *Misopates orontium*. Wild flowers were sown at densities recommended by the producer (Biodivers b.v., Reeuwijk, The Netherlands), resulting in approximately 50-80 viable seeds m^{-2} for *C. cyanus, C. segetum,* and *M. orontium,* and 80-175 m^{-2} viable seeds m^{-2} for *P. rhoeas*. Crops and annual plants were sown simultaneously. Sowing dates are given in Table 1. The numbers of wild flower plants were counted four times per season in a 1 m^2 quadrate in the centre of each plot (Table 1).

The amount of shading was measured at the end of the growing season with the SunScan Canopy Analysis System (Delta-T Devices Ltd, Cambridge, UK) which measures simultaneously the amount of light above and underneath the canopy. The ratio between the two is the proportion of transmitted light. Additionally, digital images were taken at regular intervals throughout the season from approximately 1.5 m vertically above the crop, and analysed with image analysis software, developed by the Centre for Biometry, Wageningen to determine soil cover percentage (G. van der Heijden, pers. communication).

Model for light interception and shading by the crop leaf canopy

Assume that the growth rate of the crop (kg m^{-2} d^{-1}) is proportional to the amount of incoming light (R; MJ m^{-2} d^{-1}) and the time varying fraction $i(t)$ that is intercepted. Assume further that a fixed proportion α of the biomass increase is allocated to the leaves (kg leaf biomass kg^{-1} total biomass), and that the specific leaf area (σ; area of leaf per unit of leaf biomass; m^2 leaf kg^{-1} leaf biomass) is constant. Taking for simplicity R to be constant, the rate of leaf area growth can be formulated as:

$$\frac{dL(t)}{dt} = \sigma \cdot \alpha \cdot \varepsilon \cdot i(t) \cdot R \qquad (1)$$

where L is leaf area index (m^2 leaf area m^{-2} ground area) and e is the light use efficiency (kg biomass produced per MJ radiation intercepted) (Monteith, 1977). The product $\sigma \cdot \alpha \cdot \varepsilon \cdot R \equiv \lambda$ is the maximum rate of leaf area index growth at full light interception (m^2 leaf area m^{-2} ground area d^{-1}).

Assume further that the proportion of incident light intercepted by the leaf canopy is a negative exponential function of leaf area index (Hirose, 2005):

$$i(t) = 1 - e^{-k \cdot L(t)} \qquad (2)$$

where k is the light extinction coefficient (-). Then, it can be shown from Equation 1 and 2, that leaf area will follow a time course known as expolinear growth (Goudriaan & Monteith, 1990)

$$L(t) = \frac{1}{k} \ln\left(1 + \left(e^{kL_0} - 1\right) e^{k\lambda t}\right) \qquad (3)$$

where L_0 is the leaf area index at time 0. Substituting Equation 3 into 2, it can be shown that the proportion of light interception evolves according to a logistic growth equation:

$$\frac{di(t)}{dt} = k \cdot \lambda \cdot i(t)\left(1 - i(t)\right) \qquad (4)$$

with an initial value at t=0: $i(0)=1-\exp(-k \cdot L_0)$, an upper bound of 1 for large t, and an intrinsic growth rate parameter that equals the product $k\lambda$.

In other words: Equation 4 is the solution to the differential equation:

$$i(t)=\frac{1}{1+(e^{kL_0}-1)^{-1}e^{-k\lambda t}}$$

with initial condition $i(0)=1-\exp(-k \cdot L_0)$.
Note that for annuals growing underneath a crop, the function $i(t)$ describes the proportion of incoming radiation R that is *not* available to them, i.e. $i(t)$ expresses the degree of shading by the crop. For fitting Equation 4 to observations, and after defining $e^{-k\lambda t_{50}} \triangleq (e^{kL_0}-1)^{-1}$, we parameterize a shade function $s(t)$ as:

$$s(t)=\frac{s_{\max}}{1+e^{-r(t-t_{50})}} \qquad (5)$$

where s_{max} is the maximum proportion of light interception (when the crop leaf canopy has attained its final value), r is the relative growth rate of light interception (equal to the product $k\lambda$ in Eq. 4), and t_{50} is the time at which $s(t)$ has reached 50% of its final value s_{max}. Note that it is assumed here that the minimum light interception (for $t \to -\infty$) is 0. The introduction of a parameter s_{max} accounts for the openness of some of the leaf canopies in experiments, such that they did not intercept all the incident light.

The function $s(t)$ was fitted to sixteen data sets, representing four crop systems in each of four different experiments. Generalized linear models were fitted in Genstat, using a binomial error model and a logit link and the directive GAUSSNEWTON to optimize parameters. Differences between treatments within experiments in the parameters $s$max, r and t_{50} were investigated using ANOVA. When no significant differences were present, treatments were lumped and light interception in these treatments was described with a common

Table 2. List of symbols

Name	Symbol	Units
Temperature sum	Tsum/ time	^oCd
Proportion of newly produced dry matter allocated to leaves	a	m^2 leaf biomass kg^{-1} total biomass
Specific leaf area	s	m^2 leaf area kg^{-2} leaf dry matter
Incoming radiation	R	MJ m^{-2} d^{-1}
Light use efficiency	e	kg biomass produced per MJ radiation intercepted
Leaf area index	$L(t)$	m^2 leaf area m^{-2} ground area
Maximum rate of leaf area index growth at full light interception	λ	m^2 leaf area m^{-2} ground area d^{-1}
Light extinction coefficient	k	(m^2 leaf area m^{-2} ground area)$^{-1}$
Leaf area index at time 0	L_0	m^2 leaf area m^{-2} ground area
Relative growth rate of light interception	r	
Final light interception by the canopy	s_{max}	fraction [0-1]
Time at which $s(t)$ has reached 50% of its final value $s$max	t_{50}	^oCd
Rate of recruitment	a	# m^{-2} d^{-1}
Relative rate of attrition	b	d^{-1}
Density of weeds	$N(t)$	# m^{-2}
Curvature parameter	θ	-
Curvature parameter	κ	-

logistic.

Models for recruitment and attrition of associated plants

Model conceptualization

To develop a reference model for the population dynamics of the annual plants underneath the crop canopy, we hypothesize that recruitment is proportional to the amount of light penetrating through the canopy and attrition to the amount of shading. Germination is assumed to be proportional to the density of seeds in a large seed bank, and hence no depletion of the number of seeds is accounted for. The rate of attrition is characterized by a relative rate parameter, by the effect of shade, and by the density of annual plants. The reference model (denoted as model 4; see below) is then:

$$\frac{dN(t)}{dt} = a\left(1-s(t)\right) - b \cdot s(t) \cdot N(t) \qquad (6)$$

where $N(t)$ is the density of weeds (# m^{-2}) at time t (°Cd), a is the germination rate (# m^{-2} °Cd^{-1}, b the death rate (°Cd^{-1}) and $s(t)$ denotes shading by the canopy (on a proportional scale; 0-1), as defined by Equation 5. The model is formulated in thermal time (units: °Cd) in order to allow for the effect of temperature on the rates of germination and attrition. In the remainder of this paper "time" denotes "thermal time". Temperature sum is the summation of daily average temperature above 0°C, from sowing.

Model variants

Six additional model variants are introduced and compared in order to identify which degree of complexity is necessary and sufficient to describe the population dynamic data. Model variants differ in whether or not they include the light dependency of germination and attrition and in the shape (linear or non-linear) of these relationships. All in all, there are six model variants in addition to the reference model (Equation 6). The models are numbered in order of complexity, and the reference model, which is intermediate in complexity, has number 4.

Model 1 contains no influence of shading:

$$\frac{dN(t)}{dt} = a - b \cdot N(t) \qquad (7)$$

and is an incarnation of the monomolecular growth model (e.g. Brown & Rothery, 1993), describing a gradual approach to a plateau *a/b*.

Model 2 includes a linear effect of light on germination, while attrition is independent of shading:

$$\frac{dN(t)}{dt} = a\left(1-s(t)\right) - b \cdot N(t) \qquad (8)$$

This model, and all following models, describe an initial flush of recruitment, resulting in a peak density, followed by a gradual decrease of the density.

Model 3 includes a linear effect of shading on attrition, while germination is independent of shading:

$$\frac{dN(t)}{dt} = a - b \cdot s(t) \cdot N(t) \qquad (9)$$

Model 4 (Equation 6) includes linear influences of shading on both germination and attrition.

Model 5 includes a non-linear effect of shading on germination and a linear effect of shading on attrition:

$$\frac{dN(t)}{dt} = a\left(1-s(t)\right)^{\theta} - b \cdot s(t) \cdot N(t) \qquad (10)$$

Model 6 includes a linear effect of shading on germination and a non-linear effect of shading on attrition:

$$\frac{dN(t)}{dt} = a\left(1-s(t)\right) - b \cdot s(t)^{\kappa} \cdot N(t) \qquad (11)$$

Model 7 includes non-linear influences of shading on both germination and attrition.

$$\frac{dN(t)}{dt} = a\left(1-s(t)\right)^{\theta} - b \cdot s(t)^{\kappa} \cdot N(t) \qquad (12)$$

Consequently, models 1-4 have two parameters, *a* and *b*, that need to be estimated from the data. Models 5 and 6 have three parameters, *viz.* *a* and *b* plus one extra parameter, q (model 5) or k (model 6) for curvature. Model 7 has two parameters for curvature, q and k, and hence has in total four parameters.

Model solution

Only the first model (equation 7) has a convenient analytical solution. Therefore, the models were fitted to the data using numerical model integration and parameter optimization. To run the model, the differential equations were solved using Eulerian rectilinear integration with a time step of 1 °Cd.

Stepwise procedure for model calibration and selection

Model calibration and model selection *per experiment*

Calibration was programmed in MatLab, using

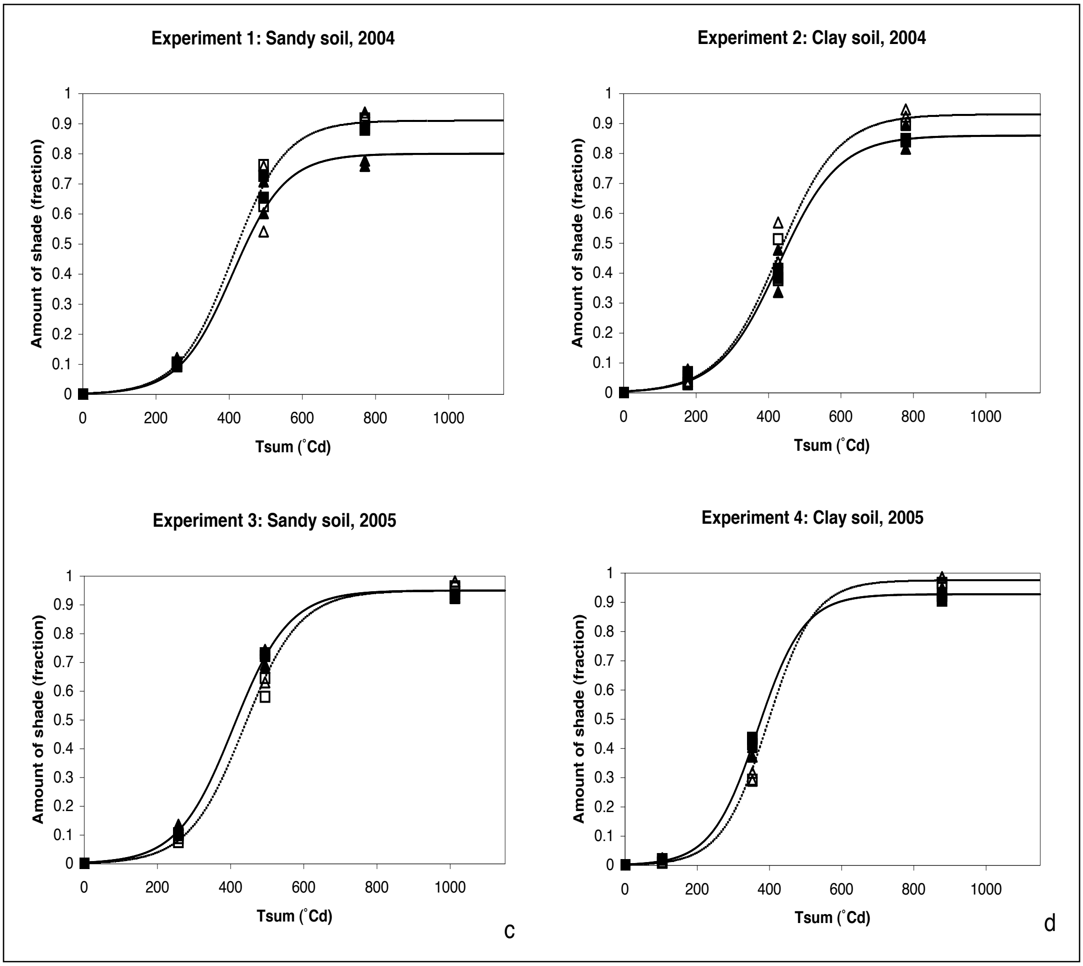


Figure 1. Fitted sigmoid curves for proportion light interception by the canopy. Each figure represents one experiment. Symbols denote crop treatments: barley (▲); rye (■), open triangles = barley pea intercrop (Δ), rye pea intercrop (□). Line types denote fitted treatments. For Experiment 1, for the hatched line type denotes the barley monocrop while the drawn line denotes the other three crop treatments. For Experiments 2, 3 and 4, the hatched line denotes the fitted curve for the intercrops while the drawn line denotes the fitted curves for the pure cereals.Figure 2. Pictures of barley monocrop (a and c) and barley-pea intercrop (b and d) at two times in the growing season taken vertically from 1.5 m above the canopy in Experiment 4 (clay soil, 2005). Pictures a and b are taken at a Temperature sum of 352 ˚Cd , pictures c and d at 943 ˚Cd. The estimated proportions of shade are 0.40, 0.33, 0.93 and 0.97, for picture a, b, c, and d, respectively

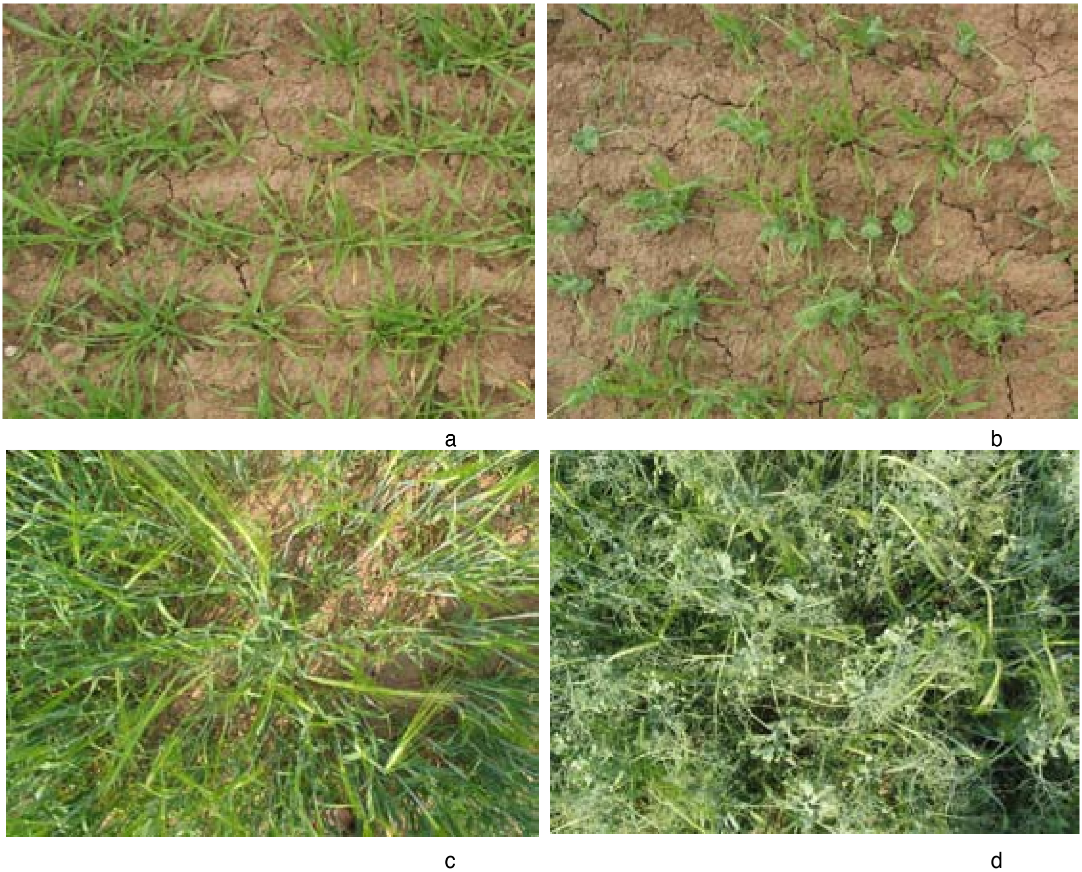


Figure 2. Pictures of barley monocrop (a and c) and barley-pea intercrop (b and d) at two times in the growing season taken vertically from 1.5 m above the canopy in Experiment 4 (clay soil, 2005). Pictures a and b are taken at a Temperature sum of 352 ˚Cd , pictures c and d at 943 ˚Cd. The estimated proportions of shade are 0.40, 0.33, 0.93 and 0.97, for picture a, b, c, and d, respectively

least squares optimization as implemented in the standard function LSQNONLIN. As indicated in Table 1, annual plants were counted four times per season. To reduce scatter in the count data and make them more amenable to model calibration, counts from the four replicates per weed species in each of the four treatments in the four experiments were averaged. This resulted in 64 data sets for model calibration: 4 plant species x 4 experiments x 4 crop treatments per site. Each of these data sets had 5 observation points including the initial zero count at sowing. In order to have sufficient data points for estimation of even the three and four parameter models, calibrations were initially carried out by fitting a common parameter set simultaneously to four data sets. The sets that were combined were those for a given plant species, but different cropping treatments in one experiment. It was considered that the fitted shade functions $s(t)$ could (at least in part) account for differences between crop treatments in the plant dynamics.

Output of a calibration included a measure for goodness of fit, pseudo-R^2, and the fitted parameters with their standard errors. Pseudo-R^2 is defined as:

$$\text{pseudo-R}^2 = 1 - \frac{SS_{residual}}{SS_{data}} \tag{13}$$

where $SS_{residual}$ is the sum of squared residuals, and SS_{data} is the corrected sum of squares of the

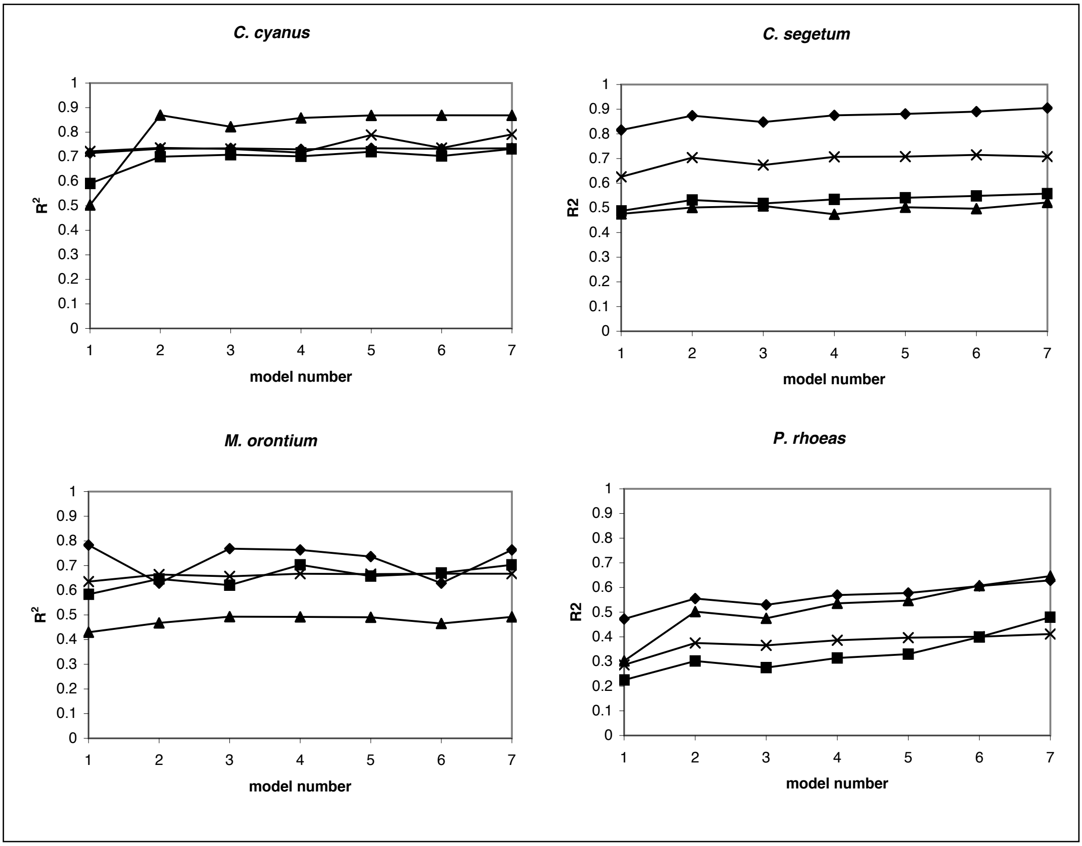


Figure 3. Pseudo-R^2 of seven fitted models (Equations 6-12) Each panel represents one plant species, and each line represents one of four experiments: Expt 1 (diamonds), Expt 2 (squares), Exp 3 (triangles), Exp 4 (crosses).

data (i.e. the sum of squared deviations from the mean). This first round of model calibration and selection was used to evaluate appropriateness of the seven model equations (Equations 6-12) and select the most promising ones for further testing and improvement. The initial model calibration resulted in 16 parameter sets and goodness of fit measures for each of the seven candidate models.

Calculation of different start times for germination of wild flower species

Based on an observed lack of fit for *P. rhoeas* in the *per experiment* calibrations (Figure 3), it was decided to recalibrate the reference model to determine optimal delay times for germination for each species. The delay time represents the time between sowing and the first emergence of countable seedlings. The goodness of fit between calibrations with different germination delays was compared and the optimal delay time was selected for each species.

Model calibration and model selection *per data set*

Models 2-4, which were found the most appropriate to describe the data in the initial *per experiment* model selection step, were further evaluated using calibration to each single data set (4 species x 4 experiments x 4 treatments = 64 data sets). This is called *per data set* calibration. Sixty four model calibrations were conducted, one for each individual data set. Adjusted germination delay times were thereby taken into

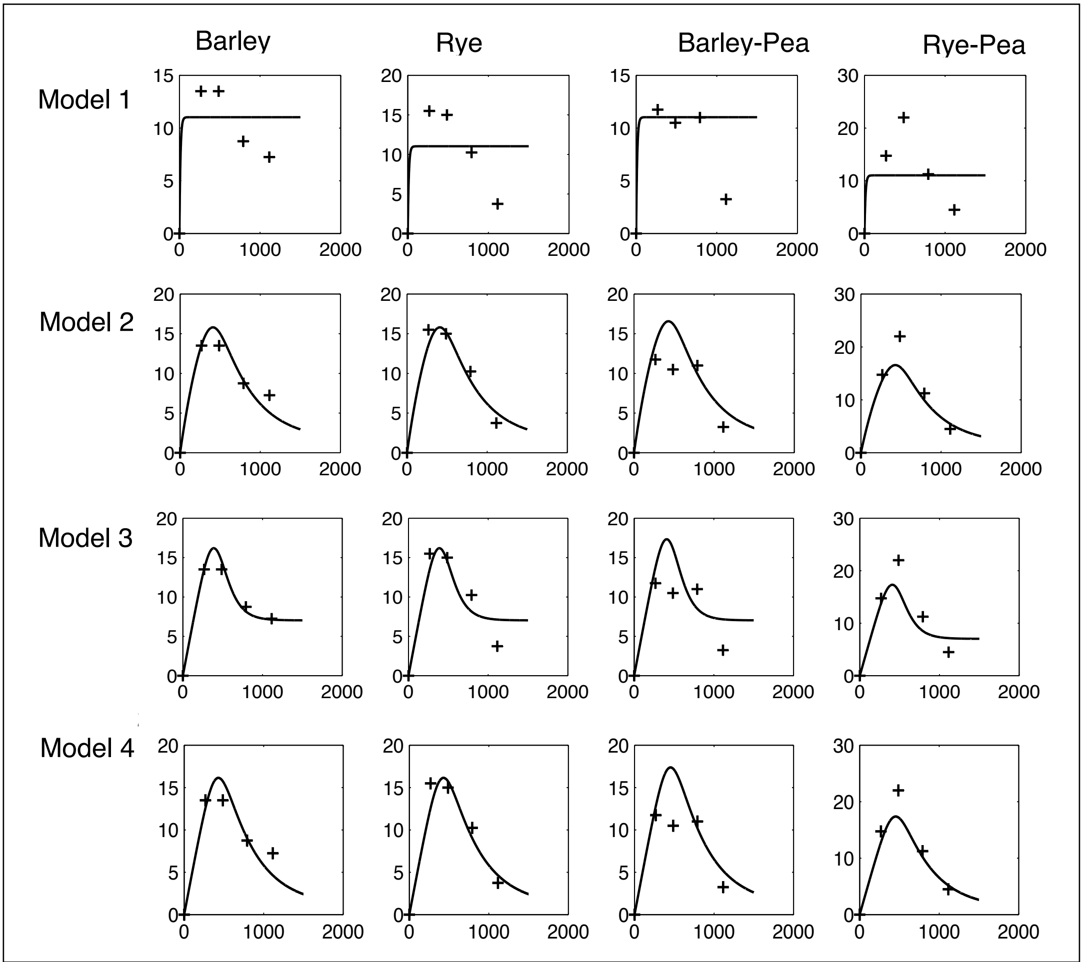


Figure 4. Fitted curves with models 1-4 for cornflower in Experiment 3.

account. The best model is selected on the basis of the goodness of fit (pseudo-R^2), biological appropriateness of the underlying assumptions, coefficient of variation of parameter estimates and the results of the ANOVA on the parameters *a* and *b*. Hereby consistency of parameter values across treatments and experiments will be interpreted as a token of model robustness, and a more robust model would be a better model.

<u>Explanatory value of the shade function *s*(*t*)</u>
The explanatory value of the fitted shade functions *s*(*t*) was assessed by comparing model calibrations (reference model 4) with a common sigmoid function for all the treatments within an experiment with calibrations in which a different sigmoid was used for each treatment. Consistency of parameter values of *a* and *b* among treatments was used as criterion for assessing explanatory value of *s*(*t*), reasoning that parameters *a* and *b* would become consistent across treatments if the shade function explained the treatment differences, whereas these parameter values would not be consistent among treatments, if the shade function could not explain treatment differences in recruitment and attrition; hence these differences would be reflected in differences in parameter values. Parameter consistency was assessed with ANOVA.

Results

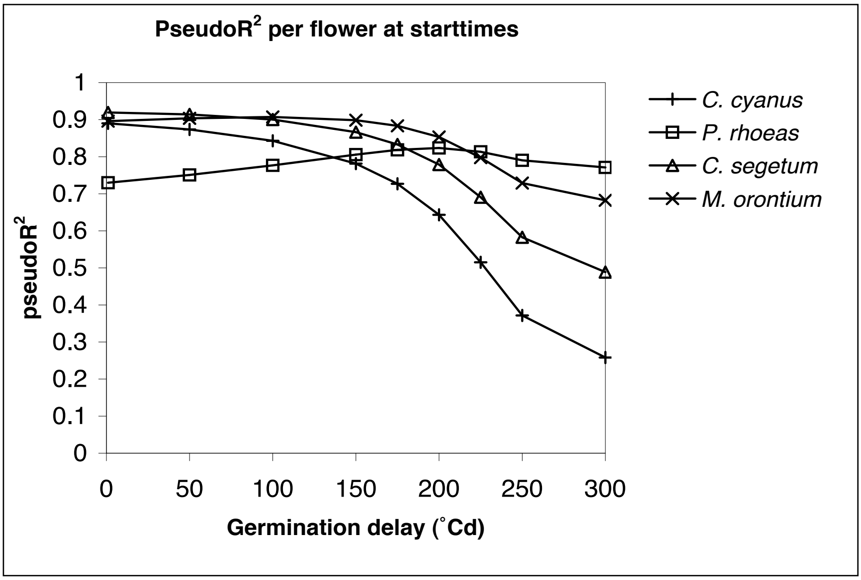
Logistic increase of light interception by the crop leaf canopy

Logistic functions (Equation 5) provided good descriptions of light interception through time in different treatments (Figure 1). No differences in the parameter *r* were found between the four fitted curves in any of the four experiments (non linear regression analysis, p values: 0.828, 0.268, 0.781, 0.093 in experiments 1, 2 ,3 , and 4, respectively), but there were significant differences in the parameter s_{max} between monocrops and intercrops in experiments 2 and 4 (p values: 0.028 and 0.022, respectively) with intercrops reaching greater soil cover than monocrops. In experiment 1, the barley monocrop had significantly lower final light interception (s_{max}) than each of the other three crop treatments (p value: 0.002). There were significant differences in the parameter t_{50} between intercrops and monocrops in experiments 3 and 4 (p values: <0.0005and 0.015, respectively). Thus, on clay soils (experiments 2 and 4), intercrops had a significantly higher final light interception than monocrops, while in 2005 (experiments 3 and 4), the monocrop treatments reached 50% of their final cover at an earlier time (t_{50}) than the intercrop treatments. After grouping treatments within experiments without significant parameter differences, eight logistic functions were obtained, two in each experiment. The slower initial development of leaf cover and the greater final value of cover in intercrops, compared to monocultures, on clay, are illustrated in Figure 2.

Model calibration and model selection per experiment

All seven models fitted the *per experiment* data for all of the four plant species, and there was only moderate variation in goodness of fit (Figure 3). Pseudo-R^2 was lowest for model 1, and this model showed lack of fit: whereas the data show generally an increase in plant density early during the season, followed by attrition later (Figure 4), this model can only describe approach to a plateau. Parameter estimates in the models were generally significantly different from zero, except in some cases in which the data suggested absence of mortality, resulting in very low estimates of parameter *b* (Appendix 1). Inclusion of curvature parameters θ and κ did not improve the model goodness of fit; moreover, the relative error in parameter estimates increased (Appendix 1).Therefore, models 5 - 7 were considered over-parameterized for these data and therefore rejected. Model 1 was also rejected because of

Figure 5. Average goodness of fit of model 4 for four wild flower species when using different values for the time between sowing and the start of germination. Germination delay (x-axis) is given in °Cd after sowing.



a lower pseudo R^2 and lack of fit. Hence, models 2 - 4 remained for further analysis.

Model calibration and model selection per data set

Optimization of the germination delay

Pseudo-R^2 was lower in *P. rhoeas* than in the other species. Fitted curves showed a lack of fit in that initial termination was too rapid. Therefore, it was investigated whether a germination delay would improve the fit. This was explored with the reference model 4. The start time of germination of each of the four species was altered with time steps of 50 ˚Cd and goodness of fit was calculated per dataset. Goodness of fit of *P. rhoeas* increased with increasing germination delay and reached an optimum with a germination delay of 200 ˚Cd after sowing (Figure 5). Goodness of fit of *M. orontium* was more or less the same at germination delays ranging from 0 to 150 ˚Cd. Therefore, germination delay for this species was set at zero. The goodness of fit for *C. segetum* and *C. cyanus* were highest if germination delay was zero. Consequently, the germination delay for these species was also set to 0.

