Op de dag dat gij u bewust wordt, dat ge niet weet, zult ge beginnen te weten.

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BIODIVERSITY AND AGRO-ECOLOGY IN FIELD MARGINS

Thesis submitted in fulfillment of the requirements
For the degree of Doctor (PhD) in Applied Biological Sciences:
Agronomy

Dutch translation of the title:
Biodiversiteit en agro-ecologie in perceelsranden

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Voorwoord

Gedurende mijn onderzoek binnen het D.W.T.C.-project 'Invasie en biodiversiteit in graslanden en perceelsranden' zijn een groot aantal mensen behulpzaam geweest die mij met raad en daad hebben bijgestaan en het werk lichter en aangenamer hebben gemaakt. Op het gevaar af personen of instanties te vergeten (waarvoor mijn welgemeende excuses) wens ik volgende personen of instanties in het bijzonder te bedanken:

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-de tapijten kleine brandnetel in mijn eerste projectjaar,…ik blijf zeker voor de rest van mijn leven gevrijwaard van reuma;…

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ANDIC	Annual non N-fixing dicotyledons
ANLEG	Annual legumes
ANMON	Annual monocotyledons
ASH	Crude ash (% on DM)
AUSPAN	Annual unsown anemochorous species
C	Carbon
C_N	Sorenson's quantitative similarity index
C_S	Sorenson's qualitative similarity index
CF	Crude fibre (% on DM)
CONTR	Unsown plant community
CP	Crude protein (% on DM)
DM	Dry matter
I%	Importance (%)
ING	Ingrowing species
K	Potassium
LSD	Least significant difference
MIXT1	Sown native plant community
MIXT2	Sown commercial plant community
MIXT3	Sown commercial plant community with addition of roadside herbage
N	Nitrogen
NEL	Netto energy for lactation
NH_4-N	Ammonium-N
NO_3-N	Nitrate-N
NS	Non significant
OM	Organic matter
OMD	Organic matter digestibility (% on OM)
P	Phosphorus
P.A.R.	Photosynthetic active radiation (in $\mu mol.m^{-2}.s^{-1}$)
PERDIC	Perennial non N-fixing dicotyledons
PERLEG	Perennial legumes
PERMON	Perennial monocotyledons

PUING	Perennial unsown rhizomatous species
PUSPAN	Perennial unsown anemochorous species
R^2	Determination coefficient
REMOV0	2 cuttings per year: no removal of cuttings
REMOV1	2 cuttings per year: removal of the first cutting
REMOV2	2 cuttings per year: removal of both cuttings
SPAN	Specialized anemochorous species
STDV	Standard deviation
VEM	Dutch feed units per kg DM (in Dutch: Voeder Eenheid Melk)
Vol%	Volumetric moisture content (%)

Chapter 1

Background and objectives

De natuur is zoals men haar nemen wil

La nature, sans doute, est comme on veut le prendre

MUSSET, La Coupe et Les Lèvres

Chapter 1

Background and objectives

1.1 Background and scope of the research

1.1.1 Biodiversity under threat

The densely populated Central and West European countries with their highly developed transport infrastructure, high density of settlement and intensive agriculture, are home to a very high proportion (24-45%) of endangered Red List plant species (both extinct in the wild as well as endangered, vulnerable or rare species) and populations (data according to OESO 2002, http://www.oecd.org/). At the end of the 90's, 23% of vascular plants, 28% of vertebrates and 33% of invertebrates are threatened in Belgium (Dumortier et al., 2003; Red List Species on webpage http://www.nara.be). Within Europe, Flanders is at the fifth and ninth position for the percentage threatened vascular plant species and vertebrate species respectively (OESO 2002, http://www.oecd.org/). According to Peeters et al. (2004) approximately 7.5% of all species (plants and animals), formerly appearing in Flanders, disappeared and 30% is threatened with extinction. In Flanders, butterfly (*Rhopalocera*) species (well studied in Europe) steadily decreased since 1900: the decrease was particularly severe from 1950 onwards. Actually, within Europe, Flanders has the highest proportion (25%) of extint butterfly species (Van Swaay & Warren, 1999).

The goal of halting the loss of biodiversity by 2010 is the subject of several key international agreements. The "Countdown 2010" initiative (http://www.iucneurope.org) takes up the unique commitment of pan-European Environment Ministers and EU Heads of State to halt the loss of biodiversity by 2010.

1.1.2 Diversity of the agricultural landscape

Bearing in mind that over 50% of the European land surface is managed by farmers, the effects of agricultural management have a significant impact on the flora, fauna and environment of the EU. Indeed, during the last decades, structural, floristic and faunistic diversity of the agricultural landscapes in Northern and Western Europe has declined considerably owing to the intensification of agriculture from the 1950's on.

Agricultural landscapes in Europe are diverse, ranging from small-scale hedged landscapes, such as the bocage in France, to large-scale open landscapes in regions with an intensive arable production. Agricultural landscapes are a mosaic of cropped land (farmers' fields) and uncropped area including human infrastructures (e.g. roads), semi-natural habitats and occasional natural habitats. Field margins, present as linear features in some form (hedges, hedgerow trees, hedge bank, watercourse bank, grass baulk, verges...) at the edges of all fields, oftenly comprise the majority of the semi-natural habitats in the agricultural landscape (Marshall, 1988; Burel & Baudry, 1999).

The term 'field margin' is defined as the whole of the pre-existing semi-natural boundary, any field margin strip present, and the crop edge (Greaves & Marshall, 1987). The boundary encompasses the barrier between fields, for example: hedges, fences, hedge and watercourse banks with associated herbaceous vegetation,... The margin strip is any strip established in the field or at the edge of the field, between the boundary and the crop. The crop edge is defined as the outer few metres of the crop.

Changes in agriculture such as intensification of production, developments in machinery, crop protection, and land re-allotment to enlarge field sizes have directly or indirectly resulted in impoverishment of structural, floristic and faunistic diversity of the agricultural landscape. Field boundaries have been reduced in size or removed, their maintenance neglected or abandoned and their diversity (in shape, type, structure, floristic and faunistic composition) reduced severely (Muir & Muir, 1987). Variation in the shape and structure of field boundaries has decreased between different areas. Next to the impact on plant species (Marshall & Arnold, 1995), the impact of modern agriculture on animal species has been significant as a direct negative effect of current agricultural systems on animal groups, as well as indirect effects via decreasing abundance and quality of the flora upon which some animal species rely (Sotherton & Self, 2000; Morris & Webb, 1987). Consequently organisms downstream the food web are affected, as e.g. the chicks of farmland birds like the partridge (*Perdix perdix*) (Campbell et al., 1997). Species composition of animals and plants in different areas has become more similar and is characterized by a few dominant and highly competitive species (Joenje & Kleijn, 1994) as a result of selection pressure and reduced stability.

Finally, landscape connectivity is partly lost which hampers the dispersal of species through the landscape acting as a corridor network and hence extinction probability of species increased.

1.1.3 Ecologisation of agriculture: key role for field margins

In 1992 the European Union (EU) launched Regulation 2078/92, a regulation which aims at integration of the environment into the Common Agricultural Policy (CAP). Environmental issues and the contribution of agriculture to biodiversity and landscape have got special attention in the successive adaptations of the EU policy. Indeed EU policy, influenced by conservational problems (loss of biodiversity and habitats, ...), environmental problems (eutrofication, water pollution, soil erosion,...), surplusses in agricultural production (milk, butter, ...), sustainability questions and changing image of society, pursuited the ecologisation and multifunctionality of agriculture.

From 1992 onwards, many member states established special subsidized field margin programmes in the light of Regulation 2078/92. Indeed, field margins presently function as remnant refugia for biodiversity in the agricultural landscape (Barr et al., 1993). Furthermore field margins do pioneering work in the ecologisation of agriculture since they are the interface between intensive farming practices and the wider environment. As transition zones between intensively managed, cultivated land and extensive, uncultivated zones, they are areas of confrontation between agriculture, nature conservation and environment.

In the entire northern and western Europe a variety of methods of extending and recreating margin habitats became available, many of which buffer adjacent habitat from disturbance from farming operations. New subsidized field margin features on ex-arable land were created, notably conservation headlands (extensively managed crop edges; Rands, 1985) and margin strips, mostly managed according to management agreement prescriptions as agreed upon by farmers and some governmental organization. In many countries, a series of subsidiary roles for field margins have been identified, reflecting agricultural, environmental, conservation and recreational interests.
The history of field margin strips in Europe dates back to the early 1980's particularly in Germany and the UK. In Germany the so called "Randstreifen-Programm" with the

supported establishment of unsprayed crop edges around arable fields, aimed to conserve arable flora. In UK, in the early 1980's, conservation headlands aimed at game and wildlife protection, were promoted by the UK Game Conservancy Trust.
From 2000 on, farmers in Flanders have the possibility to install subsidized field margin strips after subscribing a management agreement with the VLM (Vlaamse Landmaatschappij, Flemish Land Agency, http://www.vlm.be). Anno 2004, approximately 550 hectares of field margin strips are subsidized by the Flemish government. This area continues to grow.

In the future, the presence of a field margin strip might become a prerequisite for the application of some pesticides and herbicides in arable crops, particularly in fruit orchards along watercourses. In order to protect surface water quality and waterorganisms, drift reducing measures became effective in Belgium, in 2005, in the light of EU Regulation 91/414/EEG, imposing unsprayed bufferzones varying from 1 m to 150 m for fungicides, insecticides and herbicides. Minimal width of the bufferzone depends on the sort of boundary (most severe adjacent to permanent watercourses), type of herbicide or pesticide applied, spraying technique and additional drift reducing measures taken by the farmer such as the use of anti-drift spray nozzles and drift reducing hedges (detailed information on webpage www.phytoweb.fgov.be). Farmers might get financial compensation for their production losses by means of installing subsidized field margin strips.

Next to public initiatives concerning field margins, other initiatives such as the Flemish Ecological Network (VEN, Vlaams Ecologisch Netwerk) stimulates the development or restoration of the connectivity of ecological infrastructure in Flanders.

1.2 Research objectives and questions

Whilst field margins originally had and still have agricultural functions (Table 1.1), their environmental (pollution control, eutrophication, pesticides, erosion, snow and water flow, siltation,...) and conservation (species refugia, biodiversity, habitat, feeding, breeding, corridor and movement) function is becoming of greater significance. Also recreational functions (walking, hunting, driving,...) become important reflecting people's need for countryside recreation. The role and requirement of existing field margins in European farming systems have been reviewed by Marshall (1993, 1995) (Table 1.1). Marshall & Moonen (2002) summarized actual findings of field margin research reflecting the multifunctionality of field margins and their interactions with agriculture.

Despite the growing interest in field margin strips, fundamental knowledge is lacking concerning the maximization of biodiversity of permanent margin strips and their agro-ecological functions and implications.

Table 1.1. Roles, requirements and potential functions of semi-natural field margins in good agricultural practice (after Marshall, 1993)

Original roles and requirements	
1	To define the field edge
2	To be stock- or trespasser-proof, to keep animals in or out
3	To provide shelter for stock
4	To provide shelter for crops, particularly as windbreaks
5	To reduce soil erosion by wind or water
6	Not to compete with the crop for light, moisture or nutrients
7	Not to harbour weeds, pests and diseases
8	To harbour beneficial plants and animals
9	To act as a refuge or corridor for wildlife
10	To provide a source of fruits and wood
Current and potential functions of field margins	
A	Promotion of ecological stability in crops
B	Reducing pesticide use: exploiting pest predators and parasitoids
C	Enhancing crop pollinator populations
D	Reducing weed ingress and herbicide use
E	Buffering pesticide drift
F	Reducing fertilizer and other pollutant movement, especially in run-off
G	Reducing soil erosion
H	Promotion of biodiversity and farm wildlife conservation
I	Maintaining landscape diversity
J	Promotion of game species

Primarly, the creation of plant diversity is a major objective of our research. Higher species richness, particularly wildflowers, may result in higher associated invertebrate diversity (Thomas & Marshall, 1999; Meek et al., 2002) owing to higher food supply (especially when margins flower yearround) and associated higher vegetation structural diversity (favourable to spiders) (Huusela-Veistola, 1998). Also over-wintering habitat for invertebrates is provided by such margins (Thomas et al., 1994). Pest predators and parasitoids may be enhanced by flowering species rich margins to feed (Meek et al., 2002) and overwinter nearby adjacent crops. Furthermore the development of a species rich vegetation might decline potential risks of weed invasion by competitive exclusion (van Ruijven, 2005).

Secondly, effects of disturbance and shading on biodiversity and vegetation succession were determined. Indeed, field margin strips are likely to be used as turning headlands (although prohibited in many subsidized field margin programmes) and to be disturbed by wheeled or tracked machinery for farming practices and watercourse management. These farmer operations might complicate normal vegetation succession and increase weed ingress.

The question might arise whether the vegetation development differ under different light regimes since many field margin strips are preferentially installed along tree rows and hedges because the area close to tree rows is less productive owing to increased competition for light, water or nutrients, allelopathy and weed and fungi pressure (Nuberg, 1998; Brenner, 1996). Particularly shading by tall, unmanaged hedgerows, woodlots and tree rows may have serious effects on crop yields (Kleijn, 1997).

Thirdly, from an agronomical viewpoint, farmers' hesitations concerning the installation of field margin strips might be eliminated by increased knowledge about the risk of weed infestations and vegetation succession. Management requirements and techniques to establish species rich margin vegetation are still not well-defined. Furthermore knowledge is lacking concerning agronomical valorisation of the biomass produced in margin strips.

For environmental and wildlife reasons, the ability of installed permanent strips to buffer nearby watercourse and associated herbaceous vegetation was evaluated. Margin strips are mostly installed nearby meandering watercourses in order to straighten the field and to simplify farming operations like ploughing.

The present study deals with mown unfertilized and unsprayed permanent field margin strips, newly installed on arable land. Indeed, the type of created margin strip has major impacts on its possible functions for wildlife and environmental protection. This work focused on permanent grass/forbs strips since they are especially important for species that do not disperse easily in the landscape notably most plant species (Marshall, 1989). Permanent strips are not a part of the crop and are created by natural regeneration of the flora or are sown to perennial grass and/or wildflower mixtures. On the contrary, temporary strips (conservation headlands, unsprayed crop edges,...) are mostly part of the crop but are extensively managed (no use or low input of agrochemicals) and undergo a yearly cultivation. Temporary strips are especially beneficial for threatened arable weed species which require regularly cutivated crop areas or species with high movement ability in the landscape.

More in particular, this thesis adresses the following agro-ecological questions which are identified by numbers given between brackets. Research questions reflect the agricultural, environmental and conservation interests of field margin strips.

A. Nature (research questions raised in Chapter 3, 4 and 5):

A.1. Maximization of plant diversity in margin strips (questions raised in Chapter 3):

- *Is there any potential for naturally regenerated strips to develop into floristic diverse plant communities or are they depauperated of species? (1)*
- *Which mowing regime of the newly created communities maximizes species richness and how does the cutting regime direct biodiversity and vegetation succession? (2)*
- *What is the success of introducing seed mixtures differing in seed provenance to recreate a diverse semi-natural community? (3)*
- *Is the application of species rich roadside herbage useful to enhance botanical diversity? (4)*
- *Is there any similarity in the vegetation between unsown and sown communities? (5)*

A.2. Effects of disturbance and/or light intensity on plant and insect diversity (questions raised in Chapter 4 and 5):

- *What is the effect of disturbance and light regime on biological invasion? (6)*
- *How does a single disturbance affects species richness, early botanical succession and vegetation similarity at high and low light regime? (7)*

- *What is the effect of light regime and plant community on insect number, insect composition and insect diversity both in the margin strip and in the adjacent field crop. (8)*
- *Is there a relation between herbivorous insects and entomophagous insects? (9)*

B. Agriculture (research questions raised in Chapter 6 and 7):

B.1. Potential weed problems in the margin strip and the adjacent crop (questions raised in Chapter 6):

- *What is the best field margin strip management (field margin type and cutting regime) to reduce the abundance of ingrowing and/or specialized anemochorous weeds? (10)*
- *How deep do airborn seeds from margin species penetrate into adjacent crops? (11)*
- *Is a soil seedbank analysis a useful tool to predict the risk of problem weeds in the margin strip and in the adjacent crop? (12)*

B.2. Agricultural valorisation of margin herbage (questions raised in Chapter 7):

- *Does the mowing regime and/or field margin type affect dry matter yield over time? (13)*
- *What is the impact of field margin type and associated vegetation composition on herbage quality? (14)*
- *Is herbage quality affected by cutting time? (15)*
- *How useful is herbage from field margin as an animal feed? (16)*

C. Environment (research question raised in Chapter 8):

- *How do sown/unsown margin strips bordering arable crops reduce mineral N residues and loss during winter? (17)*
- *Is mineral N content and loss affected by plant community or location? (18)*
- *Which margin width is advisable to minimize soil mineral N content and loss nearby the pre-existing boundary? (19)*
- *Is species richness and botanical composition of boundary vegetation positively affected by the presence of the margin strip? (20)*

1.3 Thesis outline

The objective of this thesis was to increase our understanding of the function of permanent field margin strips in order to improve their exploitation for agricultural, environmental and wildlife benefits.

This chapter (Chapter 1) formulates the general scope and research questions of the thesis.

Both the experimental field trials as well as the recurrently used methodology is described in Chapter 2, avoiding repetition. Indeed, the results in Chapter 3 to Chapter 8 are based on two experimental field trials. Particularly, methodology concerning botanical analysis of margin strips was recurrently used throughout the thesis. Material and methods which were once-only used are described in the Section ”Specific material and methods” of Chapters 3 to 8.

Chapter 3, 4 and 5 focus on the research questions of conservation interests (questions 1 to 9). Chapter 3 evaluates different margin management techniques in order to increase species diversity. Chapter 4 investigates botanical implications of disturbed or undisturbed vegetations under shaded or unshaded conditions above the canopy. In Chapter 5 insect diversity nearby shaded or unshaded margin strips is studied

Chapter 5 (partly) and 6 investigate agronomical risks (weeds, pests) and implications of field margin strips adjacent to cropped land (question 10 to 16). In Chapter 7, biomass quantity of the margin herbage and its quality as a forage for animals is evaluated.

Chapter 8 investigates both the environmental impact of the margin strips installed between the crop edge and the watercourse boundary, on nitrogen status and loss as well as their buffering effect on the boundary flora (questions 17 to 20).

Finally, the general summary and conclusions of this thesis are formulated in “Conclusions”. A summary of the text is given in English and Dutch (Summary and Samenvatting).

Chapter 2

General materials and methods

Methode is de moeder van het geheugen

Method is the Mother of Memory

THOMAS FULLER, Histories of the Worthies, 166

Chapter 2

General materials and methods

2.1 Field trials

2.1.1 *Trial 1 (all research questions except question 6, 7, 8 and 9)*

In June 2001 a field margin experiment was established on nutrient rich arable land in a split plot design with four plant communities (main plot factor), three cutting treatments (subplot factor) and three blocks. The plant communities were randomized within the blocks and the cutting treatments were randomized within the plant communities. The split plot design was installed on two contrasting soil types in Belgium, province of West Flanders namely at Poperinge (SITE1: 50°52′N, 2°45′E, drained sandy loam soil, pH-KCl 6.8, 1.5% C; data for the topsoil 0-30 cm) and at Beernem (SITE2: 51°09′N, 3°20′E, humid sandy soil, pH-KCl 5.7, 3.3% C; data for the topsoil 0-30 cm). Analysis of topsoil (0-30 cm) (June 2001) of SITE1 showed that extractable P and K were 27 mg and 31 mg per 100 g dry soil respectively and total mineral N was 43 kg ha^{-1}. Analysis of topsoil (0-30 cm) of SITE2 showed that extractable P and K were 75 mg and 31 mg per 100 g dry soil respectively and total mineral N was 113 kg ha^{-1}. The experimental sites (360 m x 10 m each) were ploughed from 7-month-old Italian ryegrass (*Lolium multiflorum* Lamk.) in May 2001 and divided in 12 main plots (30 m x 10 m each) arranged along an east-west oriented watercourse at SITE1 and along an east-west oriented tree row with ditch at SITE2. Each main plot was subdivided in 3 subplots (10 m x 10 m each). The pre-existing boundary was constituted by a watercourse bank with irregular pattern of shrubs, pollarded trees and young trees at SITE1 and a small ditch bank along a tree row of 50-year-old oaks at SITE2. PH-KCl in the boundary was 6.1 at SITE1 and 4.5 at SITE2 (for the topsoil 0-30 cm).

The field margin experiment at SITE2 was located nearby the provincial domain Lippensgoed-Bulskampveld (225 ha), a green belt enclosing vast deciduous (oaks, beeches,...) and coniferous forests, impressive tree lanes, ditches, heath relicts, arable fields and meadows.