Model calibration and model selection

Further model selection was then carried out with models 2, 3, and 4, using calibration on the 64 available datasets per species, experiment and cropping treatment. Start time for *P. rhoeas* was set at the optimal value 200 ˚Cd while that of the other species was set at 0 ˚Cd.

Pseudo-R^2 varied little between models with an average value of 0.88 for model 2, 0.86 for model 3, and 0.88 for model 4. The range of pseudo-R^2 for individual data sets was 0.57 - 1.00 for model 2, 0.40 - 0.99 for model 3, and 0.60 - 1.00 for Model 4 (Appendix 2).

Parameter estimates for model 2 and 4 were similar whereas those for model 3 were different from those of models 2 and 4 (Appendix 3). This difference between model 3 at the one hand and models 2 and 4 at the other hand is due to the absence of an influence of shading on germination in model 3, contrary to both of the other models. As a result, germination in model 3 goes on throughout the whole growing season, which is biologically inappropriate. To compensate for the overestimation of recruitment in this model, the values of the calibrated attrition parameter *b* are increased. Model 3 is therefore rejected.

There were no strong effects of cereal species, intercropping with pea, or interaction between the two treatment factors in ANOVA. Highly significant differences were found between experiments. A breakdown of the experimental effect in a component of year (2004 vs. 2005) and soil type (sand vs. clay) demonstrated that both components as well as their interaction were significant in most cases (Appendix 4).

In short, all three models were able to fit the data. Model 2 and 4 resulted in similar population trajectories as well as parameter values, while model 3 yielded contrasting results. Model 3 was rejected on biological grounds, and also because there was some lack of fit (Figure 4). Finally, model 4 is preferred above model 2 because it appears biologically more plausible that the rate of attrition increases with shading, as in model 4, than that it is independent of shading, as in model 2. The reason that the data alone are insufficient to assign model 4 as the better model, compared to model 2, is that in both models, attrition does not start to impact the numbers until a sufficient number of annual plants have recruited to the population at which time the crop has already closed, and the shade function has approached a value near 1. In other words: attrition is initially low in model 4 because there is not enough shade, but it is also low in model 2 because there are as yet few recruited plants.

Effect of the sigmoid function

Finally, to investigate the explanatory value of the shading function, model 4 was fitted to individual data sets using a common sigmoid function for all treatments and compared to fits with sigmoid functions specific per treatment (Appendix 5). Treatment effects by general analysis of variance were bigger if one sigmoid was used compared to treatment effects if separate sigmoids were used. Thus, the use of treatment specific shade functions is shown to explain part of the variability in the rate of recruitment and attrition.

Evaluation of parameter values

There were soil type and year effects for parameter values of *a* and *b* per wild flower species (Appendix 2). Germination rate and death rate were higher in *P. rhoeas* than in the other three species (Appendix 2). All wild flower species had higher death rates in 2005 than in 2004. Accordingly, the time at which 50% of maximum shading was reached was earlier in 2005 than in 2004 (Figure 1).

Discussion

Model structure

Results in this paper show that it is possible to model the population dynamics of annual weeds under a shading crop canopy with a minimal model that includes recruitment and attrition under the influence of shading by the crop. The model consists of a single differential equation, formulated in thermal time. The reference model (without a germination delay) has two parameters, while an extended model with a germination delay has three parameters. A two-parameter model sufficed for describing count data of the species *C. cyanus, M. orontium* and *C. segetum*, whereas a three parameter model, i.e. with germination delay, was needed to adequately characterize the population dynamics of *P. rhoeas.* Model goodness of fit was good, with pseudo R^2 ranging from 0.60-1.00, with an average value of 0.88. Further refinement of the model, by inclusion of non linear relationships between light underneath the canopy and demographic parameters of the plants, did not result in better fits.

It has been often observed that leaf area dynamics or light interception of leaf canopies can be satisfactorily described with logistic functions (e.g. (Anslow and Back, 1967; Evers et al., 2007; Shield et al., 2002). As noted by Goudriaan (1990) and Goudriaan (1994), the logistic function for the proportion light interception is the derivative of the expolinear function for cumulative light interception, which is a proxy for crop production, while the expolinear equation is the antiderivative of the logistic, providing two important linkages between dynamic laws for light interception and the growth of leaf canopies.

It was shown that the inclusion of a dynamic shade function in the model was instrumental to obtaining a biologically relevant shape of the population dynamic trajectory. If an average shade function across treatments was used during model calibration, significant differences resulted between parameter values among treatments. Inclusion of treatment-specific shade functions (as far as these were significantly different between treatments) nullified the significant parameter differences in ANOVA, and thus accounted for differences between treatments in the annual plant dynamics.

Implementation of the model in practise

The model proved a good tool to describe recruitment and attrition of plants growing under a shading crop canopy. The results of the model calibration show that differences in shading by different crop types affect the population dynamics of annual plants in the crop. As shown by (Stilma et al., submitted-b) the different crop treatments also resulted in differences in the size of the associated plants between cereal and cereal-pea mixtures; associated plants were larger in the mixed systems than in the pure cereal systems.

The population dynamics of associated plants differed among the species. *P. rhoeas* was the only species with a germination delay; it germinated 200 ˚Cd later than the other wild flower species. Germination time was delayed probably because *P. rhoeas* is an autumn germinating species (Silvertown, 1981). Notably, *C. cyanus* is normally considered an autumn germinating species as well. However, a germination delay was not found for *C. cyanus*. Possibly, this species does not respond to changes in temperature and daylight (Keller and Kollmann, 1999) and showed in other experiments early emergence in spring to escape competition. *C. segetum,* is mostly a spring germinating species (Howarth and Williams, 1972) and start times were not delayed. Other characteristics that effect germination rate is seed size. Small seeded species are more likely to germinate in autumn than in spring (Silvertown, 1981). The choice of crop and wild flower species effects the interaction dynamics between the crop and the under growing flora. Further research could address possibilities for optimizing crop and wild flower relations to obtain biodiverse production systems with stable yields and high associated biodiversity.

After correcting the germination rate for the seed density and under the assumption that soil moisture is not limiting, the plant population dynamics model presented in this paper, in addition to e.g. an expolinear growth model for the crops, can be used to analyse and design production systems in which the crop and associated plant community are grown for complementary patterns of growth and resource use.

Appendix 1. Fitted values ± SE for the parameters *a* (recruitment) and *b* (attrition) in seven models (Equations 6-12) when using *per experiment* calibration. In these calibrations, data from four cropping treatments within one experiments are fitted with one single common parameter set, using the appropriate shade function for each treatment, as shown in Fig. 1.

	model 1		model 2		model 3		model 4		model 5		model 6		model 7	
	est.	se	est.	se	est.	se	est.	se	est.	se	est.	se	est.	se
C. cyanus	numbers *0.01													
	parameter a													
Exp. 1	7.41	2.27	2.11	0.04	1.91	0.03	1.88	0.03	2.02	0.06	2.02	0.39	2.02	0.48
Exp. 2	0	150	1.71	0.05	1.51	0.04	1.42	0.03	1.45	0.04	1.35	0.04	1.27	0.06
Exp. 3	0	237	7.14	0.07	5.37	0.04	4.99	0.03	5.65	0.07	6.18	0.32	5.76	0.26
Exp. 4	0	425	2.54	0.05	2.34	0.04	2.16	0.03	3.2	0.16	2.45	0.35	3.07	0.18
	parameter b													
Exp. 1	1.11	0.35	0.06	0	0.35	0.01	0.07	0	0.03	0.01	0.06	0	0.03	0.01
Exp. 2	0	33.9	0.1	0.01	0.46	0.02	0.11	0.01	0.31	0.05	0.13	0.02	0.44	0.19
Exp. 3	0	21.5	0.24	0	0.8	0.01	0.26	0	0.19	0	0.23	0	0.19	0.01
Exp. 4	0	71.9	0.1	0	0.52	0.01	0.1	0	0.05	0	0.1	0	0.06	0.01
P. rhoeas	parameter a													
Exp. 1	25	0.21	17	0.05	13.4	0.03	15.1	0.03	14.4	0.05	14.4	0.03	12.5	0.04
Exp. 2	18.8	0.19	13.2	0.04	10.5	0.03	12	0.03	11.4	0.08	12.1	0.03	9.97	0.04
Exp. 3	10.4	0.27	7.2	0.05	5.63	0.03	6.02	0.03	5.83	0.04	5.71	0.03	5.02	0.05
Exp. 4	39.6	0.12	29.3	0.04	26.1	0.03	28	0.03	26.6	0.04	27.4	0.03	24.6	0.06
	parameter b													
Exp. 1	0.49	0	0.08	0	0.33	0	0.09	0	0.14	0.02	0.22	0	0.44	0.01
Exp. 2	0.42	0	0.06	0	0.28	0	0.07	0	0.12	0.03	0.29	0	0.77	0.02
Exp. 3	0.65	0.02	0.13	0	0.47	0	0.16	0	0.22	0.03	0.42	0.03	0.81	0.09
Exp. 4	0.4	0	0.04	0	0.31	0	0.05	0	0.1	0	0.1	0	0.19	0.01
C. segetum	parameter a													
Exp. 1	7.34	0.1	4.95	0.03	4.57	0.03	4.91	0.03	4.69	0.06	4.99	0.02	4.39	0.05
Exp. 2	7.58	0.17	4.39	0.04	4.02	0.03	4.24	0.03	4.02	0.07	4.19	0.02	3.52	0.05
Exp. 3	0	116	5.41	0.05	4.53	0.04	4.34	0.03	4.4	0.04	5.14	0.35	5.77	0.67
Exp. 4	7.65	0.27	4	0.04	3.54	0.04	3.64	0.03	3.54	0.04	3.46	0.03	3.53	0.06
	parameter b													
Exp. 1	0.31	0.01	0.01	0	0.22	0	0.01	0	0.05	0.02	0.07	0.01	0.17	0.02
Exp. 2	0.4	0.01	0.02	0	0.24	0	0.02	0	0.08	0.04	0.09	0.01	0.28	0.04
Exp. 3	0	9.41	0.13	0	0.51	0.01	0.13	0	0.41	0.02	0.13	0	0.25	0.02
Exp. 4	0.68	0.03	0.06	0	0.37	0.01	0.07	0	0.09	0.01	0.12	0.01	0.08	0.01
M. orontium	parameter a													
Exp. 1	2.26	0.04	2.84	0.03	1.86	0.02	2.84	0.02	1.97	0.03	0	0	2.06	1.04
Exp. 2	5.88	0.13	3.71	0.03	3.45	0.03	3.67	0.03	3.48	0.07	3.77	0.02	2.99	0.05
Exp. 3	9.79	0.32	4.87	0.04	4.33	0.03	4.26	0.03	4.24	0.04	4.2	0.05	4.06	0.06
Exp. 4	8.87	0.14	5.47	0.04	5.08	0.03	5.29	0.03	0.03	0	0.04	0	5.22	0.06
	parameter b													
Exp. 1	0.09	0	0	0	0.07	0	0	0	0	0.01	0	0	0.05	0.02
Exp. 2	0.34	0.01	0.01	0	0.22	0	0.01	0	0.06	0.03	0.08	0.01	0.39	0.04
Exp. 3	0.71	0.03	0.08	0	0.4	0	0.09	0	0.32	0.02	0.09	0	0.33	0.04
Exp. 4	0.44	0.01	0.02	0	0.28	0	0.02	0	0.03	0	0.04	0	0.04	0

Appendix 2. Pseudo R^2 of calibrations *per data set* with model 4 (Equation 6).

C. cyanus	barley	rye	barley pea	rye pea
Exp. 1	0.93	0.93	0.84	0.87
Exp. 2	0.95	0.88	0.68	0.99
Exp. 3	0.92	0.96	0.82	0.99
Exp. 4	0.71	0.87	0.96	0.94
P. rhoeas				
Exp. 1	0.77	0.71	0.80	0.79
Exp. 2	0.60	0.73	0.91	0.78
Exp. 3	0.94	0.99	0.59	0.94
Exp. 4	0.77	1.00	0.93	0.93
C. segetum				
Exp. 1	0.98	0.93	0.86	0.93
Exp. 2	0.98	0.99	0.94	0.91
Exp. 3	0.98	0.95	0.80	1.00
Exp. 4	0.62	0.98	0.86	0.99
M. orontium				
Exp. 1	0.79	0.88	0.95	0.79
Exp. 2	0.99	0.96	0.85	0.90
Exp. 3	0.93	0.99	0.77	0.71
Exp. 4	0.93	0.95	0.97	0.99

Appendix 3. Parameter *a* (recruitment) and *b* (attrition) resulting from calibrations *per data set* with model 4 (Equation 6).

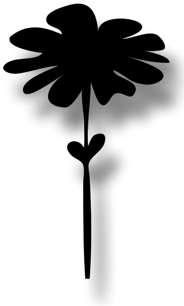
	barley		rye		barley pea		rye pea	
	estimate	se	estimate	se	estimate	se	estimate	se
	numbers * 0.01							
C. cyanus	parameter a							
Exp. 1	1.91	0.14	2.50	0.14	1.30	0.13	1.86	0.14
Exp. 2	1.77	0.14	1.26	0.15	1.42	0.16	1.23	0.15
Exp. 3	4.52	0.16	5.49	0.17	3.70	0.15	6.24	0.16
Exp. 4	1.35	0.15	2.51	0.15	2.34	0.15	2.37	0.14
	parameter b							
Exp. 1	0.08	0.02	0.07	0.01	0.04	0.02	0.08	0.02
Exp. 2	0.09	0.02	0.13	0.03	0.16	0.04	0.09	0.03
Exp. 3	0.20	0.02	0.29	0.02	0.22	0.02	0.30	0.02
Exp. 4	0.07	0.03	0.08	0.02	0.14	0.02	0.09	0.02
P. rhoeas	parameter a							
Exp. 1	24.46	0.29	37.87	0.30	39.59	0.36	34.53	0.35
Exp. 2	26.38	0.31	29.22	0.25	18.12	0.35	22.86	0.26
Exp. 3	11.30	0.32	18.36	0.40	8.79	0.33	22.91	0.41
Exp. 4	34.36	0.35	54.34	0.34	73.56	0.42	100.00	0.33
	parameter b							
Exp. 1	0.09	0.00	0.12	0.00	0.18	0.00	0.12	0.00
Exp. 2	0.13	0.00	0.11	0.00	0.23	0.01	0.19	0.00
Exp. 3	0.19	0.01	0.07	0.01	0.25	0.02	0.06	0.01
Exp. 4	0.09	0.00	0.26	0.00	0.23	0.00	0.46	0.00
C. segetum	parameter a							
Exp. 1	5.43	0.12	4.37	0.13	5.51	0.13	4.24	0.12
Exp. 2	6.98	0.13	3.24	0.13	3.78	0.14	3.69	0.12
Exp. 3	4.16	0.13	5.82	0.15	2.98	0.15	4.92	0.15
Exp. 4	2.25	0.14	3.50	0.14	4.07	0.15	4.59	0.14
	parameter b							
Exp. 1	**0.00**	0.01	0.01	0.01	0.04	0.01	**0.00**	0.01
Exp. 2	0.05	0.00	0.03	0.01	0.07	0.01	**0.00**	0.01
Exp. 3	**0.00**	0.01	0.16	0.01	0.26	0.03	0.24	0.02
Exp. 4	0.02	0.01	0.02	0.01	0.13	0.01	0.07	0.01
M. orontium	parameter a							
Exp. 1	1.78	0.12	2.74	0.12	3.59	0.12	3.51	0.12
Exp. 2	4.18	0.13	4.54	0.12	3.23	0.15	3.55	0.12
Exp. 3	3.80	0.13	6.45	0.15	2.28	0.13	5.35	0.14
Exp. 4	4.37	0.13	4.47	0.13	4.88	0.14	7.90	0.13
	parameter b							
Exp. 1	**0.00**	0.02	**0.00**	0.01	**0.00**	0.01	**0.00**	0.01
Exp. 2	0.05	0.01	**0.00**	0.01	0.11	0.01	**0.00**	0.01
Exp. 3	**0.00**	0.01	0.13	0.01	0.10	0.02	0.17	0.01
Exp. 4	**0.00**	0.01	**0.00**	0.01	0.10	0.01	0.04	0.00

Appendix 4. ANOVA results (p values) for testing main effects and interactions on the recruitment (*a*) and attrition (*b*) parameters of four plant species, estimated using models 2 (Equation 8), 3 (Equation 9) and 4 (Equation 6).

	C. cyanus		*P. rhoeas*		*C. segetum*		*M. orontium*	
Model 2	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
Cereal	0.091	ns	ns	ns	ns	ns	ns	ns
Inclusion of pea	ns	ns	ns	0.06	ns	**0.049**	ns	ns
Cereal.inclusion of pea	ns	ns	ns	ns	ns	ns	ns	ns
Soil type	**<.001**	**0.022**	**0.027**	ns	ns	ns	ns	ns
Year	**<.001**	**<.001**	ns	ns	ns	**0.012**	**0.035**	ns
Soil type.year	**0.002**	**<.001**	**0.003**	**<.001**	ns	0.052	ns	0.061
Residual								
Model 3								
Cereal	ns	ns	ns	ns	ns	ns	ns	ns
Inclusion of pea	ns	ns	ns	0.083	ns	0.059	ns	ns
Cereal.inclusion of pea	ns	ns	ns	ns	ns	0.097	ns	ns
Soil type	**<.001**	ns	**0.042**	ns	ns	ns	ns	ns
Year	**<.001**	**0.006**	0.082	0.099	ns	**0.004**	**0.03**	**0.042**
Soil type.year	**0.004**	**0.011**	**0.011**	ns	ns	0.076	ns	0.062
Residual								
Model 4								
Cereal	0.076	ns	ns	ns	ns	ns	0.069	ns
Inclusion of pea	ns	ns	ns	0.07	ns	0.05	ns	ns
Cereal.inclusion of pea	ns	ns	ns	ns	ns	ns	ns	ns
Soil type	**<.001**	**0.016**	**0.019**	0.094	ns	ns	ns	ns
Year	**<.001**	**0.002**	ns	ns	**<.001**	**0.013**	**0.036**	0.088
Soil type.year	**0.005**	**<.001**	**0.002**	**<.001**	ns	0.055	ns	0.055
Residual								

Appendix 5. ANOVA results (p values) for testing main effects and interactions on the recruitment (*a*) and attrition (*b*) parameters of four plant species, estimated using model 4, and using either (1) a separate shade function in each treatments, or (2) a common shade function for all four treatments within an experiment. Explanatory value of the shade function is demonstrated by significant effect of main factor “Intercropping with pea” on the value of the parameter *b* (attrition) estimated in model 4 for the species *P. rhoeas* and *C. segetum*. In the situation with separate shade functions per treatment, there are no significant differences between treatments, indicating that differences in shade function accounted for the differences in weed attrition between (inter)cropping treatments.

	C. cyanus		*P. rhoeas*		*C. segetum*		*M. orontium*	
Parameters	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
<u>Different sigmoids for treatments</u>								
Cereal	0.076	ns	ns	ns	ns	ns	0.069	ns
Pea	ns	ns	ns	0.07	ns	0.05	ns	ns
Cereal.pea	ns	ns	ns	ns	ns	ns	ns	ns
Soil type	<.001	0.016	0.019	0.094	ns	ns	ns	ns
Year	<.001	0.002	ns	ns	ns	0.013	0.036	0.088
Soil type x year	0.005	<.001	0.002	ns	ns	0.055	ns	0.055
R^2	0.89		0.82		0.92		0.90	
<u>One sigmoid for all treatments</u>								
Cereal	0.091	ns	ns	ns	ns	ns	0.071	ns
Pea	ns	ns	ns	**<u>0.024</u>**	ns	**<u>0.026</u>**	ns	0.08
Cereal.pea	ns	ns	ns	ns	ns	ns	ns	ns
Soil type	<.001	0.03	0.044	ns	ns	ns	ns	ns
Year	<.001	<.001	ns	ns	ns	0.004	0.07	0.045
Soil type x year	0.004	<.001	0.007	ns	ns	ns	ns	ns
R^2	0.88		0.82		0.92		0.89	



06 Development of plant diversity in cereal-based cropping systems

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To enhance biodiversity on farmland cereal-based cropping systems with different mixtures of crop species and wild flowers were designed and monitored during three successive years on a sandy soil and a clay soil. We aimed to increase the level of plant diversity in combination with a positive economic return, accepting some yield loss in favour of increased associated biodiversity. Crop mixtures were composed of barley or rye as main crop with or without pea as a companion crop and we also (re) introduced wild flower species. The population dynamics of spontaneously occurring plant species and of the sown wild flowers were studied for three consecutive years on both soils. On the clay soil, sown wild flower species were present in alternate years, while on the sandy soil sown wild flowers did not establish successfully after the first year. More spontaneously occurring plant species emerged on clay with a higher evenness compared to sand. On the poor sandy soil, the spontaneously occurring plant population was dominated by common lambsquarters (*Chenopodium album*). On that soil, barley growth was poor and the barley monocrop was not competitive having the highest number of spontaneously occurring plants and rare plant species. Rye suffered less from poor soil conditions and showed a better suppression of spontaneously occurring plant species than barley. On the more fertile clay soil, however, barley was as competitive as rye. Pea in the mixtures did not affect the number of associated plants but stimulated individual plant biomass resulting in bigger associated plants. Consequently, *Chrysanthemum segetum, Solanum nigrum* and *Polygonaceae spp.* reproduced better in mixtures with pea than in crops without pea on the clay soil. Crop production systems can be managed for high yield and high biodiversity by choosing a crop mixture that suits a location. Best plant diversity development in a productive crop production system is achieved on sufficiently fertile soils with medium crop competition without dominance of one species.

Introduction

Biodiversity is being threatened worldwide (Díaz et al., 2006) and the Netherlands is certainly no exception. Main reasons for decreasing numbers of plant and animal species in the Netherlands are habitat loss and a decline in quality of the remaining area through eutrophication, acidification, dehydration and fragmentation (Anon., 2006). Besides nature reserves also farmland, and especially field margins, wooded banks, ditches and ponds, are important habitats for flora and fauna diversity development. Biodiversity in agricultural fields has been declining as well for many decades due to intensification of agricultural production (Tilman et al., 2001; Tyler, 2008). As a consequence, many species that are dependent on specific conditions in agricultural fields are nowadays very rare (Pyšek et al., 2005; Sutcliffe and Kay, 2000). Furthermore, the extinction of plant species also threatens fauna species: diverse plant communities support a large number of invertebrate species that may serve as bird food or contribute to pest control (Green et al., 2005; Marshall et al., 2003). The Dutch government has implemented agri-environment schemes to enhance biodiversity that depends on such habitats. Unfortunately, these schemes often do not live up to expectations (Kleijn et al., 2001). There is a need to enlarge the area in which biodiversity is stimulated. Enhancing biodiversity in arable fields may be a tool to achieve that goal (Albrecht, 2003; Altieri, 1999).

We designed semi-natural arable production systems with different levels of biodiversity on a sandy soil and on a clay soil (Stilma et al., 2007). In our study we aimed to increase the level of plant diversity while at the same time taking into account the trade-offs for profitability of the production system. Associated plant diversity is defined as the sum of spontaneously occurring plant species and sown wild flowers. The optimal system is defined as a multi-species cropping system with a high diversity of associated plant species and minimal yield loss of the main cereal crops. Abundance of species should be of high value for the associated diversity, such as insects and birds, and should not reduce yield stability or crop quality. We studied the development of the associated plant community in a three-year low-input continuous cropping system on former conventional fields. Our main research questions were: 1) Do new species emerge by a transition of the conventional production method towards a mixed, multispecies low-input cropping system? 2) How do sown wild flowers perform during three consecutive years in different crop mixtures on different soil types? 3) What is the effect of crop species on the spontaneously occurring plant species composition, diversity, richness and evenness?

Materials and methods

A three-year field experiment was carried out without external input of fertilizers and pesticides from 2004 to 2006. Spring rye *(Secale cereale)* and spring barley *(Hordeum vulgare)* were grown as monocrop or intercropped with pea *(Pisum sativum)* with or without introduced wild flowers. The resulting four combinations for each cereal were: cereal monocrop, cereal intercropped with pea, cereal with introduced wild flowers, and cereal intercropped with pea and introduced wild flowers. Each treatment was replicated four times in a randomized complete block design, both on a sandy soil and on a clay soil. Plot size was 180 m^2. The cereal grain harvested in one year was used as seed source for the next season. The introduced wild flower species were *Papaver rhoeas, Centaurea cyanus, Chrysanthemum segetum, Misopates orontium* on both soils. In addition, *Matricaria recutita* was sown on the sandy soil and *Tripleurospermum maritimum* on the clay soil. The nomenclature used is according to Van der Meijden (1996). The wild flowers were sown once (in 2004). For details of the experimental design see Stilma (2007) and Stilma (submitted-b).

Plant counts refer to all plant species except the sown cereals and pea. These were split into the above-mentioned introduced wild flower species and spontaneously occurring

Table 1. Site and soil characteristics of the locations used for the four experiments.

Experiment	1	2
Co-ordinates	N 51º,59' E 5º,39'	N 51º,57' E 5º,38'
Starting year of experiments	2004	2004
Soil type	Sand	Clay
Preceding crop	Phaselia	Sugar beet
Nitrogen level prior to the experiment		
NO_3-N (mg/l extract)	0.8	2.3
NH_4-N (mg/l extract)	<.05	<.05
Available supply (N kg/ha)	8	28
Recommendation (N kg/ha)	110	110
Deficit (N kg/ha)	102	82
Nitrogen level after three years		
Last year NO_3-N (mg/l extract)	1.6	2.2
Available supply (N kg/ha)	10	14

species. Plants were counted four times every year during the growing season on 1 m^2 sub-plots positioned in the centre of each plot (Table 1).

At the end of the growing season, the plots were harvested at the soft dough stage of the cereal grain with electric hedge-shears 5 cm above soil level. In the lab, biomass was separated into cereal, pea, spontaneously occurring plants, and wild flowers. Subsamples were dried at 70 ˚C for 36 hours. For harvest dates see Table 1.

Data analysis

Number of plants, species richness and evenness through time were analysed with the repeated measures analysis of variance method in Genstat for each soil type individually. The average of the four counts per year was used to compare years (Genstat, 9th version). The data on the number of plants were log-transformed to obtain homogeneous data. The data on species richness and evenness did not require transformation. Evenness was calculated by the Shannon index (Magurran, 1988). A change in species composition over time was calculated by the Principal Response Curves (PRC) method (Van den Brink and Ter Braak, 1999). PRC is a canonical ordination technique derived from redundancy analysis (RDA). RDA is a multivariate method to evaluate treatment effects on the dynamics of biological communities. RDA can only be used for a single point in time, PRC techniques can be applied to data sets that include different assessment times. Treatment scores and species scores were calculated. In the PRC plots time is plotted on the *x*-axis and the treatment score (Cdt) on the *y*-axis. The species scores are described in a list next to the plot. The predicted number of a species in a treatment at a time point was calculated by exp(treatment score × species score) × the number of species in the 'control' group (Ter Braak and Šmilauer, 1998). We assigned one of the treatments as the control group. Treatment scores of this group were set at zero during the analysis.

The data of the last year were analysed in three groups: all plant species, introduced wild flowers, and rare spontaneous species (frequency < 3 plants m^{-2}). Shannon evenness and *H* diversity were calculated for all plant species together. Differences between treatments were calculated with the least significant difference (lsd) ($p < 0.05$) of the analysis of variance method in Genstat for each soil type individually. In the last year, more species were identified at subspecies level than in the first and second year; these subspecies are shown in Table 2a.

	Treatment	Abbreviation
1	Barley	B
2	Barley Pea	BP
3	Rye	R
4	Rye Pea	RP
5	Barley Flowers	BF
6	Barley Pea Flowers	BPF
7	Rye Flowers	RF
8	Rye Pea Flowers	RPF

Table 2. Eight crop mixtures and their abbreviations.

The amount of spontaneously occurring plant biomass and wild flower biomass was divided by the number of plants in the last count to calculate average plant weight. Analysis of variance was carried out to analyse differences between crop treatments.

Results

Trends over time in number of plants and species

On sandy soil, associated plants were dominated by *Chenopodium album* from the beginning of the experiment (Table 4). Moreover, the number of individuals of *C. album* over time increased fastest of all species. The density of the other species was much lower. Consequently, evenness of associated plant species declined after the first year (Fig. 1i, j; Table 6). In the second year 13 new species were recorded and in the third year 5 new species (Table 4). The number of different spontaneously occurring species present per treatment was the same in the first and second year (Fig. 1e) although the species composition differed (Fig. 2; Table 7,8). In the third year, the average number of spontaneously occurring plant species per treatment (without sown wild flowers) was higher than in the first two years (Fig. 1e).

In the first year, the number of associated plants was the same for barley and rye treatments (Fig. 1a, b). In the second and third year, the number of associated plants was lower in rye than in barley treatments. In barley treatments, the number of associated plants increased whereas this remained the same in rye treatments. The barley wild flower treatment showed the highest number of associated plants in all years (Fig. 1b). This difference, however, was not significant due to the high lsd value (Table 6). Pea or sown wild flowers had no effect on the number of associated plants between years.

On clay soil, the increase in abundance was dominated by *Sonchus spp.* and *Fallopia convolvulus* (Table 4). Evenness did not significantly change over time (Fig. 1k, l). In treatments without sown wild flowers, the number of spontaneously occurring plants averaged over all treatments increased significantly every year (Fig. 1c). In treatments with sown wild flowers, the number of associated plants was lowest in the second year and highest in the first and last year (Fig. 1d). The number of species followed a similar pattern. Treatments did not differ in the number of associated plants over time but they did differ in number of species (Fig. 1g, h). In the last year, the number of spontaneously occurring plant species was highest in the pea treatments without sown wild flowers, whereas initially the number of species was lowest in pea treatments without sown wild flowers (Fig. 1g). In treatments with sown wild flowers pea did not have an effect. In these treatments, the number of associated plant species was higher in the rye treatments than in the barley treatments averaged over the years (Fig. 1h). In treatments without sown wild flowers evenness was the same over time and highest in the rye monocrop treatments averaged over the years (Fig. 1k). In the treatments with sown wild flowers, evenness was the same over time (Fig. 1l).

Table 3. Dates of sowing, counting and harvesting of silage and grain plus accumulated degree days (Tbase = 0 ˚C) after sowing at the different locations.