Apart from an unsown spontaneously evolving plant community (CONTR), three different sown communities were studied (MIXT1, MIXT2, MIXT3) (Table 2.1). MIXT1 was

Table 2.1. Sown seed mixtures: composition, dose of MIXT1 (native plant community) and MIXT2 (commercial plant community)

Functional group	FT[1]	MIXT1			MIXT2		
		Dose ($g.ha^{-1}$)	**Species number**	**Origin**	**Dose ($g.ha^{-1}$)**	**Species number**	**Origin**
Non fixing dicots (wildflowers)		6560	45	Pleijboza	5000	59	Barenbrug (NL)
Legumes		9200	6		9200	6	
Medicago sativa L.	6-9	1800		Feldsaaten Freudenberger (G)	1800		Feldsaaten Freudenberger
Trifolium incarnatum L.	5-7	1500		Feldsaaten Freudenberger	1500		Feldsaaten Freudenberger
Trifolium pratense L.	5-10	2000		CLO-DvP[2] (B)	2000		Barenbrug
Trifolium repens L.	5-10	1400		CLO-DvP	1400		Barenbrug
Trifolium resupinatum L.	5-9	1500		Feldsaaten Freudenberger	1500		Feldsaaten Freudenberger
Vicia sativa L.	5-7	1000		Pleijboza	1000		Feldsaaten Freudenberger
Monocots		26500	12		26500	12	
Agrostis tenuis Sibth.	6-8	2000		collected[3]	2000		Barenbrug
Anthoxanthum odoratum L.	4-6	600		Pleijboza	600		Feldsaaten Freudenberger
Arrhenatherum elatius J. & C. Presl	5-9	3000		Pleijboza	3000		Feldsaaten Freudenberger
Cynosurus cristatus L.	6-7	1200		Pleijboza	1200		Feldsaaten Freudenberger
Festuca arundinacea Schreber	6-7	3600		collected	3600		Barenbrug
Festuca pratensis Hudson	6-9	3000		CLO-DvP	3000		Barenbrug
Festuca rubra L.	5-8	5000		CLO-DvP	5000		Barenbrug
Holcus lanatus L.	5-9	1000		Pleijboza	1000		Feldsaaten Freudenberger
Lolium perenne L.	6-9	3000		CLO-DvP	3000		Barenbrug
Phleum pratense L.	6-8	1400		CLO-DvP	1400		Barenbrug
Poa trivialis L.	5-7	700		collected	700		Barenbrug
Dactylis glomerata L.	5-8	2000		collected	2000		Barenbrug

[1] FT: Flowering Time (month interval), according to Van Der Meijden (1990)

[2] CLO-DvP: Department of Plant Genetics and Breeding, Agricultural Research Centre Merelbeke (Belgium)

[3] collected in the neighbourhood of the trials

established with a seed mixture of 63 species comprising native seeds of local provenance. For MIXT2 a commercially available seed mixture of 77 species, comprising species completely unrelated to the sowing region, was used. Plant species in MIXT1 and MIXT2 were selected from a wide range of vegetation types: annual and perennial forbs from dry to moist grassland and perennial forbs thriving in nutrient rich soils. Nitrogen-fixing dicotyledons were incorporated to improve the nutritional value of the biomass. Germinative power of incorporated wildflower species in the seed mixtures prior to installation is given in Appendix 2.1 and 2.2. The initial composition of MIXT3 was identical to that of MIXT2 but once a year, seed rich herbage originating from roadsides was spread uniformly over the plots with the intention to increase the species abundance. Roadsides were cut around the end of September. The fresh unchopped herbage was immediately transported and spread uniformly over the plots at a ratio of approximately 5 000 kg fresh herbage per hectare.
Principal seed bearing species were *Daucus carota* L., *Centaurea jacea* L., *Tanacetum vulgare* L., *Plantago lanceolata* L., *Torilis japonica* DC., *Pulicaria dysenterica* Bernh..

In the installation year 2001, the field margin plots were cut once on 15 September with removal of the cuttings. During the subsequent years (2002, 2003, 2004) the experimental plots were cut twice per year with cuttings either left or removed (within 4 days after mowing) resulting in three different cutting treatments: REMOV0, no removal of cuttings; REMOV1, removal of first cutting; REMOV2, removal of both cuttings. The cutting height was 5 cm. To allow the seed set of a major part of the species and to allow the establishment of young seedlings, the first mowing date was postponed till 15 June. The vegetation was cut a second time around 15 September. Care was taken to reduce seed dispersal due to removal of the cuttings.
The pre-existing boundary vegetation at SITE1 was mown twice a year without removal of cuttings. The boundary at SITE2 was mown once a year with removal of cuttings due to the reduced vegetation growth under the tree row.

No fertilizers nor other agrochemicals were applied to the experimental margin plots. Adjacent crops and their fertilizer, herbicide, fungicide and insecticide inputs are shown in Table 2.2.

Table 2.2. Crops adjacent to the field margins (period 2001-2004): fertilizer, herbicide, fungicide and insecticide application

		Year			
		2001	**2002**	**2003**	**2004**
SITE1	**Crop**	Sugar Beet	Winter Wheat	Silage Maize	Sugar Beet
	Fertilizer[1] (kg.ha^{-1})	**120 N :** *ammoniumnitrate 27%N* *(60 N, 22.05)* *sow slurry 0.25% N* *(60 N, 03.04)* **35 P:** *sow slurry 0.33% P_2O_5* *(03.04)* **290 K :** *muriate of potash, 40% K_2O* *(225 K, 12.05)* *sow slurry 0.32% K_2O* (65 K, 03.04)	**220 N:** *soluble N* *(80N, 11.03 + 60 N, 11.04)* *ammoniumnitrate 27%N* *(80 N, 23.05)* **0 P** **0 K**	**180 N:** *ammoniumnitrate 27%N* *(120 N, 23.04)* *sow slurry 0.25% N* *(60 N, 01.03)* **35 P:** *sow slurry 0.33% P_2O_5* *(01.03)* **65 K:** *sow slurry 0.32% K_2O* *(01.03)*	**160 N:** *ammoniumnitrate 27%N* *(100 N, 23.04)* *sow slurry 0.25% N* *(60 N, 01.03)* **35 P:** *sow slurry 0.33% P_2O_5* *(01.03)* **65 K:** *sow slurry 0.32% K_2O* *(01.03)*
	Herbicide[2]	1 x Pyramin (3 L.ha^{-1}) 4 x Betanal Progress (1.0, 1.0, 1.2, 1.5 L.ha^{-1}) 3 x Goltix (0.50, 0.25, 0.75 kg.ha^{-1}) 2 x Safari (30, 30 g.ha^{-1}) 1 x Fervinal (1.25 L.ha^{-1})	1 x IP flo (3 L.ha^{-1}) 1 x Hussar (0.2 L.ha^{-1})	1 x Aspect (2 L.ha^{-1}) 1 x Mikado (1 L.ha^{-1})	1 x Pyramin (3 L.ha^{-1}) 4 x Betanal Progress (1.0, 1.0, 1.2, 1.5 L.ha^{-1}) 3 x Goltix (0.50, 0.25, 0.75 kg.ha^{-1}) 2 x Safari (30, 30 g.ha^{-1}) 1 x Fervinal (1.25 L.ha^{-1})
	Fungicide[3]	1 x Opus Team (0.7 L.ha^{-1})	1 x Opus (0.8 L.ha^{-1}) 1 x Boscor (0.8 L.ha^{-1}) 1 x Allegro (1 L.ha^{-1})		1 x Opus Team (0.7 L.ha^{-1})
	Insecticide[4]	1 x Baythroid (0.5 L.ha^{-1})	1 x Karate Zeon (75 ml.ha^{-1})		1 x Baythroid (0.5 L.ha^{-1})
	Shortener[5]		1 x Meteor (2.2 L.ha^{-1})		
	Catchcrop		Italian ryegrass		

Table 2.2. Crops adjacent to the field margins (period 2001-2004): fertilizer, herbicide, fungicide and insecticide application (continued)

		Year			
		2001	**2002**	**2003**	**2004**
SITE2	**Crop**	Potato	Leek	Carrot	2 x Broccoli
	Fertilizer[1] (kg.ha^{-1})	**303 N:** *hair meal 14% N* *(63 N, March)* *farm yard compost 1.2% N* *(240 N, March)* **65 P:** *farm yard compost 0.8% P_2O_5* *(March)* **310 K:** *vinasse 40%K_2O* *(95 K, March)* *farm yard compost 1.3% K_2O* *(215 K, March)*	**258 N:** *farm yard manure 0.6% N* *(150 N, March)* *organic granules 6% N* *(108 N, April)* **32 P:** *farm yard manure 0.3% P_2O_5* *(March)* **320 K:** *organic granules 8% K_2O* *(120 K, April)* *farm yard manure 1.2% K_2O* *(200 K, March)*	**0 N** **0 P** **150 K:** *muriate of potash 30% K_2O* *(April)*	**200 N:** *farm yard manure 0.7% N* *(140 N, March)* *blood meal 13% N* *(60 N, March)* **32 P:** *farm yard manure 0.3% P_2O_5* *(March)* **273 K:** *muriate of potash 30% K_2O* *(60 K, March)* *farm yard manure 1.2% K_2O* *(200 K, March)* vinasse 38% K_2O (13 K, March)
	Herbicide[6]	-	-	-	-
	Fungicide[6]	-	-	-	-
	Insecticide[6]	-	-	-	-
	Catch crop	Phacelia	Winter Rye		

[1] with indication of fertilizer type and application date

[2] Pyramin (520 g.L^{-1} chloridazon); Betanal Progress (62 g.L^{-1} fenmedifam + 128 g.L^{-1}ethofumesaat + 16 g.L^{-1}desmedifam); Goltix (700 g.L^{-1} metamitron); Safari (50% triflusulfuron-methyl); Fervinal (120 g.L^{-1} sethoxydim); IP flo (500 g.L^{-1} isoproturon); Hussar (5% iodosulfuron + 15% mefenpyr-diethyl); Aspect (250 g.L^{-1} atrazin + 250 g.L^{-1} flufenacet); Mikado (300 g.L^{-1} sulcotrione)

[3] Opus Team (84 g.L^{-1} epoxiconazol + 250 g.L^{-1} fenpropimorf); Opus (125 g.L^{-1} epoxiconazol); Allegro (125 g.L^{-1} epoxiconazol + 125 g.L^{-1} kresoxim-methyl; Boscor (562 g.L^{-1} fenpropimorf + 188 g.L^{-1} fenpropidin)

[4] Baythroid (50g.L^{-1} cyfluthrin); Karate Zeon (100 g.L^{-1} lambda-cyhalothrin)

[5] Meteor (368 g.L^{-1} chloormequat + 0.8 g.L^{-1} imazaquin)

[6] No use of herbicides, insecticides, fungicides in the organic farming system at SITE2

At SITE1, herbicides were applied by a tractor-mounted sprayer at a pressure of 200 kPa and volume 350 L ha^{-1} : sprayer boom was fitted with Teejet sprayer tips and kept at a height of 0.5 m above the soil. The crops always have been sprayed when the wind blew away from our strips in order to prevent any drift. SITE2 was situated on an organic farm: so no agrochemicals were used in the adjacent crops.

At SITE1, ammoniumnitrate and muriate of potash were spread by a tractor mounted spinning disk spreader (Twindisk LELY, spinner was set for 9 m spread each side) with the tractor at 9 m from the field margin edge. Sow slurry was applied by liquid manure injectors behind a tractor-pulled tanker. Soluble N was applied by a tractor-mounted sprayer boom. At SITE2, organic granules, vinasse, hair meal and blood meal were spread by a VICON oscillating spout spreader, set for 6 m spread each side with the tractor at 6 m from the field margin edge. Farm yard manure and compost were spread by a rear-beater spreader.

Arable main crops prior to the installation of field margin strips at SITE1 were winter wheat (*Triticum aestivum* L.) in 1996, sugar beet (*Beta vulgaris* L. var. *altissima*) in 1997, winter wheat in 1998, potato (*Solanum tuberosum* L.) in 1999 and winter wheat in 2000. At SITE2, silage maize (*Zea mays* L.) was grown in monoculture from 1996 upto 2000. Italian ryegrass was installed at the end of September 2000 as a nitrogen catch crop.

Meteorological data for the experimental period 2001-2004, collected at the nearest meteorological station (Beitem, province of West Flanders, 50°55′N, 2°10′E), are shown in Appendix 2.3.

2.1.2 Trial 2 (research question 6, 7, 8, 9)

In September 2001, a field margin experiment was established on nutrient rich arable land in a strip split plot design with two light regimes (the vertical treatments), four plant communities (the horizontal treatments) and two levels of disturbance (subplot treatments) in three replicates. The two light regimes were established by installing a field margin strip along both the southern and the northern side of a tree lane consisting of two rows of very uniform 50-year-old beeches, perfectly east-west oriented, offering a sunny and a shady side.

Consequently the vegetation development in the field margin plots occurred under a high light regime on the sunny southern side and a low light regime on the northern shady side.

Within each margin strip (240 m x 10 m each), all subplots (10 m x 10 m) were arranged in a split plot design with four plant communities and two levels of disturbance in three replicates. The strip split plot design was installed in Belgium, province of West Flanders on humid, humous sandy soil (pH-KCl in the topsoil 0-30 cm: shaded side, 5.9; unshaded side, 5.6) (Carbon content in the topsoil 0-30 cm: shaded side 2.7% C, unshaded side, 3.0% C) at Beernem (51°09′N, 3°20′E) after ploughing from temporary grassland. Analysis of topsoil (0-30 cm) in September 2001 showed that extractable P and K were 65 mg and 22 mg per 100 g dry soil respectively at the shaded side and 66 mg and 28 mg per 100 g dry soil respectively at the unshaded side. Total mineral N (topsoil 0-30 cm) was 75 kg ha^{-1} at the shaded side and 120 kg ha^{-1} at the unshaded side. Trial 2 was located nearby the provincial domain Lippensgoed-Bulskampveld (see also Section 2.1.1).
The same plant communities as in trial 1 (Table 2.1, Appendix 2.1 and 2.2) were installed.
Each plant community evolved under two disturbance levels: half of the subplot vegetations were undisturbed and half were disturbed once-only on 19 September 2002 (i.e. the disturbance event) shortly after the September cutting, by a rotor cultivator, harrowing superficially (to a depth of 4 cm) the whole plot. This artificial disturbance, causing severe gap formation, was aimed to simulate the damage provoked by repeated tractor passage on margin strips.

Immediately after the disturbance event, disturbed as well as undisturbed subplots were oversown with a 1:1:1:1: mixture of four potential invader grass species (called hereafter, ‘invaders’) namely *Lolium perenne* L., *Arrhenatherium elatius* J. & C. Presl , *Dactylis glomerata* L. and *Festuca arundinacea* Schreber at a total density of 500 viable seeds per m² in order to study the susceptibility of the plant communities for being invaded (invasibility) under different levels of light and disturbance.
Native grass species of unknown invasion potential were chosen because (1) grasses have been responsible for some of the world’s most destructive invasions (Weber, 1997; White et al., 1997; Watkinson & Ormerod, 2001) and (2) invasions are often cause for concern in grassland management (Watkinson & Ormerod, 2001) and (3) grassland cultivation is a key activity in Western European agriculture. Particularly species with large seed size (except for

D. glomerata) were used: large seed mass may be an advantage during the establishment phase of invaders (Thompson et al., 2001). According to Milbau et al. (2003) invader success expressed as leaf length correlated with seed mass, germination time (invader traits) and light penetration in the gaps.

In the installation year 2001, the field margin plots were not cut. During the subsequent years (2002, 2003, 2004) the experimental plots were cut twice per year with removal of cuttings similar to REMOV2 in trial 1.

No fertilizers nor other agrochemicals were applied to the experimental margin plots. Adjacent crops and their fertilizer inputs are shown in Table 2.3. The experiment was executed on an organic farm: no pesticides were used.

Table 2.3. Crops adjacent to the field margins (period 2001-2004): crop rotation, fertilizer, herbicide and pesticide application

		Year			
		2001	2002	2003	2004
Shaded side	**Crop**	Fodder Beet	Grass/Clover/ Alfalfa	Grass/Clover/ Alfalfa	Red Beet
	Fertilizer (kg.ha^{-1})	223 N 62 P 65 K	0 N 0 P 100 K	0 N 0 P 0 K	170 N 55 P 160 K
	Herbicide[1]	-	-	-	-
	Pesticide[1]	-	-	-	-
Unshaded side	Crop	Fodder Beet	Grass/Clover/ Alfalfa	*till June*: Grass/ Clover/ Alfalfa *from June*: Leek	Red Beet
	Fertilizer (kg.ha^{-1})	223 N 62 P 65 K	0 N 0 P 100 K	50 N 0 P 150 K	170 N 55 P 160 K
	Herbicide[1]	-	-	-	-
	Pesticide[1]	-	-	-	-

[1] No use of herbicides, organic farming

Meteorological data for the experimental period 2001-2004, collected at the nearest meteorological station (Beitem, province of West Flanders, 50°55′N, 2°10′E), are shown in Appendix 2.3.

2.2 Vegetation analysis during successsion (2001-2004)

Prior to each cutting, abundance of plant species was measured on a Tansley (1954) scale (s= sporadic, r= rare; o= occasional; f= frequent; a= abundant; c= co-dominant, d= dominant) within the central 4 m x 4 m area of each 10 m x 10 m subplot. The classes of the Tansley scale were interpreted as follows: s, 1-3 individuals or tufts; r, 4-10 individuals; o, 10-20 individuals or tufts; f, tens of individuals (20-100); a, many tens or hundreds of tufts but never (co)-dominant (>100); d or c, as 'a' but species is respectively dominating (species covers more than 50% of the area) or co-dominating.

Thirty days after every mowing date, on 15 July and 15 October, species presence and importance was studied in 16 randomly placed squares (13 cm x 13 cm) within the central 4 m x 4 m area of each subplot according to the combined frequency-rank method of De Vries (De Vries & de Boer, 1959). This method allowed accurate botanical analysis of dense, highly productive grassy vegetations. Species presence was expressed in terms of importance (I%) based on the ranking of biomass contributed by the various plant species within each square. Species importance was derived from presence in 16 randomly placed squares (13 cm x 13 cm) within the central 4 m x 4 m area of each subplot. The percentage of importance (I%) was calculated as follows: within each square, ranks were assigned according to the estimated biomass of each species: rank 1 for the species with the highest contribution in total biomass, rank 2 for the second highest contribution, etc.. Then for each species the sum (I_{tot}) was made of the number of times rank 1, 2, 3 was assigned in all squares multiplied by a factor 3, 2, 1 respectively. The I% of an individual species was then calculated as I_{tot} of that species divided by the sum of I_{tot} of all occurring species. The original method was modified for use in species rich grassland containing many dicotyledons: size of squares was increased relative to the original 10 cm x 10 cm square in order to allow each occurring species, also broad leaved dicotyledons, to be recorded with an equal probability.

The I% of a functional group was calculated by adding the I% of all contributing species of that group.

Both the total number of species (species diversity) and the number of sown wildflower species, all expressed as spp./16 m², were determined by recording species occurrence (i.e. the presence or absence of each individual species) within the central 4 m x 4 m area of each 10 m x 10 m subplot.

Furthermore percentage uncovered area (i.e. exposed mineral soil inclusive litter) was estimated in eight randomly placed 80 cm x 80 cm quadrats within the central 4 m x 4 m area of each 10 m x 10 m subplot.

Similarity of vegetation development between sown and unsown plant communities within cutting treatments was compared, using both Sorenson's qualitative measure C_S and Sorenson's quantitative measure C_N (Magurran, 1988). Index C_S was solely based on species occurrence, whereas index C_N incorporated both species occurrence and species importance. In this manuscript, C_S was calculated within each block as 2j/(a+b), where j was the number of species common to both communities A and B, a and b the number of species of community A and B, respectively. C_N was calculated within each block as $\Sigma 2N_j/(N_a+N_b)$, where N_a and N_b was the total importance of the communities A (N_a=100) and B (N_b=100), respectively, and N_j was the lower of the two percentages of importance for common species of both communities.

Aside from the vegetation analysis in the margin strips, species diversity and abundance of the pre-existing boundary vegetation was yearly recorded in June on a Tansley (1954) scale.

Species nomenclature and habitats followed Van Der Meijden (1990).

Appendix 2.1. Wildflower species in wildflower mixture of MIXT1 (native plant community) and their germination rate (April 2001)

Sown wildflower species	**FG[1]**	**FT[2]**	**G%[3]**	**Sown wildflower species**	**FG[1]**	**FT[2]**	**G%[3]**
Achillea millefolium‡	PD	6-11	100 ± 1	*Leontodon hispidus*	PD	6-10	71 ± 10
Ajuga reptans†	PD	4-6	5 ± 2	*Leucanthemum vulgare‡*	PD	5-8	79 ± 4
Alchimella vulgaris†	PD	5-9	15 ± 3	*Lychnis flos-cuculi*	PD	5-7	63 ± 4
Alliaria petiolata†	PD	4-6	0 ± 0	*Malva moschata‡*	PD	7-9	17 ± 3
Anthriscus sylvestris‡	PD	5-6	0 ± 0	*Oenothera biennis†*	BD	6-9	14 ± 5
Barbarea vulgaris‡	PD	4-6	65 ± 2	*Pastinaca sativa‡*	BD	7-9	62 ± 6
Campanula glomerata†	BP	6-10	61 ± 9	*Pimpinella major†*	PD	6-9	45 ± 5
Campanula patula	BP	6-10	20 ± 4	*Plantago lanceolata‡*	PD	5-10	97 ± 1
Campanula rapunculus†	BP	5-8	79 ± 7	*Plantago media*	PD	5-6	55 ± 7
Campanula rotundifolia†	PD	6-10	24 ± 7	*Primula elatior†*	PD	3-5	0 ± 1
Centaurea jacea	PD	6-10	59 ± 6	*Primula veris†*	PD	4-6	0 ± 0
Crepis biennis†	BP	5-8	62 ± 6	*Prunella vulgaris‡*	PD	5-10	90 ± 4
Daucus carota†	BP	6-10	1 ± 1	*Rhinantus alectorolophus†*	BD	5-7	0 ± 0
Erodium cicutarium‡	PD	4-10	9 ± 3	*Rhinantus minor†*	AD	5-9	0 ± 0
Galium mollugo	PD	5-9	35 ± 8	*Rumex acetosa‡*	PD	5-6	85 ± 4
Genista tinctoria†	PD	6-8	1 ± 1	*Salvia pratensis*	PD	5-7	47 ± 8
Geranium pratense	PD	6-7	9 ± 5	*Sanguisorba officinalis†*	PD	6-9	16 ± 3
Hieracium umbellatum†	PD	7-10	8 ± 3	*Saxifraga granulata†*	PD	5-6	25 ± 9
Hypericum perforatum†	PD	6-9	87 ± 4	*Silene alba‡*	PD	5-10	92 ± 5
Jasione montana†	AD	6-8	69 ± 9	*Tanacetum vulgare‡*	PD	7-9	30 ± 21
Knautia arvensis‡	PD	6-10	34 ± 6	*Tragopogon pratensis‡*	BD	5-7	36 ± 7
Lathyrus pratensis	PD	6-8	38 ± 11	*Vicia sativa*	AD	5-7	86 ± 3
Leontodon autumnalis‡	PD	7-10	32 ± 6				

† Sown species that did not establish at all

‡ Persistent wildflower species still found in the margin strip in 2004, three years after installation

[1] FG: Functional Group; AD, annual dicots, BD, bisannual dicots, PD, perennial dicots

[2] FT: Flowering Time (month interval) according to Van Der Meijden (1990)

[3] Germination percentage (G%) was expressed as average ± standard deviation.

Seeds of the wildflower mixture were determined to species level using the seed identification manuals of Beijerinck (1947) and Martin & Barkley (1961). Germination percentage was then determined from 4 x 100 seeds laid down on wetted filter paper kept at a constant temperature of 20 °C. Germinating seeds were counted within a period of 28 days according to prescriptions of the International Seed Testing Association (I.S.T.A.).

Appendix 2.2. Wildflower species in wildflower mixture of MIXT2 (commercial plant community) and their germination rate (April 2001)

Sown wildflower species	FG[1]	FT[2]	G%[3]	Sown wildflower species	FG[1]	FT[2]	G%[3]
Achillea millefolium‡	PD	6-11	80 ± 7	*Lobularia maritima*	AD	5-9	92 ± 5
Agrostemma githago	AD	6-7	96 ± 6	*Lychnis flos-cuculi*	PD	5-7	97 ± 4
Allium schoenoprasum†	PD	5-7	80 ± 7	*Malva moschata*‡	PD	7-9	30 ± 4
Angelica archangelica†	PD	6-7	0 ± 0	*Malva sylvestris*	BD	6-10	53 ± 5
Anthriscus cerefolium	AD	5-6	55 ± 10	*Matricaria chamomilla*	AD	5-10	95 ± 9
Anthriscus sylvestris‡	PD	5-6	46 ± 7	*Medicago sativa*‡	PD	6-9	84 ± 2
Antirrhinum orontium	AD	6-10	30 ± 10	*Medicago lupulina*	PD	4-10	60 ± 2
Apium graveolens	AD	7-10	94 ± 3	*Nigella damascena*	AD	6-8	31 ± 7
Artemisia absinthium	PD	7-9	77 ± 4	*Oenothera biennis*	BD	6-9	85 ± 10
Artemisia vulgaris‡	PD	7-9	78 ± 4	*Onobrychis viciifolia*	PD	5-7	38 ± 8
Atriplex hortensis	AD	7-10	60 ± 6	*Origanum vulgare*†	PD	7-9	78 ± 7
Barbarea vulgaris‡	PD	4-6	95 ± 4	*Papaver rhoeas*	AD	6-7	79 ± 6
Bellis perennis	PD	1-12	98 ± 2	*Papaver somniferum*	AD	6-8	77 ± 5
Berteroa incana†	BD	6-9	95 ± 6	*Pastinaca sativa*	BD	7-9	54 ± 5
Borago officinalis	AD	5-10	10 ± 5	*Phalaris canariensis*	AM	6-10	60 ± 8
Brassica nigra	AD	6-9	97 ± 1	*Plantago lanceolata*‡	PD	5-10	61 ± 5
Carum carvi†	AD	5-6	34 ± 3	*Plantago media*#	PD	5-6	
Centaurea cyanus	AD	5-8	89 ± 5	*Reseda luteola*	AD	6-9	45 ± 11
Cheiranthus cheirii#	BD	5-6		*Rosa rugosa*†	PD	6-10	20 ± 5
Chenopodium album	AD	7-10	30 ± 3	*Rumex acetosa*‡	PD	5-6	89 ± 6
Chrysanthemum segetum#	AD	6-10		*Saponaria officinalis*#	PD	7-9	
Cichorium intybus	PD	7-8	83 ± 16	*Setaria viridis*	AM	7-9	95 ± 5
Coronilla varia†	PD	6-9	77 ± 5	*Sinapis alba*	AD	5-7	99 ± 1
Digitalis purpurea†	BD	5-10	87 ± 4	*Sinapis arvensis*	AD	5-9	62 ± 4
Dipsacus sylvestris	BD	7-9	96 ± 2	*Tanacetum vulgare*‡	PD	7-9	42 ± 15
Galega officinalis#	PD	6-8		*Thymus serpyllum*#	PD	6-9	
Iberis amara	AD	6-9	94 ± 3	*Trifolium pratense*‡	PD	5-10	93 ± 2
Legousia speculum-veneris†	AD	6-8	75 ± 5	*Verbascum densiflorum*†	BD	7-10	69 ± 2
Leucanthemum vulgare‡	PD	5-8	89 ± 1	*Viola cornuta*#	BD	4-8	
Linaria vulgaris†	PD	6-10	7 ± 3				

Wildflower species not found in the seed mixture

† Sown species that did not establish at all

‡ Persistent wildflower species still found in the margin strip in 2004, three years after installation

[1] FG: Functional Group; AD, annual dicots, BD, bisannual dicots, PD, perennial dicots
AM, annual monocots

[2] FT: Flowering Time (month interval), according to Van Der Meijden (1990)

[3] Germination percentage (G%) was expressed as average ± standard deviation.
Seeds of the wildflower mixture were determined to species level using the seed identification manuals of Beijerinck (1947) and Martin & Barkley (1961). Germination percentage was then determined from 4 x 100 seeds laid down on wetted filter paper kept at a constant temperature of 20 °C. Germinating seeds were counted within a period of 28 days according to prescriptions of the International Seed Testing Association (I.S.T.A.).

Appendix 2.3. Meteorological data for the experimental period 2001-2004, collected at Beitem (province of West Flanders, 50°55′N, 2°10′E) by the Royal Meteorological Institute of Belgium (KMI, http://www.meteo.be)

Year	Month	Air temperature in vented shelter(°C)			Precipitation (mm)
		Maximum	Minimum	Average	
2001	**January**	6.6	0.9	3.8	79.5
	February	8.0	2.5	5.3	79.5
	March	9.7	3.9	6.8	102.5
	April	12.2	4.9	8.6	107.4
	May	19.5	6.6	13.1	19.5
	June	20.4	10.7	13.6	29.8
	July	23.3	14.3	18.8	71.8
	August	23.9	14.2	19.1	73.8
	September	17.2	10.0	13.6	184.6
	October	18.0	10.9	14.5	34.6
	November	10.6	4.4	7.5	87.2
	December	6.0	0.6	3.3	45.0
	M[1]	*14.6*	*7.0*	*10.8*	
	Total				*915.0*
	N[2]	*13.5*	*5.6*	*9.6*	*718.0*
2002	**January**	7.2	1.7	4.5	70.9
	February	10.7	4.9	7.8	140.9
	March	11.9	3.8	7.8	57.0
	April	15.2	4.8	10.0	34.7
	May	17.3	9.7	13.5	55.7
	June	21.0	12.3	16.7	77.4
	July	21.4	13.7	17.6	68.1
	August	23.4	14.3	18.9	70.9
	September	19.6	10.4	15.0	52.5
	October	14.4	7.0	10.7	78.2
	November	11.6	6.0	8.8	113.1
	December	7.1	2.7	4.9	136.8
	M	*15.1*	*7.6*	*11.3*	
	Total				*956.0*
	N	*13.5*	*5.6*	*9.6*	*718.0*

[1] M, mean annual values

[2] N, normal annual values (average over the last 30 years)

Appendix 2.3. Meteorological data for the experimental period 2001-2004, collected at Beitem (province of West Flanders, 50°55′N, 2°10′E) by the Royal Meteorological Institute of Belgium (KMI, http://www.meteo.be) (Continued)

Year	**Month**	**Air temperature in vented shelter(°C)**			**Precipitation (mm)**
		Maximum	**Minimum**	**Average**	
2003	**January**	5.9	0.4	3.1	89.4
	February	7.4	-1.5	3.0	18.3
	March	13.6	3.5	8.6	22.2
	April	15.5	4.7	10.1	36.4
	May	18.1	9.0	13.5	85.6
	June	23.7	13.0	18.4	53.7
	July	24.1	14.3	19.2	47.1
	August	25.8	14.9	20.4	62.2
	September	21.5	9.2	15.4	25.1
	October	12.8	4.0	8.4	69.2
	November	11.5	5.2	8.3	73.0
	December	7.3	1.7	4.5	75.5
	M[1]	15.6	6.5	11.1	
	Total				657.7
	N[2]	*13.5*	*5.6*	*9.6*	*718.0*
2004	**January**	6.7	1.5	4.1	121.7
	February	8.1	3.0	5.5	37.6
	March	10.3	2.3	6.3	40.0
	April	15.3	5.5	10.4	49.8
	May	17.4	7.7	12.6	31.0
	June	20.8	11.9	16.3	58.4
	July	22.1	12.6	17.4	72.6
	August	23.5	15.3	19.4	126.8
	September	21.0	11.6	16.3	48.5
	October	15.5	8.5	11.9	29.4
	November	9.8	3.8	7.0	48.5
	December	6.0	1.4	3.6	50.7
	M	*14.7*	*7.1*	*10.9*	
	Total				*715.0*
	N	*13.5*	*5.6*	*9.6*	*718.0*

[1] M, mean annual values

[2] N, normal annual values (average over the last 30 years)

Chapter 3

Evolution of the vegetation of mown field margin strips over their first four years

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Chapter 3

Evolution of the vegetation of mown field margin strips over their first four years

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3.1 Introduction

Despite an ongoing reduction in field boundary habitats (Chapman & Sheail, 1994), a range of public initiatives has resulted in the creation of new field margin features on ex-arable land in northern and western Europe, notably conservation headlands and margin strips. Support mechanisms exist to encourage farmers to create new habitats, to restore old ones or expand existing boundaries by means of margin strips, to restore the landscape connectivity, to care for small landscape elements. Expanding existing field boundaries is generally done by taking the outer metres of an arable field out of production and allowing it to regenerate naturally or sowing it to grass or a grass/forbs mixture, usually under a mowing regime (e.g. Smith & MacDonald, 1989; Marshall & Nowakowski, 1992; Dunkley & Boatman, 1994; Hart et al., 1994).

To evaluate the long-term success of sown and unsown margin strips it is essential to record vegetation succession, species composition and richness over time. According to Hodgson (1989) the succession of naturally revegetated strips is characterized by an initial dominance of annuals and short-lived species, which are, with time, typically replaced by perennial non-woody species and secondly, if no mowing regime is applied, by shrubs and trees. After four years, species richness, biomass production and monocotyledon/dicotyledon ratio in grass, grass/wildflower strips and natural regeneration strips, mown once a year, converged to the level of the pre-existing boundary and this in three countries, UK, France and The Netherlands (Marshall et al., 1994; Kleijn et al., 1998). Kleijn et al. (1997) found within three year old strips mown once a year, that strips sown with a rich grass-wildflower mixture had higher species richness than strips sown to perennial ryegrass or strips left to revegetate spontaneously, because of limited colonisation by species from the pre-existing boundary. West and Marshall (1996) also found that mown naturally regenerated plots had lower vegetation cover and lower species diversity than mown sown plots, but species numbers remained stable in the second year whereas they decreased in the sown plots.

Unfortunately many succession studies concerning margin strips do not contain unsown plots. It is therefore impossible to know how effective the addition of seed mixtures has been in accelerating or diverting succession or species composition. Furthermore information is lacking concerning vegetation succession and botanical composition of sown and unsown strips under different cutting regimes during the first successional years. According to Marshall (1998) seed mixtures with fine grasses and wildflowers are most successful on infertile soils with regular mowing. Cutting yearly in spring and late summer, with removal of cuttings, reduced the rate of species loss in a sown grass/wildflower field margin strip over a five-year period and was recommended for maintaining plant species diversity (Marshall & Nowakowski, 1995). Concerning the mowing management a lot of knowledge is funded on botanical management of roadsides. Mowing twice a year with removal of cuttings resulted in the highest species richness in roadsides, where it enhanced also the rare flora (Zwaenepoel, 1998).

This study examines the effects of sown and unsown margin strips on early vegetation succession, species richness and composition of ex-arable land under different cutting regimes. In particular the following questions are adressed: (1) Is there any potential for naturally regenerated strips to develop into floristic diverse plant communities or are they depauperated of species? (2) Which mowing regime of the newly created communities maximizes species richness and how does the cutting regime direct biodiversity and vegetation succession? (3) What is the success of introducing seed mixtures differing in seed provenance to recreate a diverse semi-natural community? (4) Is the application of species rich roadside herbage useful to enhance botanical diversity? (5) And finally, is there any similarity in the vegetation between unsown and sown communities?

3.2 Specific material and methods

The research was based on trial 1 explained in Chapter 2, Section 2.1. Botanical analysis of margin strips was performed during the succession period from 2001 to 2004, in order to study vegetation composition under different mowing regime. Botanical analysis followed the methodology described in Chapter 2, Section 2.2. The botanical composition in terms of importance of functional groups was recorded over time by calculating the percentile contribution of all functional groups to the total importance (=100%). Species were classified into the following functional groups: annual legumes (ANLEG), perennial legumes (PERLEG), annual sown or spontaneous non N-fixing dicotyledons (ANDIC) and perennial sown or spontaneous non N-fixing dicotyledons (PERDIC), annual sown or spontaneous monocotyledons (ANMON) and perennial sown or spontaneous monocotyledons (PERMON). The I% of a functional group was calculated by adding the I% of all contributing species of that group.

To determine the vegetation succession over time (2001-2004) in terms of functional groups, a principal component analysis on a variance-covariance matrix was performed on data (July monitorings) of I% of functional groups. Regression analysis was used (SPSS10.0 for Windows) to determine the pattern of succession over time (time was expressed as days after 15 October 2001). Furthermore S-plus 2000 for Windows was used to carry out the statistical computations for a split plot design.

3.3 Results

3.3.1 Species diversity

After four successional years, total species diversity was significantly altered by the plant community and the mowing regime but not by the location. However a significant interaction between location and plant community occurred (Table 3.1). Highest species richness was observed in CONTR at SITE1 and in MIXT1 at SITE2. At SITE1, species richness in CONTR was significantly higher than in MIXT1, but inversely at SITE2. At SITE2, MIXT1 was significantly species-richer than MIXT2 but not at SITE1. Compared to MIXT2, the addition of roadside herbage increased species richness with approximately 1.5 and 5 spp./16 m^2 at SITE1 and SITE2 (significant) respectively.

The species richness was significantly higher for REMOV2 than for REMOV0 and REMOV1 which responded intermediary.

During the first four successional years, species diversity of sown plant communities decreased over time irrespective of mowing regime (Table 3.2). Species diversity of MIXT1 and MIXT2 significantly decreased between 2001 and 2004, irrespective of mowing regime

Table 3.1. Species diversity (ssp./16 m²) during succession (2001-2004). Abbreviations cf. Section 2.1

Location	**Plant community**	**Mowing regime**	**Time[1]**						
			M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
	CONTR.		10.3	22.4	21.3	17.3	17.2	13.9	13.1
	MIXT1		18.5	21.1	19.6	20.0	16.5	16.7	13.2
	MIXT2		21.9	17.8	15.3	16.0	13.8	13.7	10.9
	MIXT3		20.8	24.4	14.2	22.1	15.7	17.9	14.2
		REMOV0	18.0	18.5	16.1	17.2	14.4	12.9	11.3
		REMOV1	17.8	23.2	17.3	20.3	15.8	16.7	12.8
		REMOV2	17.9	22.6	19.4	19.1	17.2	17.0	14.5
SITE1	CONTR		9.3	25.8	23.7	17.7	16.1	12.8	15.2
	MIXT1		18.0	17.7	18.0	18.0	14.3	13.8	11.3
	MIXT2		18.1	17.1	16.0	17.2	14.9	13.9	13.7
	MIXT3		18.2	24.6	15.4	23.1	16.8	19.2	15.1
SITE2	CONTR		11.3	19.1	19.0	17.0	18.2	15.0	11.0
	MIXT1		19.0	24.4	21.2	22.0	18.7	19.6	15.0
	MIXT2		25.7	18.6	14.7	14.8	12.8	13.4	8.2
	MIXT3		23.4	24.3	12.9	21.1	14.6	16.6	13.3
SITE1		REMOV0	15.1	18.8	17.3	18.2	15.2	12.9	12.7
		REMOV1	16.2	23.0	17.4	21.1	15.3	16.2	13.8
		REMOV2	16.5	22.1	20.1	17.8	16.1	15.7	15.1
SITE2		REMOV0	20.9	18.3	14.8	16.2	13.7	12.9	9.9
		REMOV1	19.4	23.4	17.3	19.5	16.3	17.3	11.8
		REMOV2	19.3	23.1	18.8	20.5	18.3	18.3	13.9
Anova[2]:									
Location			NS	NS	NS	NS	NS	NS	NS
Plant community			***	*	***	***	*	**	*
LSD			2.6						
Mowing regime			NS	***	***	*	***	***	***
LSD					1.7	2.0	1.4	1.5	1.3
Location x Plant community			NS	*	*	***	*	*	**
LSD within location				6.1	3.0	1.7	3.2	3.4	3.2
LSD otherwise				13.0	5.3	13.2	6.3	10.1	5.7
Location x Mowing regime			NS	NS	NS	NS	NS	NS	NS
Plant community x Mowing regime			NS	*	NS	NS	NS	NS	NS
LSD within Plant community				3.6					
LSD otherwise				5.2					
Location x Plant community x Mowing regime			NS	NS	NS	NS	NS	NS	NS

[1] M1, October 2001; M2, July 2002; M3, October 2002; M4, July 2003; M5, October 2003; M6, July 2004; M7, October 2004

[2] NS, non significant; *, **, *** Significant at $p<0.05$, $p<0.01$ and $p<0.001$ respectively; LSD, Least Significant Difference ($p<0.05$)

Table 3.2. Species diversity (spp./16 m²) during succession (2001-2004) and slopes of linear regression of species diversity over time for four sown/unsown plant communities under cutting with or without removal of all cuttings. Abbreviations cf. Section 2.1

Location	**Mowing**	**Plant**	**Before**	**After mowing**[1]							**Slopes**[2]	
	regime	**community**	**mowing**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**		***R²***
SITE1	**REMOV0**	**CONTR**	34.3	8.3	24.7	21.0	17.0	16.3	12.7	15.0	-1.19	
		MIXT1	33.7	17.3	15.7	17.7	15.3	14.0	11.7	9.7	-6.76 ***	*0.47*
		MIXT2	49.7	18.0	15.7	14.3	17.0	12.7	9.7	11.7	-6.31 **	*0.37*
		MIXT3	48.7	16.7	19.0	16.3	23.3	17.7	17.7	14.3	-0.99	
	REMOV2	**CONTR**	34.3	10.0	24.7	26.7	16.0	16.0	13.0	16.0	-2.97	
		MIXT1	33.7	18.0	18.7	19.7	18.0	15.0	15.0	13.3	-4.89 **	*0.38*
		MIXT2	49.7	19.0	17.7	18.3	15.7	15.0	15.3	14.7	-4.14 *	*0.25*
		MIXT3	48.7	19.0	27.3	15.7	21.3	18.3	19.3	16.3	-3.24	
SITE2	**REMOV0**	**CONTR**	13.7	14.0	19.3	18.0	15.7	16.0	14.0	10.7	-4.10 *	*0.19*
		MIXT1	33.0	21.3	20.7	17.3	18.7	15.3	14.7	11.3	-8.21 **	*0.41*
		MIXT2	42.0	25.3	14.0	11.7	12.0	11.3	10.0	6.3	-12.87 ***	*0.64*
		MIXT3	42.0	23.0	19.3	12.3	18.3	12.0	13.0	11.3	-8.89 **	*0.33*
	REMOV2	**CONTR**	13.7	10.3	17.0	18.3	15.3	19.0	14.7	9.3	-1.12	
		MIXT1	33.3	18.3	24.7	25.7	23.0	20.3	22.0	17.3	-2.18	
		MIXT2	42.0	24.3	22.7	17.3	17.0	14.7	16.3	11.7	-10.01 **	*0.30*
		MIXT3	42.0	24.0	28.0	13.7	26.6	19.0	20.0	17.3	-4.87	

[1] M1, October 2001; M2, July 2002; M3, October 2002; M4, July 2003; M5, October 2003; M6, July 2004; M7, October 2004

[2] Slopes (10^{-3} spp.day^{-1}) of regression of species diversity (spp.) upon time (days; October 2001-October 2004)

*, **, *** $p<0.05$, $p<0.01$, and $p<0.001$ respectively

or location. Obviously commercial species were less persistent than native species particularly at SITE2 since slopes of linear regression equations were more negative for MIXT2 than for MIXT1. At SITE2 the decrease in species diversity of sown communities was hastened under REMOV0 since slopes were more negative under REMOV0 than under REMOV2.