		Sandy soil		Clay soil	
		Date *	**Tsum (˚Cd)**	**Date**	**Tsum (˚Cd)**
2004	Sowing	20 April	0	19 April	0
	Count 1	18-21 May	368	24-26 May	432
	Count 2	7-11 June	633	15-16 June	741
	Count 3	28 June -1 July	936	5-6 July	1036
	Count 4	20-23 July	1296	26-27 July	1387
	Harvest silage	28 July	1402	28 July	1411
	Harvest grains	6 September	2161	6 September	2170
2005	Sowing	30 March	0	6 April	0
	Count 1	26 April	268	28 April	208
	Count 2	17 May	486	18 May	413
	Count 3	6 June	782	7 June	711
	Count 4	27 June	1132	28 July	1069
	Harvest silage	12 July	1397	13 July	1337
	Harvest grains	17 August	1984	18 August	1926
2006	Sowing	6 April	0	23 March	0
	Count 1	11 May	369	2 May	360
	Count 2	1 June	644	24 May	701
	Count 3	20 June	951	16 June	1019
	Count 4	12 July	1357	3 July	1323
	Harvest silage	18 July	1496	18 July	1630
	Harvest grains	7 August	1924	7 August	2058

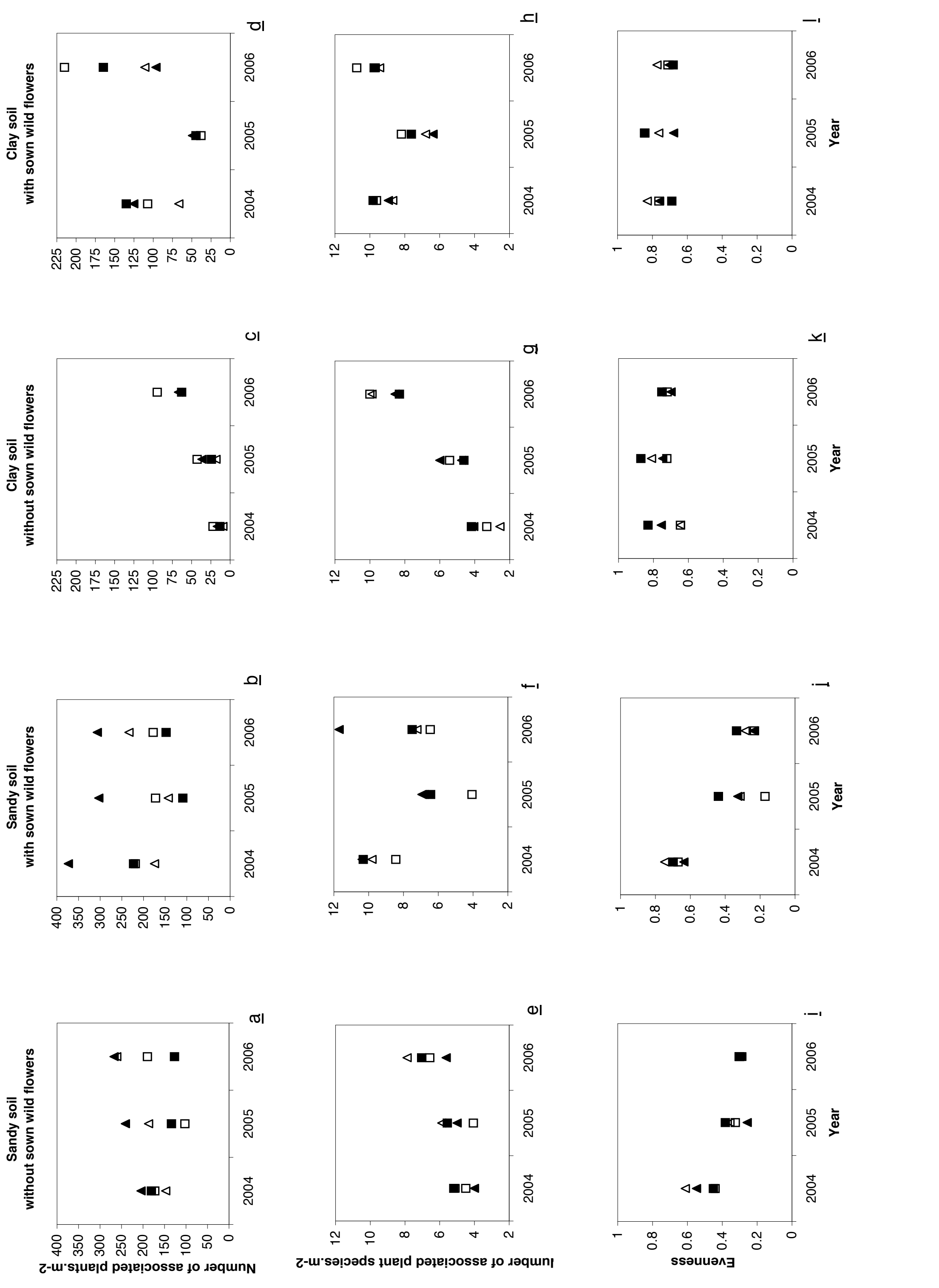
* Measurements per block were not taken at the same Tsum. Maximum difference between measurement dates one week. Data are an average of the Tsums of four blocks.

Time trends in species composition

New species emerged every year (Table 4) and species composition of associated plants changed over time on both soils (Fig. 2; Table 7,8). Species composition of associated plants changed more on the clay soil than on the sandy soil (lambda = 0.24 on clay soil vs. lambda = 0.08 on sandy soil). Treatments affected the development over time of the associated plants. On sandy soil, the effect was mostly due to a higher abundance of *Chenopodiaceae spp. Polygonum aviculare, Poa annua, Stellaria media* and *Solanum nigrum* in the barley treatments than in the rye treatments (derived from the table as follows: positive species scores and positive treatment scores represent a higher number of the species in barley treatments than in rye treatments. The average of the rye treatments was set as the control group with treatment score zero). On clay soil, species composition was different for

Figure 1 (see page 90). Number of associated plants, number of associated plant species and evenness of the plant population over time for each treatment on a sandy soil and a clay soil. Treatments with and without sown wild flowers are shown in different panels. Markers indicate different crop combinations: ■: rye monocrop; □: rye mixed with pea; ▲: barley monocrop; Δ: barley mixed with pea

Table 4 (see page 91). List of spontenously occurring plant species and sown wild flowers per m2 identified in the experiments. Numbers are an average value of the treatments and the counting dates. Spontaneously occurring plant species that were considered abundant (>3 per m2) in 2006 were coded with ‘a’. (a-s) = abundant sandy soil, (a-c) =abundant clay soil, (a-s,c) is abundant sandy and clay soil. Other spontaneously occuring plants were considered rare.


Sandy soil
without sown wild flowers
Sandy soil
with sown wild flowers
Clay soil
without sown wild flowers
Clay soil
with sown wild flowers
Number of associated plants.m-2
lumber of associated plant species.m-2
Evenness
Year
2004
2005
2006
a
b
c
d
e
f
g
h
i
j
k
l

	Sandy soil			Clay soil		
Sown wild flowers	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**
Papaver rhoeas	24	<0.1	<1	21	<1	20
Chrysanthemum segetum	10	<1	<1	9	<1	8
Misopates orontium	6	<0.1	<0.1	8	<1	15
Centaurea cyanus	3	<0.1	<1	2	<0.1	<1
Matricaria recutita	<1	0	<0.1	~	~	~
Tripleurospermum maritimum	~	~	~	<1	<0.1	<0.1
Spontaneously occurring plants						
*Chenopodiaceae spp.**	118	151	173	<0.1	2	4
Solanum nigrum (a-s)	32	5	16	5	<0.1	1
Persicaria maculosa&lapathifolia (a-s,c)*	5	6	7	2	2	5
Stellaria media (a-s)	5	3	5	<0.1	<0.1	<1
Fallopia convolvulus (a-s,c)	4	5	10	<1	3	18
Poa annua	3	2	<1	<0.1	0	<0.1
*Sonchus spp.**	<1	<1	<1	3	17	22
Trifolium spp.	<1	<1	<1	<1	0	<0.1
Unidentified spp.	<1	<1	<1	<1	<0.1	<0.1
Viola arvensis	<1	<0.1	<1	0	0	<0.1
Echinochloa crus-galli	<0.1	<0.1	<1	8	<1	<1
Persicaria amphibia (a-c)	<0.1	0	0	1	3	7
*Sinapis arvensis**	0	0	0	2	2	3
Cirisium arvense (a-c)	0	<0.1	<1	0	<0.1	4
*Vicia spp.**	<0.1	0	<0.1	<0.1	0	0
Senecio vulgaris	0	<1	<0.1	0	<1	<0.1
Capsella bursa-pastoris	0	<1	<1	0	<1	<0.1
Urtica dioica	0	<0.1	<1	0	<0.1	<1
Taraxacum officinale	0	<0.1	<1	0	3	<1
Polygonum aviculare	0	<1	<1	0	<1	<0.1
Ranunculus spp.	0	<0.1	<1	0	<1	<0.1
Lamiastrum galeobdolon	0	<0.1	<0.1	0	0	<0.1
Euphorbia platyphyllos	0	<0.1	0	0	<0.1	0
Geranium spp.	0	<0.1	0	0	<1	0
Spergula arvensis	0	<0.1	<0.1	0	0	0
Veronica chamaedrys	0	<0.1	<0.1	0	<0.1	<0.1
Convolvulus arvensis	0	0	<0.1	<0.1	0	<0.1
Anagallis arvensis	0	0	<0.1	0	0	<0.1
Lactuca serriola	0	0	<0.1	0	0	0
Equisetum arvense	0	0	<0.1	0	0	0
*Brassicaceae spp.**	0	0	<0.1	0	0	1
Galeopsis tetrahit	0	<0.1	0	0	0	<0.1
Heracleum sphondylium ~~L.~~	0	0	0	0	0	<0.1
Epilobium hirsutum	0	0	0	0	0	<1
Lamium amplexicaule	0	0	0	0	0	<0.1
Galium aparine	0	0	0	0	0	<0.1
Tussilago farfara	0	0	0	0	0	<0.1
Myosotis arvensis	0	0	0	0	0	<0.1
Volunteer plants						
Phacelia tanacetifolia	2	3	4	<0.1	<0.1	0
Solanum tuberosum	<0.1	<0.1	<0.1	<0.1	<1	<0.1
Beta vulgaris	0	<0.1	0	*0*	0	<1
Helianthus tuberosus	0	<0.1	0	0	0	0

* see Table 5

<u>Asteraceae</u>	***<u>Sinapsis arvensis</u>***
Lapsana communis	*Sinapsis arvensis*
<u>Chenopodiacea spp.</u>	*Crambe abyssinica*
Chenopodium album (a-s)	***<u>Sonchus spp.</u>***
Chenopodium polyspermum	*Sonchus arvensis*
Atriplex patula	*Sonchus asper (a-c)*
Chenopdium ficifolium	*Sonchus oleraceus*
<u>Other *Brassicacea spp.*</u>	***<u>Vicia spp.</u>***
Erysimum cheiranthoides	*Vicia sativa*
Arabidopsis thaliana	*Vicia tetrasperma*
Sisymbrium officinale	
<u>Polygonaceae spp.</u>	
Polygonum pallidum	
Polygonum persicaria	

Table 5. Species groups that were identified per species in the last year.

mixtures with or without pea, especially in 2006. The effect was mostly due to a higher abundance of *Brassicaceae spp., Persicaria amphibia, Persicaria maculosa* and *P. lapathhifolia, Sinapis arvensis and Solanum nigrum* and a lower abundance of *Cirsium arvense* in mixtures with pea than in mixtures without pea (Fig. 2; Table 7,8). Abundance of species was unevenly spread over the field on both soil types, as shown by a significant block effect (Table 8).

Diversity in the third year

More species were present on the clay soil than on the sandy soil. Shannon evenness of species was higher on the clay soil than on the sandy soil. H diversity was similar for the treatments on both soils (Table 9).

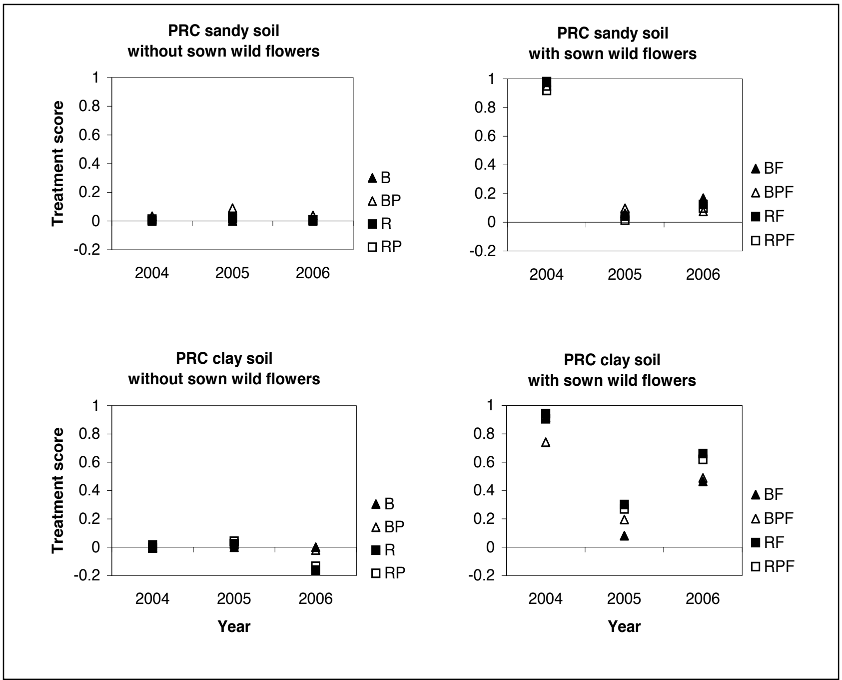
On sandy soil, barley treatments had a higher total number of associated plants than rye treatments (p = 0.005). The barley with sown wild flower treatment (BF) had the highest number of spontaneously occurring plants and sown wild flowers as well as the highest total number of species (Table 9). Rye monocrop had the lowest number of associated plants as well as the lowest number of (rare) species.

On clay soil, the rye with pea and sown wild flower treatment (RPF) had the highest number of spontaneously occurring plants and sown wild flowers. Rye with pea (RP) had the highest number of rare species. Notably, total number of sown wild flower plants was not significantly different in the last year although the abundance of sown wild flowers in the rye treatments was about 50% higher than in the barley treatments. Sown wild flowers formed patches in the third year and results did not become significant due to a high variation in numbers of sown wild flowers.

Discussion

The number of plant species increased during the three years in both experiments. An increase in plant number and species richness is normally observed after conversion from conventional to organic production (Albrecht, 2005; Hole et al., 2005). Apparently, seeds of many species are still present in the soil seed bank. These species have been declining in number for many years by current agricultural production (Sutcliffe and Kay, 2000) and did not get the opportunity to set ripe seeds due to the use of herbicides. But also after a long time seeds of numerous species may survive in the seed bank (Radosevich et al., 1997; Thompson et al., 1997; Zhang et al., 1998). Once the conditions become favourable for them, many of these seeds will germinate and the seedlings may survive if no herbicides are used. This was probably the case in our

Figure 2. Principal Response Curves (PRC) on sandy and clay soil. Treatment scores of the analysis of all treatments together are displayed in the figures. The corresponding species scores are displayed in Table 7. The predicted number of a species in a treatment at a time point is calculated by exp(treatment score × species score) * the number of species in the 'control'. The control has treatment score = 0 (Ter Braak and Šmilauer, 1998) . For Statistics see Table 8. For abbreviations of treatments see Table 2.



experiments, as new species emerged every year. However, it is also possible that seeds have been dispersed into the field by other means. In order to obtain a well established population more years might be needed. After conversion from conventional to organic farming during a 6-year period the number of species increased in the first three years and stabilized in the last three years (Albrecht, 2005). Full establishment will take longer.

The development of the associated plant community was different at the two locations. The rate of increase of new species was higher on the clay soil than on the sandy soil while the total plant number remained lower (Fig. 1). Consequently evenness and H diversity were higher on the clay than on the sandy soil. Soil type *per se* does not affect emergence of new species as has been determined in earlier studies (Pyšek et al., 2005). Several other factors could have caused the difference. One factor may have been the diversity of species present in the seed bank, or the species richness in the surrounding landscape from where seeds invade the field (Gabriel et al., 2006; Ogden and Rejmánek, 2005).

Soil fertility, especially nitrogen level, is known to affect plant populations. A fertile soil is a good growing substrate for many species: in soils with a severe limitation of nutrients like phosphorus or sulphur species richness is low (Everaarts, 1992; Roem et al., 2002). However, rich soils tend to have a lower species diversity than poor soils because on highly fertilized soils some species grow faster than others (Andersson and Milberg, 1998) and suppress other slow-growing species. A low species diversity is therefore caused by the competition of more dominant species (Huston, 1994; Yin et al., 2006).

The ideal situation in a biodiverse arable production system is a plant community in equilibrium with a crop that is not too dominant to suppress the development of associated plants and a crop that is not outcompeted by the associated plants. As discussed in the above paragraph, nitrogen level should therefore be adequate. Crop stand should not be too dense as an open crop allows abundant species to multiply but also gives room for more rare species to emerge (Mulder et al., 2004; Poggio, 2005). It was confirmed in our experiment that the poorest

Table 6. Significant differences for total plant number, species richness, eveness and species distribution between treatments presented in Figure 1.

		Abundance (log)		**Species richness**		**Evenness**	
Sandy soil	Df	p value	lsd	p value	lsd	p value	lsd
Barley vs Rye	1	*	0.11	*	0.78	ns	.-
Pea vs no pea	1	ns	.-	ns		ns	.-
WF vs no WF	1	ns	.-	**	0.78	ns	.-
Cereal×Pea	1	ns	.-	ns		ns	.-
Cereal×WF	1	ns	.-	ns		ns	.-
PeaxWF	1	ns	.-	*	1.10	ns	.-
Time	2	*	0.09	**	0.68	**	0.07
Time.Barley	2	*	0.15	ns		ns	.-
Time.Pea	2	ns	.-	ns		ns	.-
Time.Wild Flowers	2	ns	.-	**	1.08	*	0.11
Clay soil							
Barley vs Rye	1	ns	.-	*	0.43	ns	.-
Pea vs no pea	1	ns	.-	ns		ns	.-
WF vs no WF	1	**	0.13	**	0.43	ns	.-
Cereal×Pea	1	ns	.-	ns		*	0.06
Cereal×WF	1	ns	.-	*	0.60	ns	.-
PeaxWF	1	ns	.-	ns		**	0.06
Time	2	**	0.12	**	0.64	ns	.-
Time.Barley	2	ns	.-	ns		ns	.-
Time.Pea	2	ns	.-	*	0.84	ns	.-
Time.Wild Flowers	2	**	0.19	**	0.84	ns	.-

* = alpha between 0.01 and 0.05 ** = alpha < 0.01; ns = not significant

crop treatment (barley monocrop on sandy soil in 2004 (Stilma et al., submitted-b)). had the most abundant associated plant population with the highest number of species (Table 9). Additionally, the plant population should not be dominated by one or a few species. Controlling a dominant species can give more room to other species (Ogden and Rejmánek, 2005). Ogden & Rejmánek (2005) succeeded to increase the number of rare species by controlling the dominant species; this, however, only occurred at one of the two sites. The successful site was a small field situated in a heterogeneous landscape as opposed to the other site, which was a large field situated in a homogeneous environment. The small-scale plot had a rich seed bank and possibilities of seed dispersal from its surroundings. It is a challenge to overcome dominance of one or a few species. An uneven distribution of species in a community is very common (Mulder et al., 2004). Only 26 of the 346 arable weed species are problematic (Albrecht, 2005). Other researchers have acknowledged this problem

Table 7 (right page). Principal Response Curves (PRC) on sandy and clay soil. Species scores of the analysis of all treatments together, the species scores and treatment scores of the analysis of barley against rye (BvsR), pea against not pea (PvsnP) and sown wild flowers against not sown wild flowers (WFvsnWF). The predicted number of a species in a treatment at a time point is calculated by exp(treatment score × species score) * the number of species in the 'control'. The control has treatment score = 0.(Ter Braak and Šmilauer, 1998). For Statistics see Table 8.

Sown wild flowers	**Sandy soil** Treatment	**Clay soil** Treatment	**Sandy soil** BvsR	PvsnP	WFvsnWF	**Clay soil** BvsR	PvsnP	WFvsnWF
Centaurea cyanus	**2.0**	**1.3**	-0.3	**-1.0**	**2.0**	-0.2	-0.5	**1.4**
Chrysanthemum segetum	**3.2**	**3.0**	0.4	0.2	**3.2**	1.2	**2.1**	**3.0**
Matricaria recutita	0.5	.-	-0.2	-0.2	0.5	.-	.-	.-
Misopates orontium	**2.5**	**3.3**	0.1	0.6	**2.6**	0.9	0.0	**3.3**
Papaver rhoeas	**3.9**	**4.2**	0.0	-0.1	**4.0**	**3.5**	**-1.2**	**4.2**
Tripleurospermum maritimum	.-	0.3	.-	.-	.-	0.6	-0.2	0.3
Spontaneously occurring plants								
Chenopodiaceae spp.	-0.2	0.2	**1.7**	-0.9	-0.2	**1.6**	-0.9	0.2
Anagallis arvensis	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0
Brassicacea spp.	0.0	-0.2	0.0	0.1	0.0	0.0	**1.0**	-0.2
Capsella bursa-pastoris	0.0	-0.1	0.7	0.2	0.0	0.7	0.1	-0.1
Cirisium arvense	0.0	-0.1	-0.6	-0.7	0.0	0.6	**-1.2**	-0.2
Convolvulus arvensis	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
Echinochloa crus-galli	0.0	0.3	0.6	0.1	0.0	-0.4	0.4	0.3
Epilobium hirsutum	.-	-0.1	.-	.-	.-	0.0	0.2	-0.1
Equisetum arvense	0.0	.-	-0.1	0.1	0.0	.-	.-	.-
Euphobia platyphyllos	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Galeopsis tetrahit	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.0
Galium aparine	.-	0.0	.-	.-	.-	0.0	0.2	0.0
Geranium spp.	0.0	0.0	0.0	-0.1	0.0	-0.4	-0.2	0.0
Heracleum sphondylium	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0
Lamiastrum galeobdolon	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0
Lamium amplexicaule	.-	0.0	.-	.-	.-	0.0	0.1	0.0
Myosotis arvensis	.-	0.0	.-	.-	.-	0.0	0.2	0.0
Poa annua	0.8	0.0	**2.5**	**-1.4**	0.7	0.0	0.0	0.0
Persicaria amphibia	.-	0.1	-0.1	-0.1	0.1	-0.1	**2.2**	0.2
Polygonum aviculare	0.1	0.0	**1.2**	-0.3	0.0	-0.1	-0.3	0.0
Fallopia convolvulus	-0.4	0.3	0.7	**-3.0**	-0.4	0.0	0.0	0.2
Persicaria maculosa&lapathifolia	-0.1	0.3	0.4	**-4.7**	-0.1	**2.8**	**1.5**	0.3
Ranunculus spp.	0.0	0.0	0.1	-0.1	0.0	-0.8	0.2	0.0
Senecio vulgaris	0.0	0.0	0.0	-0.2	0.0	1.0	-0.1	0.0
Sinapis arvensis	.-	0.0	.-	.-	.-	**2.0**	**1.1**	-0.1
Solanum nigrum	0.6	-0.7	**4.6**	-0.2	0.4	**-2.4**	**4.6**	-0.6
Sonchus oleraceus	0.4	0.5	0.4	-0.7	0.4	0.3	0.5	0.5
Spergula arvensis	0.0	.-	0.3	-0.1	0.0	.-	.-	.-
Stellaria media	-0.2	0.1	**1.9**	0.6	-0.3	-0.2	-0.1	0.1
Taraxacum officinale	0.0	0.0	0.0	-0.1	0.0	**1.4**	-0.4	0.0
Trifolium spp.	0.0	0.2	-0.2	**-1.1**	0.0	0.0	0.3	0.2
Tussilago farfara	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Unidentified spp.	0.1	0.0	0.1	0.3	0.1	0.0	-0.3	0.0
Urtica dioica	0.0	-0.1	-0.1	0.1	0.0	0.0	0.7	-0.1
Veronica chamaedrys	0.0	0.0	0.0	0.0	0.0	0.1	-0.2	0.0
Vicia spp.	0.0	0.0	0.1	-0.1	0.0	0.1	0.0	0.0
Viola arvensis	0.1	0.0	-0.5	-0.1	0.1	0.0	0.1	0.0
Treatments score	**Treatment scores**		**Sandy soil**			**Clay soil**		
see Figure 2	B *2004		0.243			-0.075		
	B *2005		0.333			-0.152		
	B *2006		0.492			0.001		
	R *2004		0.000			0.000		
	R *2005		0.000			0.000		
	R *2006		0.000			0.000		
	P *2004			0.075			-0.0016	
	P *2005			0.133			-0.0810	
	P *2006			0.087			0.2235	
	nP *2004			0.000			0.0000	
	nP *2005			0.000			0.0000	
	nP *2006			0.000			0.0000	
	WF *2004				0.954			0.877
	WF *2005				0.019			0.191
	WF *2006				0.101			0.635
	nWF*2004				0.000			0.000
	nWF*2005				0.000			0.000
	nWF*2006				0.000			0.000

Table 8. Statistics corresponding to Figure 2 and Table 7. Displayed are p values and eigenvalues (lambda) Statistics are calculated for spontaneously occurring plants (SP), sown wild flowers (WF) and the sum of both: associated plants (AP).

	SP		**WF**		**AP**	
Sandy soil	p value	Lambda	p value	Lambda	p value	Lambda
Block	**	0.17	ns	0.00	**	0.11
Time	**	0.08	**	0.34	**	0.18
Barley vs Rye	*	0.03	ns	0.00	*	0.02
Pea vs no pea	ns	0.01	ns	0.00	ns	0.01
WF vs no WF	ns	0.02	**	0.59	**	0.23
CerealxPea	ns	0.02	ns	0.00	ns	0.01
CerealxWF	ns	0.01	ns	0.00	ns	0.01
PeaxWF	ns	0.02	ns	0.00	ns	0.02
Clay soil						
Block	*	0.03	ns	0.01	ns	0.02
Time	**	0.24	**	0.17	**	0.15
Barley vs Rye	ns	0.01	ns	0.01	ns	0.01
Pea vs no pea	*	0.02	ns	0.01	*	0.01
WF vs no WF	*	0.02	**	0.63	**	0.28
Cereal×Pea	ns	0.01	ns	0.00	ns	0.00
Cereal×WF	ns	0.02	*	0.02	*	0.01
Pea×WF	ns	0.01	ns	0.01	ns	0.01

* = alpha between 0.01 and 0.05; ** = alpha < 0.01; ns= not significant

as well. Storkey (2007) investigated how to manage a few dominant species in a community. A possible solution they raised was the selective use of herbicides. In our experiment on the sandy soil rye was found to be more suppressive to associated plants than barley. A reason could be that rye monocrop was more competitive than barley monocrop. The amount of light interception affects the attrition and recruitment of associated plants (Stilma et al., submitted-a). Poor growth of barley resulted in low biomass (Stilma et al., submitted-b) and lower light competition (Stilma et al., submitted-a). Rye and barley are known to have allelopathic ability (Barnes and Putnam, 1983; Wu et al., 1999). Rye was found to be allelopathic against *Chenopodium album* (Ercoli et al., 2007) and *Stellaria media* (Pimentel, 2002) both species were lower in rye treatments than in barley treatments in our experiments. Once the effects of allelopathy are better understood, crops with allelopathic ability could be used to control dominant species.

Pea had an effect on the development of the associated plant species on clay soil. In pea mixtures, more rare species had emerged than in mixtures without pea (Table 9). The difference in species composition between treatments with and without pea was significant on clay soil (Table 8), especially in the last year (Fig. 2). This effect was mainly caused by *Chrysanthemum segetum, Solanum nigrum* and *Polygonaceae spp.* They were more abundant in mixtures with pea than in cereal monocrops (Table 7). On sandy soil a difference in species composition in mixtures with and without pea was mostly due to *Polygonaceae spp.* In the last year, the total number of rare species was slightly higher in treatments with pea than in treatments without pea (Table 9). Poggio (2005) found no differences in spontaneously occurring plant species diversity between a pea barley intercrop and a barley monocrop.

Table 9. Number of species and number of individuals of 1) associated plants (sown wild flowers and spontaneously occurring plants) 2) sown wild flowers, and 3) rare spontaneously occurring species (< 3 per m2) presented per treatment on a sandy soil and a clay soil. Shannon evenness and H diversity indexes of the associated plants are presented as well. Different numbers mean that values are significantly different calculated with lsd at 5% confidence as displayed below the column. For abbreviations of treatments see Table 2.

	Associated plants				**Sown wild flowers**				**Rare, spontaneously occurring plants**			**Evenness**	**H diversity**
Sandy soil	species		total		species		total		species		total		
B	9	a	201	(ab)	0	a	0	a	4	(a)	14	0.4	0.8
BP	12	ab	254	(ab)	1	a	0	a	6	(ab)	8	0.4	1.0
R	9	a	126	(a)	0	a	0	a	4	(a)	2	0.4	0.8
RP	11	a	154	(a)	0	a	0	a	5	(ab)	6	0.4	0.9
BF	15	b	338	(b)	2	b	7	c	8	(b)	12	0.3	0.9
BPF	12	ab	197	(ab)	2	b	2	ab	6	(ab)	5	0.4	1.0
RF	11	a	145	(a)	3	b	4	b	4	(a)	5	0.4	1.1
RPF	11	a	162	(a)	2	b	2	ab	4	(ab)	7	0.3	0.7
p value	0.048		0.057		<.001		0.003		0.084		0.174	0.789	0.729
lsd	3.7		.(129.7)		1.2		3.2		.(3.05)		.-	.-	.-
Clay soil													
B	15		67	ab	3	bc	3	(ab)	9	a	13	0.7	1.8
BP	17		67	ab	2	b	4	(ab)	11	ab	15	0.7	2.0
R	15		63	a	1	a	1	(a)	9	a	11	0.7	1.8
RP	19		95	ab	1	a	1	(a)	14	b	20	0.7	1.9
BF	17		97	ab	4	cd	52	(ab)	9	a	9	0.6	1.8
BPF	15		111	ab	4	cd	57	(ab)	8	a	11	0.7	1.9
RF	17		165	bc	4	d	107	(ab)	9	a	22	0.6	1.7
RPF	18		215	c	4	cd	121	(b)	11	ab	13	0.6	1.8
p value	0.29		0.05		<.001		0.08		0.03		0.72	0.7	0.9
lsd	.-		101		1.04		.(98.1)		3.18		.-	.-	.-

Pea in the mixtures did not have an effect on number of plants on either soil type. This lack of effect on number of plants is consistent with other research where no differences in competitiveness to associated plants was found for barley monocrop and barley pea intercrop (Hauggaard Nielsen et al., 2001; Poggio, 2005). Total silage biomass of cereal pea mixtures was higher than that of cereal monocrop (Stilma et al., submitted-b) and silage weights per plant were higher in cereal pea mixtures than in monocrops. An explanation is that in monocrops the suppression of the associated plant population is mostly determined by crop plant density (Liebman and Altieri, 1988). In cereal-legume intercrop systems other factors than crop plant density play a role. Although the plant density of mixtures can be similar, shading over time differs from that in monocrops (Stilma et al., submitted-a), which has consequences for the associated plants. Monocrops give more shade on the soil early in the season, whereas shading in intercrops is higher in a full-grown canopy. In addition, the competition for nitrogen is lower in intercrops of cereal-legumes. Cereals benefit from the low competition but so do the associated plants. This means that although yields are higher in cereal-legume intercrops (Mead and Willey, 1980), intercrops still leave room for associated plant diversity (Hauggaard Nielsen et al., 2001; Poggio, 2005) as was confirmed in our experiments. Plants growing in competition produce fewer main leaves at flowering and show a reduced rate of leaf appearance (Brainard et al., 2005). These plants produced 50% less viable seeds than plants growing without competition. Delayed seed-setting and low seed weights have also been observed for crops at low nitrogen levels (Arisnabarreta and Miralles, 2004; Kleemola et al., 1994). In our experiment, competition for nitrogen was lower in cereal-pea mixtures than in monocrops, resulting in a larger individual associated plant size. Hypothetically, associated plants in mixtures with pea will reproduce faster than in cereal monocrops if biodiverse production systems were continued for more years.