Species diversity of CONTR slightly decreased during succession, irrespective of location or mowing regime (Table 3.2). As for the sown communities the decrease in species diversity of CONTR at SITE2 was higher for REMOV0 than for REMOV2. Since initially, species diversity was significantly higher for the sown communities (Table 3.1) and since the unsown community revealed a lower decrease (SITE1) in species diversity, species diversity of sown and unsown communities converged during the first four successional years, irrespective of mowing regime or location.

The annual addition of roadside herbage after the September cutting caused an annual peak (15 July) in species richness. However the survival of introduced species by the addition of roadside herbage was unstable which could explain the whimsical pattern (Table 3.2) of species richness over time. Furthermore all slopes of regression equations of MIXT3 were less negative than the corresponding equations of MIXT2 irrespective of location or mowing regime. This means that the addition of roadside herbage delayed the loss of species.

3.3.2 Fate of sown wildflowers

Upon establishment 72% of the sown wildflower species emerged in MIXT2 and MIXT3, and 42% in MIXT1 (Table 3.3). During the following years the number of sown wildflowers decreased significantly, irrespective of plant community, mowing regime or location.

At SITE2 but not at SITE1, diversity of sown wildflower species in MIXT1 and MIXT2 decreased at higher rate under REMOV0 since slopes of regression equations were more negative under REMOV0 than under REMOV2 (Table 3.3).

In October 2004, the mowing regime ($p=0.01$) significantly determined the total number of surviving sown wildflower species. A significant interaction between location and plant community occurred ($p<0.001$). The highest number of sown wildflower species was recorded under REMOV2 (2.8 spp.) which significantly differed from REMOV1 (2.1 spp.)

Table 3.3. Number of surviving sown wildflower species (spp./16 m²) during succession (2001-2004) for sown margin strips under cutting with or without removal of cuttings. Abbreviations cf. Section 2.1

Location	Plant community[1]	Mowing regime	Before mowing	After mowing[2]							Slope[3]	
				M1	M2	M3	M4	M5	M6	M7		*R²*
SITE1	**MIXT1**	**REMOV0**	19.0	7.0	3.7	4.0	3.7	3.7	3.0	2.3	-3.15 **	*0.35*
		REMOV2	19.0	7.3	7.7	5.7	5.3	4.0	4.3	3.3	-4.01 ***	*0.53*
	MIXT2	**REMOV0**	41.0	6.7	5.7	4.7	4.7	3.0	3.3	3.3	-3.13 ***	*0.54*
		REMOV2	41.0	8.0	7.3	6.3	4.3	4.0	4.0	3.7	-4.29 ***	*0.46*
	MIXT3	**REMOV0**	41.0	5.3	7.0	5.0	5.3	4.0	4.3	3.3	-2.19 *	*0.27*
		REMOV2	41.0	6.7	8.7	4.3	6.3	4.7	4.3	4.3	-2.72 *	*0.27*
SITE2	**MIXT1**	**REMOV0**	19.0	8.3	6.7	6.0	4.7	3.3	3.7	3.0	-4.78 ***	*0.55*
		REMOV2	19.0	6.3	7.0	10.0	6.7	6.3	5.7	6.3	-1.35	
	MIXT2	**REMOV0**	42.0	7.3	2.7	3.0	1.0	1.0	1.0	0.7	-5.12 ***	*0.62*
		REMOV2	42.0	8.0	4.7	3.3	1.7	2.3	2.3	1.7	-4.91 ***	*0.64*
	MIXT3	**REMOV0**	42.0	5.3	5.3	3.3	2.3	1.7	1.3	2.0	-3.81 *	*0.25*
		REMOV2	42.0	8.3	7.7	3.0	4.7	3.3	4.3	3.0	-4.12 *	*0.29*

[1] Initial number of sown wildflower species in seed mixture: MIXT1, 45 spp.; MIXT2, 59 spp.; MIXT3, 59 spp.

[2] M1, October 2001; M2, July 2002; M3, October 2002; M4, July 2003; M5, October 2003; M6, July 2004; M7, October 2004

[3] Slope (10^{-3} spp.day^{-1}) of regression of species diversity upon time (days) :*, **, *** p<0.05, p<0.01, and p<0.001 respectively

and REMOV0 (1.8 spp.) (LSD=0.6 spp.). At SITE2 number of sown wildflower species in MIXT1 (4.7 spp.) was significantly higher than in MIXT2 (1.0 spp.) and MIXT3 (2.2 spp.) but not at SITE1 (MIXT1, 2.8 spp.; MIXT2, 3.7 spp.; MIXT3, 3.7 spp.; LSD within location=1.1 spp.).

3.3.3 Botanical composition

General succession patterns:

Principal components analysis revealed that the principal components (Z) explained 56.4% (Z1); 36.9% (Z2), 6.1% (Z3), 0.6% (Z4), 0.1% (Z5) and 0.0% (Z6) of the total variance. Since the first two components accounted for 93.3% of the total variance, all other components were ignored further on. The first component (Z1) was 0.815(ANDIC) +0.506(PERDIC)+0.275(ANLEG)+0.720(ANMON)-0.070(PERLEG)-0.952(PERMON). The coefficients of Z1 primarily contrasted on the one hand I% of PERMON and on the other hand I% of ANDIC, PERDIC and ANMON. The second component (Z2) was 0516(ANDIC)+ 0.172(PERDIC)+0.362(ANMON)+0.303(PERMON)-0.228(ANLEG)-0.990(PERLEG) which primarily contrasted I% of PERLEG and I% of other functional groups. Time-trajectories of plant communities at SITE1 and SITE2 were plotted against the first two principal components Z1 and Z2 under REMOV2 (Figure 3.1 A) and REMOV0 (Figure 3.1 B).

Vegetation succession in the period 2002-2004 was characterized by a steady increase in I% of perennials at the expense of annuals since values of Z1 decreased over time. Furthermore plant communities became more grassy over time since values of Z2 increased while values of Z1 decreased over time. The I% of legumes decreased over time irrespective of mowing regime, location or plant community except for CONTR under REMOV2 revealing an increase over time at SITE1 or a stable I% at SITE2.

Vegetation succession differed considerably between locations irrespective of mowing regime or plant community: At SITE1, legumes were more abundant than at SITE2 since succession patterns revealed lower values of Z2. Under REMOV0, the I% of monocotyledons increased at higher rate than under REMOV2 since values of Z1 were more negative under REMOV0. Similarly, the decrease in I% of legumes occurred at higher rate under REMOV0 since values of Z2 were less negative for REMOV0 compared to values of REMOV2.

Furthermore, time-trajectories of CONTR and sown communities converged over time,

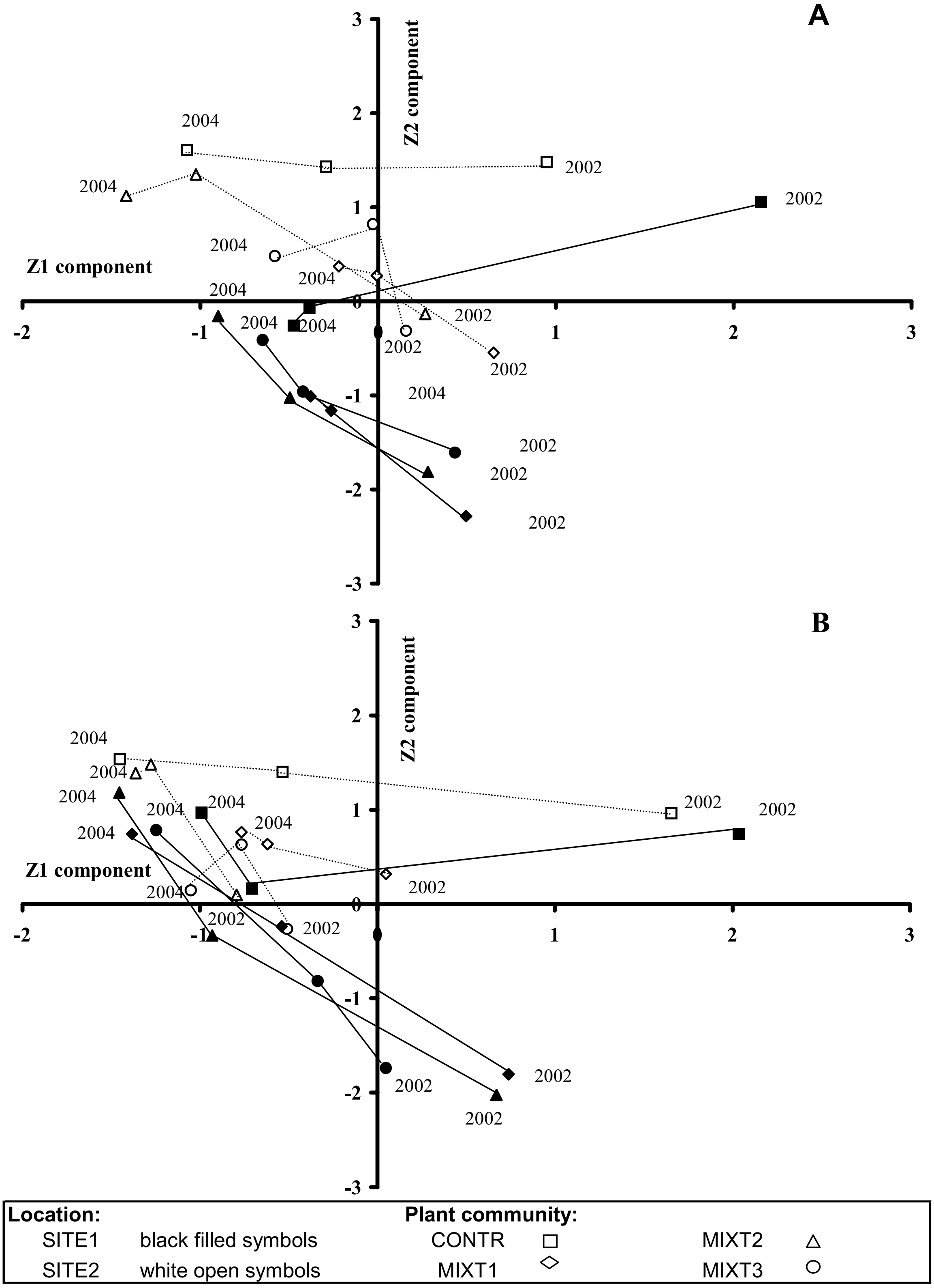


Figure 3.1. Time-trajectories of sown and unsown plant communities plotted against the first two principal components Z1 and Z2 for variables of functional groups, at two sites under REMOV2 (A) and REMOV0 (B). Abbreviations cf. Section 2.1

irrespective of mowing regime or location. So, similarity in vegetation composition in terms of functional groups occurred between sown and unsown communities.

Succession patterns within functional groups:

During succession the I% of perennials significantly increased at the expense of the I% of annuals which significantly decreased irrespective of plant community, mowing regime or location (Table 3.4, Appendix 3.1). In the installation year, annuals showed a high I% and were even dominant in the unsown community. The decrease in I% of annuals occurred within all functional groups (monocotyledons, non fixing dicotyledons and legumes). The increase in I% of perennials, on the other hand, was predominantly attributed to the increase of perennial monocotyledons and to a lesser extent to perennial non fixing dicotyledons or legumes.

The significant decrease in I% of annuals and inversely the significant increase in perennials was modified by mowing regime and plant community. The decrease (annuals) and increase (perennials) occurred at higher rate under REMOV0 (except for MIXT2 at SITE2) since slopes of linear regression equations were more negative and positive for annuals and perennials respectively. Similarly, in sown communities, the decrease of annuals and increase of perennials was hastened in the vegetation of MIXT2.

The I% of monocotyledons increased significantly over time, irrespective of mowing regime, plant community or location with lowest rates in MIXT1. Furthermore the I% of monocotyledons increased at higher rate under REMOV0 except for MIXT2 at SITE2. The increase in I% of monocotyledons was attributed to the increase in I% of perennial monocotyledons (both sown and unsown) since annual monocotyledons (sown and unsown) decreased over time.

Three years after installation, in October 2004, the actual I% of monocotyledons was characterized by a significant interaction between location and plant community and between location and mowing regime (Table 3.5). At SITE1, CONTR was significantly less grassy than the sown plant communities but not at SITE2, except for MIXT2 which was significantly more grassy than all other communities. The addition of roadside herbage provoked a significantly less grassy vegetation at SITE2 but not at SITE1. CONTR and MIXT2 were significantly more grassy at SITE2 than at SITE1. At SITE1, communities under REMOV0 were significantly more grassy than communities under REMOV1 and REMOV2. At SITE2 no significant differences were found.

Table 3.4. Slopes (x 10^{-2} %.day^{-1}) of regression equations of importance (I%) of functional groups over time (days) for sown and unsown communities under cutting with or without removal of cuttings (period 2001-2004). Abbreviations cf. Section 2.1

Functional group	**SITE1**											
	CONTR				**MIXT1**				**MIXT2**			
	REMOV0		**REMOV2**		**REMOV0**		**REMOV2**		**REMOV0**		**REMOV2**	
	Slope	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***
perennials	5.457 ***	*0.65*	5.199 ***	*0.68*	0.646 *	*0.18*	0.296 *	*0.20*	2.198 ***	*0.57*	1.411 ***	*0.42*
annuals	-5.457 ***	*0.65*	-5.199 ***	*0.68*	-0.646 *	*0.18*	-0.296 *	*0.20*	-2.198 ***	*0.57*	-1.411 ***	*0.42*
legumes	0.950 *	*0.18*	2.945 ***	*0.71*	-4.011 ***	*0.60*	-1.498 *	*0.30*	-4.972 ***	*0.73*	-2.292 ***	*0.62*
annual legumes									-1.030 *	*0.30*	-0.650 *	*0.28*
perennial legumes	0.950 *	*0.18*	2.945 ***	*0.71*	-4.011 ***	*0.60*	-1.498 *	*0.30*	-3.941 ***	*0.61*	-1.642 ***	*0.44*
non fixing dicots	-5.982 ***	*0.66*	-6.863 ***	*0.81*	-1.163 *	*0.18*	-0.887 *	*0.29*	-1.516 *	*0.27*	-0.928 *	*0.21*
perennial sown non fixing dicots					-0.592 *	*0.29*	-0.759 *	*0.30*	-0.052		-0.132	
annual sown non fixing dicots									-0.752 **	*0.34*	-0.441 *	*0.28*
annual spontaneous dicots	-4.315 ***	*0.82*	-4.257 ***	*0.76*	-0.646 *	*0.18*	-0.246 *	*0.18*	-0.415 *	*0.25*	-0.319 *	*0.19*
perennial spontaneous dicots	-1.667 *	*0.21*	-2.606 ***	*0.56*	0.075		0.119		-0.401 *	*0.21*	-0.036	
monocots	5.032 ***	*0.69*	3.918 ***	*0.61*	5.174 ***	*0.80*	2.385 ***	*0.48*	6.489 ***	*0.90*	3.221 ***	*0.73*
annual spontaneous monocots	-1.142 *	*0.22*	-0.942 *	*0.19*			-0.050					
perennial spontaneous monocots	6.174 ***	*0.74*	4.860 ***	*0.66*	2.647 **	*0.31*	1.302 ***	*0.47*	2.119 *	*0.28*	1.652 ***	*0.45*
perennial sown monocots					2.527 **	*0.31*	1.133 *	*0.18*	4.370 ***	*0.49*	1.570 *	*0.30*

Table 3.4. Slopes (x 10^{-2} %.day^{-1}) of regression equations of importance (I%) of functional groups over time (days) for sown and unsown communities under cutting with or without removal of cuttings (period 2001-2004). Abbreviations cf. Section 2.1 (continued)

Functional group	**SITE2**											
	CONTR				**MIXT1**				**MIXT2**			
	REMOV0		**REMOV2**		**REMOV0**		**REMOV2**		**REMOV0**		**REMOV2**	
	Slope	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***
perennials	7.111 ***	*0.78*	6.298 ***	*0.76*	1.863 ***	*0.55*	1.589 **	*0.40*	2.412 **	*0.40*	3.699 ***	*0.77*
annuals	-7.111 ***	*0.78*	-6.298 ***	*0.76*	-1.863 ***	*0.55*	-1.589 **	*0.40*	-2.412 **	*0.40*	-3.699 ***	*0.77*
legumes	-0.259		-0.222		-2.005 ***	*0.51*	-2.063 ***	*0.45*	-2.617 ***	*0.50*	-2.661 ***	*0.57*
annual legumes									-1.072 **	*0.42*	-0.935 **	*0.42*
perennial legumes	-0.259		-0.222		-2.005 ***	*0.51*	-2.063 ***	*0.45*	-1.545 **	*0.36*	-1.726 ***	*0.42*
non fixing dicots	-5.451 ***	*0.79*	-4.396 ***	*0.61*	-1.327 *	*0.19*	-1.176 *	*0.19*	-1.185 **	*0.32*	-2.377 ***	*0.56*
perennial sown non fixing dicots					-0.674 *	*0.18*	-0.202		-0.306		-0.115	
annual sown non fixing dicots											-0.041	
annual spontaneous dicots	-5.746 ***	*0.77*	-4.982 ***	*0.71*	1.571 ***	*0.51*	-1.368 *	*0.29*	-0.860 *	*0.19*	-2.503 ***	*0.65*
perennial spontaneous dicots	0.294		0.586 *	*0.18*	0.918 *	*0.18*	0.394 *	*0.29*	0.019		0.283 *	*0.18*
monocots	5.710 ***	*0.82*	4.618 ***	*0.67*	3.332 ***	*0.51*	3.240 ***	*0.59*	3.801 ***	*0.58*	5.038 ***	*0.80*
annual spontaneous monocots	-1.366 ***	*0.46*	-1.316 **	*0.31*	-0.292 ***	*0.45*	-0.221		-0.480 **	*0.34*	-0.220 *	*0.20*
perennial spontaneous monocots	7.076 ***	*0.85*	5.934 ***	*0.73*	0.777		0.247		0.935 **	*0.32*	0.075	
perennial sown monocots					2.847 ***	*0.48*	3.214 ***	*0.67*	3.346 **	*0.42*	5.183 ***	*0.81*

*,**,*** $p<0.05$, $p<0.01$ and $p<0.001$ respectively

The I% of both annual and perennial legumes significantly decreased over time in all sown communities. At SITE1, this decrease in I% in sown communities was more pronounced under REMOV0 than under REMOV2. At SITE2, the decrease of legumes was not affected by mowing regime since slopes of linear regression equations were similar for REMOV0 and REMOV2. In CONTR, the I% of legumes decreased at SITE2 but not at SITE1 where they significantly expanded at high rate; the significant expansion was hastened under REMOV2.

In October 2004 the actual I% of legumes was not significantly determined by plant community but was significantly characterized by a significant interaction between location and mowing regime and between location and plant community (Table 3.5). At SITE1, the I% of legumes was significantly higher under REMOV2 than under REMOV1 and REMOV0: no differences were found at SITE2. The I% of legumes under REMOV1 and REMOV2 were significantly two- to fourfold higher at SITE1 than at SITE2. Compared to SITE2, SITE1 showed significant higher share of legumes in all plant communities except for MIXT3 at SITE1.

During succession, the I% of non fixing dicotyledons significantly decreased at the benefit of the monocotyledons which significantly increased over time, irrespective of mowing regime, location or plant community. The highest rate of change was found in CONTR followed by MIXT2. The rate of decrease of non fixing dicotyledons was higher under REMOV0 than under REMOV2 except for CONTR at SITE1 and MIXT2 at SITE2. The I% of annual non fixing dicotyledons significantly decreased over time irrespective of plant community, mowing regime or location. In sown plots, the I% of perennial sown non fixing dicotyledons significantly decreased over time, irrespective of mowing regime, location or plant community. On the contrary, the I% of perennial spontaneous non fixing dicotyledons increased slightly over time at SITE2 but decreased at SITE1, except for MIXT1. In CONTR, the I% of perennial spontaneous non fixing dicotyledons increased slightly at SITE2 but decreased significantly at SITE1. The I% of spontaneous non fixing dicotyledons became inferior to the I% of spontaneous monocotyledons, irrespective of mowing regime, location or plant community, despite the initial higher I% of spontaneous non fixing dicotyledons.

In October 2004, the I% of non fixing dicotyledons was not significantly altered by mowing regime (Table 3.5). A significant interaction was found between plant community and location.

Table 3.5. Importance (I%) of functional groups on 15 October 2001 (M1) and 15 October 2004 (M7). Abbreviations cf. Section 2.1

Location	**Plant community**	**Mowing regime**	**Non N-fixing dicotyledons**[1]		**Legumes**		**Monocotyledons**	
			M1	**M7**	**M1**	**M7**	**M1**	**M7**
SITE1			37.6	9.5	39.5	22.8	22.8	67.7
SITE2			38.8	15.5	28.0	9.4	33.2	75.1
	CONTR		80.3	19.1	0.9	13.2	18.8	67.7
	MIXT1		26.5	13.4	43.8	18.7	29.7	68.0
	MIXT2		23.4	4.5	43.6	13.5	33.0	82.0
	MIXT3		22.7	12.9	46.6	19.0	30.6	68.0
		REMOV0	38.1	12.4	33.3	9.3	28.6	78.3
		REMOV1	38.5	13.1	33.1	18.9	28.4	68.0
		REMOV2	38.1	12.0	34.9	20.0	27.0	68.0
SITE1	CONTR		87.9	17.3	1.2	25.3	11.0	57.3
	MIXT1		17.8	6.2	52.2	24.8	30.1	69.0
	MIXT2		23.0	5.4	51.8	20.8	25.2	73.9
	MIXT3		21.9	9.1	53.0	20.2	25.1	70.7
SITE2	CONTR		72.7	20.9	0.7	1.0	26.6	78.1
	MIXT1		35.2	20.6	35.5	12.5	29.3	66.9
	MIXT2		23.8	3.7	35.4	6.1	40.8	90.2
	MIXT3		23.6	16.8	40.3	17.8	36.1	65.4
SITE1		REMOV0	37.6	10.4	40.5	9.9	21.9	79.7
		REMOV1	39.4	9.8	38.3	26.7	22.3	63.5
		REMOV2	35.8	8.2	39.8	31.8	24.4	60.0
SITE2		REMOV0	38.6	14.3	26.1	8.7	35.4	77.0
		REMOV1	37.6	16.5	27.8	11.1	34.6	72.5
		REMOV2	40.3	15.8	30.1	8.3	29.6	76.0
Anova[2]**:**								
Location			NS	NS	NS	*	NS	NS
Plant community			***	***	***	NS	NS	***
LSD			16.3		9.3			
Mowing regime			NS	NS	NS	***	NS	***
Location x Mowing regime			NS	NS	NS	***	NS	**
LSD within Location						4.6		6.8
LSD otherwise						12.1		10.8
Location x Plant community			NS	*	NS	*	NS	***
LSD within Location				6.6		10.6		7.3
LSD otherwise				7.4		12.2		11.3
Plant community x Mowing regime			NS	NS	NS	NS	NS	NS
Location x Plant community x Mowing regime			NS	NS	NS	NS	NS	NS

[1] Time: M1, 15 October 2001; M7, 15 October 2004

[2] NS, non significant; *, p<0.05; **, p<0.01; ***, p<0.001
LSD, Least Significant Difference (p<0.05)

At SITE1, a significant higher fraction of dicotyledons was observed within CONTR than within sown communities: at SITE2 no significant differences were found except for MIXT2. The addition of roadside herbage in MIXT3 provoked a significantly higher I% of non fixing dicotyledons at SITE2 but not at SITE1. MIXT1 and MIXT3 showed a significant higher fraction of dicotyledons at SITE2.

3.3.4 Similarity of succession

In general C_S significantly increased during the early succession period 2001-2004: all regression equations had a significant positive slope, with p values between 0.05 and 0.0001 except for MIXT2 at SITE2 (Figure 3.2, Table 3.6). This means that species composition of sown and unsown communities within mowing treatments became more similar over time. Furthermore at SITE1, but inversely at SITE2, slopes of all equations under REMOV2 were higher than under REMOV0, irrespective of plant community, indicating that similarity in species occurrence occurred at higher rate when cuttings were removed. At SITE2, slopes of equations were higher for MIXT3 with the addition of roadside herbage than for MIXT2, irrespective of mowing regime. A similar result was found under REMOV0 at SITE1.
In October 2004, no significant factors or interactions were found for C_S.

C_N increased significantly between 2001-2004 at SITE1 with the slopes of all linear equations being positive with p-values between 0.05 and 0.006 (Figure 3.2, Table 3.6). MIXT2 revealed higher rates of convergence than MIXT1 at SITE1. On the contrary, minor changes in C_N were found at SITE2, with in general slightly negative slopes under REMOV2 and slightly positive slopes under REMOV0.

Three years after installation, in October 2004, C_N was not significantly determined by the plant community but was characterized by a significant interaction between location and mowing regime (p=0.001) and between location and plant community (p=0.05). C_N was significantly higher for REMOV2 (0.36) than for REMOV1 (0.25) and REMOV0 (0.26) at SITE1, but inversely at SITE2 (REMOV2, 0.13; REMOV1, 0.13; REMOV0, 0.26; LSD within location=0.08). Under REMOV1 and REMOV2, C_N was significantly higher at SITE1 than at SITE2 (LSD otherwise=0.12).

Table 3.6. Slopes (x 10^{-4}.day^{-1}) of regression equations of Sorenson's similarity measures between sown and unsown communities within mowing regimes, over time (period 2001-2004). Abbreviations cf. Section 2.1

Comparison pair	Location		C_N[1]		C_S[1]	
			REMOV0	REMOV2	REMOV0	REMOV2
MIXT1-CONTR	**SITE1**	Slope	1.584 *	1.570 **	2.518 **	2.515 **
		R²	*0.24*	*0.21*	*0.37*	*0.44*
	SITE2	Slope	0.229	-1.376 *	0.954 *	0.170
		R²		*0.19*	*0.18*	
MIXT2-CONTR	**SITE1**	Slope	2.287 *	3.401 ***	2.030 **	2.558 ***
		R²	*0.18*	*0.47*	*0.34*	*0.57*
	SITE2	Slope	-0.247	-1.846 **	0.588	-0.158
		R²		*0.34*		
MIXT3-CONTR	**SITE1**	Slope	1.465 *	1.371 *	2.282 ***	2.464 ***
		R²	*0.19*	*0.18*	*0.43*	*0.63*
	SITE2	Slope	1.551 *	0.219	2.609 **	2.106 **
		R²	*0.30*		*0.36*	*0.34*

[1] C_N, quantitative Sorenson's index; C_S, qualitative Sorenson's index

At SITE2, C_N was not influenced by the plant community (MIXT1, 0.19; MIXT2, 0.16; MIXT3, 0.17) whereas at SITE1, C_N was significantly higher for MIXT2 (0.40) than for MIXT1 (0.21) and MIXT3 (0.26) (LSD within location=0.12). C_N for MIXT2 was significantly higher at SITE1 than at SITE2 (LSD otherwise=0.19).

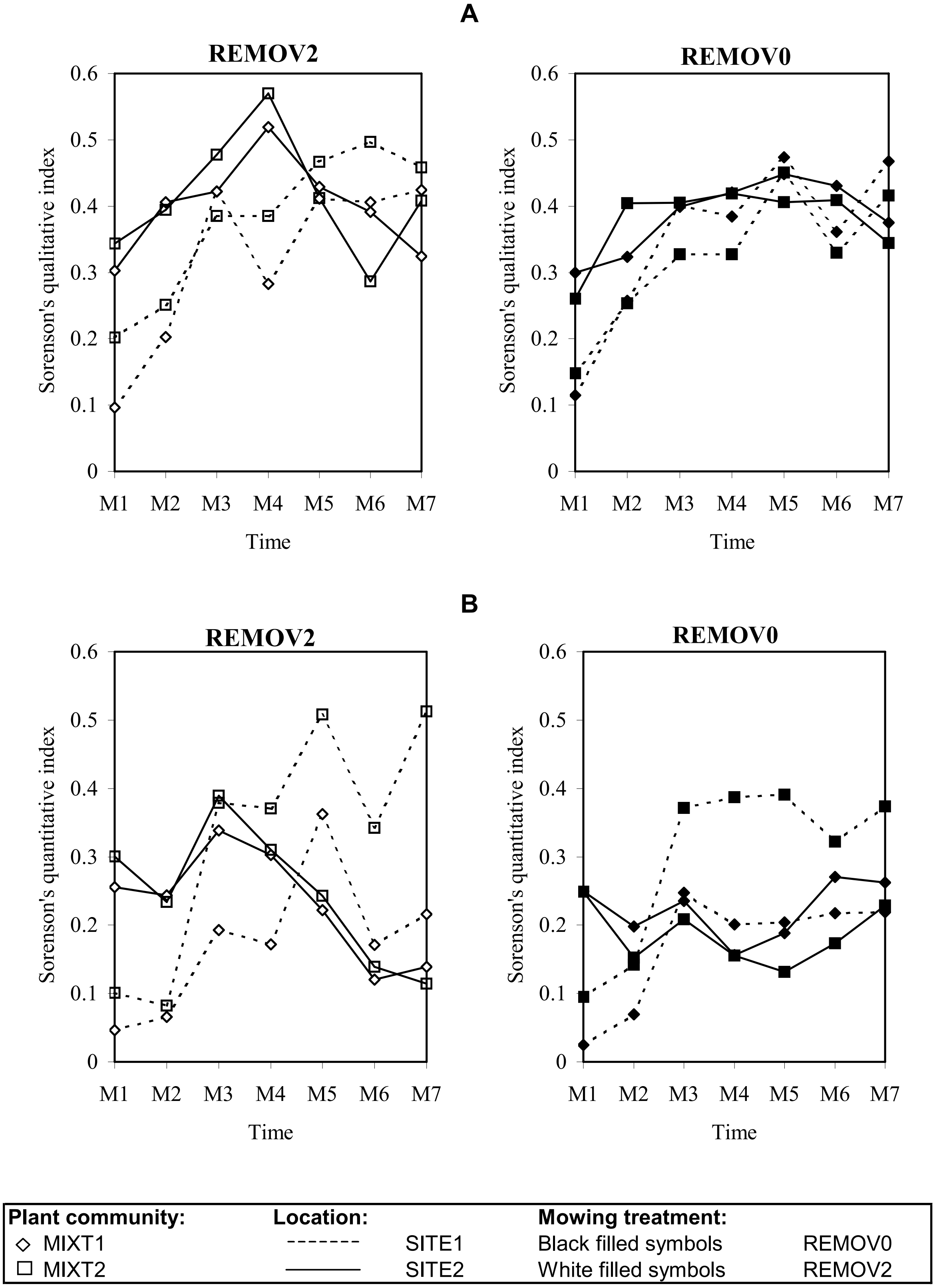


Figure 3.2. Sorenson's qualitative (A) and quantitative (B) similarity index over time (2001-2004) for MIXT1 and MIXT2 under REMOV0 and REMOV2. M1, October 2001, M2, July 2002, M3, October 2002, M4, July 2003, M5, October 2003, M6, July 2004, M7, October 2004. Abbreviations cf. Section 2.1

3.4 Discussion and conclusions

Species diversity of unsown and sown communities converged during the first three successional years after establishment on ex-arable land. So, species diversity on the long term seemed unaffected by the type of plant community that was installed. Initially, species diversity was significantly increased by sowing species-rich mixtures. However, in the subsequent years, floristic diversity of sown communities decreased. Meanwhile the unsown community became species richer. This is in accordance with West & Marshall (1996) who found naturally regenerated plots to have lower species diversity than sown plots during the first year, but species numbers remained stable in unsown plots in the second year whereas they decreased in the sown plots. Also Marshall & Nowakowski (1995) found that over a five-year period, species diversity of sown flower strips decreased over time on fertile soils. However Kleijn et al. (1997) found that, after four years of succession, species numbers only reached considerable levels when species were sown, irrespective of any relationship between vegetation productivity and species-richness.

The rates of successional changes in species diversity were significantly directed by the mowing regime and the plant community. The decrease in species diversity in sown communities was hastened under a mowing regime without the removal of cuttings and/or when the plant community was based on a commercial seed mixture of foreign provenance instead of a native seed mixture (SITE2).

Three years after installation, species diversity was significantly higher under a mowing regime with complete removal of cuttings than under a regime with no or partial removal of the biomass. Indeed, the non removed biomass hampered the growth in the aftermath and prevented the introgression of species. The deleterious effect of subsequent cuttings without removal of herbage on species richness is in accordance with van Schaik & van den Engel (1994) who clearly demonstrated that mowing a herbaceous vegetation without removing the cuttings, or not mowing at all, resulted in a species-poor ruderal vegetation. Also Persson (1995) found that yearly mowing with removal of cuttings was necessary to keep high number of species in roadsides, especially the low-growing ones.

The annual addition of roadside herbage on margin strips offers opportunities to enhance species-richness. The annual addition of seed rich roadside herbage significantly increased both the floristic diversity as well as the proportional importance of dicotyledonous species. The evolution of the species richness over time was however irregular. A single addition of roadside herbage was not sufficient to increase species richness in a sustainable way during the early successional stage. Many emerging species of roadside provenance were subdued due to high vegetation productivity.

The number of occurring sown wildflower species decreased over time in sown communities, irrespective of plant community, location or mowing regime. However, the decrease was hastened under a mowing regime without the removal of cuttings and/or when the plant community was based on a commercial seed mixture of foreign provenance instead of a native seed mixture.

Vegetation succession during the first three successional years caused drastic changes in the proportional importance of functional groups. Annuals, although initially highly present (even dominant in unsown plots), steadily decreased in importance whilst perennials steadily increased in importance. These changes occurred at higher rate when cuttings were not removed and/or in vegetations based on commercial seed mixtures.

Generally, during early succession the importance of non fixing dicotyledons significantly decreased over time whilst the importance of monocotyledons increased steadily after any subsequent cutting, irrespective of location, community or mowing regime. Furthermore the importance of legumes declined significantly in the sown communities, irrespective of mowing regime or location. This is in accordance with Bokenstrand et al. (2004) who found the cover of clovers to have decreased or disappeared in sown grass/clover strips after nine years of succession, while both sown and unsown grasses had increased.

However mowing regime, location and plant community significantly influenced rates of change of functional groups over time. Generally, mowing without removal of cuttings and/or sowing a commercial community hastened the increase in importance of grasses and the decrease of legumes. The fastened decrease of legumes may be explained by the lower nutrient depletion of soil when cuttings are not removed. Generally, cutting without removal of cuttings and/or sowing a commercial community showed higher rates of decrease in importance of non fixing dicotyledons.

Three years after installation, the importance of monocots and dicots differed between the two locations: in general monocots were more important on the richest soil. Also Kleijn & Snoeijing (1997) demonstrated that monocots increased and perennial dicots decreased significantly with increasing nutrient levels. Compared to SITE2, the higher share and importance of legumes in sown and unsown plant communities at SITE1 corresponded with lower share and importance of non fixing dicotyledons. The nutrient status of the soils might explain this correspondance: the less N in the soil, the better legumes are thriving. These legumes may facilitate the spread of grasses by the mineralization of fixed nitrogen (Jefferies et al., 1981), preventing indirectly non fixing dicots to persist by competitive exclusion from grasses.

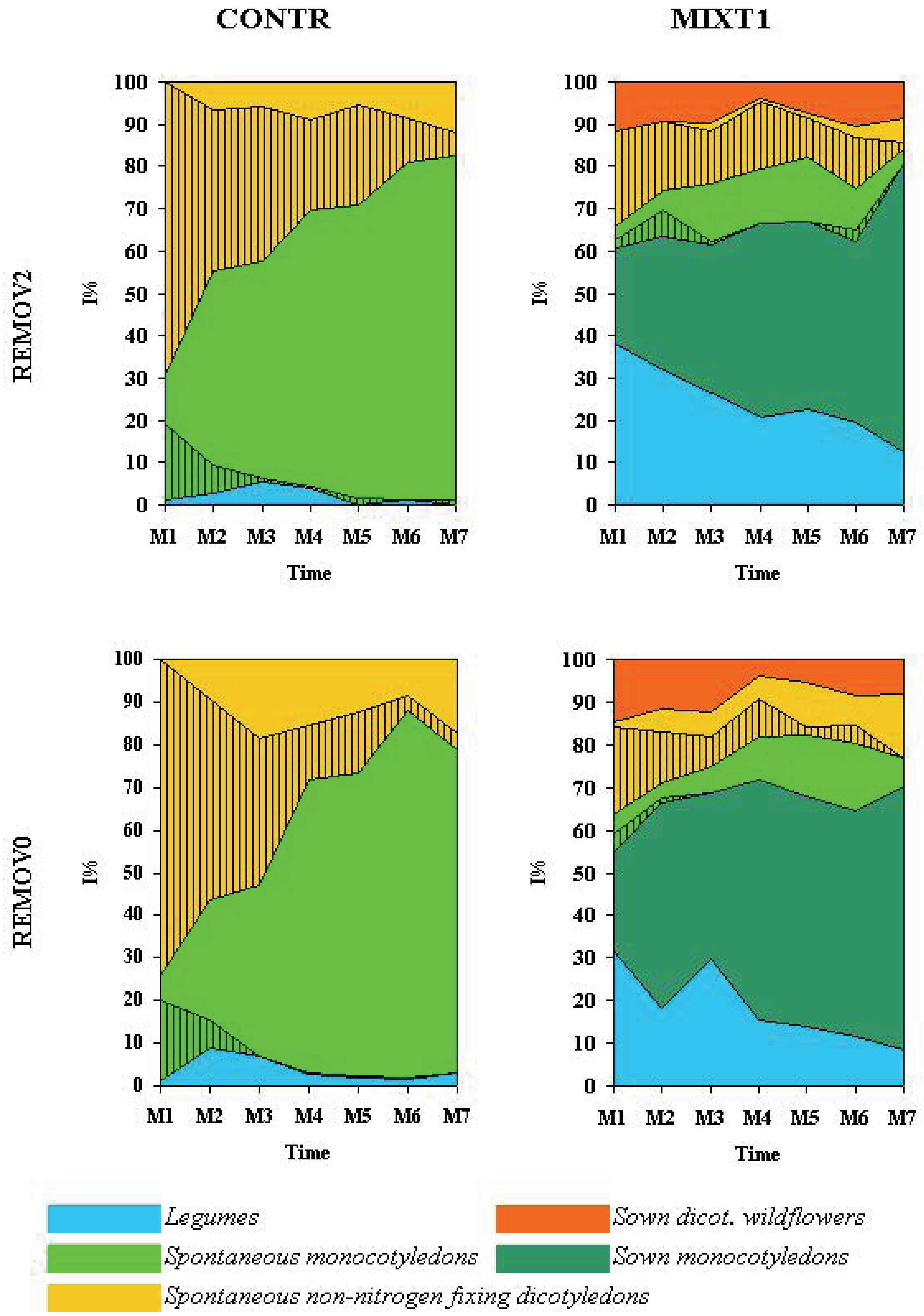
Despite the higher importance of legumes at SITE1, total species diversity was not lower compared to SITE2. This is not in accordance with Warren (2000) who suggested that *Trifolium repens* might contribute toward the loss of species diversity during grassland habitat creation on ex arable land. Furthermore, legumes have been considered detrimental to succesfully create a species-rich grassland (Flora locale, 1998). In our experiment, legumes contribute more to the decline in importance of spontaneous non fixing dicots rather than to act on species occurrence or diversity. The initial presence of legumes could be beneficial for the species richness on the long term since mineral depletion, (especially P) by removal of cuttings could be enhanced by the positive effect of legumes on biomass production in an unfertilized grassy vegetation.

Convergence in species occurrence between pairs of sown and unsown communities within mowing treatments was observed irrespective of sown communities or location. This is not in accordance with Warren et al. (2002) who found, over a six-year period, that the cut and/or grazed vegetation in sown and non-sown plots, installed on ex-arable land, converged in terms of abundance of species rather than in the number of species they contained. After four successional years similarity of species occurrence was no longer significantly determined by the type of plant community or mowing regime. However, dissimilar with species occurrence, convergence in species importance between pairs of sown and unsown communities within mowing treatments only occurred at SITE1 whilst a slight divergence was observed at SITE2. The lack of similarity in species importance between unsown and sown communities at SITE2 might be due to the exclusion of spontaneous introgressing

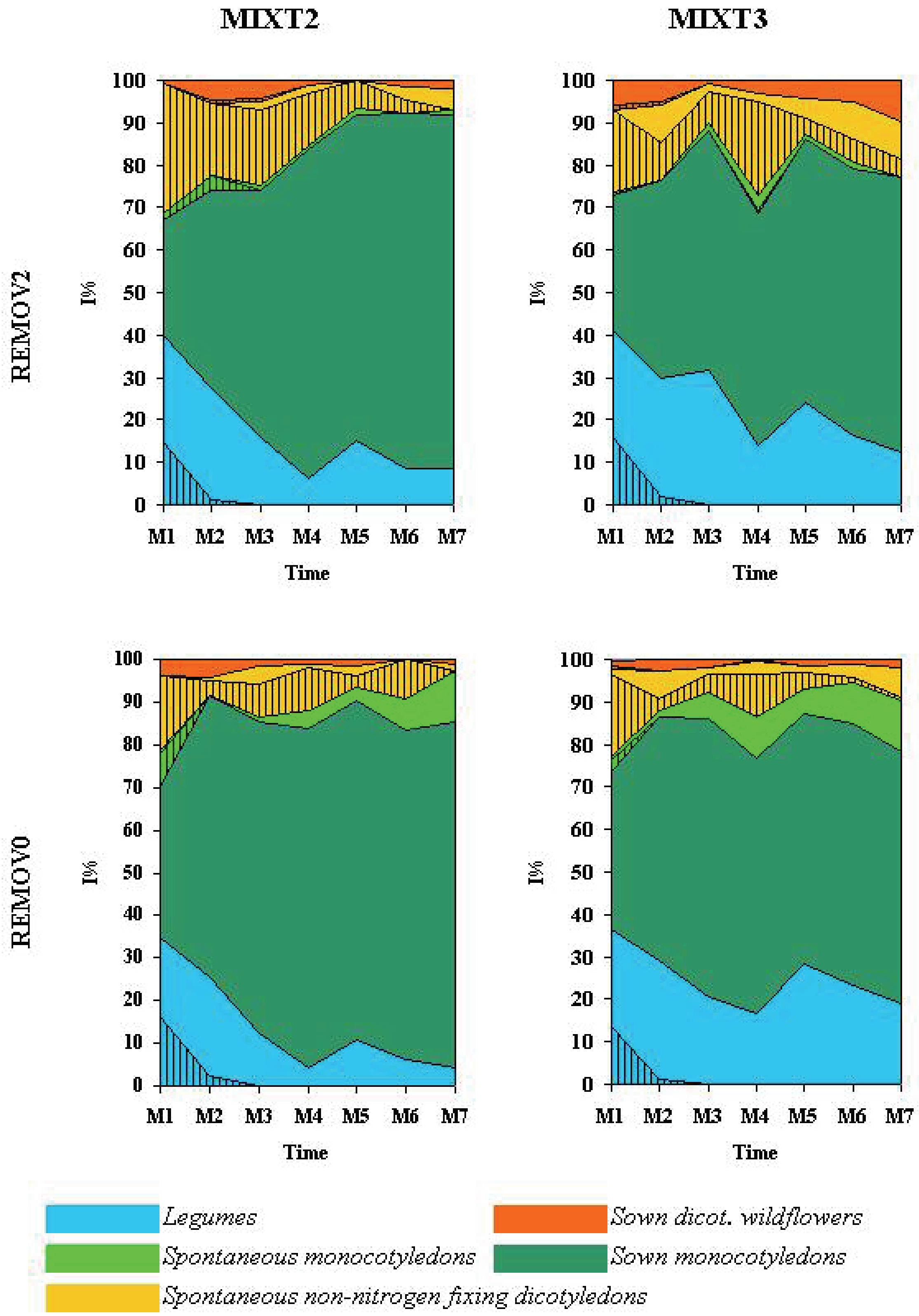
species by competitive species, promoted by the nutrient rich soil. McLendon & Redente (1991) found that increased soil nitrogen delayed the rate of succession.
Mowing with removal of cuttings significantly fastened similarity between sown and unsown communities. Such a mowing regime creates gaps in the canopy which are prone to colonisation by introgressing species. In our experiment, non removed biomass covered the vegetation for at least three weeks preventing the introgressing of species during this period. However, on the long term the non removed biomass might enhance spontaneous rhizomatous species to spread into the vegetations (see Chapter 6). This explains the higher similarity in species importance under this mowing regime at SITE2. Three years after installation, the highest similarity was found between the unsown community and the sown community with species of foreign provenance. Since species of foreign provenance tended to disappear faster than species of indigenous provenance, more gaps were created offering better opportunities for spontaneous species to introgress.