In the second year, sown wild flowers did not emerge on either of the soils. In the third year, they did not emerge on sandy soil, whereas they were abundantly present on the clay soil. The most logical explanation for the high abundance on clay soil in alternate years is that seeds were stored in deeper soil layers after soil tillage in the second year and were brought back to the soil surface after cultivation in the third year (Marshall and Brain, 1999). On sandy soil sown wild flowers did not return in the third year. Supposedly, sown wild flowers had not set enough viable seeds in the first year. On sandy soil, the initial amount of nitrogen was very low in 2004 (8 kg N/ha compared to 28 kg N/ha on the clay soil (Stilma et al., submitted-b)). Growth of sown wild flowers may also have been delayed by low nitrogen. These results suggest that in order to obtain a viable wild flower population, sown wild flowers should be sown at least two years in a row. Moreover, success of sown wild flowers is only achieved if sown wild flowers set seeds successfully in the first two years after introduction.

Intensive tillage is known to disturb biological processes in the soil. No-till agricultural ecosystems were found to increasingly resemble soils of natural ecosystems (Adl et al., 2006; Neher, 1999). However, we decided to use conventional tillage for two reasons. First, a shift from tillage to no-till systems causes a shift in species diversity from annual broad-leaved species to perennial grassland species (Hyvönen and Salonen, 2002; Menalled et al., 2001; Tørresen et al., 2003; Tuesca et al., 2001). We wanted to support species that grow particularly in crop production (eco)systems. Second, a conversion from a conventionally tilled soil to a no-tillage soil takes a transition process. During the transition process, soil life takes over the function of ploughing. However, before the soil ecosystem is stabilised, many problems can occur (Peigne et al., 2007). Our experiment did not last long enough to go through that transition process.

Biodiverse production systems were designed for high yield but should also leave room for development of associated diversity (Stilma et al., 2007). Results of this experiment show that the locations and the crop treatments had different effects on the development of the associated plant population. On the poor sandy soil, rye was more suppressive than barley, but on the more fertile clay soil both cereals were equally competitive. Pea in the mixture did not affect the number of associated plants but enhanced individual plant weight. Consequently, establishment of associated plant species over time was better in mixtures with pea. In order to produce a viable crop with high plant diversity, crops should be grown on sufficiently fertile soils. The associated plant population should not be dominated by one or few species in order to give room for development of rare species.

Acknowledgments

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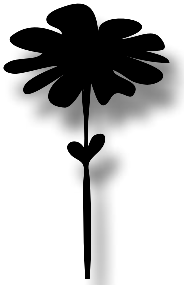


07 Effect of crop mixtures on beetle diversity (Coleoptera: Carabidae, Coccinellidae, Curculionidae) over time on two soil types in the Netherlands

Eveline S.C. Stilma, Theodoor Heijerman, Paul C. Struik, Hein Korevaar, Ben Vosman

Pesticides applied in agriculture often also affect non-target, functional microfauna and mesofauna. Stimulating populations of natural enemies of pest insects by improving habitat quality in the production system has environmental advantages and may also be effective against pests. We investigated whether habitat diversification could be achieved within a cropping system. Cropping systems with different levels of plant diversity were designed. We hypothesized that more plant diversity would enhance diversity of insects. Spring rye was cropped as monocrop, or intercropped with semi-leafless pea, with sown wild flowers, or with pea plus sown wild flowers, on sandy and clay soils in the Netherlands. Spontaneously occurring flora and fauna were not removed; fertilizers, herbicides or pesticides were not used. Carabidae (beneficial), Coccinellidae (beneficial) and Curculionidae (harmful) beetle species were continuously collected throughout the growing season to assess the effect of different levels of plant diversity on beetle diversity in these production systems. Changes in the composition of the beetle community over time were analysed using the Principal Response Curves technique. The composition of the beetle community differed at different locations. Both beneficial and harmful beetles were more abundant in stands with pea than in stands without pea on sandy soil. On the clay soil, only Curculionidae numbers were higher in stands with pea. Sown wild flowers had no effect on Carabidae diversity, probably because spontaneously occurring plants were abundant in all treatments. This study suggests that crop stand diversity may enhance beetle diversity.

Additional keywords: Semi-natural agro-ecosystems, production systems, arthropod, barley, rye, pea, biodiversity

Introduction

In conventional arable production systems, pests are being controlled by agrochemicals which not only control pest insects but often also kill non-target species with potential beneficial effects (Menalled et al., 2007). Insect predators are important in sustainable agricultural systems as they contribute to natural pest control thus reducing the risk of pest outbreaks (Booij and Noorlander, 1992). In organic production systems, pests are not chemically controlled and in such systems pest control is far more dependent on naturally occurring fauna in the crop itself or its immediate surroundings (Ferron and Deguine, 2005). Managing the agricultural habitat to increase faunal diversity is a challenge. A more diverse landscape structure increases the natural enemy population and reduces pest pressure (Bianchi et al., 2006). Landscape heterogeneity is mostly achieved by variation in non-crop areas surrounding agricultural fields (Pfiffner and Luka, 2000). Habitat diversification could, however, also be achieved by diversification in the cropping system itself (Tscharntke et al., 2007). A cropping system may become a better habitat for associated biodiversity if the crop is grown in a less dense stand (Phillips and Cobb, 2005) or by growing a more diverse crop combination in which associated plants are allowed to develop (Bianchi et al., 2006).

Carabidae form an important group of beetles in arable fields. Some species are natural pest control agents feeding on other insects while other species are feeding on weed seeds (Hough-Goldstein et al., 2004). They respond rapidly to vegetation changes (Phillips and Cobb, 2005; Thomas et al., 2006). Carabidae are therefore often used as an indicator of above-ground diversity in agricultural systems (Kromp, 1999). A change of habitat of Carabidae was found to be influenced by temperature or humidity extremes, food conditions, presence and distribution of competitors, and life history and season (Lövei and Sunderland, 1996). For production systems it was found that Carabidae prefer half-shade crop canopies (Honek and Jarosik, 2000) and that they are attracted by weedy crops (Honek et al., 2007; Pfiffner and Luka, 2003; Thomas et al., 2002), and crops with a rich prey insect density (Kromp, 1999). The activity of Carabidae species depends on the season and on their life history but may also change in response to changes in vegetation height, soil temperature and humidity (Lövei and Sunderland, 1996).

We designed production systems with different levels of biodiversity (Stilma et al., 2007). No pesticides or fertilization were applied and weeds were not controlled. These systems were not designed to provide maximum attainable yield but to combine acceptable yields with a high biodiversity. Ecosystem performance was assessed by continuously capturing beetles (Carabidae, Coccinellidae and Curculionidae) throughout the growing season. We wanted to assess whether beetles were attracted to specific crop stands and whether the diversification of the beetle community would increase during the growing season.

Material and methods

Field experiments with similar set-up were carried out in 2005 without external input of fertilizers, pesticides or herbicides, one on a sandy soil and one on a clay soil. The cereal crop spring rye (*Secale cereale* cv. 'Sorom') was intercropped with pea (*Pisum sativum* cv. 'Integra') with or without sown wild flowers. The resulting four combinations were: rye monocrop, rye intercropped with pea, rye with sown wild flowers, and rye intercropped with pea plus sown wild flowers. Each treatment was replicated four times in a randomized complete block design. Individual plot size was 180 m^2. The sown wild flower species were *Papaver rhoeas, Centaurea cyanus, Chrysanthemum segetum, Misopates orontium.* In addition, *Matricaria recutita* was sown on sandy soil plus *Tripleurospermum maritimum* on clay soil. The nomenclature used is according to Van der Meijden (1996). Sowing dates were 30 March 2005 for the sandy soil and 6 April 2005 for the clay soil. Harvest dates were 17-18 August 2005. For details of the experimental set-up see Stilma (submitted-b).

Table 1. Carabidae, Coccinellidae and Curculionidae species collected in four types of biodiverse production systems at two sites (a sandy soil and a clay soil) in Wageningen, the Netherlands. Numbers represent total number of beetles collected in 64 traps per site from 20 April to 10 August 2005.

CARABIDAE	Sand	Clay	Feeding habit	**COCCINELLIDAE**	Sand
Amara spreta (Dejean)	2212	0	p/c	*Coccinella septempunctata* (Linnaeus)	187
Anchomenus dorsalis (Pontoppidan)	1226	2144	c	*Tytthaspis sedecimpunctata* (Linnaeus)	135
Pterostichus melanarius (Illiger)	554	9688	c/s	*Propylea quatuordecimpunctata* (Linnaeus)	63
Poecilus versicolor (Sturm)	486	0	c	*Rhyzobius litura* (Fabricius)	41
Calathus erratus (C.R.Sahlberg)	478	0	c		
Pseudoophonus rufipes (Geer)	446	1410	p/c	number of other species	5
Harpalus affinis (Schrank)	407	38	p/c	number of other individuals	26
Bembidion lampros (Herbst)	342	7	c		
Clivina fossor (Linnaeus)	330	54	c	*total species*	*9*
Poecilus cupreus (Linnaeus)	196	459	c	*total Coccinellidae*	*452*
Loricera pilicornis (Fabricius)	185	43	c		
Agonum muelleri (Herbst)	153	104	c	**CURCULIONIDAE**	
Amara plebeja (Gyllenhal)	73	1	p(/c?)	*Sitona lineatus* (Linnaeus)	2022
Calathus cinctus (Motschulsky)	69	0	c	*Trachyphloeus scabriculus* (Linnaeus)	86
Bembidion properans (Stephens)	68	5	c	*Philopedon plagiatus* (Schaller)	62
Bembidion tetracolum (Say)	65	7	c	*Sitophilus granarius* (Linnaeus)	24
Bembidion femoratum (Sturm)	64	0	c	*Phyllobius vespertinus* (Fabricius)	23
Harpalus tardus (Panzer)	63	2	p/c	*Ceutorhynchus erysimi* (Fabricius)	5
Demetrias atricapillus (Linnaeus)	60	18	c	*Barypeithes pellucidus* (Boheman)	0
Pterostichus vernalis (Panzer)	47	10	c		
Amara fulva (Müller)	44	0	p(/c?)	number of other species	25
Amara aenea (Geer)	40	4	p/c	number of other individuals	75
Amara familiaris (Duftschmid)	40	2	p/c		
Clivina collaris (Herbst)	39	1	c	*total species*	*31*
Nebria brevicollis (Fabricius)	39	32	c	*total Curculionidae*	*2297*
Calathus fuscipes (Goeze)	35	0	c		
Harpalus distinguendus (Duftschmid)	33	4	p/c		
Calathus melanocephalus (Linnaeus)	31	0	c/s		
Amara similata (Gyllenhal)	24	106	p		
Harpalus signaticornis (Duftschmid)	22	0	p/c		
Bembidion obtusum (Serville)	0	963	c		
Notiophilus biguttatus (Fabricius)	0	64	c		
Pseudoophonus griseus (Panzer)	5	0	p/c		
number of other species	31	27			
number of other individuals	122	142			
total species	*62*	*50*			
total Carabidae	*7998*	*15308*			

* feeding group
c=Carnivorous, p = Phytophagous, a= Aphid eater

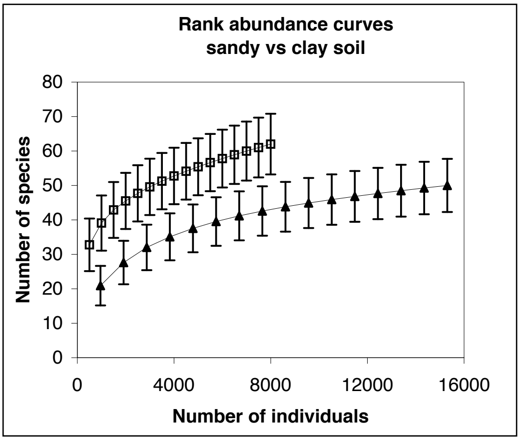


Figure 1. Rank abundance curves of the Carabidae population on sandy soil and clay soil in Wageningen, the Netherlands, 2005. Vertical bars represent the 95 % upper bound and 95% lower bound confidence interval. □ Sandy soil, ▲ Clay soil

Data collection

Four pitfall traps (9 cm diameter, 0.5 litre), half-filled with formaldehyde solution (4%) to kill and conserve the beetles, were placed in each plot. The traps were carefully buried in the soil with their rims at ground level. No bait was used. Traps were covered with an aluminium cover ca 5 cm above the soil to avoid flooding by rainfall. The four traps were placed at equal distances from each other and from the edge of the plot. The traps were emptied nine times at regular intervals during the season (2, 13, 23 May; 1, 15, 29 June; 8, 25 July; 4 August 2005). Beetles were removed from the traps by sieving and were then stored in tubes in a 70% alcohol solution until identification. The number of individuals caught in pitfall trap catches is known to be a function of population density and species activity, resulting in a quantity usually referred to as activity-density. Not only Carabidae but Coccinellidae and Curculionidae beetles were also caught in the pitfall traps and identified at species level according to Turin (2000) for Carabidae, Heijerman (1993) for Curculionidae and Kovár (2007) for Coccinellidae. Although using pitfall traps is a reliable method to catch Carabidae (Phillips and Cobb, 2005), this method is less frequently used for Coccinellidae and Curculionidae species. Coccinellidae species are more abundant in upper parts of the vegetation. Most Curculionidae species are also more abundant in upper parts of the standing crop as they are phytophagous and climb in the plants. Despite pitfall trapping being not the most effcient way to collect Coccinellidae and Curculionidae species they can be used to compare abundances between treatments.

Data analysis

Differences per treatment per family were analysed with general analysis of variance, repeated measurements in Genstat (10^{th} edition). Numbers were log-transformed before analysis to obtain homogenous data. Significance between treatments was assessed with the least significance difference method (lsd) at 5 % confidence. Shannon diversity and evenness per treatment per family for each site were calculated (Magurran, 1988).

The accumulation of species richness as a function of the number of individuals was computed with rank abundance curves in EstimateS, version 7.5 (Colwell, 2005). The terminology of rank abundance curves was used as described by Gotelli (2001) and confidence intervals (95%) were calculated by 'EstimateS' using the theory as described by Colwell (2004).

Principal Response Curves (PRC) were analysed with Canoco for Windows 4.5. PRC is a canonical ordination technique derived from redundancy analysis (RDA). RDA is a multivariate method to evaluate treatment effects on the dynamics of biological communities. RDA can only be applied at one time point, PRC techniques can be applied for data sets including repeated measurements. A treatment score and a species score were calculated. In the PRC figures time is plotted on the x-axis and treatment score (Cdt) on the y-axis. Species scores are described in a list next to the figure. The estimated number of a species in a treatment at a time point is calculated by exp(treatment score × species score) × the number of species in the 'control' group (Ter Braak and Šmilauer, 1998).

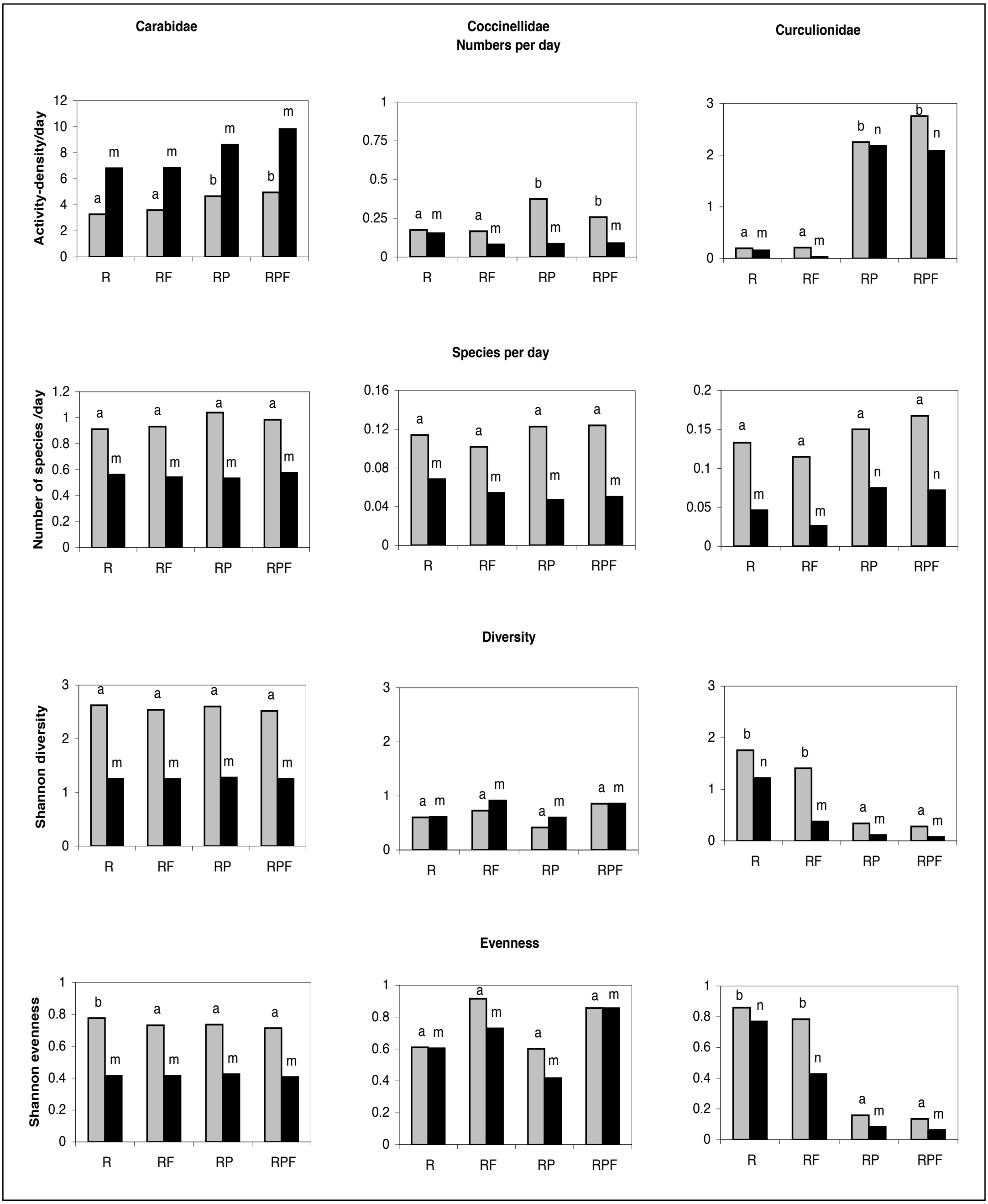


Figure 2. Number of individuals, number of species, Shannon diversity and evenness of Carabidae, Cocinellidae and Curculionidae per treatment (sum of four traps) for two soil types averaged over the nine measurements through time. Values along the y-axis differ per figure. Analysis carried out per individual soil type. Different letters indicate significant differences by the lsd method (alpha < 0.05) (a,b, for sandy soil, m,n for clay soil). Grey bars = sandy soil, black bars = clay soil. R = rye, RF= rye flowers, RP = rye pea, RPF = rye pea flowers.

	Pea vs no Pea		WF vs no WF	
Sandy soil	p value	lambda	p value	lambda
Carabidae	0.008	0.044	0.652	0.004
Coccinellidae	0.074	0.038	0.17	0.045
Curculionidae	0.002	0.574	0.39	0.008
Clay soil				
Carabidae	0.002	0.037	0.066	0.011
Coccinellidae	0.224	0.037	0.744	0.1
Curculionidae	0.002	0.551	0.346	0.005

Table 2. Table of significance from PRC analysis (p value and lambda) to compare effects of crop treatments pea vs no pea and sown wild flowers (WF) vs not wild flowers (nWF) on Carabidae, Coccinellidae and Curculionidae.

Results

Beetles

A total of 27,989 individuals from 123 different species were collected of the Carabidae, Curculionidae and Coccinellidae families (Table 1). Rank abundance curves were different for the Carabidae population between the two different sites (Fig. 1). Carabidae beetles were less abundant on sandy soil than on clay soil, but more species were found on the sandy soil. The most abundant species on sandy soil was *Amara spreta* while many other species showed high abundances as well (Table 1). The clay soil population was dominated by *Pterostichus melanarius* (63% of all Carabidae) with the following four species also showing high abundances: *Anchomenus dorsalis*, *Pseudoophonus rufipes*, *Bembidion obtusum* and *Poecilus cupreus*. Similar site effects on abundances were observed for the Curculionidae and Coccinellidae families (Table 1).

Activity-density, measured as the number of beetles caught per day, of Carabidae and Coccinellidae was higher in mixtures with pea than in mixtures without pea on sandy soil and the activity-density of Curculionidae was higher in mixtures with pea than in mixtures without pea on both sand and clay (Fig. 2). There were no differences in numbers of Carabidae and Coccinellidae species caught per day or between the cropping systems. The number of Curculionidae species was higher in mixtures with pea than in mixtures without pea on the clay soil. Sowing wild flowers had no effect on beetle numbers and species numbers. Carabidae were more evenly distributed in rye on sandy soil than in the other treatments (Fig. 2). Shannon diversity and evenness was higher in cereal monocrop than in pea mixtures at both sites for Curculionidae.

Differences in species composition between treatments were largest in the middle of the season when Carabidae were abundant (Fig. 3). The differences were caused by a higher abundance of some specific species in pea mixtures (Fig. 3; Fig. 4; Table 2). Carabidae attracted to pea were mostly carnivorous species (Table 1; Table 3). Early in the season, activity-density of Carabidae beetles was higher on sandy soil than on clay soil (Fig. 4; Table 2). Activity-density of Coccinellidae and Curculionidae was highest at the beginning of the season in mixtures with pea (Fig. 4). Sown wild flowers had no effect on species composition of the Carabidae, Coccinellidae and Curculionidae population (Table 2), although a trend was observed for Carabidae on clay soil (p = 0.066) (Table 2).

Discussion

Species diversity of Carabidae was higher on sandy soil than on clay soil (Table 1; Fig. 1; Fig. 3). On clay soil, the population was dominated by *P. melanarius*. This species was found to be among the most abundant species in many other cropping systems as well (Booij and Noorlander, 1992; Carcamo et al., 1995; Honek and Jarosik,

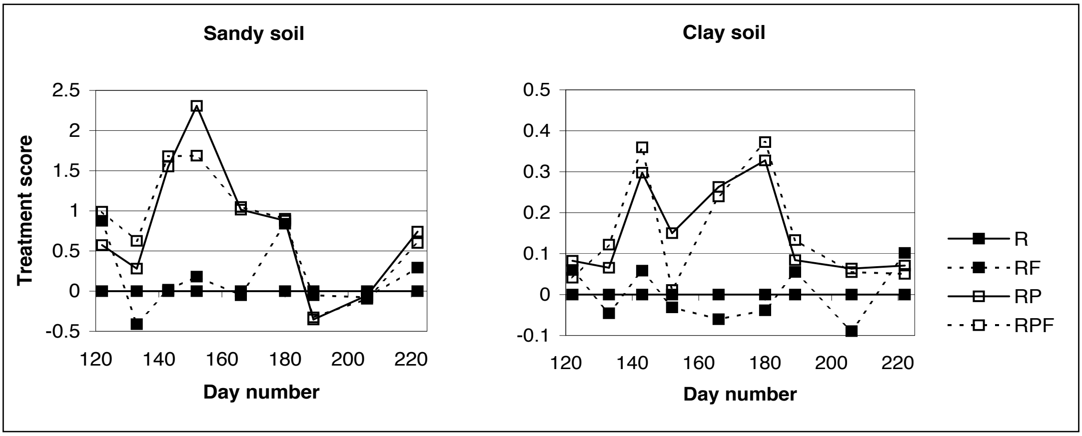


Figure 3. Result of the Principal Redundancy Analysis displaying the change in Carabidae species composition over time in two soil types in four crop mixtures.Treatment score (Cdt, y-axis) and day number (x-axis) are displayed in the Figure. Daynumber 122 corresponds with May 2, 2005, daynumber 222 with August 10, 2005. Species scores are displayed in Table 3.
The estimated number of a species in a treatment at a time point is calculated by exp(treatment score x species score) x the number of species in the 'control' group (Ter Braak and Šmilauer, 1998). R = rye, RF= rye flowers, RP = rye pea, RPF = rye pea flowers.

2000; Kromp, 1999; Mauchline et al., 2005). On the sandy soil, species diversity was high and also some species quite rare species were collected like *Harpalus signaticornis* and *Pseudoophonus griseus*. Our experimental sites on clay and sand were 4.4 km apart. Sites can differ in species composition because of habitat preferences, soil type (especially soil clay content), soil moisture, and soil pH (Holland and Luff, 2000). The composition of surrounding landscape elements (Bianchi et al., 2006; Purtauf et al., 2005), soil tillage method (spring or autumn) (Purvis and Fadl, 2002) and currently grown crop (Booij and Noorlander, 1992; Butts et al., 2003) play an important role as well.

In our experiment, species abundance at the beginning of the season was higher on sandy soil than on clay soil (Fig 4). Some species were caught more frequently in the beginning of the season than at the end because they reproduce early in the season (Honek, 1997b). *Anchomenus dorsalis* was abundant on both soils and was caught earlier in the season on sandy soil. Activity-density of a single species is affected by soil temperature and *A. dorsalis* prefers bare soil at < 16 °C and shaded crops at 18–25 °C (Honek, 1997b). Thermal conductivity of sandy soils is higher than that of clay soils (Abu-Hamdeh and Reeder, 2000); this means that in the same year, the sandy soil was heated faster than the clay soil. Throughout the growing season a crop becomes more attractive for beetles due to increasing soil cover (Booij and Noorlander, 1992; Heyer et al., 2003; Honek, 1997a). At too dense crop canopies, however, the number of Carabidae declines again (Honek and Jarosik, 2000). The crop covered the soil sooner sand than on clay. The initial amount of nitrogen was higher on the sandy soil, resulting in more crop biomass (Stilma et al., submitted-b) and the crop was sown two weeks earlier on the sandy soil, causing earlier soil cover. On sandy soil the crops reached 50% soil cover between 8 and 12 May, and on clay soil between 19 and 21 May (Stilma et al., submitted-a); the first dates concern the cereal monocrop and the latter dates the cereal-pea mixtures.

Pea increased the number of individuals caught per day of Carabidae and Coccinellidae on sandy soil, and of Curculionidae on both soils (Fig. 2). Diversity and evenness, however, were lower for Curculionidae in pea mixtures on both soils due to abundance of only one species (*Sitona lineatus*). Curculionidae species were dominated by *S. lineatus* that feed on Fabacea, which explains the high abundance

Species	Species score	Species	Species score
Poecilus cupreus	0.3164	*Poecilus cupreus*	2.3348
Poecilus versicolor	0.314	*Anchomenus dorsalis*	1.8334
Bembidion lampros	0.2972	*Amara similata*	0.7419
Amara spreta	0.2652	*Pterostichus niger*	0.7346
Clivina collaris	0.2159	*Trechus sp.*	0.6969
Bembidion guttula	0.2032	*Limodromus assimilis*	0.6479
Pterostichus nigrita	0.2032	*Anisodactylus binotatus*	0.5024
Bembidion properans	0.1972	*Acupalpus meridianus*	0.4813
Harpalus latus	0.1867	*Bembidion obtusum*	0.4801
Amara familiaris	0.1834	*Amara aenea*	0.4415
Amara plebeja	0.1592	*Bembidion lampros*	0.402
Pterostichus melanarius	0.1366	*Carabus monilis*	0.2842
Dyschirius thoracicus	0.119	*Pterostichus vernalis*	0.2743
Trechus sp.	0.1109	*Bembidion guttula*	0.2605
Pseudoophonus rufipes	0.1077	*Agonum afrum*	0.2378
Harpalus affinis	0.0974	*Nebria brevicollis*	0.2331
Clivina fossor	0.0939	*Amara aulica*	0.2313
Amara similata	0.0917	*Amara bifrons*	0.1941
Harpalus distinguendus	0.0878	*Pterostichus melanarius*	0.1745
Trechus quadristriatus	0.0825	*Trechus quadristriatus*	0.1595
Bembidion lunulatum	0.0824	*Pseudoophonus rufipes*	0.1589
Bradycellus harpalinus	0.0808	*Asaphidion curtum*	0.1272
Anchomenus dorsalis	0.0723	*Harpalus rubripes*	0.1173
Calathus fuscipes	0.0664	*Badister sodalis*	0.0954
Amara apricaria	0.0626	*Leistus terminatus*	0.0636
Amara consularis	0.061	*Harpalus distinguendus*	0.0042
Philorhizus melanocephalus	0.061	*Loricera pilicornis*	0.0025
Amara lunicollis	0.058	*Bembidion tetracolum*	-0.0098
Agonum muelleri	0.0577	*Bembidion lunulatum*	-0.0552
Calathus melanocephalus	0.0496	*Amara ovata*	-0.058
Oxypselaphus obscurus	0.0396	*Notiophilus biguttatus*	-0.1786
Loricera pilicornis	0.0363	*Trechoblemus micros*	-0.1942
Amara lucida	0.0359	*Carabus auratus*	-0.2083
Pseudoophonus griseus	0.0302	*Patrobus atrorufus*	-0.2162
Asaphidion flavipes	0.0298	*Bembidion properans*	-0.2195
Ophonus puncticeps	0.0251	*Agonum sexpunctatum*	-0.2354
Acupalpus meridianus	0.0243	*Bembidion quadrimaculatum*	-0.2601
Harpalus rubripes	0.0204	*Lasiotrechus discus*	-0.288
Amara convexior	0.0156	*Harpalus tardus*	-0.3323
Amara bifrons	0.0129	*Stomis pumicatus*	-0.3338
Calathus cinctus	0.009	*Agonum muelleri*	-0.3734
Amara fulva	0.0066	*Amara familiaris*	-0.4656
Calathus erratus	0.0023	*Badister bullatus*	-0.51
Harpalus laevipes	0.0006	*Harpalus affinis*	-0.5487
Amara aulica	-0.0004	*Amara plebeja*	-0.6997

Sandy soil		Clay soil	
Species	Species score	Species	Species score
Trechus obtusus	-0.0034	*Chlaenius nigricornis*	-0.7249
Syntomus foveatus	-0.0047	*Clivina collaris*	-0.7564
Leistus terminatus	-0.0062	*Clivina fossor*	-0.7736
Harpalus signaticornis	-0.0069	*Notiophilus palustris*	-0.8623
Amara aenea	-0.0074	*Demetrias atricapillus*	-0.8979
Olisthopus rotundatus	-0.013		
Bembidion femoratum	-0.0156		
Harpalus tardus	-0.017		
Pterostichus vernalis	-0.022		
Bembidion quadrimaculatum	-0.0314		
Demetrias atricapillus	-0.0324		
Anisodactylus binotatus	-0.0335		
Pterostichus niger	-0.0567		
Badister sodalis	-0.0981		
Nebria brevicollis	-0.1121		
Amara communis	-0.1526		
Bembidion tetracolum	-0.2295		

Table 3. Species scores corresponding to treatments scores displayed in Figure 3.
For further details see caption of Figure 3.

of Curculionidae in the pea-containing mixtures. In addition, a different microclimate between the crop mixtures and monocrop could have had an effect. Temperature and humidity measurements at 60 cm height within the canopy were carried out in a similar experiment in the same year at the end of the growing season. Results of these measurements show that temperature was lower and humidity higher in cereal-pea intercrops than in cereal monocrops (unpublished data). Lower temperatures in legumes than in cereals at the end of the growing season were also measured by others (Williams and Gordon, 1995). In other experiments, Carabidae were also frequently found to be abundant in the pea crop. In pea-barley intercrops, Carabidae were most attracted to pea, then to the intercrop, and least to the barley monocrop (Butts et al., 2003; Hatten et al., 2007). In an experiment with pea-barley intercrop, and monocrops of faba bean, fescue and barley, the intercrop attracted the highest number of Carabidae beetles (Carcamo and Spence, 1994). The special attraction to the pea crop could be caused by effects of plant diversity on herbivores and predators (Siemann et al., 1998). A higher plant diversity enhances host diversity for insects. In our experiment, the Carabidae and Coccinellidae species attracted to pea were carnivorous species. Coccinellidae feed on aphids on pea (Losey and Denno, 1998).