This research revealed that the development of species rich field margin strips was not strongly affected by the installed type of margin strip since species diversity converged over time, whether strips were sown or not. Convergence between unsown and sown margin strips occurred also in terms of species composition: unsown and sown strips became similar over time. Mowing without removal of cuttings significantly reduced species richness, yielded more grassy margin strips and delayed similarity in species composition between sown and unsown margin strips.

On the long term sowing field margins may be preferable to naturally regenerated field margins irrespective of claims of nature conservation, agronomy and environment. Initially, spontaneous colonisation (mostly weedy annuals and rhizomatous perennials) is minimized in sown margins, thus diminishing potential risks of weed infestations in both the adjacent crop and the field margin itself. Shortly after installation, the perennial sown vegetation becomes increasingly look-alike to the spontaneous vegetation leaving opportunities for spontaneous introgression thus encouraging nature conservation on the long term. As farmers are afraid of the development of weedy annual and rhizomatous species, they prefer a sown to a spontaneously emerging vegetation (Van der Meulen et al., 1996). A cutting management fits into their perception of ‘clean’ fields. Hence the promotion of field margins might be more successful if farmers are advised to use a seed mixture upon installation of the margin and if they are advised to cut the margin twice a year. A cutting management of a productive vegetation with removal of the cuttings will accelerate mineral depletion of the soil, promoting the development of a botanically diverse vegetation.



Appendix 3.1. Mean changes over time in importance (I%) of functional groups in sown and unsown margin strips during succession (M1, October 2001; M2, July 2002; M3, October 2002; M4, July 2003; M5, October 2003; M6, July 2004; M7, October 2004). Vertical hatched = annuals; non hatched = perennials. Abbreviations cf. Section 2.1



Appendix 3.1. Mean changes over time in importance (I%) of functional groups in sown and unsown margin strips during succession (M1, October 2001; M2, July 2002; M3, October 2002; M4, July 2003; M5, October 2003; M6, July 2004; M7, October 2004). Vertical hatched = annuals; non hatched = perennials. Abbreviations cf. Section 2.1. Continued.

Chapter 4

Post-disturbance effects on early succession of field margin strips along the shaded and unshaded side of a tree lane

This chapter was redrafted following:

De Cauwer, B., Reheul, D., D'hooghe K., Nijs, I., Milbau, A., 2005. Disturbance effects on early succession of sown and unsown field margins along the shaded and unshaded side of a tree lane. Agriculture, Ecosystems and Environment. In Press.

Chapter 4

Post-disturbance effects on early succession of field margin strips along the shaded and unshaded side of a tree lane

4.1 Introduction

Agricultural operations are likely to have a major impact on the flora of adjacent field margins, through mechanical disturbance, fertilizer deposition and pesticide drift (Marshall & Arnold, 1995). Grime (1979) considered disturbance as one of the most important factors that shape the composition of plant communities. Disturbances play a keyrole in plant ecology and evolution, by providing novel conditions for seedling establishment and plant growth, and opportunities for plants to access resources that are otherwise unavailable (Canham & Marks, 1985).
Disturbance in field margin strips can be caused by regular farming operations or by spot application of broad-spectrum herbicides (de Snoo, 1995). Field margin strips are likely to be used as turning headlands (although prohibited in many subsidized field margin programmes) and to be disturbed by wheeled or tracked machinery for farming practices and watercourse management.

However, mechanical disturbance of margins strips should be avoided to limit opportunities for annual weedy species to colonize and to encourage perennial, herbaceous species (Marshall, 1989b; Moonen & Marshall, 2001; McLendon & Redente, 1991). Disturbance of vegetations eliminate sensitive species resulting in gap formation and in these gaps seeds may germinate (McLendon & Redente, 1991; Wilby & Brown, 2001). The first species to colonize these gaps are annuals and ruderal perennial species (Corbet, 1995). Froud-Williams et al. (1984) demonstrated the effect disturbance has on seed emergence. Seeds of sixteen weed species showed an increased emergence after soil disturbance. When the vegetation is not disturbed a close perennial vegetation develops resulting in less light penetration under the canopy (Moonen & Marshall, 2001; Schippers & Joenje, 2002). In order to prevent the development of weedy vegetation and at the same time maintain perennial herbal vegetation, the disturbance level must be relatively low. High levels of disturbance generally facilitate annuals (Grime, 1979; Wilson & Tilman, 1991; Schippers et al., 2001), which are often weedy species. Simulations (Schippers & Joenje, 2002) indicated that disturbance levels

<20% of total area per year prevented growth of annuals and facilitated a diverse perennial vegetation.
Disturbance induces plant mortality that might decrease species diversity, and opens up space for colonisers from elsewhere, which might increase species diversity (Begon et al., 1990). Disturbance can create the conditions necessary for increased species richness, but an increase in species richness occurs in response to mechanisms, such as seed dispersal or germination, not directly associated with a disturbance event (Collins et al., 1995). A single disturbance may eliminate some species, and repeated disturbances at the same location will further reduce richness by altering habitat structure and eliminating intolerant species (Connel, 1978; Collins, 1992). The intermediate disturbance hypothesis (Connel, 1978; Begon et al., 1990), so far only tested on natural or semi-natural communities (Vetaas, 1997) predicts that species richness will be highest in communities with moderate levels of disturbance and at intermediate time spans following disturbance. The prediction is based on the assumption that the disturbance prevents monopolization of some limiting resource (e.g. space) by more vigorously growing species, without restricting the persistence of rare species. A second model of succession, initial floristic composition, states that nearly all species, including late serial species are present at the start of succession (Egler, 1954; Wilson et al., 1992). According to this model species richness should be highest during early successional stages, which means that species richness is expected to be highest immediately after the disturbance.

Besides the fact that intensive intermediate disturbance resulted in loss of species (Kleijn, 1997) and the introgression of weed species (Kleijn, 1997; Moonen & Marshall, 2001; Schippers & Joenje, 2002; Wilby & Brown, 2001) it is not clear how a single mechanical disturbance affects vegetation succession, biological invasion and species diversity in early successional stages of newly created field margins. Furthermore the question arises whether disturbance effects on vegetation development differ under different light regimes since many field margin strips are preferentially installed along tree rows and hedges because the area close to tree rows is less productive owing to increased competition for light, water or nutrients, allelopathy and weed and fungi pressure (Nuberg, 1998; Brenner, 1996). Particularly shading by tall, unmanaged hedgerows, woodlots and tree rows may have serious effects on crop yields (Kleijn, 1997).

Our study examines the responses of four different field margin communities along the shaded and unshaded side of a tree lane to a single artificial disturbance. In particular the following questions are adressed: (1) What is the effect of disturbance and light regime on biological invasion? (2) How does a single disturbance affect species richness and early botanical succession at high and low light regime? (3) What is the effect of a disturbance event on vegetation similarity between unsown and sown communities?

4.2 Specific material and methods

The research was based on trial 2 explained in Chapter 2, Section 2.1. Abiotic conditions at the shaded and unshaded side are illustrated in Chapter 5, Figure 5.1 (soil water status) and Figure 5.2 (light availability). Botanical analysis of margin strips was performed during the succession period from 2002 to 2004, in order to study vegetation composition under different light availability and disturbance level. Vegetation analysis (species diversity, species importance, uncovered area) followed methodology described in Chapter 2, Section 2.2. The botanical composition in terms of importance of functional groups was recorded in time by calculating the percentile contribution of functional groups to the total importance (=100%). Species were classified into the following functional groups: annual and perennial sown or spontaneous legumes, annual and perennial sown or spontaneous non N-fixing dicotyledons, annual and perennial sown or spontaneous monocotyledons and inserted invaders. The I% of a functional group was calculated by adding the I% of all contributing species of that group.

Similarity of vegetation development between sown and unsown plant communities within disturbance levels was compared using both Sorenson's qualitative measure C_S and Sorenson's quantitative measure C_N (explained in Chapter 2, Section 2.2). Regression analysis was used (SPSS10.0 for Windows) to determine the pattern of succession and post-disturbance changes over time (time was expressed as days after 15 July 2002). S-plus 2000 for Windows was used to carry out the statistical computations for a split plot design.

4.3 Results

4.3.1 Percentage uncovered area

Prior to disturbance (July 2002), the percentage uncovered area showed a significant interaction between light regime and plant community (Table 4.1). On the unshaded side, no significant differences were found between plant communities. On the shaded side CONTR showed significantly higher percentage uncovered area than the sown communities (CONTR, 35.2% versus MIXT3, 10.5%; MIXT1, 7.9%; MIXT2, 8.1%; LSD=8.5%).

Table 4.1. Significance of main factors and their interactions (ANOVA) during early succession for species diversity and percentage uncovered area

	Pre-disturbance	Post-disturbance [1]			
	M1	**M2**	**M3**	**M4**	**M5**
Uncovered area (%):					
Light regime	NS[2]	*	NS	NS	NS
Plant community	***	***	*	***	*
Disturbance level	-	***	*	*	*
Light regime x Plant community	***	NS	*	NS	NS
Light regime x Disturbance level	-	NS	NS	NS	NS
Plant community x Disturbance level	-	**	NS	NS	NS
Plant community x Disturbance level x Light regime	-	NS	NS	NS	NS
Species diversity (spp./16 m^2):					
Light regime	NS	NS	**	NS	NS
Plant community	***	**	**	**	**
Disturbance level	-	NS	NS	NS	NS
Light regime x Plant community	NS	*	NS	NS	**
Light regime x Disturbance level	-	**	*	NS	NS
Plant community x Disturbance level	-	NS	NS	NS	NS
Plant community x Disturbance level x Light regime	-	NS	NS	NS	NS

[1] M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004

[2] NS non significant, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Shortly after disturbance (October 2002), the percentage uncovered area was significantly linked to the light regime (Table 4.1). The shaded side showed a significantly higher percentage uncovered area (shaded, 39.3% versus unshaded 34.7%; LSD=3.5%). Furthermore, a significant interaction occurred between disturbance level and plant community. MIXT3 showed a significantly higher percentage uncovered area than MIXT2, MIXT1 and CONTR, which did not differ significantly irrespective of disturbance level (MIXT3, 66.0% versus MIXT1, 28.9%; MIXT2%, 27.4% and CONTR, 25.9%; LSD=7.7%). Within all plant communities, the percentage uncovered area was significantly higher in disturbed plots (disturbed, 54.0%, undisturbed, 19.3%; LSD=3.7%) (Figure 4.1).

In July 2004, 21 months after the disturbance event, the percentage uncovered area was significantly explained by disturbance level. There was also a significant interaction between plant community and light regime. Contrary to one month after the disturbance event, the percentage uncovered area was significantly lower in disturbed plots (disturbed, 7.2% versus undisturbed, 12.2%)(LSD=2.9%). At the unshaded side, CONTR showed a lower percentage uncovered area than the sown communities (CONTR, 1.2% versus MIXT1, 9.3% and MIXT2, 12.2%; LSD=5.3%): no significant differences were found at the shaded side. The percentage uncovered area was significantly higher at the shaded side for CONTR (shaded, 11.3% versus unshaded, 1.2%) and MIXT3 (shaded, 15.2% versus unshaded, 7.6%; LSD=6.0%).

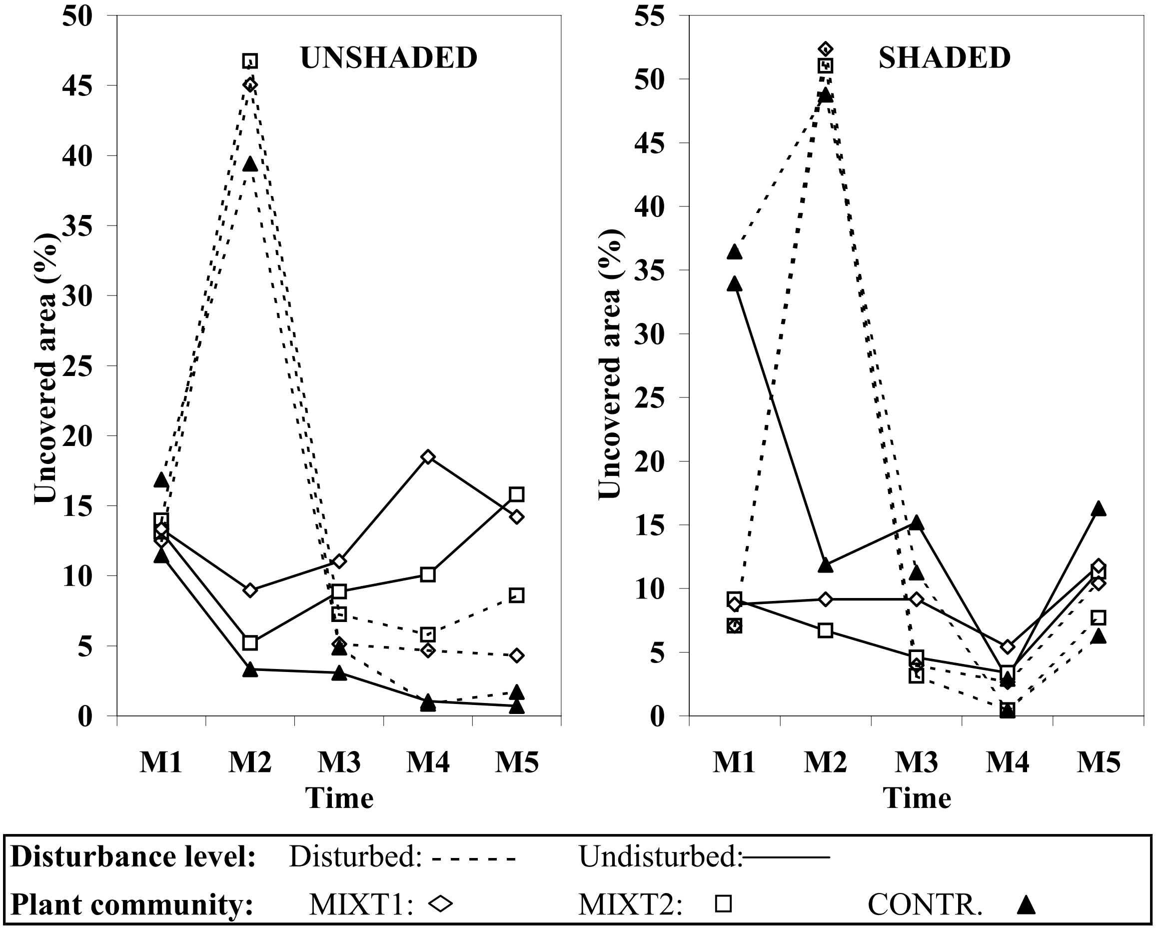


Figure 4.1. Uncovered area (%) during succession (2001-2004) for sown and unsown plant communities on the shaded and unshaded side of a tree lane with or without disturbance (disturbance event: 19 September 2002) (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004). Abbreviations cf. Section 2.1

In general, the percentage uncovered area decreased over time (Figure 4.1, Table 4.2) irrespective of plant community, light regime or disturbance level. The percentage uncovered area decreased at higher rate within disturbed plant communities despite the significant increase shortly after the disturbance event.

Table 4.2. Slopes (x 10^{-2} /day) of regression equations of uncovered area (%) and species diversity (spp./16 m²) over time (days) for sown and unsown communities under different disturbance level and light regime (period 2001-2004) (in brackets, R²). Abbr. cf. Section 2.1

Plant community	**Disturbance level**	**Uncovered area**		**Species diversity (spp./16 m²)**	
		Unshaded	*Shaded*	*Unshaded*	*Shaded*
CONTR	Undisturbed	-1.18 **[1]	-1.90 *	0.40 *	-0.48
		(0.45)	*(0.21)*	*(0.23)*	
	Disturbed	-4.06 **	-6.00 ***	0.14	-0.31
		(0.50)	*(0.68)*		
MIXT1	Undisturbed	0.57	0.21	-0.88 **	-1.43 ***
				(0.53)	(0.63)
	Disturbed	-3.57 *	-2.94 *	-0.78 *	-1.51 ***
		(0.33)	*(0.18)*	*(0.41)*	*(0.72)*
MIXT2	Undisturbed	-0.71 *	0.15	-1.09 ***	-1.10 ***
		(0.19)		*(0.56)*	*(0.61)*
	Disturbed	-3.27 *	-3.25 *	-0.87 *	-0.92 ***
		(0.28)	*(0.19)*	*(0.37)*	*(0.58)*
MIXT3	Undisturbed	-2.24	-0.98	-0.48	-0.61 *
					(0.20)
	Disturbed	-4.04 *	-3.60	-0.32	-0.60
		(0.20)			

[1] *,**,*** p<0.05, p<0.01 and p<0.001 respectively

4.3.2 Total species diversity

The levels of significance for the experimental factors during pre- and post-disturbance period are given in Table 4.1.

Prior to disturbance (July 2002), the total species diversity was significantly determined by plant community but not by light regime. The unsown community had a significantly lower species diversity than the sown communities (CONTR, 11.5 spp versus MIXT1, 23.0 spp.; MIXT2, 22.8 spp. and MIXT3, 21.7 spp.; LSD=3.6 spp).

However, one month after the disturbance event (October 2002), significant interactions between light regime and plant community and between light regime and disturbance occurred. On the unshaded side, total species diversity in CONTR (13.0 spp.) was significantly lower than species diversity in MIXT1 (19.2 spp.) and MIXT2 (16.7 spp) but not on the shaded side (MIXT1, 20.3 spp.; MIXT2, 17.8 spp.; CONTR, 19.8 spp.; LSD=3.6 spp.). The addition of roadside herbage caused a significantly lower species diversity on the shaded side (MIXT3, 13.3 spp. versus MIXT2, 17.8 spp; LSD=3.5 spp) but not on the unshaded side (MIXT3, 15.7 spp. versus MIXT2, 16.7 spp.; LSD= 3.5 spp). MIXT1 showed highest total species diversity irrespective of light regime (unshaded, 19.2; shaded, 20.3 spp; LSD=3.6 spp.). Disturbance caused a significantly higher species diversity on the unshaded side (undisturbed, 15.3 spp. versus disturbed, 16.9 spp.) but a significantly lower diversity on the shaded side (undisturbed, 19.0 spp. versus disturbed, 16.7 spp.) (LSD=1.5 spp.). Similar results were found in July 2003.

However, 21 months after the disturbance event (July 2004) species diversity was no longer influenced by the disturbance level but was characterized by a significant interaction between light regime and plant community. At the unshaded side CONTR showed significantly lower species diversity than MIXT1 and MIXT3 (CONTR, 12.2 spp. versus MIXT1, 15.3 spp. and MIXT3, 18.5 spp.; LSD=2.2 spp.): no significant differences were found at the shaded side. At the unshaded side but not at the shaded side, the addition of roadside herbage significantly increased species diversity with 4.5 species (unshaded MIXT3, 18.5 spp. versus unshaded MIXT2, 14.0 spp.). Within plant communities, no significant differences in species diversity were found between light regimes.

The temporary increase in species diversity could be attributed to the increase in number of annual species one month after the disturbance event. Disturbance caused a significantly higher number of annual species on the unshaded side (undisturbed 1.8 spp. versus disturbed 3.4 spp.; LSD=0.7 spp.) but not on the shaded side (undisturbed 3.0 spp. versus disturbed, 2.8 spp.). Furthermore, a significantly higher number of annual species was found in disturbed MIXT3 (undisturbed, 0.7 spp.; disturbed, 2.5 spp.; LSD=1.3 spp.) and disturbed MIXT2 (undisturbed, 2.0 spp. versus disturbed 3.5 spp.; LSD =1.3 spp.).

In general, during the first 3 successional years, species diversity of sown communities significantly decreased over time on both shaded and unshaded side of the tree lane irrespective of disturbance level (Table 4.2, Figure 4.2). The species diversity of CONTR

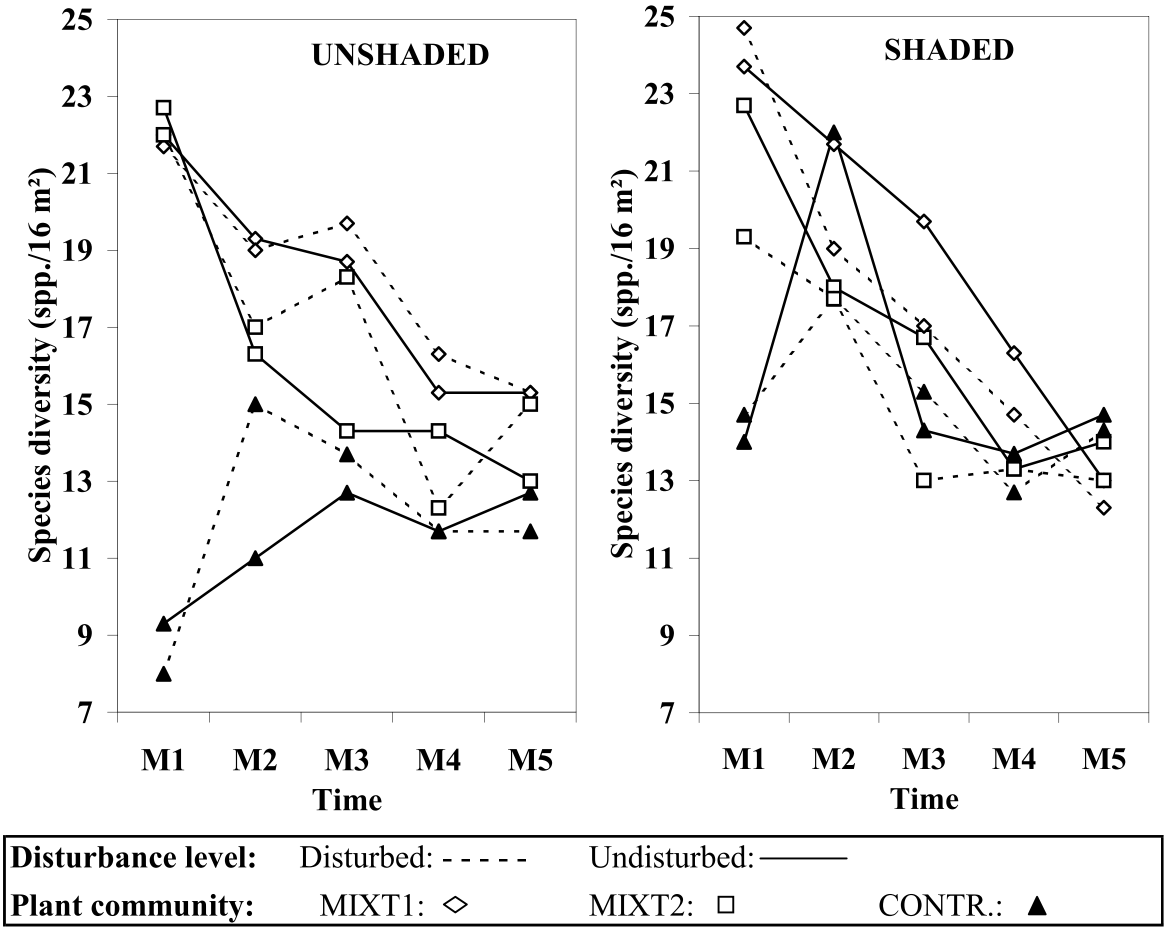
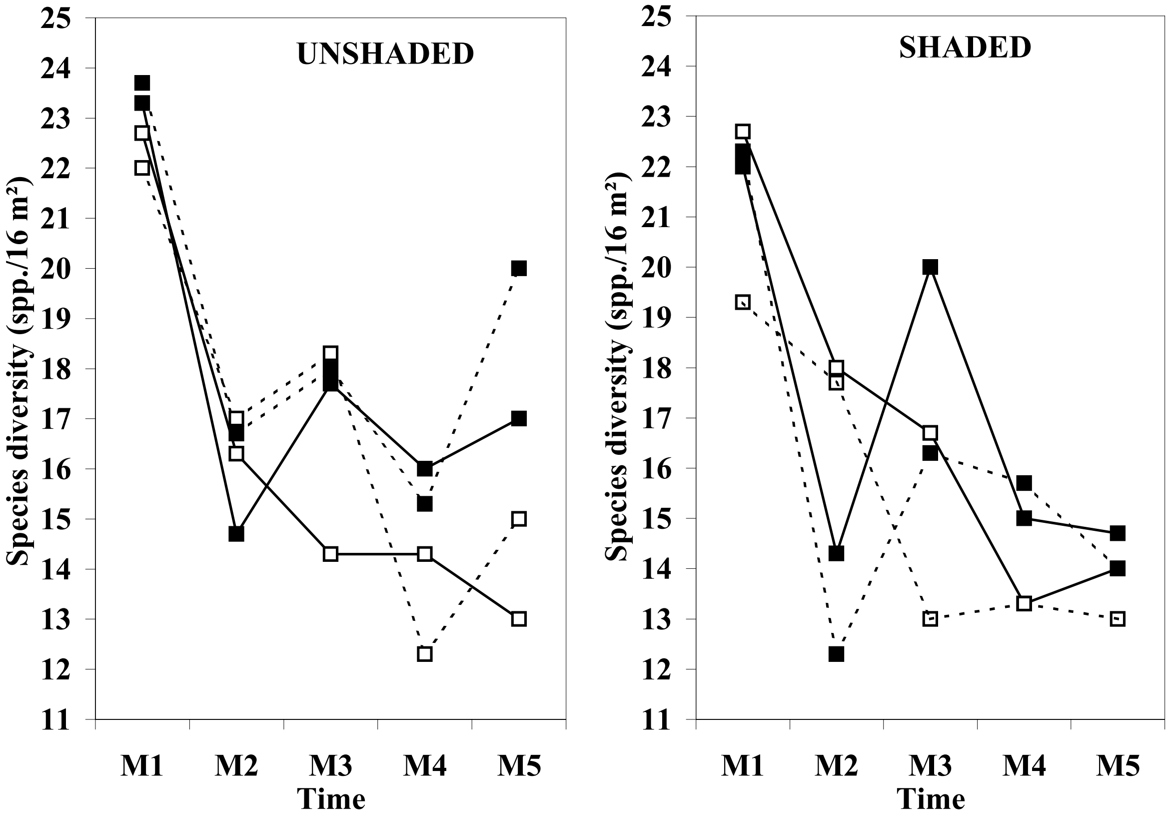


Figure 4.2. Species diversity (spp./16 m^2) during succession (2001-2004) for sown and unsown plant communities on the shaded and unshaded side of a tree lane with or without disturbance (disturbance event: 19 September2002) (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004). Abbreviations cf. Section 2.1

increased on the unshaded side and decreased (but at lower rate than sown communities) on the shaded side. So, species diversity converged irrespective of light regime or disturbance level (Figure 4.2).

The annual addition of roadside herbage caused a decrease in species diversity shortly after the addition followed by an increase eight months later (Figure 4.3). Nevertheless, species richness on the long term was increased by yearly addition of roadside herbage. Despite the decreasing trend in species diversity of sown communities, disturbed unshaded sown communities showed a temporal increase in species diversity between October 2002 and July 2003 with a peak 8 months after the disturbance event (Figure 4.2). The disturbed unshaded CONTR however, showed the highest species diversity shortly after the disturbance event.



Disturbance level:	Disturbed: - - - - -	Undisturbed:———
Plant community:	MIXT2: □	MIXT3: ■

Figure 4.3. Species diversity (spp./16 m^2) during succession (2001-2004) for the sown commercial community with (MIXT3) or without (MIXT2) addition of roadside herbage on the shaded and unshaded side of a tree lane with or without a single disturbance (disturbance event: 19 September 2002) (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004)

4.3.3 Vegetation composition (Table 4.3, Appendix 4.1, 4.2,4 .3)

Functional groups:

During the first three successional years the I% of perennials significantly increased at the expense of the I% of annuals, which significantly decreased irrespective of plant community, light regime or disturbance level. The decrease of annuals and corresponding increase of perennials occurred at higher rate in disturbed communities (Table 4.3) despite the temporary increase of annual spontaneous dicotyledons shortly after the disturbance event (Appendix 4.1, 4.2, 4.3). The decrease in I% of annuals occurred within all functional groups (monocotyledons, non-fixing dicotyledons and legumes) irrespective of plant community, light regime or disturbance level. On the shaded side, the increase in I% of perennials in disturbed sown plant communities, was predominantly attributed to the significant increase of perennial spontaneous monocotyledons. Contrary to the shaded side the increase in I% of perennials in disturbed sown plant communities on the unshaded side, was predominantly attributed to the increase of perennial sown monocotyledons. However, 21 months after the disturbance event, the I% of perennials or annuals was not significantly determined by plant community, light regime or disturbance level.

In general the I% of legumes (sown and unsown) significantly decreased in sown communities but increased in the unsown community. Changes were more pronounced in disturbed plant communities than in undisturbed plant communities, irrespective of light regime.
In July 2004, the I% of legumes was characterized by significant interactions between light regime and disturbance level (p=0.005) and between plant community and disturbance level (p=0.006). At the shaded side but not at the unshaded side, the I% of legumes was significantly higher in disturbed plots (disturbed, 10.3% versus undisturbed, 5.4%; LSD=2.8%). Disturbed CONTR showed significantly higher I% of legumes than undisturbed CONTR (disturbed, 10.7% versus undisturbed, 2.9%; LSD=4.0%). However in October 2002, shortly after the disturbance event, the I% of legumes was significantly determined by disturbance level (p=0.000) with significantly lower I% in disturbed plots (undisturbed, 26.6%; disturbed, 20.2%) (LSD=2.9%).

The I% of non-fixing dicotyledons decreased over time in sown plant communities irrespective of light regime or disturbance level but rates of decrease were higher in disturbed plots. In the unsown CONTR, non-fixing dicotyledons decreased in disturbed plots but increased in undisturbed plots, irrespective of light regime. Within the sown non-fixing dicotyledons, both annuals (not significant) and perennials (significant) decreased over time irrespective of plant community, light regime or disturbance level. Annual spontaneous non-fixing dicotyledons decreased over time irrespective of plant community, light regime or disturbance level despite the temporary increase of annual spontaneous non-fixing dicotyledons in disturbed plots shortly after the disturbance event. But after October 2002, the I% of annual spontaneous dicotyledons decreased again, predominantly at the expense of perennial sown and spontaneous monocotyledons (Appendix 4.1). In CONTR, perennial spontaneous non-fixing dicotyledons increased over time with highest rates of increase in undisturbed plots and on the shaded side.

In July 2004, the I% of non-fixing dicotyledons showed a significant interaction between light regime, plant community and disturbance level (p=0.003). Within MIXT1, MIXT2 and MIXT3 no significant differences were found irrespective of light regime or disturbance level. Within CONTR, disturbance caused a significantly lower I% on the shaded side (disturbed, 11.7% versus undisturbed 32.4%) but not on the unshaded side (LSD= 5.5%). Furthermore, CONTR on the shaded side showed significantly higher I% than the sown communities irrespective of disturbance level (disturbed CONTR, 11.7% versus sown communities, 2.4-7.8%; undisturbed CONTR, 32.4% versus sown communities 1.5-8.5%; LSD=3.5%). Shortly after the disturbance event, the I% of non-fixing dicotyledons showed significant interactions between light regime and disturbance level (p=0.04) and between light regime and plant community (p=0.008). The I% of non-fixing dicotyledons was higher in disturbed plots but was only significant on the unshaded side (unshaded: disturbed, 19.2% versus undisturbed, 8.1%, shaded: disturbed 17.2% versus undisturbed 13.4%) (LSD within light regime=5.0%). CONTR showed significantly higher I% of non-fixing dicotyledons on the shaded side (shaded, 32.3% versus unshaded, 15.3%) (LSD=8.7%). The sown communities revealed no significant differences between light regimes (MIXT1: shaded, 12.6% and unshaded, 10.1%; MIXT2: shaded, 11.5% versus unshaded, 15.7%). However, MIXT3 with addition of roadside herbage showed significantly lower I% on the shaded side (shaded, 4.8% versus unshaded 13.6%).

Shortly after the disturbance event, the I% of annual spontaneous dicotyledons was only significantly determined by disturbance level (p=0.0004) but not by plant community or light regime. Disturbance caused a significantly higher I% (disturbed, 11.8% versus undisturbed, 4.7%; LSD=3.3%). One year later, the I% of annual spontaneous dicotyledons was no longer significantly determined by the disturbance level.

The I% of monocotyledons increased over time in sown communities irrespective of light regime or disturbance level. Disturbance caused lower rate of increase on the shaded side and higher rates of increase on the unshaded side. In CONTR, the I% of monocotyledons decreased except on the unshaded side. Annual spontaneous monocotyledons significantly decreased over time irrespective of plant community, light regime or disturbance level. Perennial, spontaneous monocotyledons increased (mostly significant) over time irrespective

Table 4.3. Slopes (x 10^{-2} %/day) of regression equations of importance (I%) within functional groups over time (days) for sown and unsown communities growing in a different light regime with and without disturbance (period 2001-2004). Abbreviations cf. Section 2.1

Functional group	**Unshaded**											
	CONTR				**MIXT1**				**MIXT2**			
	Undisturbed		**Disturbed**		**Undisturbed**		**Disturbed**		**Undisturbed**		**Disturbed**	
	Slope	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***
perennials	5.137 **[1]	*0.49*	7.020 ***	*0.69*	0.348 *	*0.19*	0.713 *	*0.18*	1.383 *	*0.27*	2.903 **	*0.45*
annuals	-5.137 **	*0.49*	-7.020 ***	*0.69*	-0.348 *	*0.19*	-0.713 *	*0.18*	-1.383 *	*0.27*	-2.903 **	*0.45*
legumes	0.163		0.589 **	*0.44*	-1.611 *	*0.22*	-2.229 *	*0.39*	-2.473 *	*0.39*	-1.977 *	*0.27*
annual legumes									-0.513 *	*0.31*	-0.926 *	*0.34*
perennial legumes	0.163		0.589 **	*0.44*	-1.611 *	*0.22*	-2.229 *	*0.39*	-1.960 *	*0.30*	-1.051	
non fixing dicots	0.185		-1.374 *	*0.37*	-0.940 *	*0.27*	-1.335 *	*0.36*	-0.497		-1.771 *	*0.25*
annual sown non fixing dicots											-0.095	
perennial sown non fixing dicots					-0.699 ***	*0.57*	-0.921 **	*0.55*	-0.530 *	*0.36*	-0.265	
annual spontaneous dicots	-0.709 *	*0.29*	-1.456 **	*0.43*	0.037		-0.329		-0.163		-1.327	
perennial spontaneous dicots	0.524 *	*0.23*	0.082		-0.279		-0.084		0.195 *	*0.23*	-0.084	
monocots	0.022		0.785		2.551 ***	*0.45*	3.563 ***	*0.56*	2.970 **	*0.51*	3.748 **	*0.48*
annual spontaneous monocots	-4.428 **	*0.45*	-5.563 **	*0.50*	-0.385 *	*0.28*	-0.384 **	*0.45*	-0.708 *	*0.25*	-0.555 *	*0.23*
perennial spontaneous monocots[2]	4.450 **	*0.44*	6.349 ***	*0.58*	-0.034		1.395 *	*0.20*	0.425		1.230	
perennial sown monocots[2]					2.971 *	*0.37*	2.551 *	*0.36*	3.253 ***	*0.78*	3.073 **	*0.42*
invaders	1.272 *	*0.35*	3.244 **	*0.55*	2.347 **	*0.49*	1.926 *	*0.25*	5.300 ***	*0.66*	2.712 *	*0.22*

Table 4.3. Slopes (x 10^{-2} %/day) of regression equations of importance (I%) within functional groups over time (days) for sown and unsown communities growing in a different light regime with and without disturbance (period 2001-2004). Abbreviations cf. Section 2.1 (Continued)

Functional group	**Shaded**											
	CONTR				**MIXT1**				**MIXT2**			
	Undisturbed		**Disturbed**		**Undisturbed**		**Disturbed**		**Undisturbed**		**Disturbed**	
	Slope	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***	**Slope**	***R²***
perennials	6.529 ***	*0.57*	6.700 ***	*0.58*	1.100 ***	*0.67*	1.313 **	*0.50*	1.255 ***	*0.59*	1.756 ***	*0.57*
annuals	-6.529 ***	*0.57*	-6.700 ***	*0.58*	-1.100 ***	*0.67*	-1.313 **	*0.50*	-1.255 ***	*0.59*	-1.756 ***	*0.57*
legumes	0.443 *	*0.18*	2.375 **	*0.49*	-3.304 ***	*0.66*	-2.316 **	*0.54*	-3.433 ***	*0.60*	-1.947 *	*0.27*
annual legumes									-0.450 *	*0.31*	-0.728 *	*0.36*
perennial legumes	0.443 *	*0.18*	2.375 **	*0.49*	-3.304 ***	*0.66*	-2.316 **	*0.54*	-2.983 **	*0.47*	1.219	
non fixing dicots	1.656 *	*0.20*	-1.069		-1.118 ***	*0.64*	-1.687 **	*0.46*	-0.523		-1.067 *	*0.32*
annual sown non fixing dicots									-0.028		-0.060	
perennial sown non fixing dicots					-0.911 **	*0.55*	-0.977 **	*0.45*	-0.450 *	*0.33*	-0.365 *	*0.22*
annual spontaneous dicots	-1.434 *	*0.40*	-1.229 **	*0.49*	-0.437 *	*0.27*	-0.834 *	*0.20*	-0.344 *	*0.21*	-0.574	
perennial spontaneous dicots	3.090 **	*0.45*	0.161		0.230 *	*0.18*	0.144		-0.298		-0.068	
monocots	-2.100 *	*0.24*	-1.306		4.423 ***	*0.86*	4.002 ***	*0.73*	3.957 ***	*0.61*	3.013 **	*0.51*
annual spontaneous monocots	-5.095 **	*0.44*	-5.470 **	*0.47*	-0.663 *	*0.35*	-0.479 *	*0.39*	-0.433 *	*0.19*	-0.396 *	*0.24*
perennial spontaneous monocots[2]	2.996 *	*0.35*	4.164 *	*0.33*	1.368 *	*0.21*	2.420 *	*0.37*	0.567 *	*0.25*	2.254 ***	*0.71*
perennial sown monocots[2]					3.718 **	*0.55*	2.062 *	*0.21*	3.814 ***	*0.61*	1.155	
invaders	0.487 *	*0.22*	1.903 *	*0.27*	2.143 ***	*0.58*	0.885 *	*0.18*	3.301 ***	*0.61*	-0.515	

[1] *, $p<0.05$; **, $p<0.01$; ***, $p<0.001$

[2] inclusive invaders

of plant community, light regime or disturbance level: rates of increase were higher in disturbed communities. Perennial, sown monocotyledons increased over time irrespective of plant community, light regime or disturbance level: the rate of increase being higher in undisturbed plots. In July 2004, the I% of monocotyledons was characterized by a significant interaction between light regime and plant community (p=0.001) but not by disturbance level. At the shaded side, CONTR showed significantly lower I% of monocotyledons than sown communities (CONTR, 67.6% versus MIXT2, 94.8%, MIXT1, 87.7% and MIXT3, 82.7%; LSD= 8.0%). No significant differences between plant communities were found at the unshaded side. Also shortly after the disturbance event, the I% of monocotyledons was not significantly determined by disturbance level.

In July 2004, the I% of spontaneous perennial monocotyledons was significantly determined by the disturbance level (p=0.001). There was also a significant interaction between plant community and light regime (p=0.009). The I% was significantly higher in disturbed plots (undisturbed, 27.7% versus disturbed, 34.7%; LSD=3.7%). Sown communities showed higher I% on the shaded side than on the unshaded side (MIXT1, unshaded, 29.3% versus shaded, 21.9%; MIXT2: unshaded, 10.2% versus shaded, 8.2%; MIXT3, unshaded, 12.7% versus shaded, 10.7%; LSD=12.2%). CONTR showed significantly higher I% on the unshaded side (unshaded, 89.4% versus shaded, 67.6%) (LSD=12.2%). In sown communities, no significant differences were found between light regimes.

Invader grasses:

The I% of invader grasses increased over time irrespective of plant community, light regime or disturbance level except for the shaded disturbed MIXT2. The I% of invader grasses increased at higher rate on the unshaded side since slopes of regression equations (Table 4.3, Appendix 4.1) were more positive on the unshaded side than on the shaded side. Generally, the increase in I% in sown communities was less pronounced in disturbed plots. The inverse was true in the unsown community with significantly higher rate of increase in disturbed plots. Within disturbed communities the rate of increase of invaders was highest in the unsown community.

In July 2004, the I% of invaders was significantly determined by light regime (p=0.04). Furthermore, there was a significant interaction between plant community and disturbance level (p=0.006). The I% of invaders was significantly higher on the unshaded side than on the shaded side (unshaded, 41.2% versus shaded 30.0%; LSD=10.5%). The I% of invaders was lower in sown disturbed communities MIXT1 (undisturbed, 40.7% versus disturbed, 32.4%) and MIXT2 (undisturbed, 58.8% versus disturbed, 41.7%) but was higher in unsown disturbed CONTR (undisturbed, 7.4% versus disturbed, 23.3%; LSD=12.2%). However, in sown communities care should be taken in the interpretation since the invader grasses were already present in the pre-disturbance vegetation (part of the initial sowing mixture in Table 2.1, Section 2.1). In disturbed sown communities, the capacity of the oversown invader grasses to invade, could probably be masked by the detrimental effect of disturbance on the pre-disturbance importance of the invader grasses. Nevertheless in undisturbed sown communities, the increase in importance of invader grasses over time was not an invasion effect since no new propagules were found shortly after the disturbance event contrary to the undisturbed unsown community. This also means that the unsown community was more susceptible to being invaded.