Sown wild flowers did not have a clear effect on beetle activity-density. Only one (phytophagous) species (*Amara spreta*) was significantly more abundant in species with sown wild flowers in the first count. As seeds had just been sown, these species could have been feeding on the newly sown seeds. *Amara* spp. are considered phytophagous (Hengeveld, 1979) and are found to be attracted to herb fields that are established after cereal production (Tyler, 2008). Other effects of the introduction of wild flowers were not observed. This result did not meet our expectations based on the fact that Carabidae are known to be attracted to weedy crops (Honek et al., 2003; Pfiffner and Luka, 2003). The difference

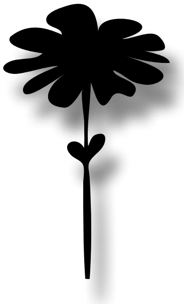
Sandy soil									
2 May	13 May	23 May	1 June	15 June	29 June	8 July	25 July	10 August	
111	44	74	95	74	73	35	40	48	All Carabidae species
									Abundant species:
67	15	21	<u>15</u>	5	14	8	4	3	*Amara spreta*
9	4	**2**	2	1	2	1	1	1	*Bembidion lampros*
6	2	4	6	5	4	2	1	1	*Harpalus affinis*
6	7	<u>12</u>	<u>9</u>	3	2	0	0	1	*Poecilus versicolor*
2	1	6	5	3	2	1	2	5	*Clivina fossor*
1	3	13	<u>30</u>	30	<u>17</u>	5	3	1	*Anchomenus dorsalis*
0	0	1	5	<u>11</u>	<u>12</u>	5	5	3	*Pterostichus melanarius*
2	1	5	5	3	6	2	4	5	*Pseudoophonus rufipes*
0	0	0	0	3	2	3	*10*	*13*	*Calathus erratus*
2	8	<u>16</u>	<u>9</u>	2	2	1	1	<u>1</u>	All Coccinellidae species
<u>24</u>	<u>94</u>	<u>43</u>	<u>21</u>	5	2	1	2	3	All Curculionidae species
Clay soil									
24	59	46	57	252	249	205	150	114	All Carabidae species
									Abundant species:
14	43	18	1	2	1	0	0	0	*Bembidion obtusum*
0	0	0	2	2	2	1	0	0	*Amara similata*
1	1	4	35	210	202	113	88	63	*Pterostichus melanarius*
3	3	7	4	<u>8</u>	<u>6</u>	3	2	1	*Poecilus cupreus*
0	3	<u>10</u>	10	<u>27</u>	<u>23</u>	<u>52</u>	<u>35</u>	11	*Anchomenus dorsalis*
1	1	2	0	2	13	31	21	33	*Pseudoophonus rufipes*
0	1	3	3	4	1	1	0	1	All Coccinellidae species
<u>5</u>	<u>71</u>	<u>57</u>	<u>15</u>	<u>6</u>	1	1	<u>2</u>	2	All Curculionidae species

Figure 4. Abundant beetle species per soil type summed for four traps in four treatments divided by number of days of the trapping period Dates with the highest abundances are dark grey, days with medium abundance light grey, and dates with the lowest abundance are white.
Underscored values are significantly ($p < 0.05$) higher in mixtures with pea. Bold numbers are significantly higher in mixtures with wild flowers. Italic values are significantly lower in fields with wild flowers.

between plots with or without sown wild flowers may have been obscured by the high numbers of spontaneously occurring plant species or the number of sown wild flower species being too low (Stilma et al., submitted-c).

Conclusions

The composition of the beetle population was affected by soil type and crop cover. The number of beetle species was higher on the sandy soil than on the clay soil whereas the number of individuals was higher on the clay soil. Carabidae beetles were attracted to the crops earlier in the season on sandy soil than on clay soil. The high number on clay soil resulted from the dominance of *P. melanarius*. The mixtures with pea attracted more Carabidae, Coccinellidae, and Curculionidae species. Pea was attractive to Curculionidae (in particular *S. lineatus*) as they feed on pea and to Carabidae and Coccinellidae as they feed on pest insects, such as aphids, attracted to pea. Sown wild flowers had only little effect on the occurrence of beetles, probably because of their low abundance compared to the crop. These results clearly show that beetle diversity and number can be increased by changes in the cropping system. Crop mixtures with pea support a higher number of beetles than cropping systems without pea. Species composition over time was different between soils probably due to soil temperature and amount of crop shading.



08 Nematode population development in biodiverse arable production systems in the Netherlands

Eveline S.C. Stilma, Jan van Bezooijen, Hein Korevaar, Paul C. Struik, Ben Vosman

Plant-parasitic nematodes can greatly reduce crop production. Other nematodes can be beneficial for crop production as they help to control pests and diseases. Saprophytic nematodes are involved in breaking down organic matter into valuable components for plants. Plant-parasitic nematodes were found to be a lesser problem in extensive production systems than in high-input production systems. More beneficial nematodes and fewer herbivores were found in the extensive systems. We set up eight low-input production systems with different levels of diversity in which associated plants were not controlled. The systems were maintained for three subsequent years on a sandy soil and on a clay soil and included all treatment combinations of a cereal (spring rye or a mixture of spring barley varieties) with or without pea, and with or without five introduced wild flower species. We expected that lower inputs would increase beneficial nematodes and reduce plant-parasitic nematodes. On the sandy soil, these trends were indeed observed. On the clay soil, however, beneficial nematodes remained constant over time and plant-parasitic nematodes increased. Differences between treatments were found for *Tylenchorchynchus spp*. in sandy soil. The increase over time was faster in barley than in rye, and faster in mixtures with pea than in monocrops. In view of the initially low levels and the low multiplication rates of plant-parasitic nematodes, nematodes are assumed to hardly affect crop yield. Our results suggest that in low-input production systems outbreaks of plant-parasitic nematodes are unlikely but that the rate of increase is likely to be location-dependent.

Additional keywords: biodiversity, intercrop, barley, *Hordeum vulgare*, rye, *Secale cereale*, pea, *Pisum sativum,* cereal

Introduction

Soil nematodes are small, 0.3 to 5.0 mm long, worm-like animals. They can be very abundant, counting up to millions per m^2 taking all genera together (Yeates and Bongers, 1999). If present in large numbers they can be a serious pest for susceptible crops causing strong yield reductions (Yeates and Bongers, 1999). In natural ecosystems, however, they are much less aggressive and dominant than in agro-ecosystems, a fact often ascribed to the higher plant and soil diversity, the mutual food-web relations, and the enhanced competitive interactions in natural soils (Van der Putten et al., 2006). Plant-parasitic nematodes respond much stronger to changes in the cropping system than other soil organisms (Korthals et al., 2001). Nematodes are therefore often used as indicators of biological soil quality (Bongers and Bongers, 1998; Yeates, 2003).

Not all nematodes are pests and many of them are even beneficial. Bacterivorous, carnivorous and fungivorous nematodes assist in suppressing soil-borne pests and diseases. Saprophytic nematodes are involved in breaking down organic matter into nutrients that are taken up by plants (Bongers and Bongers, 1998). The importance of these 'beneficial' nematodes for ecosystem functionality is becoming increasingly acknowledged. For example, changes in the composition of nematode communities were used to assess soil health (Yeates, 2003). Other research indicated that the composition of the nematode community in a soil depends on the presence of the various feeding sources which changes under the influence of management (Griffiths et al., 2003). For example, bacterivores were abundant in heavily grazed grasslands whereas fungivores were abundant in unmanaged sites (Yeates, 2003). The composition of the nematode community is also affected by ecological relations with other organisms within the soil foodweb. These organisms can moderate the effect of the nematode community on crop production. A higher diversity of the soil flora in low-input systems (Bardgett and Cook, 1998) was found to prevent nematode outbreaks. For example, in an experiment 95% of *Heterodera avenae* was suppressed by fungal parasites (Kerry et al., 1982). Another example is that mycorrhizas were found to interact with nematodes (Ingham, 1988). Monocots that have a symbiosis with mycorrhizas were resistant to some nematode species (Freckman and Caswell, 1985). It is a challenge to design systems in which beneficial nematodes are enhanced while suppressing harmful ones at the same time (Kimpinski and Sturz, 2003).

We measured beneficial nematodes and plant-parasitic nematodes in different low-input production systems. Production systems with different levels of biodiversity were designed for optimal yield that can be obtained if associated diversity is allowed to develop as described in an earlier paper (Stilma et al., 2007). We assessed whether the nematode community would develop into a positive direction, i.e., with fewer herbivores and more beneficial nematodes. The systems were maintained for three successive years on a sandy soil and on a clay soil without the use of external fertilizers or biocides, allowing associated biodiversity (both flora and fauna) to develop. The systems included eight combinations of a cereal (rye or barley), with or without pea, and with or without introduced wild flowers. We hypothesized that beneficial nematodes would increase in number and that an outbreak of plant-parasitic nematodes would not occur in low-input production systems (Van der Putten et al., 2006). It was also hypothesized that the development of plant-parasitic nematodes would be different in different crops (Deyn et al., 2004).

Materials and methods

Field experiments

On two different soil types (sand and clay) three-year field experiments were carried out during 2004–2006. Spring rye (*Secale cereale* cv. 'Sorom') and a mixture of 11 spring barley varieties (*Hordeum vulgare* Pasadena, Jersey, Prestige, Class, Madonna, Extract, Reggae, Orthega, Aramir, Apex and Saloon) were monocropped or intercropped with pea

Table 1. Susceptibility and reproduction rate in sandy soil of plant-parasitic nematodes present in rye, barley and pea (Anonymous, 2007).

		Soil[1]	Rye	Barley	Pea
Pratylenchus	*crenatus*	S	ooo	ooo	o
P.	*neglectus*		?	?	?
P.	*penetrans*	S	ooo	oo	ooo
P.	*thornei*	C	?	?	?
P.	*vulnus*		oo	.-	?
Paratylenchus	*bukowinensis*	S/C	?	?	?
Pa.	*projectus*		?	?	?
Rotylenchus	*uniformis*	S	o	o	o
Paratrichodorus	*pachydermus*		ooo	ooo	o
Trichodorus	*similis*		ooo	ooo	o
Tr.	*viruleferus*		?	?	?
Tylenchorhynchus	*dubius*	S	ooo	ooo	ooo
Meloidogyne	*chitwoodi*	S	ooo	o	o
M.	*fallax*	S	oo	o	o
M.	*naassi*	S	oo	ooo	.-
Globodera	*rostochiensis*		.-	.-	.-
Heterodera	*avena*	S/C	ooo	ooo	.-

legend

Damage	
unknown	
zero	
little	
medium	
great	
Reproduction rate	
unknown	?
zero	.-
low	o
medium	oo
high	ooo

[1] S = sandy soil, C = clay soil

(*Pisum sativum* cv. Integra), with or without introducing wild flowers in the cropping system. The resulting four combinations for each cereal were: cereal monocrop, cereal intercropped with pea, cereal with introduced wild flowers, and cereal intercropped with pea and introduced wild flowers (Table 1). Each treatment was replicated four times in a randomized complete block design. Individual plot size was 180 m^2. No fertilizers or biocides were used. The cereal grain harvested in one growing season was used as seed in the next season whereas new pea seed was used every year. Wild flowers were sown in the first year only. The following wild flower species were sown on both soil types: *Papaver rhoeas, Centaurea cyanus, Chrysanthemum segetum,* and *Misopathes orontium.* In addition, *Matricaria recutita* was sown on the sandy soil and *Tripleurospermum maritimum* on the clay soil.The nomenclature used is according to (Van der Meijden, 1996). Soil pH at the beginning of the experiments was 7.1 for clay soil and 5.5 for sandy soil. Details on the experimental design are given in (Stilma et al., submitted).

Recording nematode populations

Each year at the beginning of the growing season, and in the third year also at the end of the growing season, a soil sample was taken from each plot, consisting of 60 prods at regular distances using a hand auger of 20 cm length and a diameter of 1.7 cm. The soil samples were collected in plastic bags and stored at 4°C. Material collected from the four replicates of each cereal/pea/flower combination was pooled into one sample before analysis to reduce costs. Nematodes were identified and counted by a certified laboratory (Bedrijfslaboratorium voor grond en gewasonderzoek (blgg), Oosterbeek, the Netherlands) using standard procedure (Oostenbrink, 1960). Numbers of plant-parasitic nematodes known to be a pest for the crops grown were assessed at individual species level. These are the species listed in Table 2. Samples were also analysed for *Aphelenchoïdes spp.,*

Table 2. Statistics related to Figure 1. P values and degrees of freedom (d.f.) are based on the ANOVA from general analysis of variance, repeated measurements.

Sandy soil

	d.f.	*P. crenatus*	*P.neglectus*	*Paratlynchus spp.*	*Tylenchorchynchus spp.*	*R.uniformis*	*(Para)Trichodorus*	*M. Chitwoodi*	Beneficial nematodes
		p value							
"Cereal type"	1	ns	0.025	ns	0.019	ns	ns	ns	ns
"Inclusion of pea"	1	ns	ns	ns	0.048	ns	ns	ns	ns
"Inclusion of wild flowers"	1	ns	ns	ns	ns	ns	ns	ns	ns
Residual	4								
Time	2	ns	0.015	ns	0.003	0.044	0.023	ns	0.043
Time."Cereal type"	2	ns	ns	ns	ns	ns	ns	ns	ns
Time."Inclusion of pea"	2	ns	ns	0.039	ns	ns	ns	ns	ns
Time."Inclusion of wild flowers"	2	ns	ns	ns	ns	ns	ns	ns	ns
Residual	8								

Clay soil

	P.neglectus	*P.thornei*	*Tylenchorchynchus spp.*	*Rotylenchus spp*	Beneficial nematodes
"Cereal type"	ns	ns	ns	ns	ns
"Inclusion of pea"	ns	ns	ns	ns	ns
"Inclusion of wild flowers"	ns	ns	ns	ns	ns
Residual					
Time	ns	<.001	0.003	<.001	0.042
Time."Cereal type"	ns	0.011	ns	ns	ns
Time."Inclusion of pea"	ns	ns	ns	ns	ns
Time."Inclusion of wild flowers"	ns	0.013	ns	ns	ns
Residual					

Hemicycliophora spp., and *Radopholus spp.*; these species are not listed in the table because they were not detected in our experiment. Susceptibility of barley, rye and pea to the plant-parasitic nematode species detected in our experiments is listed in Table 2 (Anonymous, 2007). The remaining species were counted as one group and will be referred to as "beneficial nematodes". This group consisted of nematode species that cause no damage in rye, barley or pea. The results are based on direct soil extraction. No incubation was performed to extract *Meloidogyne* spp.

Data analysis

Data analysis was performed using Genstat (9th edition). For the data obtained from samples taken at the beginning of each growing season,

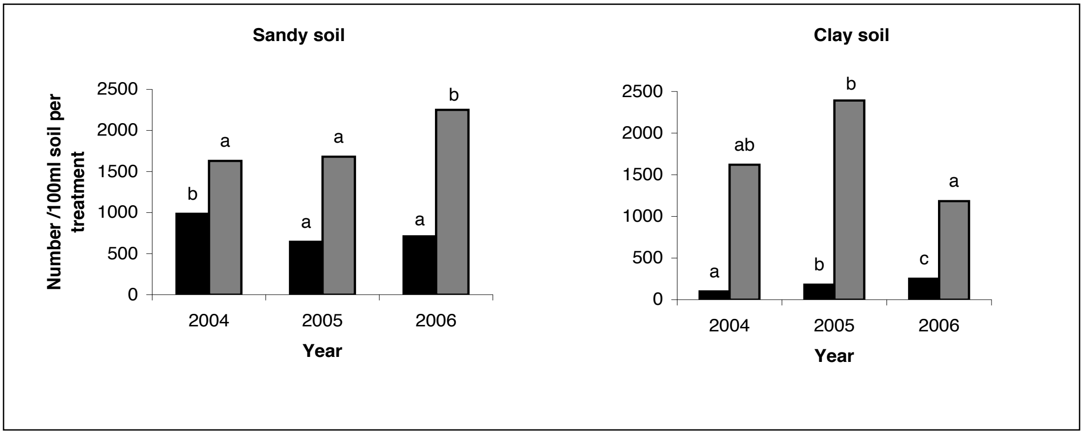


Figure 1. Development over time of plant-parasitic nematodes and beneficial nematodes on sandy soil and on clay soil. Total numbers of individuals over treatments. Statistical analysis carried out for each soil type, separately for plant-parasitic and beneficial nematodes. Significant differences are calculated by lsd (a < 0.05). Black columns = plant-parasitic nematodes; grey columns = beneficial nematodes.

changes in numbers of nematodes over time were evaluated by analysis of variance for repeated measurements. This method is used to describe how treatment effects develop. Significant differences were calculated with least significant difference (lsd). Changes over time per nematode species were calculated for all treatments together. Because replicates were combined, statistical analysis of the effects of cereal species, pea and/or wild flowers was carried out on main effects, corrected for the other effects; treatments were, e.g., cereal type + with/without pea + with/without wild flowers.

Data on the number of nematodes at the end of the last growing season are presented to discuss the maximum potential risk after three years of continuous cropping of the eight systems. Data were analysed with general analysis of variance. Treatments were cereal type + with/without pea + with/without wild flowers.

Results

Total number of nematodes

The trends in plant-parasitic nematodes versus other nematodes were analysed over time (Figure 1). Averaged over all treatments per year, the total number of plant-parasitic nematodes was lower in clay soil than in sandy soil. In sandy soil, the total number of plant-parasitic nematodes decreased after the first year. The number of beneficial nematodes, however, increased significantly after the second year. In clay soil, the total number of plant-parasitic nematodes increased significantly every year. The number of beneficial nematodes remained constant over the three years (with exception of the number in the rye-flowers treatment in 2005, which most likely should be considered as an outlier; Figure 2). The different treatments had no effect on total number of plant-parasitic nematodes and on the number of beneficial nematodes in either soil.

Nematode species in the different soils

In sandy soil, the differences in abundance amongst species were larger in the first year than in the last year (Figure 2; Table 3). In the first year dominant species were *Pratylenchus crenatus*, *P. neglectus* and *Paratylenchus spp.* Less abundant were *Rotylenchus uniformis, (Para)trichodorus spp., Tylenchorchynchus spp.* and *M. chitwoodi.* Averaged over all treatments, *P. neglectus* significantly decreased over time. *P. crenatus* also decreased over time, but this trend was just not significant (p = 0.052). The number of *Paratylenchus spp.* and *Meloidogyne chitwoodi* remained constant over time, whereas

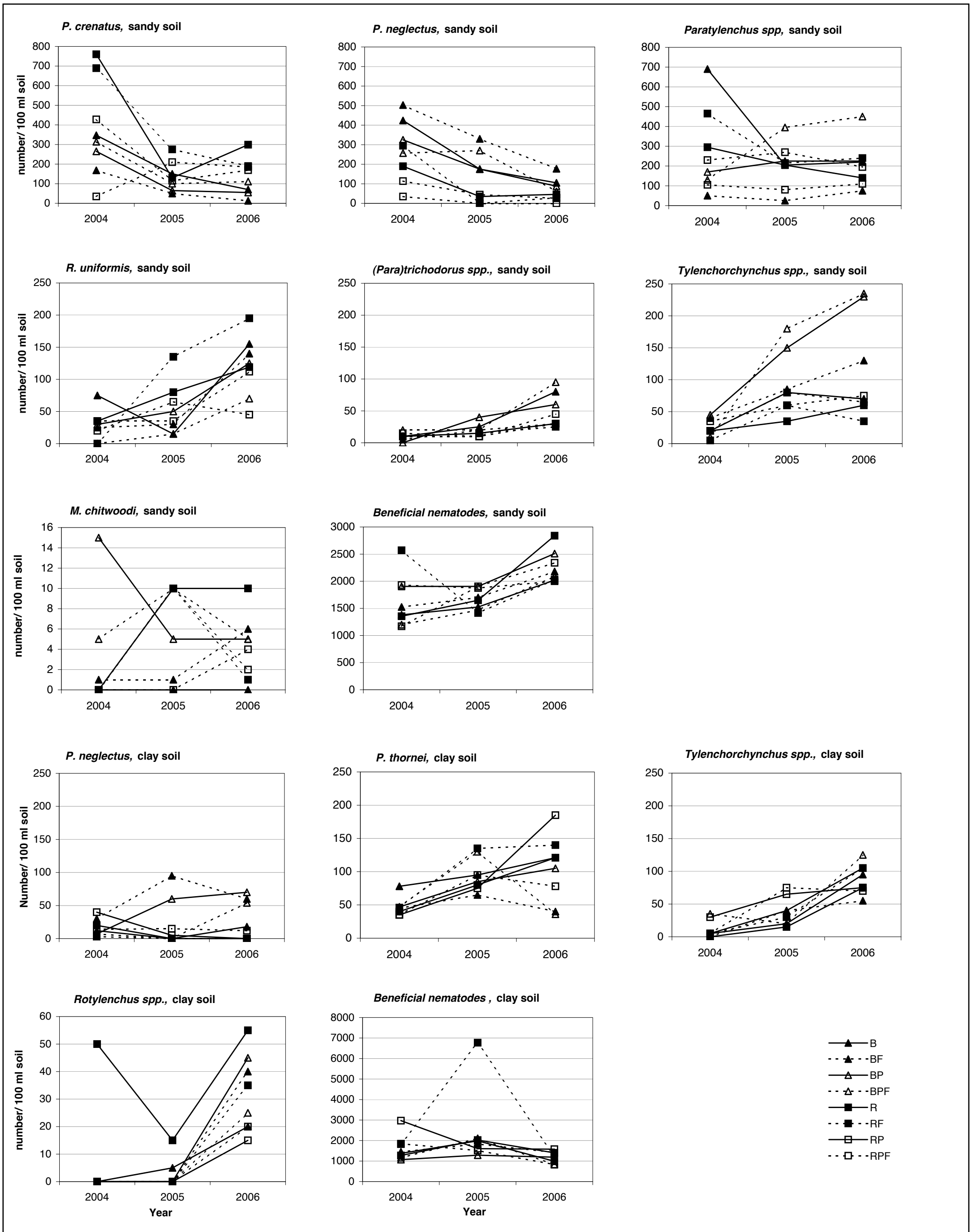


Figure 2. Development of plant-parasitic nematodes and beneficial nematodes present in our experiments displayed per species per treatment over time on sandy soil and on clay soil. Values on the y-axis differ for each figure. For abbreviations see Table 5.

Table 3. Number of nematodes at the end of the final growing season (numbers/100 ml soil)
For abbreviations see Table 5. The data are based on nematodes in the soil only. Treatment effects were analysed with genereal analysis of variance. P values of treatment effects are displayed if > 0.05. C = cereal type, P = pea vs not pea, WF = wild flowers vs not wild flowers.

Sandy soil										p value		
		B	**BF**	**BP**	**BPF**	**R**	**RF**	**RP**	**RPF**	**C**	**P**	**WF**
Pratylenchus	*crenatus*	233	222	168	326	221	210	260	267	ns	ns	ns
P.	*neglectus*	116	148	61	23	34	140	40	97	ns	ns	ns
P.	*penetrans*	0	0	0	0	0	0	0	0			
P.	*thornei*	0	0	0	0	0	0	0	0			
P.	*other spp*	1	0	1	1	0	0	0	1			
Paratylenchus	*bukowinensis*	0	65	84	244	36	0	0	0	ns	ns	ns
Pa.	*projectus*	690	130	231	366	73	140	335	215	ns	ns	ns
Pa.	*other spp*	0	0	0	0	1	0	0	0			
Rotylenchus	*uniformis*	119	365	195	90	178	445	100	184	ns	ns	ns
R.	*other spp*	51	0	0	0	77	0	0	21			
Paratrichodorus	*pachydermus*	4	34	8	0	0	0	0	12	ns	ns	ns
Trichodorus	*similis*	20	0	51	0	0	6	39	36	ns	ns	ns
Tr.	*viruleferus*	0	0	0	0	11	0	0	24			
(Para)trichodorus	*other spp*	16	81	26	90	24	24	26	48			
Tylenchorchynchus	*dubius*	70	380	670	635	65	90	195	540	ns	0.017	ns
T.	*other spp*	0	0	0	0	0	45	0	0			
Meloidogyne	*chitwoodi*	0	0	5	7	10	14	11	15	0.00	ns	ns
M.	*fallax*	0	0	0	0	0	5	0	0			
M.	*naassi*	0	5	0	2	0	0	3	0			
M.	*other spp*	0	0	0	1	0	1	1	0			
Beneficial nematode species		2280	1730	2410	2460	1880	2280	1930	3830	ns	ns	ns

Clay soil												
		B	**BF**	**BP**	**BPF**	**R**	**RF**	**RP**	**RPF**			
Pratylenchus	*crenatus*	0	0	0	0	0	0	0	0			
P.	*neglectus*	74	38	143	111	37	36	28	28	ns	ns	ns
P.	*penetrans*	0	12	0	0	0	0	0	0			
P.	*thornei*	205	139	52	74	242	234	112	182	0.04	0.016	ns
P.	*other*	1	1	0	0	1	0	0	0			
Paratylenchus	*bukowinensis*	0	0	0	0	0	0	0	0			
Pa.	*projectus*	0	0	0	0	0	0	0	0			
Pa.	*other spp*	0	0	0	0	0	5	0	0			
Rotylenchus	*uniformis*	0	0	0	0	0	0	0	0			
R.	*other spp*	50	25	15	25	95	55	20	20	ns	ns	ns
Paratrichodorus	*pachydermus*	0	0	0	0	0	0	0	0			
Trichodorus	*similis*	0	0	0	0	0	0	0	0			
Tr.	*viruleferus*	0	0	0	0	0	0	0	0			
(Para)trichodorus	*other spp*	0	0	0	0	0	0	0	0			
Tylenchorchynchus	*dubius*	0	6	0	0	0	0	0	0			
T.	*other spp*	245	54	180	180	190	155	55	125	ns	ns	ns
Meloidogyne	*chitwoodi*	0	0	0	0	0	0	0	0			
M.	*fallax*	0	0	0	0	0	0	0	0			
M.	*naassi*	0	0	0	10	0	5	5	0			
M.	*other spp*	0	0	0	0	0	0	0	0			
Beneficial nematode species		1210	1300	2135	1075	1410	1520	900	1590	ns	ns	ns

the numbers of *R. uniformis, (Para)trichodorus spp.* and *Tylenchorhynchus spp.* increased.

There were significant treatment effects on *Tylenchorhynchus spp.* The number of these nematodes increased faster in the barley treatments than in rye treatments, and faster in mixtures than in monocrops. *P. neglectus* was more abundant in barley treatments than in rye treatments; this difference, however, was caused by unequal distribution of the population at the beginning of the first year. *Paratylenchus spp.* were also unequally distributed in the first year (Figure 2; Table 3).

The number of species and their abundance were lower in clay soil than in sandy soil. The most abundant species present were *P. neglectus, P. thornei, Tylenchorchynchus spp.,* and *Rotylenchus spp.* None of the species had decreased in number on the clay site. *P. neglectus* showed highly variable results per year and per treatment with zero values in the second and third year. No consistent time trend was observed for the average of the treatments for this species. Averaged over all treatments, numbers of *P. thornei*, *Tylenchorhynchus spp.* and *Rotylenchus spp* increased over time.

Averaged over the years, *P. thornei* showed no differences between treatments. However, *P. thornei* increased in all treatments at the same rate after the first year; after the second year, the increase was higher in rye treatments than in barley treatments, and higher in treatments without wild flowers than in treatments with wild flowers (Figure 1; Table 3).

Table 4. Soil pH and nutrient availability of the soils.

	Year	Clay soil	Sandy soil
pH	2004	7.1	5.5
	2005	7.1	5.4
NO_3-N (mg/l extract)	2004	2.3	0.8
	2005		
	2007	2.2	1.6
Available N (kg/ha)	2004	28.0	8.0
	2005		
	2007	13.8	9.8
Organic matter	2004	3.9	3.5
	2005	3.2	2.5

Number of nematodes at the end of the final growing season

On the sandy soil, the most abundant species at the end of the final growing season were *P. crenatus, P. projectus, T. dubius* and *R. uniformus,* with an average number of 263 nematodes per 100 ml soil for each of these species (Table 4). Less abundant were *P. neglectus, Paratylenchus bukowinensis* and *(Para)trichodorus spp.* with per species 59 individuals per 100 ml. *M. chitwoodi, M. fallax and M. naassi* were present in very low numbers. Numbers of *T. dubius* were higher in mixtures than in monocrops. *M. chitwoodi* numbers were higher in mixtures with rye than in mixtures with barley (Table 4). On the clay soil, the most abundant nematodes were *P. thornei* and *Tylenchorchynchus spp.* with an average number of 152 individuals for each of these species per 100 ml soil (Table 4). Less abundant were *P. neglectus* and *Rotylenchus spp.* with per species 50 individuals per100 ml soil. *P. penetrans* and *M. naassi* were present in low numbers. *P. thornei* numbers were higher in rye treatments than in barley treatments and higher in monocrops than in mixtures (Table 4).

Cyst nematodes and larvae

On the sandy soil, *Heterodera avena* cysts and larvae were occasionally present in the soil samples of some treatments in numbers between 0–2 for cysts and 0–45 for larvae. Also *Globodera rostochiensis* cysts and larvae were occasionally present in some treatments in some soil samples in numbers between 0–2 for cysts and 0–60 for larvae (data not shown).

Nematode population development was different for the two soils. In clay soil, the number of "beneficial nematodes" was constant. In the sandy soil, the number of beneficial nematodes increased over time. Nematode populations in soils are affected by soil pH, organic matter content, and soil structure (Griffiths et al., 2003; Koppenhöfer and Fuzy, 2006). For example, nematodes are less abundant in acidic soils (Doroszuk et al., 2007; Korthals et al., 1996; Melakeberhan et al., 2004). In our experiment, pH was medium in sandy soil and high in clay soil (Table 5); pH was probably not a cause of the slow increase in the population of plant-parasitic nematodes over time. A beneficial nematode community responds to changes in soil organic matter and the amount of feeding material (Freckman, 1988; Griffiths et al., 2003). By their feeding habit, saprophytic nematodes feeding on microbes are involved in decomposition and nutrient release in soils (Griffiths, 1994). Organic matter is also positive because it can suppress plant-parasitic nematodes. Organic material stimulates reproduction of microorganisms that are antagonistic to plant parasitic nematodes (Akhtar and Malik, 2000). Although the amount of organic material could have been added by incorporation of the same amount of crop residues in both soils, in clay soils, organic matter does not become available for microorganisms as fast as in other soils due to binding of organic material to mineral particles (Akhtar and Malik, 2000; Lutzow et al., 2006). In our experiment, organic matter content was medium to low for both soils in the beginning of the experiment and decreased more on the sandy soil after the first year (Table 4). Organic matter can also not explain the differences between the locations.

Discussion

Nematode population development

Nematode population development was different for the two soils. In clay soil, the number of “beneficial nematodes” was constant. In the sandy soil, the number of beneficial nematodes increased over time. Nematode populations in soils are affected by soil pH, organic matter content, and soil structure (Griffiths et al., 2003; Koppenhöfer and Fuzy, 2006). For example, nematodes are less abundant in acidic soils (Doroszuk et al., 2007; Korthals et al., 1996; Melakeberhan et al., 2004). In our experiment, pH was medium in sandy soil and high in clay soil (Table 5); pH was probably not a cause of the slow increase in the population of plant-parasitic nematodes over time. A beneficial nematode community responds to changes in soil organic matter and the amount of feeding material (Freckman, 1988; Griffiths et al., 2003). By their feeding habit, saprophytic nematodes feeding on microbes are involved in decomposition and nutrient release in soils (Griffiths, 1994). Organic matter is also positive because it can suppress plant-parasitic nematodes. Organic material stimulates reproduction of microorganisms that are antagonistic to plant parasitic nematodes (Akhtar and Malik, 2000). In our experiment, organic matter content was medium to low for both soils in the beginning of the experiment and was lower on the sandy soil than on the clay soil after the first year (Table 4). The reason for differences between soils are unknown?

A decrease in the total number of plant-parasitic nematodes in sandy soil was mainly caused by a decrease in *Pratylenchus spp.* In a compost experiment the number of *Pratylenchus spp.* was found to be lower in plots with higher amounts of organic amendments than in plots with lower amounts of organic amendments (Leroy et al., 2007). *Pratylenchus spp.* may also be low because no fertilizers were applied and numbers of *Pratylenchus spp.* were found to be lower in soils with lower amounts of artificial fertilizer because of poorer crop growth (Yeates and Bongers, 1999). The increase of all plant-parasitic nematodes was low at both locations, probably due to poor plant growth as result of low nitrogen levels.

Table 5. Crop mixtures and their abbreviations

	Treatment	Abbreviation
1	Barley	B
2	Barley Flowers	BF
3	Barley Pea	BP
4	Barley Pea Flowers	BPF
5	Rye	R
6	Rye Flowers	RF
7	Rye Pea	RP
8	Rye Pea Flowers	RPF

Meloidogyne spp. are considered the most damaging nematodes (Barker and Koenning, 1998). They have a high reproduction rate with several reproduction cycles in one growing season. Moreover, many plant species, including weeds, are susceptible to *Meloidogyne spp.* and depending on their host plant efficiency, *Meloidogyne spp.* show a lower or higher multiplication rate (Belair and Benoit, 1996). Because of their high pathogenicity and high reproduction rate, *Meloidogyne spp.* are considered a risk even if they are present in the soil in low numbers. In all years of our experiment, *Meloidoygne spp.* were only present in low numbers in the sandy soil. This is remarkable, because pea, barley and rye are hosts for *Meloidogyne spp.* (Table 1). A possible explanation could be that reproduction of *Meloidogyne spp.* was inhibited by antagonists like the plant-parasitic nematode *P. neglectus* (Umesh and Ferris, 1994). *P. neglectus* was present in the soil and may have suppressed an outbreak of *Meloidogyne spp.*

Effect of the different treatments on population development

Replicates were put together before analysis which reduced the degrees of freedom for comparison between treatments. Small effects between treatments may not have been detected. However, based on the trends shown (Fig. 2) differences between treatments were not large except for *Tylenchorchynchus spp.,* which increased faster in barley than in rye. As the multiplication rate was the same in both crops (Table 2), these results indicate that rye is less sensitive to *Tylenchorchynchus spp.* than barley. *Tylenchorchynchus spp.* increased faster in cereal pea mixtures than in cereal monocrops. This was unexpected as well, given the reproduction rates for rye, barley or pea (Table 2). The presence of pea in combination with a barley crop seems to enhance the reproduction rate of *Tylenchorchynchus spp.* The mechanism behind this enhancement is unclear. *P. thornei* in clay soil, however, appeared to increase slightly faster in rye than in barley after the second year.

Wild flowers had a minor negative effect on the reproduction of *P. thornei* on clay soil. In earlier research, the effects of weeds in intercropping systems were diverse. Their effects on biodiversity and crop production were either positive or negative (Norris and Kogan, 2005). In grassland experiments, increased plant diversity *per se* did not affect the abundance of the plant-parasitic nematode population although plant species composition did (Deyn et al., 2004). However, total nematode diversity is normally higher in mixed swards than in monocultures. A mixed sward attracts more host-specific plant-feeding nematodes and indirectly affects other feeding groups by differences in soil texture, soil moisture, and soil fertility in successive soil layers due to a different rooting pattern of the plant species (Van der Putten et al., 2006; Yeates and Bongers, 1999).

Effect of nematodes on crop production

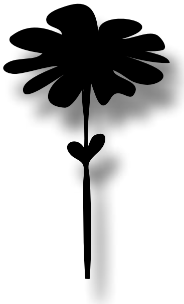
Yields of biodiverse cropping systems over time are known (Stilma et al., submitted). Biomass of pea in the cereal mixtures in the third year, averaged over all the treatments, was only 12% of the pea biomass in the first year. Biomass of barley and rye in mixtures and in monocrop then was 91% of the biomass in the first year. So, pea biomass was much more reduced than barley or rye biomass. Because no nitrogen was applied, a lower cereal biomass could have been caused by a low nitrogen level in the soil. Pea benefits from nitrogen fixation by its symbionts; this means that the severe reduction in pea biomass was probably not related to low soil nitrogen. If nematodes would be responsible, the nematode species that increased in this experiment would be expected to have caused the decline in pea yield. Species that increased were *Rotylenchus spp., Tylenchorchynchus spp., Paratrichodorus spp.* in sandy soil and *P. thornei, Rotylenchus* and *Tylenchorchynchus spp.* in clay soil. Pea is more sensitive to *Rotylenchus spp.* and *Paratrichodorus spp.* than barley or rye. The nematodes present in the soil may have caused a greater biomass loss in pea than in barley or rye. Pea biomass was equally low on both soils. Unfavourable weather conditions for pea in

2006 may also have affected pea (Stilma et al., submitted).

The numbers of nematodes in our experiments were relatively low (Carter et al., 2003; Taylor et al., 1999; Timper et al., 2004). The degree of damage by these nematode numbers is influenced by environmental conditions such as type of nutrient supply (Timper et al., 2004), soil texture and soil moisture (Griffiths et al., 2003; Vicente et al., 1999), differences in susceptibility between varieties (Vanstone et al., 1998), or ecological interactions like an inhibitory effect of one nematode species on the other (Freckman and Caswell, 1985).

Conclusion

The number of plant-parasitic nematodes in the experiments remained low, even after three years of continuous cropping. In sandy soil, the number of plant-parasitic nematodes decreased and the number of beneficial nematodes increased, resulting in a decrease of the ratio between plant-parasitic and non-plant-parasitic nematodes. Plant-parasitic nematodes were more suppressed by rye than by barley. This is in line with the order of susceptibility of most of the nematode species as derived from the literature (Table 2). However, some species responded differently than was to be expected from the data in Table 2. The low input and intercropping may have altered the effect of plant-parasitic nematodes on the crops. If nematodes were the cause of the yield decline observed in these experiments it is to be expected that yield loss was associated with a strong increase in specific nematode species. *Tylenchorchynchus spp.* on sandy soil may have affected barley-pea mixtures. The numbers of nematodes, however, were low, even at the end of the last growing season.



09 A short note on genetic development of a mixture of 11 spring barley varieties over time grown in crop mixtures with different levels of diversity

Eveline.S.C. Stilma, Danny Esselink, Linda Kodde, Wendy P.C. van 't Westende, Yolanda Noordijk, Paul C. Struik, Hein Korevaar, Ben Vosman

Agriculture is intensively managed in the Netherlands and therefore puts a mark on the environment and biodiversity. To reverse these negative consequences, we designed new cropping systems with different levels of biodiversity. Cropping systems were based on spring barley (*Hordeum vulgare*) and grown on clay and sandy soil. The different mixtures evaluated, consisted of the barley monocrop; barley in combination with semi-leafless pea; barley with five indigenous wild flower species (*Papaver rhoeas, Centaurea cyanus, Chrysanthemum segetum, Misopates orontium, Matricaria recutita* (sandy soil)/*Tripleurospermum maritimum* (clay soil); and barley with pea and wild flower species. The barley component consisted of a mixture of 11 spring barley varieties (Table 1). We studied the effect of the different barley cropping systems on possible changes in composition of the variety mixture and hypothesised that the composition of the mixture would develop differently on the two soils and in the different systems.

Variety	Germination	Thousand grain weight	Number of grains sown
	%	(g/1000 grains)	(grains10^6/ha)
Apex	98	52	2.2
Aramir	x	46	2.5
Class	95	60	1.9
Extract	96	55	2.1
Jersey	99	51	2.2
Madonna	95	45	2.5
Orthega	97	49	2.3
Pasadena	97	53	2.2
Prestige	95	57	2.0
Reggae	95	50	2.3
Saloon	99	52	2.2

Table 1. Features of the barley varieties sown, including the germination percentage, thousand grain weight of seeds in the first year of the experiment and the number of seeds sown per variety per ha based on a sowing density of 115 kg barley seed/ha for the entire mixture. Germination percentage for Aramir was not known.

Short description of materials and methods

Systems were grown for three consecutive years on a sandy soil and on a clay soil. No fertilizers, herbicides or pesticides were applied, to allow the associated flora and fauna to develop within the systems. Seeds were sown at equal weight per variety (115 kg/ha in total). The number of seeds per variety in the mixture was calculated based on thousand grain weights of the varieties (Table 1). Germination percentage for the varieties was also determined to assess viabilities of the different seeds. Grains harvested in one year were used as seeds in the following year. Pea seeds were renewed every year and wild flowers were sown only in the first year. The barley-pea-wild flower mixture on sandy soil had been contaminated with rye seeds and was therefore not analysed. At the end of the last growing season, 42 barley seeds per treatment were analysed by DNA

Table 2. Number of seeds of barley varieties at the beginning and at the end of the experiment on sandy and on clay soil. 'Start' means number of seeds sown in the first year based on a sample of 42 seeds, calculated by thousand grain weight of varieties in the first year. The numbers per variety after the third year of the experiments were identified by DNA analysis. B= barley, BF is barley flowers, BP = barley pea, BPF = barley pea flowers. There are no data for BPF on sandy soil (see text).

	Start	Sandy soil				Clay soil			
Variety		B	BF	BP	BPF	B	BF	BP	BPF
apex	3.7	8	4	6	*	4	4	4	2
aramir	4.0	2	1	1	*	2	3	4	2
class	4.3	4	5	8	*	5	5	4	10
extract	3.9	0	3	2	*	0	2	0	1
jersey	3.8	8	6	1	*	2	2	2	1
madonna	3.4	4	6	3	*	10	6	12	6
orthega	3.3	7	3	5	*	4	9	3	5
pasadena	4.4	2	4	4	*	4	5	7	3
prestige	3.8	1	1	4	*	6	1	2	2
reggae	3.6	4	5	7	*	3	5	2	8
saloon	3.9	2	4	1	*	2	0	2	2

Table 3. Shannon diversity and evenness for the different treatments and F probability of the analysis of variance. The treatment structure used was pea+ wild flowers+ soil type.

	Number of species	Number of individuals	Shannon Diversity	Shannon Evenness
Sand B	10	42	2.13	0.92
Sand BF	11	42	2.29	0.95
Sand BP	11	42	2.19	0.92
Clay B	10	42	2.17	0.94
Clay BF	10	42	2.16	0.94
Clay BP	10	42	2.10	0.91
Clay BPF	11	42	2.14	0.89
Source of variation	F probability			
Pea	0.064			
Wild Flowers	0.971			
Soil	0.668			

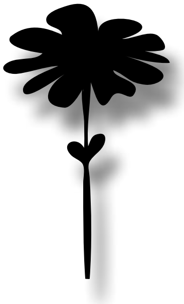
identification. The composition of the barley mixtures harvested from each of the treatments was determined. DNA was isolated from the grains (DNeasy plant minikit, www.qiagen.com) and SSR-markers (Bmac0067, Bmac0093, Bmac0316, Bmag0120, Bmag0211, Bmag0321, Bmag0323, Bmag0603, EBmac0679, HvM36, HvM54) (Hackauf and Wehling, 2002; Ramsay et al., 2000; Saal and Wricke, 1999) were used to identify individual varieties present in the mixtures. Shannon diversity and evenness were calculated (Magurran, 1988). Analysis of variance was carried out on the diversity and evenness numbers. The treatment structure was Pea+Wild flowers+Soil type.

Results and discussion

The numbers of seeds per variety in the sample of 42 seeds per treatment are presented in Table 2. The numbers of seeds per variety were different in the last year from those in the first year. Extract and Saloon had disappeared from the mixtures in some treatments, Madonna and Class were present in other mixtures at three times higher abundance at the end than at the beginning of the experiment.

Shannon and evenness indexes are presented in Table 3. Results of the analysis of variance suggested that the composition of the cereal variety mixtures grown in combination with pea (with or without wild flowers) was less evenly distributed than the composition of cereal variety mixtures grown in monocrops (with or without sown wild flowers) ($p = 0.064$). Soil type and the presence or absence of introduced wild flowers had no detectable effect on the composition of the barley variety mixture.

These results suggest that a barley variety mixture can adjust to the component crop. Reasons that could have caused a shift in variety composition were not analysed within this experiment. Further research should focus on mechanisms causing the change in species composition.



10 Short note on the effects of aboveground biodiversity on belowground biodiversity in arable cropping systems

Joeke Postma, Els H. Nijhuis, Eveline S.C. Stilma

Introduction

Aboveground crop biodiversity is assumed to have an effect on belowground biodiversity. In earlier studies, an association was found between crop rotation and soil microbial community composition and diversity (Garbeva et al., 2006). In the present study, the influence of cereal type, and the presence of mixed crops on the bacterial and fungal population diversity and community composition was assessed.

Materials and methods

Eight production systems with different levels of biodiversity were designed (Chapter 2). Two cereal types (spring rye and a mixture of 11 modern spring barley varieties) were grown in monocrop or mixed with either pea, five wild flower species or both during three subsequent years on two soil types. Each production system was present in four replicate field plots. Soil samples of the upper 20 cm were taken at the end of the last growing season. These samples were used to extract DNA. The composition of fungi, bacteria, and the bacterial genus *Pseudomonas* were assessed with the molecular fingerprinting technique PCR-DGGE (polymerase chain reaction-denaturing gradient gel electrophoresis) (Garbeva et al., 2004; Garbeva et al., 2006; Postma et al., 2008). Diversity and composition of the populations were expressed as Shannon diversity index (*H'*) and the relative band intensity per location in the fingerprint, respectively. Multivariate analyses were conducted to assess correlations between soil microbial populations and above ground diversity. Log-transformed data of the intensity of DGGE bands were analysed with canonical correspondence analyses (CCA) using CANOCO (Ter Braak, 1995) with replicates as covariable.

Results and discussion

Microbial composition as well as the diversity index were different for the samples of both soil types. Bacterial diversity was high showing many DGGE bands, but the composition was similar for all eight production systems on a soil type (Fig. 1). There were some trends suggesting that the composition of fungi and the bacterial genus *Pseudomonas* in the soil correlated with the treatments (i.e. production systems). The fungal population (Fig. 2) in clay was influenced

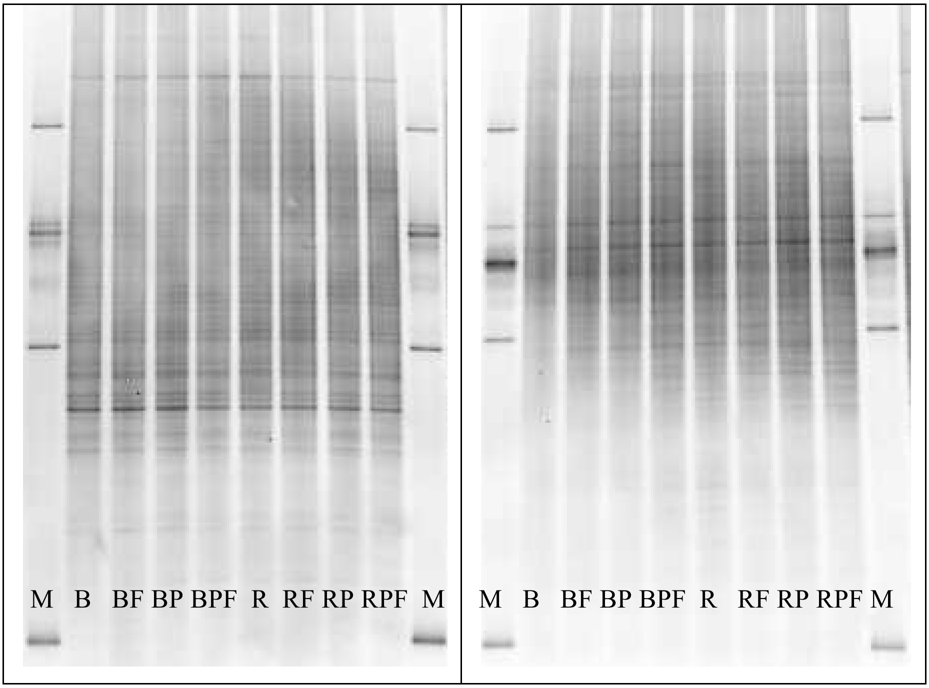


Figure 1. Bacterial community in eight different production systems on clay (left) and sand (right) with the molecular fingerprinting technique PCR-DGGE (1 replicate). M is a standard marker; B, R, F, and P correspond with barley, rye, wild flower and pea.

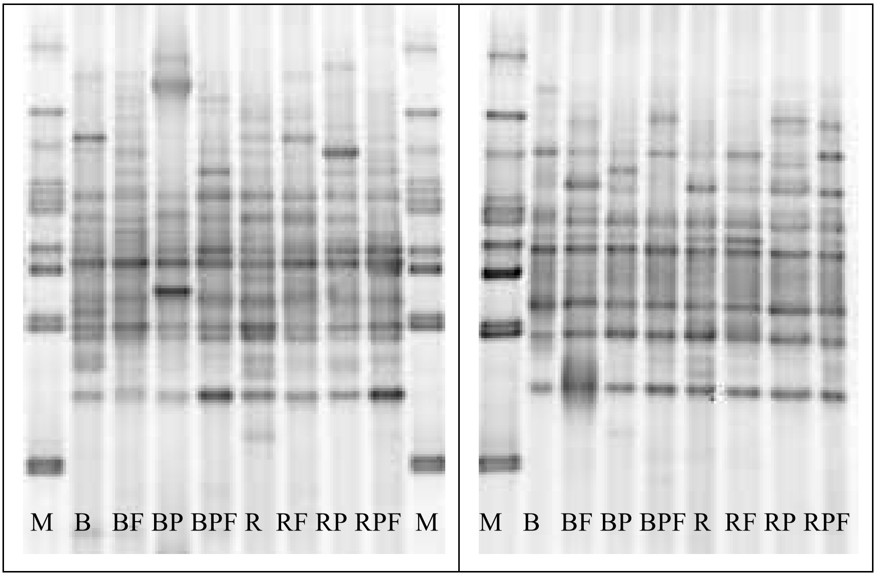


Figure 2. Fungal community in eight different production systems on clay (left) and sand (right) with the molecular fingerprinting technique PCR-DGGE (1 replicate). M is a standard marker; B, R, F, and P correspond with barley, rye, wild flower and pea.

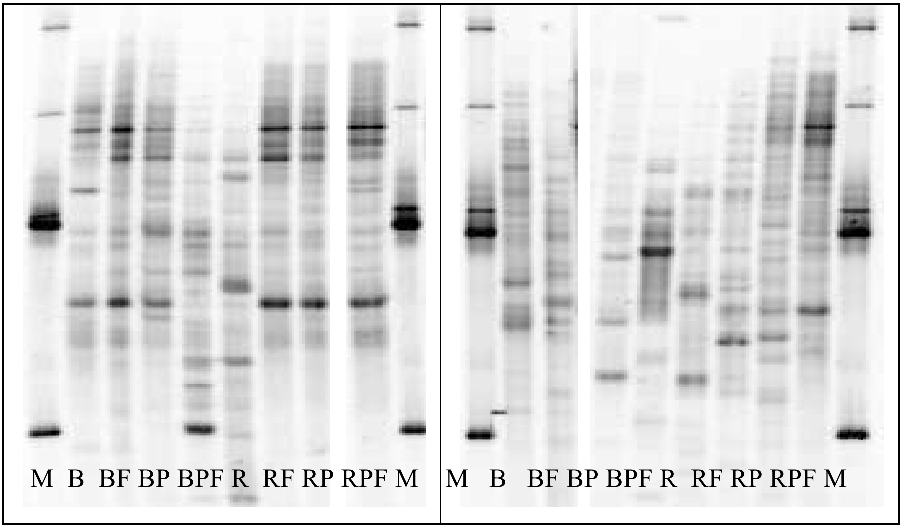
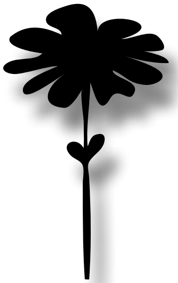


Figure 3. *Pseudomonas* community in eight different production systems on clay (left) and sand (right) with the molecular fingerprinting technique PCR-DGGE (1 replicate). M is a standard marker; B, R, F, and P correspond with barley, rye, wild flower and pea.

most distinct, but not significant, by cereal type (P = 0.07). The *Pseudomonas* population on sand (Fig. 3) was influenced most distinctly by having flowers included in the mixture (P = 0.10). Significant correlations were detected between the soil communities and the measured aboveground abundances or diversity (i.e., results on the performance of crops and wild flowers in the different production systems, Chapter 2). The presence of wild flowers, either biomass or number or species number, significantly influenced the composition of *Pseudomonas* and fungi in clay as well as sandy soil ($P < 0.05$).

Conclusion

The microbial communities and diversity indices were clearly different between the soil types. The hypothesis that the aboveground diversity of the crop-production system would correlate with an increased microbial diversity in soil could not be confirmed. However, the aboveground plant diversity, especially the wild flowers, did have a significant effect on the composition of belowground microbial populations, i.e. fungi and the bacterial genus *Pseudomonas*.



11 General discussion

Eveline S.C. Stilma

Introduction

Production systems with different levels of biodiversity were designed to 'create space in the Netherlands'. We aimed for high-quality crops that were produced in such a way that room was created for associated diversity to develop and that were an asset to landscape scenery. In our experiments, the systems were tested for aspects of ecology, economy and sociology.

In this thesis I describe the design process of the production systems for the Netherlands (Chapters 1, 2) and the evaluation of the different designs by field experiments (Chapters 3 – 10). In this general discussion I integrate and discuss the results of the evaluation of the different production systems with respect to system performance. First, I analyze the effects of cereal type, pea and wild flowers on profit, biodiversity and their value for the landscape scenery. Second, I suggest issues for further research to improve the systems. Third, I discuss the implementation of biodiverse production systems on farms and in society. Finally, I discuss the research methodology used.

System performance

The aim was to design systems with high yield of good quality in which associated biodiversity is given space to develop and which are attractive elements in the landscape. The following systems were evaluated on a sandy and a clay soil: spring rye *(Secale cereale)* and a mixture of 11 varieties of barley *(Hordeum vulgare)* were grown as monocrops or in mixed cropping with pea *(Pisum sativum)* with or without introduced wild flowers. The resulting four combinations for each cereal were: cereal monocrop, cereal mixed with pea, cereal with introduced wild flowers and cereal mixed with pea and introduced wild flowers. In order to be able to integrate the results of the different experiments, radar figures were made. In these figures the results of all aspects measured were combined to address differences between treatments on overall system performance (Figure 1; Table 1).

Yield performance

Yields from the different production systems were obtained without inputs of fertilizer or control of weeds, pests and diseases (Chapter 4). Treatments responded differently to these agronomically poor circumstances and responses depended on the location, weather and stage of the experiment. Yields were highest in the first year of production, when crops still benefited from the residual nitrogen in the soil from previous years. Establishment of the treatments on the sandy soil in 2004 had been preceded by a year of fallow, resulting in a lower initial soil nitrogen level compared to the other location × year of establishment combinations (“loc × year combinations”). The barley varieties used were bred to give high yields at high N-application levels. Our results showed that barley growth was poor on the sandy soil in 2004 whereas barley gave high yields at the other loc × year combinations that had not been preceded by a year of fallow. Rye is no longer common in the Netherlands. Rye is known for its high yielding ability on poor soils. We found that the production of rye silage was high at all loc × year combinations, although silage quality of rye was always lower than that of barley.

Pea-cereal mixtures are known for their ability to give higher yields than their combined monocrops (Mead and Willey, 1980). We also found that including pea enhanced yield and quality, especially on poor soils. Success of pea depended, however, on the weather and the companion crop. Pea production was most successful in 2005 and pea was less suppressed in barley than in rye (Figure 1 b,e).

Weeds compete with the crop thus reducing yield. A great result was that we found that the sown wild flowers did not significantly affect crop yield. Notably, the effects of the spontaneously occurring plants on crop yield were not part of the experimental design and were not assessed. Not all ‘weed’ species are highly competitive (Marshall et al., 2003) and the wild flower mixture we had sown was certainly no threat.

Associated diversity

Several factors were measured in the experiments to assess the effect of the cropping systems on associated diversity. Diversity of plant, nematodes, Coleoptera, soil fungi/bacteria and the changes in allele frequencies of the barley variety mixture were measured. The initial composition of the community of spontaneously occurring associated flora and fauna differed amongst locations. Locations normally differ in biodiversity because fields have a different cropping history and are located in different environments (Bianchi et al., 2006; Holland and Luff, 2000).

Treatments affected the performance of the associated diversity. As described above, crop performance per treatment depended on the location and the year of production, and treatments affected the associated diversity differently at locations. Additionally, the composition of the associated biodiversity was different at locations and accordingly followed a different pattern of development. However, treatments affected the associated floral and faunal community differently and the most prominent effects will be discussed.

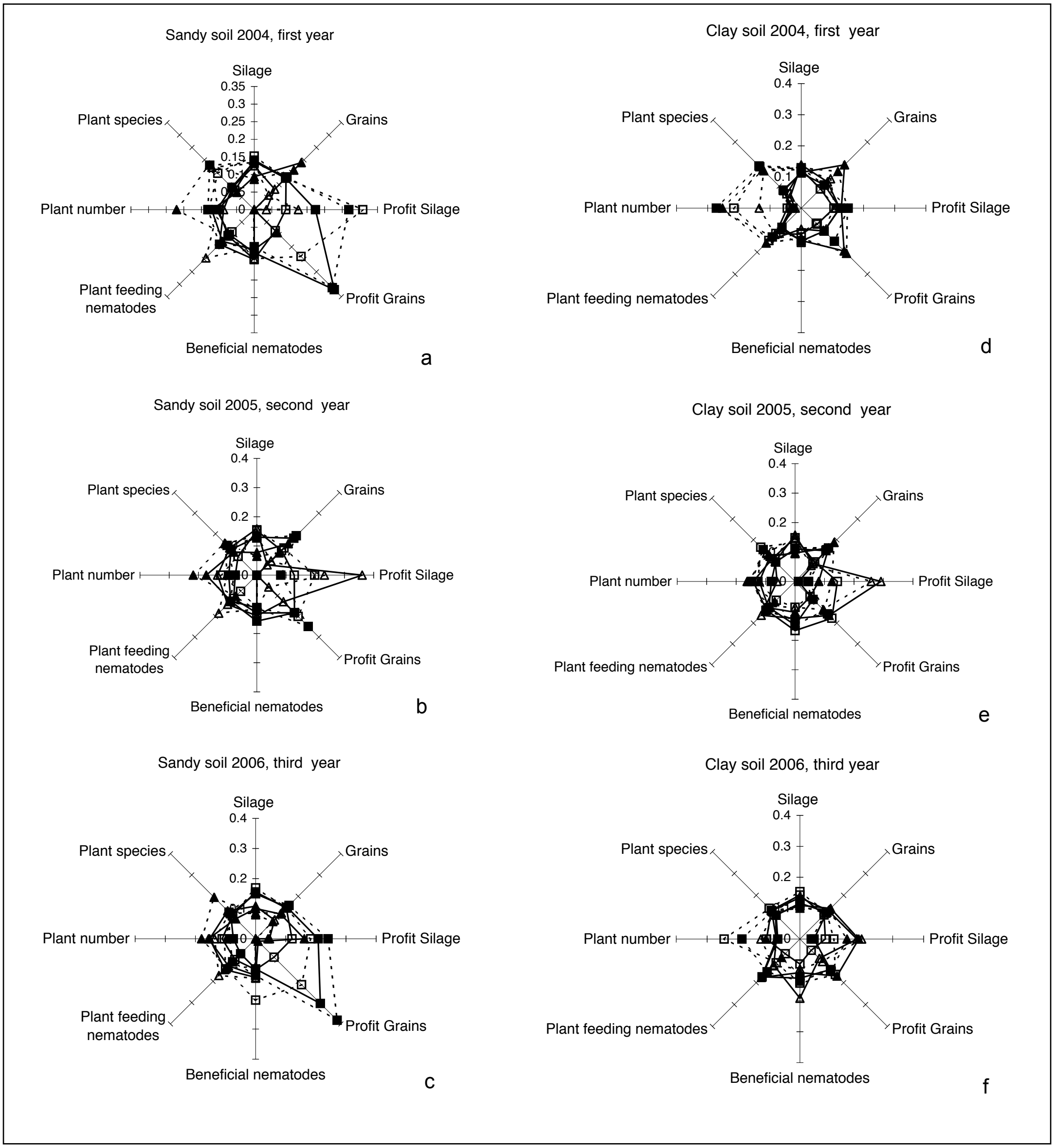


Figure 1. Relative data from each chapter are summarised by radar figures per location per year for three years in the development experiments. Data from the other experiments are summarised in Table 1. Symbols used are Barley: B = ▲▬, Barley flowers: BF = ▲----, Barley pea: BP = Δ ▬, Barley pea flowers: BPF = Δ---, R = ■▬, Rye flowers: RF= ■---, Rye pea: RP= □▬ Rye pea flowers: RPF= □---. Relative silage yield and grain yield was based on tonne/ha. Relative silage profit and grain profit was based on Euro/ha. Negative values were set at 0. Relative beneficial and plant feeding nematodes were based on number / 100 ml soil. Nematode numbers that were measured at the beginning of 2005 were used for 2004. Nematode numbers at the beginning of 2005 were used for 2006. Nematode numbers at the end of 2006 were used for 2006.

Coleoptera species respond directly to crop architecture and soil characteristics. Spontaneously occurring plants, nematodes and soil fungi/ bacteria are less mobile than Coleoptera species and their development pattern depends more on long term effects, such as changes in soil structure. Interpretation of processes that cause a shift in communities requires therefore

Table 1. The results from the different chapters per location per year are summarised by use of radar figures. For treatments codes see Figure 1. For perception of fields, the order of treatments was defined by ranking order of the pictures. For Coleoptera, the relative order of treatments was based on number of individuals per treatment per day. For bacteria/fungi relations the order was based on composition of species after the third year of the system development experiments. For genetic diversity, the order was based on evenness of the barley variety mixture after the third of the system development experiments.

Perception		**Genetic diversity**			
ranking order pictures (%)		Shannon Eveness (absolute value)			
All locations		Sandy soil 2006		Clay soil 2006	
▲---	0.17	▲---	0.95	▲▬	0.94
□---	0.16	▲▬	0.92	▲---	0.94
∆---	0.16	∆▬	0.92	∆▬	0.91
■---	0.14	∆---	*	∆---	0.89
▲▬	0.14				
∆▬	0.09				
□▬	0.08				
■▬	0.08				

Coleopterae					
	Carabidae (%)		**Coccinellidae (%)**		**Curculionidae (%)**
	Sandy soil (2), 2005				
□---	0.30	□▬	0.38	□---	0.51
□▬	0.28	□---	0.27	□▬	0.42
■---	0.22	■▬	0.18	■---	0.04
■▬	0.20	■---	0.17	■▬	0.04
		Clay soil (2), 2005			
□---	0.31	■▬	0.38	□▬	0.49
□▬	0.27	□---	0.22	□---	0.47
■---	0.21	□▬	0.21	■▬	0.03
■▬	0.21	■---	0.20	■---	0.01

Bacteria/ fungi					
	Fungi	**Bacteria pseudomonas**		**Fungi**	**Bacteria pseudomonas**
Sandy soil			Clay soil		
all ---	no difference	all ---	all ---	no difference	all ---
all ▬	no difference	all ▬	all ▬	no difference	all ▬

better understanding of other associated (soil) processes.

The initial associated plant species community at the start of the experiment was determined by the composition of the soil seed bank. The management method determines which species germinate and how vigorously they will grow. Vigorous growth within a crop causes higher reproduction (Brainard et al., 2005) affecting the next generation. Succession of vegetation community in natural areas without management shows that plants species composition develops naturally over time (Billings, 1938). In agricultural areas research has shown that weed communities are related to the environment and respond to the management method (Andersson and Milberg, 1998a; Barberi and Lo Cascio, 2001; Tuesca et al., 2001). The crops grown in our experiments affected the associated plant community. The crop competes with the associated plants for available resources including light, nutrients and water (Kropff and Spitters, 1991; Rajcan and Swanton, 2001). We chose not to apply fertilizers and to grow the crop at normal sowing densities. We found in our experiments that barley monocrop treatments had a poor competitiveness for light on the poor sandy soil (Chapter 5) leaving room for growth of the associated plants (Fig. 1a). On the other hand, rye-pea mixtures on clay soil had a poor competitiveness for nutrients because they fix nitrogen from the air, also giving room for growth of and reproduction of associated plants and sown wild flowers (Fig. 1f).

Coleoptera prefer half-shaded canopies (Honek and Jarosik, 2000) and are affected by the microclimatic factors such as soil temperature and soil moisture (Kromp, 1999). They are attracted to soil humus and benefit from soil organic matter (Holland and Luff, 2000). Different species prefer different microclimates. They also respond to the feeding source present which can be the crop itself, the associated plants or the insects attracted to the crop depending on the feeding habit of the Coleoptera species. We found that cereal-pea mixtures provided a better climate for Coleoptera pests (Curculionidae) and natural enemy species (Cocinellidae) causing a higher species diversity in cereal-pea mixtures than in cereal monocrops. Soil temperatures increased faster early in the season which was attractive for the beetles (Chapter 7).

Soil nematodes respond to the availability of their feeding source. Saprophytic nematodes are involved in breaking down organic matter; plant feeding nematodes feed on plants. There are many strategies to control soil nematodes. Control practices include use of a cover crop, crop rotation, a year of fallow, soil fumigation, and use of resistant crops (Barker and Koenning, 1998). We applied a mixed cropping method without fertilizers. Not much research is done on the effect of mixed cropping on nematodes. Plant feeding nematodes directly respond to the crops grown (Bongers and Bongers, 1998; Korthals et al., 2001). The development of nematodes in a mixture is therefore attributed to the species present in the mixture (Deyn et al., 2004). In our experiments *Tylenchorchynchus* spp. in sandy soil had increased fastest in barley-pea mixtures. Pea is sensitive to nematodes and cereal is a known host for nematodes. Nematodes did not increase greatly in our experiments, which was probably caused by the extensive production method making the crop less attractive for the nematode population.

Changes in soil diversity were expressed by bacterial and fungal soil diversity. It was hypothesised that above-ground crop diversity is related to below-ground diversity. A relation between above-ground and below-ground diversity was found in earlier studies (Garbeva et al., 2006). We found no differences in diversity and evenness of diversity between treatments; we did find an indication that species composition was affected by wild flowers in the mixture.

A cereal variety mixture was sown with the idea that the crop would be more resistant against pests and diseases than monocultures (Booth and Grime, 2003; Finckh et al., 2000). We found that crop yield was not reduced by a pest or a disease. The results of the development of the barley variety mixture suggested that barley varieties responded differently to the companion crop.

In conclusion, the above mentioned shows that many factors beyond crop competition affected the associated diversity. Crop treatments affected the associated diversity, but the effect was different at different locations. Low competition for light of barley on the poor soil resulted in a large community of associated plants. Low competition for nutrients by including pea caused vigorous associated plant growth. The development of nematodes was different at both locations. Coleoptera diversity was higher in cereal-pea mixtures than in cereal monocrops. Soil bacterial and fungal species composition was affected by wild flowers. The development of the barley variety mixture differed for monocrops compared with cereal-pea mixtures.

Contribution to landscape scenery

Perception of biodiverse production systems was assessed as described in Chapter 2. The scenery of the countryside changed since the intensification of agriculture. Before the reallocation of land the landscape view was featured by small 'weedy' fields surrounded by natural elements, like wood edges, ponds and small lanes between the fields. After the intensification, fields were large, cropped to monocultures. The results from the study on perception of agricultural fields in the landscape (Chapter 3) showed that elder people brought back images of the former landscape. Half of the respondents favoured a diversified landscape and most of the respondents appreciated wild flowers in the fields. Young people, who were not raised with these images but who had knowledge about the use of biodiversity appreciated a wild look in the fields as well. However, respondents, who did not have a relation with nature or agriculture, typically raised in the city, appreciated field with biodiversity less. They favoured a park-like landscape. After it was explained why biodiversity was important, however, they appreciated the fields much better. Also farmers, who looked upon fields from an economic point of view, were hesitant about wild flowers in the fields. Respondents from all groups appreciated barley more than rye, and rye-pea mixtures were better appreciated than barley- pea mixtures (Chapter 3). Pea in barley looked messier than pea in rye and pea was therefore less appreciated in barley than in rye.

Further research to improve the systems

The results of our experiments, as summarised above, show that high yields can be obtained while allowing associated diversity to develop within the fields. However, success was not always achieved. In our experiments, barley monocrop treatments gave low yields on the poor sandy soil. Poor growth was associated with high numbers of associated plants. Barley monocrop gave high yields on the rich(er) clay soil. Production on clay soil was associated with lower number of associated plants. An intermediate yield level should be aimed for to find a balance between competition with the associated flora and yielding ability and quality.

We did not apply nitrogen to allow associated plants to grow in the fields. Competition at high nitrogen level benefits the crop more than most of the associated plants because crops have higher nitrogen use efficiency (NUE) than associated plants resulting in stronger competitive ability for light (Andersson and Milberg, 1998b; Goldberg and Miller, 1990). A dense canopy suppresses growth of the associated plants (Chapter 4). However, at low nitrogen levels, yield and quality of the cereal crop were poor (Chapter 4) and the ratio between crop biomass and associated flora biomass became unbalanced. We found that sown wild flowers grew more abundantly on nitrogen rich soils than on the poor sandy soil (Chapters 4, 6), which was unexpected as we thought low nitrogen would benefit the wild flowers. Based on these results, fertilizers could be applied in future practice to enhance crop yield and quality and to stimulate growth of the wild flowers. An optimum fertilizer application level should be found. Accordingly, competition for light could then be decreased by sowing at a lower crop density (Carlson and Hill, 1985). A lower density may give lower yield but of good quality. A lower crop density is more attractive for faunal species like beetles as well (Honek and Jarosik, 2000). Additionally, organic fertilizers enhance Carabidae (Holland and Luff, 2000). We measured no crop yield reduction by competition with sown wild flowers. However, the abundance of spontaneously occurring plants increased over time, and *Chenopodium album* was taking over competition on the sandy soil causing a threat to crop production (Chapter 6). Therefore, the associated flora should be managed for desired wild flower species but dominant (weed) species should be controlled

(Storkey and Westbury, 2007). Management methods should be developed. Options are precision control through use of robots or use of allelopathic ability (of crops in the mixtures or by crop rotation) or cover crops.

Pea was included in the mixtures to overcome poor growth without application of nitrogen. Pea enhanced crop yield and crop quality by protein content confirming results by others (Carr et al., 2004; Carr et al., 1998; Juskiw et al., 2000). Number of associated plants and species was also higher in mixtures with pea. Although pea enhanced yield and quality, yield stability was not achieved because pea was sensitive to weather and competition of the companion crop. Unstable pea yields were found before (Anonymous, 2003; Carr et al., 1998; McPhee and Muehlbauer, 1999). McPhee and Muehlbauer (1999) showed that pea yield was high if precipitation was evenly distributed throughout the growing season. Other leguminous species could be investigated, although pea is known as a good option so far. For example, lupine is a species that gives more stable yields, but of lower quality than pea (Knudsen et al., 2004). Field bean is a crop that gives high quality (Gooding et al., 2007), but matures later than pea (Knudsen et al., 2004). Additionally, the management method could be adjusted. Cereal crop yield is also enhanced in a rotation in which a legume is sown in alternate years with the cereal (Christiansen et al., 2000). The effect of enhanced soil nitrogen by the pea crop is measured a year after production because of incorporation of pea residues into the soil (Chapter 4).

Associated diversity

Sown wild flowers grew abundantly in the first year. However, on the sandy soil they almost disappeared after the first year, probably because of poor seed setting on that soil. Sowing of wild flowers was expensive and successful establishment is therefore important. Establishment of wild flower species was investigated in grassland meadows (Jones and Hayes, 1999). Competition is a main reason for establishment of one species over another (Hitchmough, 2000). In grasslands, an increase in fertilizers benefits the grasses more than the wild flowers, decreasing wild flower diversity (Warren, 2000). However, without competition, wild flowers that thrive on rich soils also benefit from higher levels of fertilization, only wild flowers that thrive on poor soils do not (Tamis et al., 2005). Vigorous growth should be obtained in the first year such that flowers can reproduce profusely. Establishment of nitrogen rich thriving species can be achieved by a sufficient initial amount of soil nitrogen while decreasing the competition of the crop. Sowing of wild flowers in more years enhances the chance of establishment. Additionally, more species could be added to the wild flower mixture.

A mixture of 11 common barley varieties was used. Common varieties were used that were bred for European countries that aim at successful yields in favourable environments. Little breeding work has been done so far on varieties that perform well in poor environments (Ceccarelli, 1994). Effort could be put in developing a suitable barley variety mixture for high yield on poor(er) soils and low competition with associated diversity. Results of our experiments suggest that the composition of the barley variety mixture changed over time and that changes were different for monocrops and mixtures (Chapter 9). The cultivar mixture could be adjusted for monocropping or mixed cropping systems as was shown by another study in which performance between two millet cultivars was the same in the monocrop, but one cultivar performed better in intercrop (Yadav and Yadav, 2001). The choice of pea cultivar could also affect total yield efficiency of the mixed crop (Hauggaard-Nielsen and Jensen, 2001).

Most of the indicators we investigated captured above-ground diversity. An important part of diversity and competition, however, takes place below ground (Casper and Jackson, 1997). Effects of the different treatments were measured on nematodes and on fungi/bacteria. However, the underlying processes were not assessed. No inorganic nitrogen was applied, although organic manure could have improved soil quality and thus ecosystem performance. Organic manure stimulates biological activity

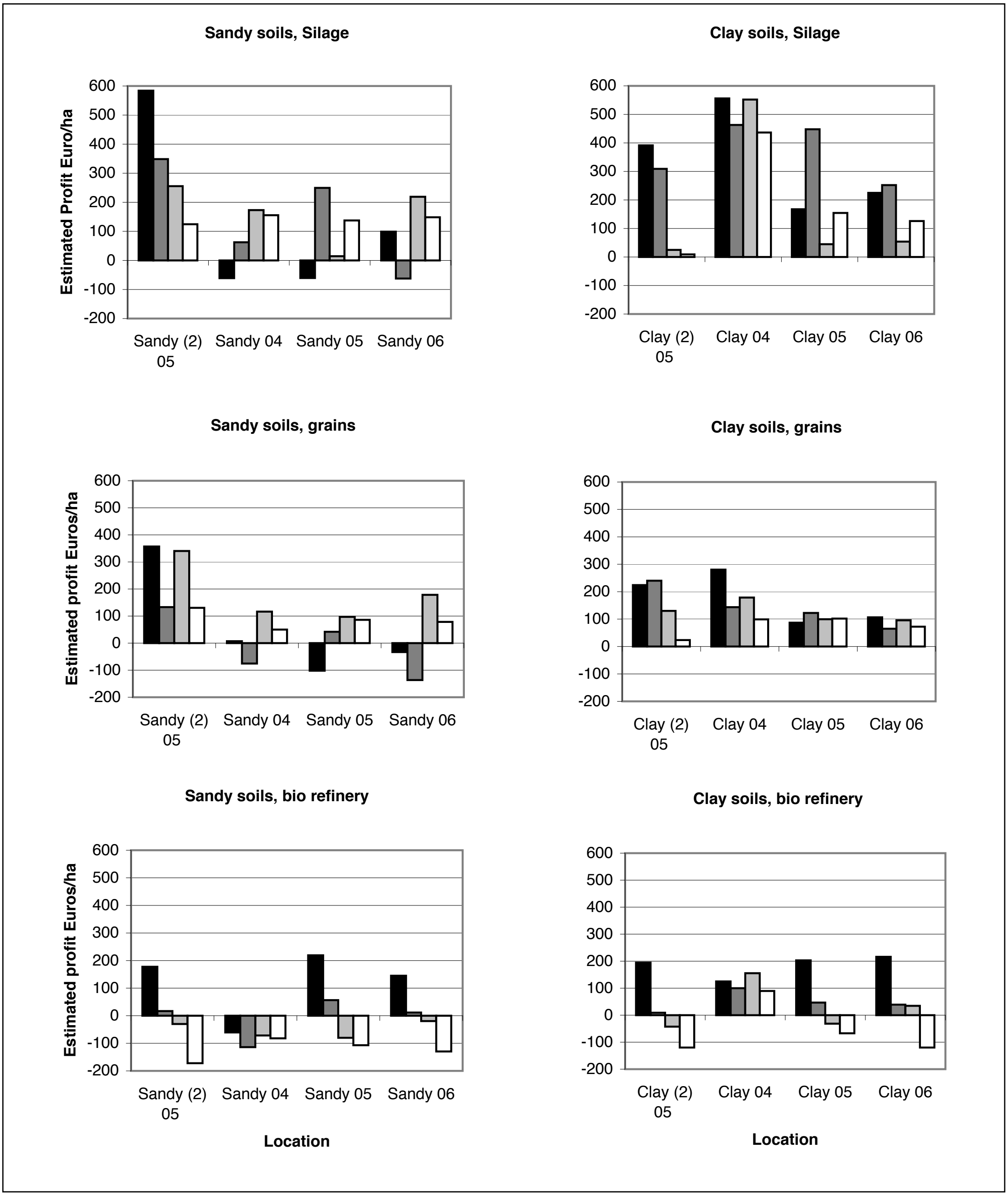


Figure 2. Profit from biodiverse production systems. An average of the results of treatments with and without sown wild flowers is given. The source used to calculate the gross margins of the different crops was KWIN (2006). Profit was calculated for whole plant silage, grains and biorefinery (Fig 1). Biorefinery means that the harvested product is processed to separate the components (starch, protein) that then may be sold as separate products (Van Dam et al., 2005). Black bars = barley, dark grey = barley pea, light grey = rye, white = rye pea.

more than artificial fertilizers (Maeder et al., 2002). Soil aggregate stability is enhanced that stimulates microbial and earthworm biomass. Macro fauna families (beetles (Coleoptera), flies (Diptera) and earthworms (Haplotaxida)) are attracted to organic matter (Lahr and Pol, 2007) as well as other fauna families including mites (Acari), potworms (Enchytraeidae), and nematodes (Nematoda). Microbial organisms reduce leaching of nutrients (Maeder et al., 2002). To improve biodiverse production systems further, the relation between below-ground and above-ground diversity should be investigated more.

Wild flowers are expected to affect a diversity of faunal species like hoverflies (Weiss and Stettmer, 1991), bees (Banaszak, 1992) or arthropod fauna (Wyss, 1996). The benefit of wild flowers to other species may be investigated in more detail in the future. The positive effect of flying insects on the perception of systems could also be investigated.

Contribution to the landscape scenery

The management of the landscape is increasingly taken care for. Besides the application of agri-environment schemes, which already contribute to a diversification of the landscape, plans are being made to re-arrange the agricultural landscape, by integration of food production with societal goals. Plans are made to integrate agricultural fields with houses (Van Spruijt et al., 2004). Studies are done on the preference of inhabitants for landscape elements. An example is the study towards the preference for tidy or wilderness kinds of landscapes (Van den Berg and Koole, 2006). Biodiverse production systems could be part of future landscape design projects. Signposts could be placed besides the fields with background information. Farmers who incorporate recreation activities at their farms could be educated such that they can pass on information to their guests.

Implementation of biodiverse production systems on farms and in society

Profit

Profit from production systems was high especially in the first year of growth compared to current production systems (Figure 2; Table 2). Profit was high at some locations but unprofitable yields were also obtained (Figure 2). Pests and disease had not destructed yield in any of the years and profit was high because pesticides and fertilizers were not used. Yield stability is important for implementation of the systems at farm level (Lammerts van Bueren et al., 2002). A farmer has to take great risks if crop yields are insecure. The aim of production should be taken into account in order to apply biodiverse production systems. If the aim is to bring back endangered plant species in arable fields that only thrive on poor soils, a cereal crop should be chosen that gives adequate yields on poor soils. In our experiment that would mean that rye was a better option than barley, although silage quality

Table 2. Silage yield, grain yield and calculated profit from current conventional and organic cropping systems (KWIN, 2006).

Conventional		Grains (kg/ ha)	Silage (kg/ ha)	Profit (Euro/ha)
Clay	Spring barley	6600	3300	526
Clay	Peas	5800		475
Sandy soil	Peas	5800		463
<u>Organic</u>				
Clay	Peas	4000		1595
Clay	Spring barley	4250	2750	291
Sandy soil	Winter rye	3500	2500	-24

Source (Kwin, 2006)

of rye was low. Perhaps other cereal types or barley varieties could be used that give adequate yields on poor soils. If the aim of production is high yield potential and associated diversity is a side effect, perhaps a common (high yielding) crop variety should be grown, but sown at a lower crop density. If the aim is to create a beautiful landscape, a short cereal should be chosen that leaves the landscape open and in which wild flowers can grow above the crop. If the aim is to increase crop diversity without fertilizers, pea should be included in the mixture. However, pea in barley was not perceived as beautiful unless respondents valued the biodiversity aspect of pea and this mixture could therefore not be used if landscape aesthetic is an important objective.

The choice of the cropping systems depends on the environment and on the background of the inhabitants. (Conventional) farmers appreciated systems that radiate high production, whereas nature devotees appreciated the fields with the wildest look. Nature conservation followers commented by creation of habitats only for natural germination of endangered species. Therefore, biodiverse production systems with wild flowers and pea could best be grown near areas where people appreciate a wilderness look, whereas cereal monocrops could be grown in areas where inhabitants value fields with a neat look. Current practice already shows that profit by external services is highest if the measures are adjusted to the needs of society near the production area (Visser et al., 2004). Extra services on farms are implementation of agri-environment schemes, producing energy (wind mills) or recreation facilities at the farm (Râmniceanu and Ackrill, 2007; Schoorlemmer et al., 2006). Recreation was most successful in semi-urban areas, whereas energy crop production was most successful in less densely populated areas.

To facilitate the application of systems in the beginning, the government should facilitate and compensate by means of agri-environmental schemes for the lower yields until management and technology have developed biodiverse systems that gives medium to high, stable yields.

Associated diversity

The way people looked upon the management of biodiversity influenced the way people judge 'success of system performance'. Nature conservationists want to leave 'natural areas' alone and are against sowing of (endangered) species. Agronomists feel biodiversity can be managed. They have fewer problems with sowing of (endangered) species. Literature reports that it is almost impossible to bring back endangered species naturally on common agricultural soils due to a lack of seeds of these species in the seed bank and the surrounding fields. It succeeded only on fields of conservation areas that were recovered before 1940-1950 (Anonymous, 2008; Hyvönen, 2007). For agricultural soils, sowing of species appears the best way to bring back agricultural plant diversity.

Novel of this study was that biodiversity is managed within fields. If these systems will work in the future, a big advantage towards environmental management could be achieved. Reason is that the area that is managed for biodiversity will increase as it encompasses (large) areas that were previously not being managed for biodiversity.

Contribution to the landscape

Implementation at farm level is most successful if farmers understand the reason behind the measure (Juntti and Potter, 2002). Farmers tend to implement environmental management policies on their farms by sticking to policy rules to obtain subsidies or they might implement measures without proper knowledge of the rules and miss the subsidies. Educated farmers can contribute more to successful implementation (Wilson and Hart, 2001). In order to bring about policy rules, intermediates should understand the incentives of farmer's practices, which sometimes go beyond individual farm level. Farmers might decide about implementation of landscape elements on their farms depending on the actions undertaken by their neighbours. Understanding farmer communities is best achieved by use of co-operative concepts (Siebert et al., 2006). Compared to other EU countries, farmers in the

Netherlands are highly engaged in co-operations. As farmers in a cooperation learn from each other and from advisors, applications become more successful (Siebert et al., 2006).

Research methodology

In-depth analyses per expertise have been carried out for a long time. Now it is becoming increasingly acknowledged that bridges need to be built between disciplines in order to apply in-depth knowledge in a rapidly changing society (Von Wiren Lehr, 2001). Initially, papers were written to describe methodologies to facilitate the work on multi-disciplinary farming systems (Van Mansvelt, 1997; Vereijken, 2002; Von Wiren Lehr, 2001). At the moment, experts from different research groups are working together to substantiate technical research by social studies (Schenk, 2008). The work described in this thesis is also based on a multi-disciplinary approach. The methodology used was, however, not common. Normally, experimental set ups are built upon one hypothesis. In addition, results are integrated by review articles. In our experiment one system, with some variations, was designed and tested for aspects of ecology, economy and sociology. Here we discuss the advantages and disadvantages of our methodology.

The aim of the study was to design a system that could be applied in society. Therefore it was necessary that the systems were successful on all aspects (as described in Chapter 2). Typically, common research is focussed on one aspect ignoring functionality at other aspects. A hypothetical example is that an optimal flower mixture for field margins is made to obtain maximal diversity ignoring the fact that some species might be hosts for pathogens that may then survive during winter. Additionally, our focus on implementation in society gave insight into social factors that would not have been brought up without the stakeholder's consultation.

Explanation of the research context per individual chapter was very important. As was described in the design article, compromises between (sub) design goals were necessary to obtain an overall functioning production system (Chapter 2). For example: when barley and rye were sown in autumn the germination and establishment of wild flower species would be enhanced. Most of the typical wild flower species of arable crops are germinating in autumn after the harvest or after a vernalisation period. However, including pea in the production systems is only possible when cereal crops were sown in spring. Our main focus was to describe the development of a whole cropping system and analyse the contribution of different aspects to the whole system. The extra value in this thesis comes from the integration of all these aspects presented in previous chapters. As such, systems could be designed from which different sides were highlighted through which the choice to apply such systems in society can be made with better consideration as it is based on more background knowledge.

Conclusion

Results of this study show that it is possible to grow productive cereal crops of high quality with a high associated diversity that enriches the landscape. Success was achieved for some of the crop treatments in our experiments and depended on the crop, the site and the weather. If systems are produced in the future they should be chosen per site and considering the aim of the production.

Summary

Summary

Introduction

The Netherlands is a small and densely populated country and space is needed for housing, industry, infrastructure, recreational purposes, nature conservation and agriculture. Biodiverse production systems were designed to 'create space in the Netherlands' by integrating aspects of ecology, economy and sociology within one agricultural field. Agriculture is now intensively being managed, especially in the Netherlands. Since 1870, a green revolution caused an intensification of agriculture in Europe during which the use of artificial fertilizers and pesticides increased. Additionally, maximum production was stimulated by European policy (CAP).

Although the economy has greatly benefited from an expansion in agricultural production, intensive management had its drawback on the environment. Plants that thrive in agricultural fields are becoming extinct. Numbers of farmland birds are declining as their feeding source, consisting of plants and insects associated with agriculture, is reduced. Therefore, there is a need to develop new kinds of cropping systems, which have high yields of good quality, but also leave room for associated biodiversity.

This thesis is about development of such systems with different levels of biodiversity. The initial design was based on a literature review. The design was discussed with stakeholders. Stakeholders were involved in sustainable agricultural production, like farmers, representatives from nature conservation organizations, scientists, consultants from intermediary institutes and policy makers. Their input was used to improve the design, but also to develop indicators to test the design for system performance. Success of system performance was based on success on the aspects of economy, ecology, and sociology. Success factors per aspect were listed and important aspects were chosen as 'indicators' to determine success of system performance. The design process and the evaluation of the different cropping systems are described in the thesis.

Experimental set up

Production systems consisting of a genetically diverse and species rich crop mixture were established at two locations (one on sandy soil and one on clay soil) for three consecutive years to allow the crop and the associated diversity to develop in so-called 'system development experiments'. No measures were taken to control diseases, pests or weeds. Also no fertilizers were applied to reduce the competitive strength of the main crop and to allow for development of wild flower plant species and other associated diversity. Cereal-legume mixtures were chosen as they are known for their high yields in mixtures compared to the sum of their sole crop yields under poor growing conditions. Cereal species were either 11 spring barley varieties (*Hordeum vulgare*; cvs Apex, Aramir, Class, Extract, Jersey, Madonna, Orthega, Pasadena, Prestige, Reggae, and Saloon) or one spring rye variety (*Secale cereale* cv. Sorom). Only one spring rye variety was used as rye is a cross pollinator, whereas barley is a self pollinator. Barley is known for its high yield of high quality, and rye is known for its good performance under poor growing conditions. Spring cereals were used to allow for simultaneously sowing the legume crop. The legume was a semi-leafless pea variety (*Pisum sativum*, cv. Integra). Additionally, a mixture of five indigenous wild flowers species (*Centaurea cyanus*, *Chrysanthemum segetum, Misopathes orontium, Papaver rhoeas* (both soils) and *Matricaria recutita* (sandy soil) or *Tripleurospermum maritimum* (clay soil) was introduced within these crop mixtures, resulting in eight treatments composed of a cereal in monocrop, a cereal with pea, a cereal with wild flowers and a cereal with both pea and wild flowers. Cereal seeds were harvested and used as sowing material for the next year, pea seeds were renewed every year and wild flower seeds were sown once in the first year. The experimental set up was a randomized complete block design with four blocks in each field. Individual plots were 180 m^2 in size. In 2005, repetition experiments were carried out at two other locations (one on a sandy soil and one on a clay soil). These experiments were maintained for one year.

Several indicators to measure system performance were used. To investigate whether production systems fulfilled aspects of 'economy', the silage and grain yields and the quality of these crops were analysed. For the aspects 'ecology', the development over time in number and species composition of the accompanying flora was analysed. Moreover, a model was developed to describe the effect of shading by the crop on the population dynamics of wild flowers within one growing season. Additionally, the beetle population in one growing season was analysed. Furthermore, the development of the nematode population was assessed each year for three consecutive years. The development of the composition of the barley variety mixture over time was analysed by use of DNA analysis. Soil fungi/ bacteria relations were analysed. As an aspect of 'sociology', the perception of biodiverse production systems by the people was analysed by interviews.

Profitability

To assess profitability of the production systems, the silage and grain yields as well as silage and grain quality were assessed in the system development experiments and in the repetition experiments. Dry matter yields of whole crop silage were assessed (including cereal, pea, wild flowers, spontaneously occurring plants). Biomass of the different crop components were also measured. Silage quality was determined using the criteria dry matter, crude protein, crude fibre, crude ash, starch and digestible organic matter. Cereal grain yields were assessed separately. Grain quality was determined by assessing germination percentage and thousand grain weight. Results showed that high yields were obtained, especially in the first year. However, the yields and quality depended on the crop, the site and the year of production. Barley gave high yields of good quality on three of the four locations. Barley performed poorly in the system development experiment on the sandy soil. On that soil the experiment was preceded by a year of fallow, resulting in a relatively low soil nitrogen level. Rye gave higher yields than barley in that experiment, but silage quality of rye treatments was lower than that of barley treatments. When pea was included in the mixture, yield was enhanced, but only on soils that had poor to medium fertility. Pea is sensitive to adverse weather conditions and shows a large year-to-year variation in yield. Pea yield was highest in 2005. In that year, pea and barley matured simultaneously. Quality of the mixture was enhanced by the high protein content in the pea. Pea is also sensitive to competition and the pea crop was suppressed more by rye than by barley. Sown wild flowers did not affect yield. Germination percentage of cereal seeds from barley monocrop treatments was highest except for the barley monocrop treatments on the poor sandy soil. Germination percentage of barley and rye increased over the years on both soils, thousand grain weights decreased over the years.

Plant species development

The development of the associated plant population was monitored in the system development experiments. Therefore, all associated plant species (sown wild flowers and spontaneously occurring plants) were counted four times per growing season on 1 m^2 within each plot. All plant species were identified and numbers per species per 1 m^2 were recorded. The abundance of the associated plants, the number of species, the evenness of the abundance per species and the composition of the community (presence of species) were analysed. The species composition was different between the sandy soil and the clay soil. The abundance of species at the beginning of the experiments was higher on the sandy soil than on the clay soil. The population on the sandy soil was strongly dominated by *Chenopodium album* causing a lower evenness than on the clay soil where no specific species showed such a large dominance. New species emerged on both soils, but more new species emerged on the clay soil than on the sandy soil. Number of associated plants in mixtures with pea was the same as in cereal monocrops, however, the individual plants had larger size, and the number of species was higher in mixtures with pea in the last year than in monocrops. Abundance of associated plants was highest in the barley monocrop on the poor sandy soil. Wild flowers grew abundantly in the first year on both soils and in the third year on clay soil. On clay soil, they returned most abundantly in the rye-pea-wild flower treatment. The abundance and species number of associated plants increased over time. However, there is a risk of dominance by associated plants, especially when the cereal crop is a poor competitor due to low soil nitrogen. Therefore, systems should be managed in such a way that associated plants flourish in association with the crop, as long as dominance by the associated plant community is controlled. Methods to manage the associated plant community need to be developed in the future.

Relation between dynamics of crop growth and attrition and recruitment of sown wild flowers

A mathematical model was developed that describes the growth of the crop canopy and the effect on the recruitment and attrition of the sown wild flowers. Canopy growth was described by a sigmoid function. The sigmoid was derived from common crop growth functions. Crop treatments differed in the course of shading over time. The largest difference was measured between cereal monocrop treatments and cereal pea mixtures. Overall, cereal-pea mixtures reached 50% soil cover later in the season than cereal monocrops did, but maximum soil cover at the end of the season was higher in cereal-pea mixtures. Consequently, when the difference in shading between treatments was captured by the sigmoid function, the parameters to describe attrition and recruitment were similar for the various treatments. That means that attrition and recruitment were directly affected by shading. Attrition and recruitment differed between soils, and wild flower species. We derived from the calculations that *P. rhoeas* had a germination delay of 200 degree days compared to the crop and the other wild flower species. Germination and death rate was higher in *P. rhoeas* than in the other three species. Soils in 2005 had higher death rates than soils in 2004 for all wild flower species.

Beetles

Beetles (Coleoptera: Carabidae, Coccinellidae, Curculionidae) were captured continuously throughout one growing season (year 2005) in rye treatments of the repetition experiments. Four pitfall traps were placed in each plot that were emptied nine times at regular intervals. The beetle community appeared to be different at the two soils. On the sandy soil, the number of species was higher, but abundance was lower than on the clay soil. On clay, the population was dominated by *Pterostichus melanarius.* Rye-pea treatments on sandy soil attracted more Carabidae, Coccinellidae and Curculionidae. On clay soil only Curculionidae were higher in rye-pea treatments than in rye-monocrop treatments. Attraction to pea occurred mainly in the beginning and in the middle of the growing season. Number of beetles was higher earlier in the growing season on sandy soil than on clay soil, possibly due to higher soil temperature on sandy soils. The beetle species composition changed over time because some species were attracted to the pea crop. Surprisingly, wild flowers had no significant effect.

Nematodes

The nematode community was assessed over time as nematodes were expected to become a threat during continuous cropping, especially to pea. Therefore, nematodes were measured from soil samples of the system development experiments at the beginning of the growing season and in the last year also at the end of the growing season. Plant feeding nematodes that are known to affect crops included in the experiments were analysed per species and other nematodes known to be not harmful for crop production (beneficial nematodes) were analysed as one group. The latter group was expected to be beneficial for crop production as they are involved in soil processes that benefit crop production, e.g. by releasing plant nutrients. A nematode outbreak did not occur, and the number of beneficial nematodes even increased on sandy soil suggesting a positive development of the nematode population. Differences between treatments were prominent on sandy soil for *Tylenchorchynchus* spp. that had increased fastest in barley-pea mixtures. Notably, pea is more sensitive to most species of this genus than barley or rye, and the same number of nematodes could have affected pea more. However, nematodes were not expected to have caused major crop losses.

Perception of biodiverse production systems

Biodiverse production systems were designed to improve landscape aesthetics. To assess whether systems were appreciated, 30 respondents were interviewed. The experimental methodology was qualitative, meaning that the research question was focusing on the reasoning behind the answers. In quantitative research, the research is based on the amount of respondents that give similar answers to multiple choice questions. The results are then statistically founded. However, in quantitative research the answers of the multiple choice questions have to be made up by the scientist in advance. In qualitative research, the questions are open and the answers are given by the respondent. The advantage is that different kinds of visions about perception of agricultural fields are being brought up, which was the aim of this research. Different kinds of respondents were chosen to obtain a large variety in answers. Half of the respondents were selected based on age, gender and education, whereas the other half was selected based on their residence and their relation to biodiversity and agriculture. These respondents came from the Kempen and were farmers, inhabitants, policy makers and tourists with a permanent caravan on a campsite in the neighbourhood. Pictures of the experimental fields were presented, as well as pictures from three prevailing production systems; maize, tulip and field margins. Questions were asked to determine respondents' relation to agriculture and nature and their vision on these topics. There was a relation between the background in nature/agriculture and respondents' appreciation of the systems shown. Farmers appreciated fields that radiated high yields, whereas respondents that valued naturalness appreciated fields with a wilderness look. Respondents who had no relation with agriculture or nature appreciated fields that were neat and tidy, resembling a park kind of landscape. Overall, barley was appreciated more than rye. Important aspect was the ability to look over systems to see the rest of the landscape. Pea in the mixtures was valuated negatively in barley and indifferently in rye. Wild flowers greatly enhanced the beauty of production systems. Only some respondents did not appreciate wild flowers. Conventional farmers appreciated them less because of the association with yield loss caused by weeds, and respondents not related to nature appreciated them less as they associated wild flowers with stinging insects.

Development of the barley variety mixture over time

A mixture of 11 spring barley variety was sown in equal densities at the beginning of the first growing season. Barley is a self-pollinator. The composition of the barley variety mixture was analysed at the end of the third growing season by DNA identification. The evenness of the variety composition was slightly higher in barley monocrop treatments than in barley-pea mixtures.

Relation between above- and below-ground biodiversity; soil bacteria/fungi diversity

To relate above- and below-ground diversity, soil fungi diversity and bacterial diversity were analysed. Soil samples were taken at the end of the last (third) growing season in the system development experiments. Diversity in fungi and bacteria was different between soil types, but not different between treatments. However the composition of DNA bands that represent presence of specific soil-borne species was related to the presence of wild flowers on both soils.

Discussion

The results show that it was possible to establish biodiverse production systems with high yield of good quality and with associated diversity, especially in the first year of production. Even after three years adequate yields were obtained. As associated sown wild flowers did not affect the yield of the crop significantly, allowing these wild flower species to mix with the crop is an alternative to field margins. Biodiverse production systems were perceived as beautiful. However, high yields were not always obtained depending on the crop, the location, and the weather. It is suggested to carry out future research on the effects of organic manure. Nitrogen enhances quality. Organic manure stimulates soil fertility, and enhances natural processes in soil and stimulates soil faunal diversity. High nitrogen levels normally increases the competitive ability of the crop against the associated plants, but if needed this ability can be reduced by a lower crop stand density. Including pea in the mixture reduced the competition for soil nutrients, and increased attraction of associated diversity. However, pea was sensitive to adverse weather and pea did not always increase yield. Therefore, other leguminous crops should be tested. Crop systems could also be designed with a crop rotation or cereals and legumes instead of a mixed crop. Additionally, an effort should be made to improve the barley variety mixture. A mixture of 11 common European barley varieties was used that were bred for high yield under high inputs. However, other selections could have been made, for instance by selecting varieties that grow well on poor soils or in competition. The relation between above-ground and below-ground diversity could be investigated more intensively; the same is true for the effects of organic manure on crop production and soil faunal diversity.

To increase the change of successful application of biodiverse production systems in society, some aspects could be considered. The type of production systems chosen should be site-specific. That means for example that when the landscape needs to be open, barley is a better option than rye; when production on poor soils is required, rye performs better than barley. Second, because high yields were not always obtained, the government should compensate for yield losses in poor years until systems have been improved. Third, success of implementation at farm level is enhanced if farmers understand the reasoning behind the production systems.

Samenvatting

Samenvatting

Inleiding

Nederland is een klein en dichtbevolkt land. Ruimte is nodig voor huizen, industrie, infrastructuur, recreatie, natuur en landbouw. De gangbare landbouw wordt op dit moment intensief bedreven in Nederland. Rond 1870 was er sprake van een 'groene revolutie' waarbij het gebruik van kunstmest en chemische bestrijdingsmiddelen sterk toenam en maximale productie werd nagestreefd. Dit werd gestimuleerd door Europese wetgeving (CAP).

Alhoewel de economie sterk gebaat is bij een hoge landbouwproductie, heeft intensieve teelt een negatief effect op de omgeving. Planten die goed gedijen op akkers verminderen sterk in aantal of sterven uit. Het aantal weidevogels neemt af doordat hun voedsel dat bestaat uit planten en insecten, schaarser wordt. Daarom is het nodig om nieuwe teeltsystemen te ontwerpen, die hoge opbrengsten van goede kwaliteit leveren maar ook ruimte laten voor de ontwikkeling van de aan de landbouw geassocieerde biodiversiteit.

Dit proefschrift gaat over het ontwikkelen en toetsen van teeltsystemen met verschillende verschillende niveaus van biodiversiteit. Een eerste ontwerp werd besproken met belanghebbenden ("stakeholders"). Belanghebbenden zijn personen betrokken bij de landbouw, zoals boeren, vertegenwoordigers van natuurbeheer, wetenschappers, mensen van landbouwadviesbureaus en beleidsmakers. Hun reacties zijn gebruikt om het ontwerp te verbeteren, maar vooral ook om indicatoren te ontwikkelen om de teeltsystemen te evalueren. Functionaliteit van de systemen werd getoetst in de gebieden economie, ecologie en sociologie. Daarvoor werd per gebied een lijst van indicatoren opgesteld waarvan er een aantal zijn gebruikt voor de toetsing van het ontwerp.

Onderzoeksopzet

Biodiverse teeltsystemen (bestaande uit een genetisch en soortenrijk gewassenmengsel) werden geteeld op twee locaties (een zand- en een kleigrond) gedurende drie opeenvolgende jaren om de ontwikkeling van het gewas en de bijkomende biodiversiteit mogelijk te maken. Er werden geen beheersmaatregelen tegen ziekten, plagen of onkruiden genomen. Ook werd er niet bemest om de concurrentiekracht van het gewas te beperken en dus de ontwikkeling van wilde plantensoorten en andere biodiversiteit een kans te geven. Naast graan in monocultuur is gebruik gemaakt van graan-erwt mengsels omdat deze bekend staan om hun hoge opbrengsten in mengteelt vergeleken met de gecombineerde opbrengsten in monocultuur op arme bodems. De gebruikte graansoorten waren gerst en rogge. Bij gerst, dat een zelfbestuiver is, is gebruik gemaakt van een mengsel van 11 zomergerstrassen (*Hordeum vulgare,* cvs Apex, Aramir, Class, Extract, Jersey, Madonna, Orthega, Pasadena, Prestige, Reggae en Saloon). Bij rogge (*Secale cereale*), dat een een kruisbestuiver is, is één zomerroggeras (cv. Sorom) gebruikt. Gerst staat bekend om zijn hoge opbrengst op nutriëntenrijke bodems. Rogge gedijt goed op arme bodems. Zomergranen werden gebruikt zodat ze gelijktijdig met de erwt ingezaaid konden worden. De erwt was een semi-bladloos erwtenras (*Pisum sativum*, cv. Integra). Daarnaast werd in een aantal veldjes een mengsel van vijf inheemse wilde plantensoorten (*Centaurea cyanus*, *Chrysanthemum segetum*, *Misopathes orontium*, *Papaver rhoeas* (beide bodems) en *Matricaria recutita* (zandgrond) of *Tripleurospermum maritimum* (kleigrond) geïntroduceerd. Het resultaat was acht behandelingen: een graan in monocultuur, een graan- erwtmengsel, een graan-wilde bloemenmengsel en een graan-erwt-wilde bloemenmengsel op zowel klei als zandgrond. Het geoogste graanzaad werd gebruikt als zaaizaad voor het daaropvolgende jaar, erwtenzaad werd elk jaar opnieuw gekocht en wilde bloemen werden alleen in het eerste jaar ingezaaid. Het proefontwerp was een gewarde blokkenproef met vier blokken per akker. De plotgrootte was 180 m^2. In 2005 werden herhalingsexperimenten ingezaaid op twee andere locaties (een zand- en een kleigrond). Deze experimenten werden maar één jaar gecontinueerd.

Verschillende indicatoren werden gebruikt om functionaliteit van het systeem te toetsen. Voor het aspect ‘economie’ werden de silage- en korrelopbrengsten en -kwaliteit gemeten. Hieruit werden conclusies getrokken met betrekking tot de winstgevendheid van het systeem. Voor het aspect ‘ecologie’ werd de ontwikkeling van de bijkomende flora in de tijd, in aantal en soortensamenstelling, gemeten. De loopkeverpopulatie en bacteriesamenstelling werden binnen één groeiseizoen gemeten. De nematodenpopulatie werd gedurende drie opeenvolgende jaren geanalyseerd. Daarnaast werd een model ontwikkeld om het effect van beschaduwing op kieming en sterfte van bijkomende planten binnen één groeiseizoen te beschrijven. Voor het aspect ‘ sociologie’ werd de belevingswaarde van de systemen onderzocht aan de hand van persoonlijke interviews.

Winstgevendheid

Om de winstgevendheid van de systemen te bepalen werden de silage- en korrelopbrengsten en de silage- en korrelkwaliteit bepaald. Drogestof opbrengsten werden bepaald van het gehele gewas en per onderdeel (graan, erwt, gezaaide wilde bloemen en spontane wilde planten). Om de silagekwaliteit te meten werden het drogestofgehalte, ruw eiwit, ruwe vezel, ruw as, zetmeel en verteerbaar organisch materiaal bepaald. Voor korrelkwaliteit werden het kiemingspercentage en het duizendkorrelgewicht gemeten. Resultaten laten zien dat er, vooral in het eerste jaar, hoge opbrengsten werden behaald. Echter, de opbrengst en kwaliteit hingen af van de behandeling, de locatie en het jaar van productie. Gerst gaf hoge opbrengsten van goede kwaliteit op drie van de vier locaties. Eén perceel had voor de aanvang van het experiment braak gelegen waardoor de starthoeveelheid nitraat in de bodem relatief laag was, hetgeen mogelijk geresulteerd heeft in de lagere opbrengst. Op die locatie gaf rogge een hogere opbrengst, maar de silagekwaliteit van de roggebehandelingen was lager dan die van de gerstbehandelingen. Als erwt was bijgevoegd in het mengsel was de opbrengst hoger, echter alleen op bodems met arme tot gemiddelde bodemvruchtbaarheid. Erwt is gevoelig voor slechte weersomstandigheden en geeft een hoge jaar-tot-jaar variatie in opbrengst. De erwtopbrengst was het hoogst in 2005. In dat jaar waren erwt en gerst op hetzelfde moment rijp. De silagekwaliteit van het mengsel was hoog door de erwt in het mengsel. Erwt bleek ook gevoelig voor concurrentie; erwt werd meer onderdrukt door rogge dan door gerst. Ingezaaide wilde bloemen beïnvloedden de opbrengst niet significant. Kiemingspercentage van het graanzaad van gerst-monocultuurbehandelingen was het hoogst, behalve voor gerst-monocultuurbehandelingen op de arme zandgrond. Kiemingspercentage van gerst en rogge nam elk jaar toe, duizendkorrelgewicht nam elk jaar af.

Plantensoortenontwikkeling

De ontwikkeling van de populatie van geassocieerde plantensoorten werd onderzocht. Alle bijkomende plantensoorten (ingezaaide wilde bloemen en spontaan opkomende plantensoorten) werden vier keer per seizoen geteld op 1 m^2 in elk plot. Alle plantensoorten werden gedetermineerd en de aantallen per soort werden geteld. De aantallen geassocieerde planten, het aantal soorten, de verdeling van het aantal per soort en de samenstelling van de populatie (aanwezigheid van soorten) werd onderzocht. De soortensamenstelling op de zand- en de kleigrond was verschillend. Op de zandgrond was het aantal planten hoger dan op de kleigrond. Op zandgrond werd de populatie overheerst door *Chenopodium album* terwijl op de kleigrond geen enkele soort overheerste, alle soorten waren in ongeveer gelijke aantallen aanwezig. Nieuwe soorten kwamen er bij op beide bodems, maar op de kleigrond was het aantal nieuwe soorten dat opkwam hoger. Het aantal geassocieerde planten in mengsels met erwt was hetzelfde als in de graan-monocultuurbehandelingen, echter de planten waren groter. Ook waren er in het laatste jaar meer soorten aanwezig in mengsels met erwt dan in graan-monocultuurbehandelingen. Het aantal planten was het hoogst in de gerst-monocultuurbehandelingen op de arme zandgrond. Wilde bloemen groeiden uitbundig op beide bodems in het eerste jaar, en op kleigrond in het laatste jaar. Op de kleigrond kwamen ze het meest uitbundig terug in de rogge-erwt-wilde bloemen mengsels. Het aantal planten en het aantal soorten namen toe in de tijd. Echter, er bestaat een risico dat bepaalde soorten te dominant worden, in het bijzonder wanneer het graan zwak concurreert door een te lage stikstofvoorraad in de bodem. Daarom zou er bij het beheer van zulke systemen voor gezorgd moeten worden dat bijkomende planten goed gedijen in het gewas, maar niet te concurrentiekrachtig worden. Deze beheersmethoden moeten in de toekomst verder ontwikkeld worden.

Relatie tussen dynamiek van de gewasgroei en de dynamiek van kieming en sterfte van de ingezaaide wilde bloemen

Een wiskundig model werd ontwikkeld dat de groei van het gewas en het effect op de kieming en sterfte van de ingezaaide wilde bloemen beschrijft. Het model beschrijft gewasgroei met een sigmoide. De sigmoide functie werd samengesteld door middel van een combinatie van andere (bestaande)gewasgroeifuncties. Na het doorrekenen van de formule bleek dat de behandelingen een verschillend patroon van gewasgroei in de tijd vertoonden. Graan in monocultuur en de graan-erwt mengsels verschilden het meest in het patroon van gewasgroei. In het algemeen bereikten graan-erwt mengsels het moment van 50% gewasbedekking later in het seizoen dan de graanmonoculturen. Maximale bodembedekking aan het einde van het seizoen was het hoogste in de graan-erwt mengsels. Per behandeling werden gemeten data gebruikt in de berekeningen waarop de formule afgesteld werd. Hierdoor bleek dat de invoer van de gemeten groeidata van het gewas ervoor zorgde dat de berekende data van de kieming en sterfte van de ondergroeiende planten gelijk bleven tussen de behandelingen. Dat betekent dat kieming en sterfte direct gerelateerd waren aan beschaduwing door het hoofdgewas.

Kieming en sterftesnelheid verschilden tussen bodems en wilde bloemensoorten. Uit de berekeningen kon worden afgeleid dat *P. rhoeas* een kiemingsvertraging had van 200 graaddagen ten opzichte van de andere wilde bloemensoorten. Kieming en sterfte was hoger in *P. rhoeas* dan in de andere drie soorten. De sterftecijfers waren in 2005 hoger dan in 2004 voor alle wilde bloemensoorten.

Kevers

Kevers (Coleoptera: Carabidae, Coccinellidae, Curculionidae) werden gedurende het hele groeiseizoen van 2005 gevangen in de behandelingen met rogge van de herhalingsexperimenten. In elk van de vier plotjes van de roggebehandelingen werden vier bodemvallen geplaatst. Deze potten zijn negen keer in het seizoen geleegd met gelijke tussenpozen. De samenstelling van de keverpopulatie was verschillend tussen de twee bodems. Op de zandgrond was het aantal soorten hoger, maar het aantal individuen lager dan op de kleigrond. Op klei werd de populatie gedomineerd door *Pterostichus melanarius.* Rogge-erwt behandelingen op zandgrond waren aantrekkelijk voor Carabidae, Coccinellidae en Curculionidae. Op kleigrond waren alleen de Curculionidae hoger in de twee rogge-erwtbehandelingen dan in de twee roggemonocultuurbehandelingen. Erwt was het meest aantrekkelijk in het begin en het midden van het seizoen. In het begin van het groeiseizoen was het aantal loopkevers hoger op zandgrond dan op kleigrond, hetgeen waarschijnlijk veroorzaakt werd door een hogere bodemtemperatuur op de zandgrond dankzij een snellere opwarming. De keversamenstelling veranderde door de tijd in de behandelingen doordat sommige soorten zich naar de erwtbehandelingen verplaatst hadden. Verrassend genoeg hadden de wilde bloemen geen effect.

Nematoden

De samenstelling van de nematoden werd gemeten door de tijd omdat verwacht werd dat nematoden een bedreiging zouden vormen in de continuteelt, met name in de mengsels met erwt. Daarom werden aan het begin van het groeiseizoen en in het derde jaar aan het einde van het groeiseizoen bodemmonsters genomen en onderzocht op nematoden. Plantenparasitaire nematoden waarvan bekend is dat ze een gevaar vormen voor het gewas werden gedetermineerd op soortsniveau. De verwachting was dat de rest van de nematoden geen gevaar zouden opleveren voor het gewas of daarop zelfs een positief effect zou kunnen hebben omdat ze betrokken zijn bij bodemprocessen (bijvoorbeeld het vrijmaken van nutriënten). Deze nematoden werden als één groep beschouwd. Op zandgrond nam het aantal gunstige nematoden in aantal toe. Echte uitbraken van een bepaalde soort schadelijke nematoden deden zich niet voor. Wel waren er verschillen tussen behandelingen, met name voor de schadelijke *Tylenchorchynchus* spp. soorten die het sterkst toenamen in de behandelingen met erwt. Erwt is gevoeliger voor deze nematodensoort dan gerst en rogge. Op zandgrond nam het aantal gunstige nematoden zelfs toe, hetgeen zou kunnen wijzen op een positieve ontwikkeling van de nematodenpopulatie. Op basis van de waarnemingen is het niet waarschijnlijk dat de afname in opbrengst in de tijd verband houdt met veranderingen in nematodendichtheden.

Belevingswaarde van de biodiverse teeltsystemen

Biodiverse teeltsystemen werden mede ontworpen om een positieve bijdrage te leveren aan de beleving van het landschap. Om te bepalen hoe de systemen werden beoordeeld werden gesprekken gevoerd met 30 personen. De methodologie was kwalitatief, hetgeen betekent dat de onderzoeksvraag was gericht op de achterliggende gedachten bij de antwoorden. Het voordeel is het openleggen van een verscheidenheid aan visies over beleving van akkers, en dat was waar het in dit onderzoek om draaide. Om de verscheidenheid aan antwoorden zo hoog mogelijk te maken werd er een gevarieerde groep respondenten samengesteld. De helft van de respondenten werd geselecteerd op leeftijd, geslacht en opleidingsniveau. De andere helft van de respondenten werd gekozen binnen een gemeente en hadden ieder op een eigen manier belang bij akkerbouw. De respondenten kwamen uit de Kempen en waren boeren, bewoners, beleidsmakers en vakantiegangers met een vaste stacaravan in de omgeving. Foto's van de experimentele velden werden voorgelegd, en daarnaast ook foto's van drie gangbare systemen namelijk maïs, tulp en akkerranden. Er werden vragen gesteld om de relatie van de respondenten tot natuur en landbouw en hun visie op deze onderwerpen te achterhalen. Het resultaat liet zien dat er een relatie was tussen achtergrond in landbouw/natuur en de belevingswaarde van de systemen op de foto's. Boeren waardeerden velden die een hoge opbrengst uitstraalden, terwijl respondenten die natuurlijkheid belangrijk vonden systemen met een wilde uitstraling waardeerden. Respondenten die geen affiniteit met landbouw en natuur hadden, waardeerden nette velden (lijkend op een parkachtige omgeving) het meest. Over het algemeen werd gerst hoger gewaardeerd dan rogge omdat het bij gerst mogelijk is om over de velden heen kijken. Erwt in de mengsels werd voornamelijk negatief beoordeeld in de systemen met gerst en speelden geen rol in de beoordeling van de systemen met rogge. Wilde bloemen verhoogden de waardering voor systemen erg. Sommige respondenten waardeerden wilde bloemen echter juist niet. Conventionele boeren associeerden ze met opbrengstverlies door onkruiden en respondenten die geen affiniteit hadden met natuur associeerden ze met stekende insecten.

Ontwikkeling van het rassenmengsel van gerst in de tijd

Aan het begin van het eerste groeiseizoen werd een mengsel van 11 gerstrassen in gelijke dichtheden ingezaaid. De samenstelling van het rassenmengsel werd weer geanalyseerd aan het einde van het groeiseizoen van het derde jaar met behulp van DNA-analyse. Hierbij bleek dat er in enkele behandelingen verschuivingen waren opgetreden. De aantallen zaden per soort in gerstmonocultuur-behandelingen waren meer gelijk verdeeld dan in gerst-erwtbehandelingen.

Relatie tussen bovengrondse en ondergrondse diversiteit

Om een verband te leggen tussen boven- en ondergrondse diversiteit, werden bodemschimmels en bacteriën gemeten. Aan het einde van het derde groeiseizoen werden er in de systeemontwikkelingsexperimenten bodemmonsters genomen. De diversiteit in de schimmel- en bacteriepopulatie verschilde voor de twee bodems. De samenstelling van de DNA-banden die de aanwezigheid van specifieke grondgebonden organismen weergeven, vertoonde op beide bodems een effect van de aanwezigheid van wilde bloemen.

Discussie

De resultaten laten zien dat het mogelijk was om biodiverse productiesystemen op te zetten met veel bijkomende biodiversiteit en vooral in het eerste jaar hoge opbrengst van goede kwaliteit. Ook na drie jaar werden nog hoge opbrengsten gehaald. Aangezien de ingezaaide wilde bloemen de gewasopbrengst niet significant beïnvloedden, lijkt het mogelijk deze wilde bloemensoorten toe te laten in het veld als een alternatief voor de akkerranden. Echter, opbrengsten waren niet altijd hoog, en bleken sterk afhankelijk van het gewas, de locatie en het weer. In de toekomst kunnen dergelijke systemen wellicht bemest moeten worden met organische meststoffen. Stikstof bevordert de kwaliteit van het oogstproduct, organische stof stimuleert de bodemdiversiteit, mede door het stimuleren van de natuurlijke processen in de bodem. Echter, hoge nitraatgehalten verhogen gewoonlijk de concurrentiekracht van het gewas ten opzichte van de planten die gewenst zijn als biodiversiteitscomponent. Indien nodig, zou deze concurrentiekracht verlaagd kunnen worden door het gewas in een lagere dichtheid te zaaien. Toevoeging van erwt verlaagde de competitie om bodemnutriënten en verhoogde de aantrekkingskracht voor bepaalde vormen van diversiteit. Echter, de groei van de erwt was sterk weersafhankelijk en daardoor was de opbrengst van mengsels met erwt niet in elk jaar hoger. Bij andere leguminosensoorten is dit probleem wellicht minder. Ook kunnen teeltsystemen worden ontworpen op basis van een gewasrotatie van granen en erwten, in plaats van een mengteeltsysteem. Bovendien zou gewerkt moeten worden aan het verbeteren van het rassenmengsel van gerst. In ons onderzoek werd een mengsel van elf gangbare rassen gebruikt. De rassen waren veredeld op hoge opbrengsten bij een rijke stikstofgift. Er zou ook gekozen kunnen worden voor een mengsel gebaseerd op rassen die goed groeien op arme bodems en juist onder die omstandigheden concurrentiekrachtig zijn. De relatie tussen boven- en ondergrondse diversiteit verdient meer aandacht in het onderzoek; hetzelfde geldt voor de effecten van organische mest op gewasopbrengst en bodemdiversiteit.

Om het succes van implementatie van biodiverse productiesystemen te verhogen moeten de volgende aspecten in acht worden genomen. Het type productiesysteem moet afgestemd worden op de locatie van de productie. Dat betekent bijvoorbeeld dat wanneer een open landschap gewenst is, gerst een betere keuze is dan rogge. Wanneer de teelt op arme bodems plaatsvindt, is rogge een beter alternatief. Alhoewel hoge opbrengsten mogelijk zijn, is er geen garantie voor hoge opbrengst; de overheid zou moeten compenseren voor mogelijk opbrengstverlies totdat de systemen zijn verbeterd. Daarnaast is het succes van implementatie op het boerenbedrijf meer verzekerd als boeren begrijpen wat het doel van een maatregel is. Hier moet aandacht aan besteed worden.

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Stilma, E.S.C., P.C. Struik, Vosman B., and H. Korevaar. submitted-b. Development of plant diversity in cereal-based cropping systems.

Stilma, E.S.C., B. Vosman, H. Korevaar, and P.C.

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Stilma, E.S.C., J. van Bezooijen, H. Korevaar, P.C. Struik, and B. Vosman. submitted-d. Nematode population development in biodiverse arable production systems in the Netherlands. Submitted.

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Curricuum vitae

Curriculum vitae

Eveline Stilma werd geboren op 19 Februari 1979 in Eindhoven. Na het behalen van haar VWO diploma op het Rythovius College in Eersel in 1997 begon ze aan de studie plantenteeltwetenschappen in Wageningen. Een periode van haar studie heeft ze gestudeerd aan de Landbrükshøgschole in Ås, Noorwegen. Tevens heeft ze haar studie een jaar onderbroken om deel te nemen in de VeSte fractie van de studentenraad. In september 2003 studeerde ze af op een afstudeervak bij de vakgroep Plantaardige Productiesystemen en bij de vakgroep Biologische bedrijfssystemen. Daarna is ze gaan werken bij Plant Research International en de vakgroep Gewas en Onkruidecologie in Wageningen waar dit promotieonderzoek is uitgevoerd. Vanaf Juni 2008 is ze werkzaam als onderzoeker bedrijfssystemen bij het Proefstation voor praktijkonderzoek Plant en Omgeving in Lelystad.

Publications

Publications

Published

Scientific

Stilma, E.S.C. Vosman B., Korevaar H., Poel-Van Rijswijk M.M., Smit A.B., Struik P.C. (2007). Designing biodiverse arable production systems for the Netherlands by involving various stakeholders. *NJAS Wageningen Journal of Life Sciences.* 55 (1), 1-20.

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Congress

Stilma, E.S.C.,Vosman, B., Korevaar, H., Struik, P.C. (2007). Development of semi-natural agro-ecosystems. *Aspects of Aplied Biology*, 81, 87-90.

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Scientific

Stilma, E.S.C., Smit A.B., Geerling-Eiff F. A., Struik P.C., **Vosman B., Korevaar H.,** Perception of biodiversity in arable production systems in the Netherlands. Submitted 2008

Stilma, E.S.C., Vosman, B., Korevaar, H., Struik, P.C., Crop yield and quality in biodiverse production systems designed for the Netherlands, Submitted 2008

Stilma, E.S.C., Struik, P.C., Vosman B., Korevaar, H., Development of plant diversity in cereal-based cropping systems, Submitted 2008.

To be submitted

Scientific

Stilma, E.S.C., Keesman, K., Korevaar H., Vosman, B., Struik P.C., Werf, W van., Modelling the recruitment and attrition of associated plants growing under a shading crop canopy; a system identification approach

Stilma, E.S.C., Bezooijen, J. van, Korevaar, H., Struik, P.C., Vosman, B. Nematode population development in biodiverse arable production systems in the Netherlands

Stilma, E.S.C., Heijerman, T., Struik P.C., Korevaar, H., Vosman, B. Effect of crop mixtures on beetle diversity (Coleoptera: Carabidae, Coccinellidae, Curculionidae) over time on two soil types in the Netherlands

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PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of Literature (5.6 ECTS)

- Effects of intercropping systems and aspects of agricultural biodiversity (2003)

Writing of PhD Project Proposal (7.0 ECTS)

- Designing biodiverse arable production systems for the Netherlands (2003)

Post-Graduate Courses (4.2 ECTS)

- Safe handling with radioactive materials; Larenstein (2003)
- Advanced statistics; PE&RC (2005)
- Multivariate analysis; PE&RC (2007)

Competence Strengthening / Skills Courses (2.7 ECTS)

- Techniques for writing and presenting a scientific paper: Wageningen Graduate Schools (2004)
- Scientific writing; Wageningen University Language Centre (2006)

Discussion Groups / Local Seminars and Other Scientific Meetings (4.6 ECTS)

- Plant and Crop Ecology discussion group (2003, 2004)
- PRI Literature meetings (2006)
- Master Class Matt Liebmann (2005)
- Klankbordgroep overleg (2003-2006)

PE&RC Annual Meetings, Seminars and the PE&RC Weekend (2.1 ECTS)

- Introduction Weekend (2004)
- PE&RC Days (2003-2005)
- Study Nature, Value Nature: Symposium Stuart Pimm - Heiniken Prize (2006)

International Symposia, Workshops and Conferences (7.0 ECTS)

- Gene Plant Crop Relations (2006)
- Delivering Arable Biodiversity (2007)
- Crop Weed Interactions (2006)
- Cereal Crop Diversity (2006)

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