4.3.4 Similarity of succession

Sorenson's qualitative measure (C_S):

In general, Sorenson's qualitative measure (C_S) of similarity between treatments significantly increased during the early succession period 2001-2004, irrespective of light regime or disturbance level (Table 4.4, Figure 4.4) as indicated by the significant positive slopes.

Table 4.4. Slopes (x 10^{-4}/day) of regression equations over time (2001-2004) of Sorenson's similarity measures between sown and unsown communities within disturbance level and light regime (in brackets, R^2). Abbreviations cf. Section 2.1

Index	**Disturbance level**	**MIXT1-CONTR**		**MIXT2-CONTR**		**MIXT3-CONTR**	
		Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded
C_S[2]	Undisturbed	2.816 *	2.817 *	1.833 *[1]	2.248 *	2.710 *	4.193 ***
		(0.30)	*(0.35)*	*(0.22)*	*(0.21)*	*(0.39)*	*(0.67)*
	Disturbed	4.441 **	5.511 ***	3.930 *	4.235 *	4.712 **	3.620 *
		(0.47)	*(0.56)*	*(0.30)*	*(0.34)*	*(0.53)*	*(0.30)*
C_N[2]	Undisturbed	-1.570	1.630 *	-0.093	1.584 *	1.419 *	3.341 **
			(0.26)		*(0.32)*	*(0.20)*	*(0.49)*
	Disturbed	2.086 *	3.292 *	2.104 *	4.159 **	3.023 *	3.384 *
		(0.21)	*(0.36)*	*(0.20)*	*(0.45)*	*(0.40)*	*(0.38)*

[1] *,**,*** $p<0.05$. $p<0.01$ and $p<0.001$ respectively

[2] C_N, quantitative Sorenson's index; C_S, qualitative Sorenson's index

In general, similarity between sown and unsown communities occurred earlier when plant communities were disturbed.

In Table 4.5 the significance levels of experimental factors is given for the vegetation analyses prior and next to disturbance. Prior to disturbance, no significant factors occurred. In July 2004, C_S was significantly altered by disturbance level and light regime. Disturbance caused a significantly higher C_S (undisturbed, 0.52 versus disturbed, 0.66; LSD=0.08). C_S was significantly higher at the shaded side (shaded, 0.64 versus unshaded, 0.54; LSD=0.03)

Table 4.5. Significance of main factors and their interactions (ANOVA) during early succession for qualitative (C_S) and quantitative (C_N) Sorenson's index (Disturbance event: September 2002)

Sorenson's similarity index	**Pre-disturbance**	**Post disturbance** [1]			
	M1	**M2**	**M3**	**M4**	**M5**
C_S[2]:					
Light regime	NS[2]	NS	NS	NS	**
Plant community	NS	NS	*	NS	NS
Disturbance level	-	**	**	***	**
Light regime x Plant community	NS	NS	NS	NS	NS
Light regime x Disturbance level	-	NS	NS	NS	NS
Plant community x Disturbance level	-	NS	NS	NS	NS
Plant community x Disturbance level x Light regime	-	NS	NS	NS	NS
C_N[2]:					
Light regime	NS[2]	**	NS	*	*
Plant community	NS	*	NS	NS	NS
Disturbance level	-	**	***	**	***
Light regime x Plant community	NS	NS	NS	NS	NS
Light regime x Disturbance level	-	NS	NS	NS	NS
Plant community x Disturbance level	-	NS	NS	NS	NS
Plant community x Disturbance level x Light regime	-	NS	NS	NS	NS

[1] M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004

[2] NS non significant, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

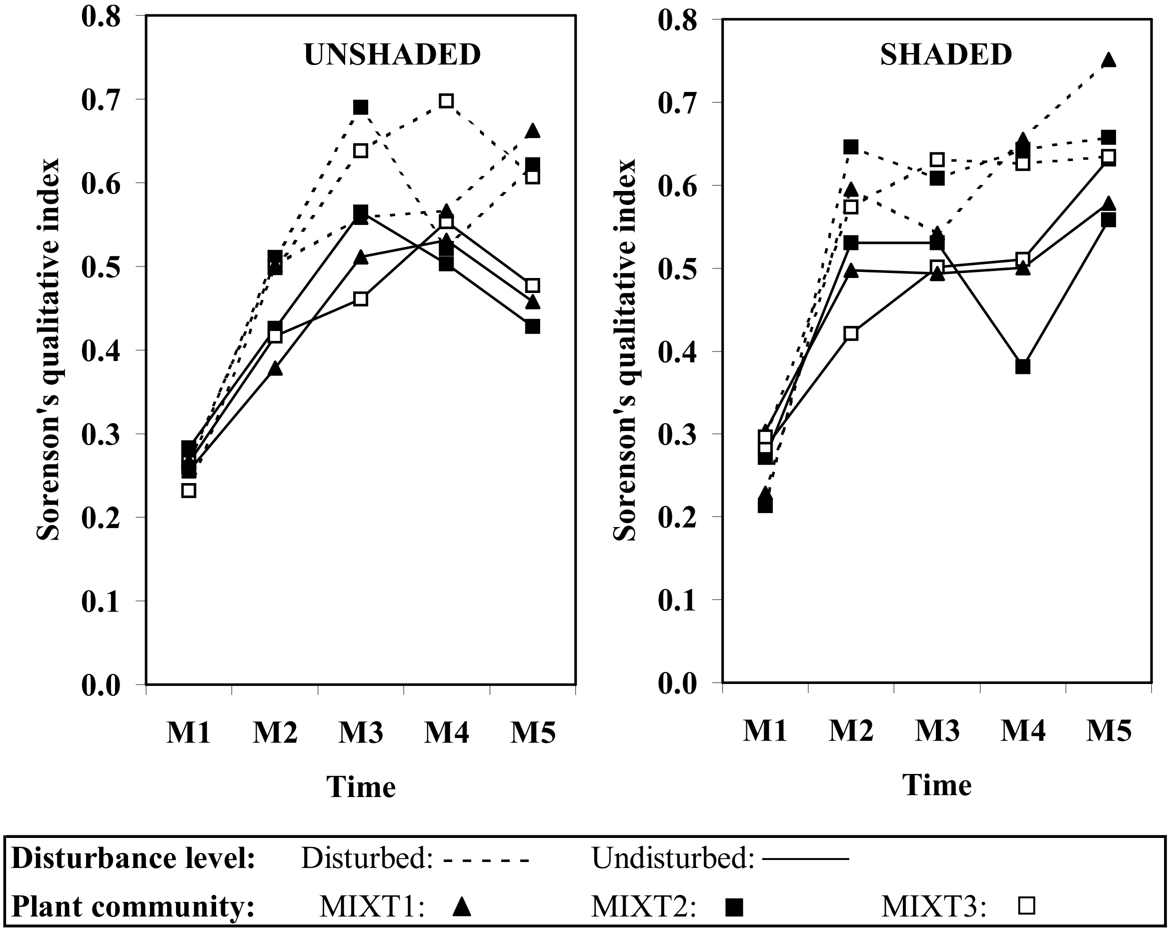


Figure 4.4. Sorenson's qualitative similarity index between pairs of sown and unsown communities over time (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004), on the shaded and unshaded side of a tree lane with or without disturbance. Abbreviations cf. Section 2.1

Sorenson's quantitative index (C_N):

Results of the similarity of species importance assessed by the Sorenson's quantitative index (C_N) are given in Figure 4.5. C_N increased significantly (except for the undisturbed, unshaded MIXT1 and MIXT2) between 2001-2004 with slopes of all linear equations being positive (Table 4.4). C_N increased at higher rate (higher positive slopes) when communities were disturbed. C_N between sown and unsown communties occurred earlier (higher positive slopes) for communities on the shaded side.

In Table 4.5 significance levels of experimental factors are given for the pre and post disturbance succession. Prior to disturbance, C_N showed no significant factors. In July 2004, 21 months after the disturbance event, C_N was significantly influenced by light regime and disturbance level. C_N was significantly higher on the shaded side (shaded 0.49 versus unshaded 0.33 (LSD=0.10). C_N within disturbance level was significantly higher in disturbed plots (disturbance, 0.49 versus undisturbed, 0.32 LSD=0.08).

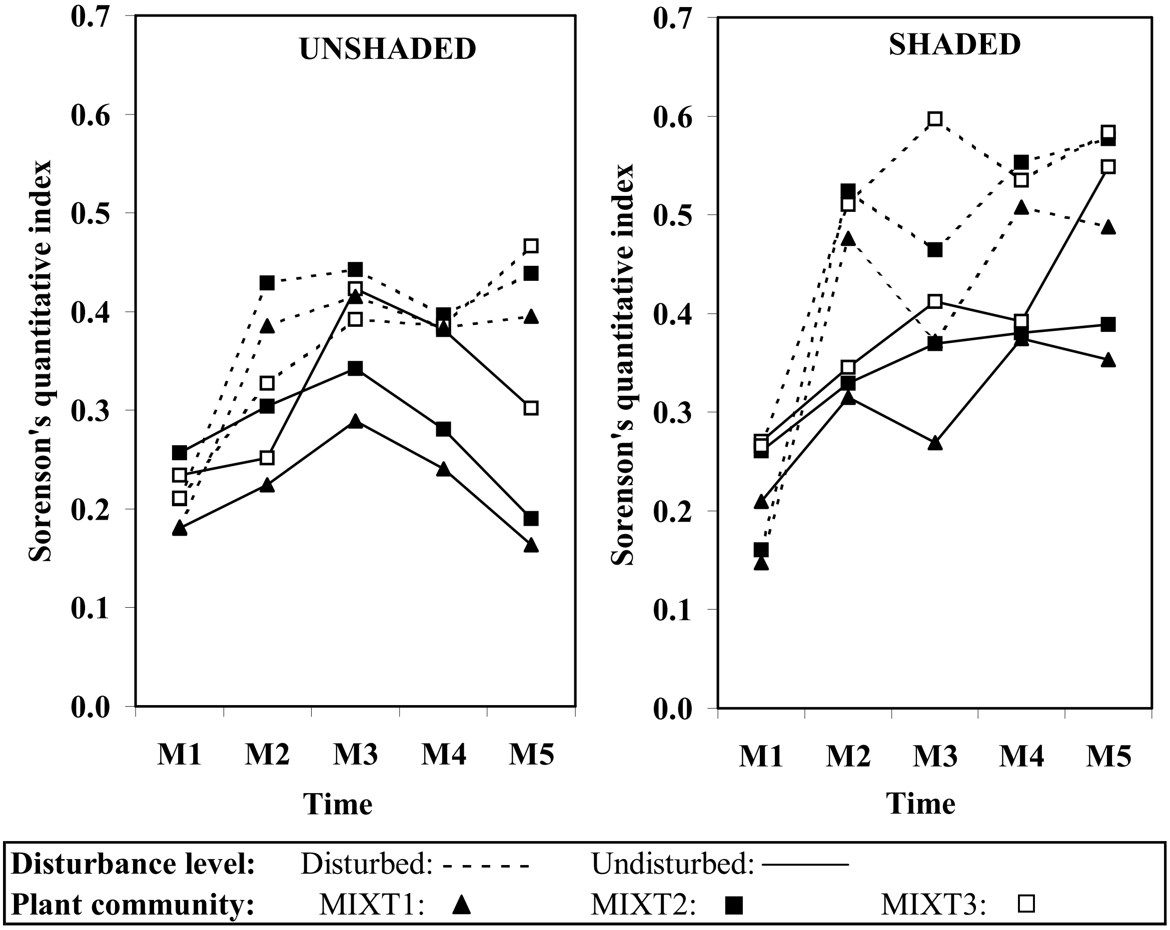


Figure 4.5. Sorenson's quantitative similarity index between pairs of sown and unsown communities over time (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004), on the shaded and unshaded side of a tree lane with or without disturbance. Abbreviations cf. Section 2.1

4.4 Discussion and conclusions

Twenty one months after the disturbance event, species diversity of plants was not altered by disturbance, despite the significantly higher and lower species diversity in the disturbed plots on respectively the unshaded and shaded side shortly after the disturbance event. So, disturbance caused only a temporary effect. The temporary increase in species richness on the unshaded side of the tree lane could be explained by the higher light penetration in disturbed communities, favouring spontaneous introgression in temporary gaps created by disturbance. Predominantly annual species introgressed shortly after the disturbance event. On the shaded side, spontaneous introgressing species apparently could not compensate for the loss of species by the detrimental effect of disturbance on plant survival because of restricted light availability. Moreover, disturbance caused no significantly higher number of annual species on the shaded side. This dual disturbance effect on species diversity reflects findings of Begon et al. (1990) who stated that disturbance induces plant mortality that might decrease species diversity, and opens up space for colonisers from elsewhere, which might increase species diversity.

In disturbed, sown communities species diversity was highest at intermediate time spans following disturbance similar to the intermediate disturbance hypothesis (Connel, 1978; Begon et al., 1990). However, in the disturbed unsown community, species richness was highest immediately following disturbance. This agrees with the succession model of initial floristic composition (Egler, 1954; Wilson et al., 1992).

Species diversity converged during the first three successional years irrespective of light regime, disturbance level or plant community. So, installing species-rich mixtures in field margin strips, offered no surplus value in maximizing species richness. This does not confirm Bokenstrand et al. (2004) who found long-lasting effects of sowing wild-flower mixtures in field margins. During early succession (2001-2004) species diversity in sown communities showed a significantly decreasing trend irrespective of light regime or disturbance level. Dissimilar to sown communities, species diversity in unsown community showed an increasing trend on the shaded side but a decreasing trend (but at lower rate of decrease than in sown communities) on the unshaded side. Above mentioned trends of species diversity over time are in accordance with West & Marshall (1996) who found naturally regenerated plots to have lower species diversity than sown plots during the first year, but species numbers remained stable in unsown plots in the second year whereas they decreased in the sown plots.

Vegetation succession during the first three successional years was characterized by drastic changes in the proportional importance of functional groups. Annuals although highly present, were steadily replaced by perennials. Sown plant communities became more grassy over time at the expense of dicotyledons irrespective of plant community or light regime. Changes were more pronounced after disturbance. Dissimilar succession patterns were found in unsown plant communities: the share of monocotyledons and dicotyledons during succession was mediated by light regime and disturbance. Probably seedbank composition differed on both sides of the tree lane as a direct or indirect result (for example moisture content) of the light regime. Disturbance caused a temporarily significant increase of the importance of annual spontaneous dicotyledons one month after the disturbance event. This was due to the temporary increase of uncovered area after disturbance. The facilitation of spontaneous annual dicotyledons by disturbance was also reported by several authors (Grime, 1979; Wilson & Tilman, 1991; Schippers et al., 2001). Later on, the annual spontaneous dicotyledons were quickly replaced by predominantly perennial spontaneous monocotyledons. Similar succession patterns were reported by Hodgson (1989) in naturally revegetated strips with initial dominance of annuals and short-lived species, which are, with time, typically replaced by perennial non-woody species (under mowing regime).

As a result of the successional changes within and between functional groups, communities became increasingly similar as indicated by Sorenson's qualitative index (solely based on species occurrence) and quantitative index (based on species occurrence and importance). Similarly also Warren et al. (2002) found vegetation similarity between sown and non-sown plots converging in terms of abundance of species. However sown and unsown communities became more similar after disturbance. This could be attributed to the increase in proportional importance of spontaneous species within the functional groups in disturbed plots. Disturbance created more gaps (higher percentage uncovered area) which were predominantly colonized by spontaneous species: at first annuals which were increasingly replaced by perennial monocotyledons. During succession, disturbance increased the proportion of spontaneous species within monocotyledons on the shaded side due to the faster increase of perennial spontaneous monocotyledons than sown monocotyledons. Similarly, the proportion and importance of spontaneous dicotyledons within non-fixing dicotyledons increased following disturbance due to the faster decrease of sown non- fixing dicotyledons in disturbed plots.

Sorenson's quantitative and qualitative indices were significantly higher on the shaded side of the tree lane. The significantly higher percentage uncovered area on the shaded side during early succession probably offered more opportunities for spontaneous species (mainly monocotyledons and to a lesser extent dicotyledons) to colonize. We expect germination of spontaneous species in gaps to be facilitated by the higher soil moisture content on the shaded side (cf. data in Chapter 5, Section 5.3.1).

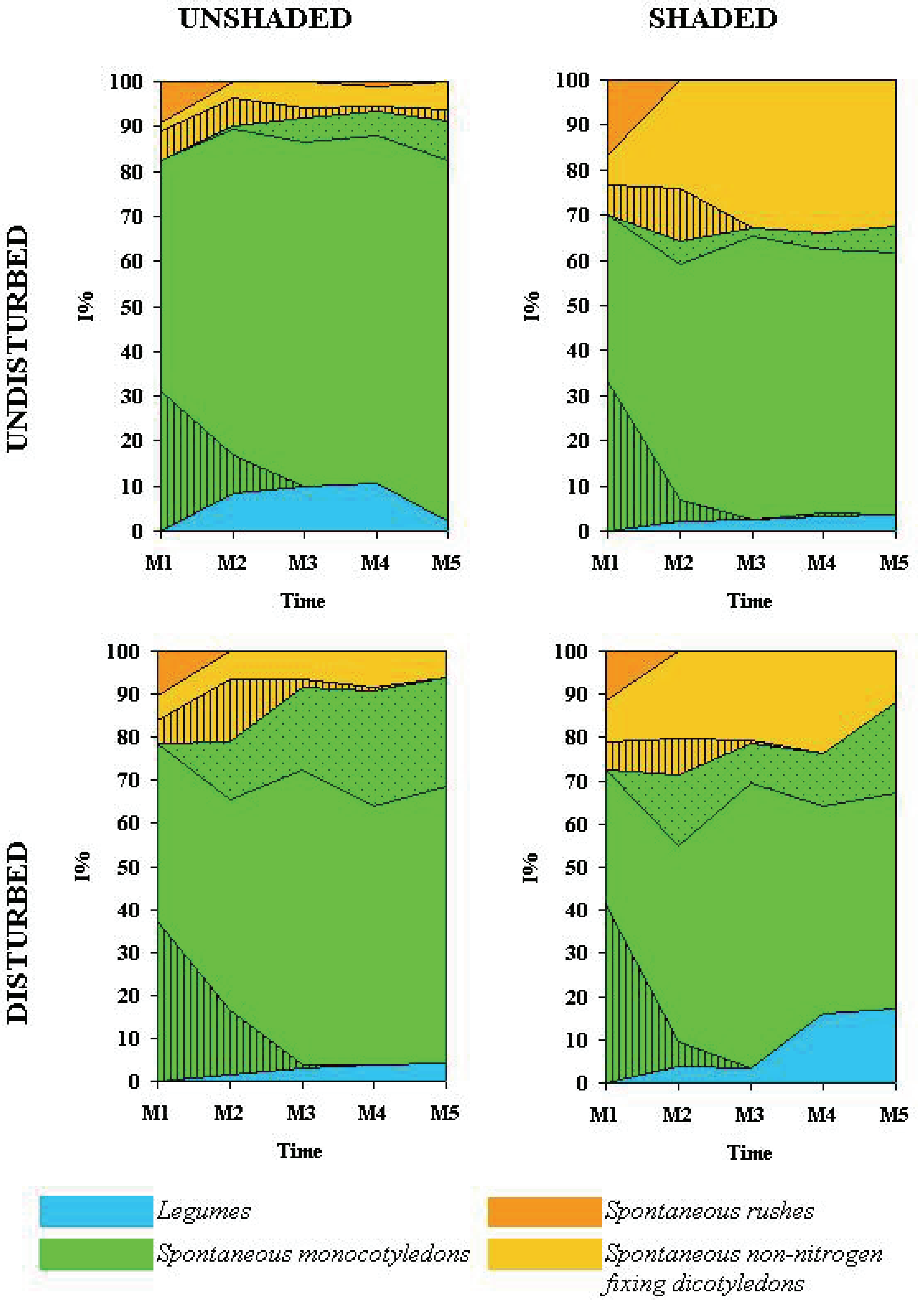
Twenty one months after the disturbance event, the importance of invaders was significantly higher on the unshaded side irrespective of disturbance level. So, the invasive success of invaders was more successful at higher light intensity because of higher light availability in prevailing gaps. The effect of plant community on the importance of invader grasses was significantly influenced by disturbance level: the unsown community showed the highest invasibility under disturbance contrary to sown communities.

Field margin strips are likely to be disturbed by wheeled or tracked machinery whether prohibited or not. From an agronomical viewpoint, it is therefore advisable at unshaded field sites to install field margins by sowing to minimize the risk of biological invasion. Biological invasions are often cause for concern in grassland management (Watkinson & Ormerod, 2001). Invasive species might spread into the adjacent crop causing pernicious weed problems. The minimization of the risk of biological invasion is also of concern for nature conservation: biological invasions are considered an increasing threat to biodiversity (D'Antonio & Vitousek, 1992; Watkinson & Ormerod, 2001). Sown field margins do not conflict with nature conservation purpose: our results show that shortly after installation, the perennial sown vegetation became increasingly similar to the spontaneous vegetation, leaving opportunities for spontaneous introgression thus encouraging nature conservation on the long term. At shaded field sites, the installation of new field margins by sowing has no surplus value compared to spontaneous revegetation since there is little risk of biological invasion under low light availability.

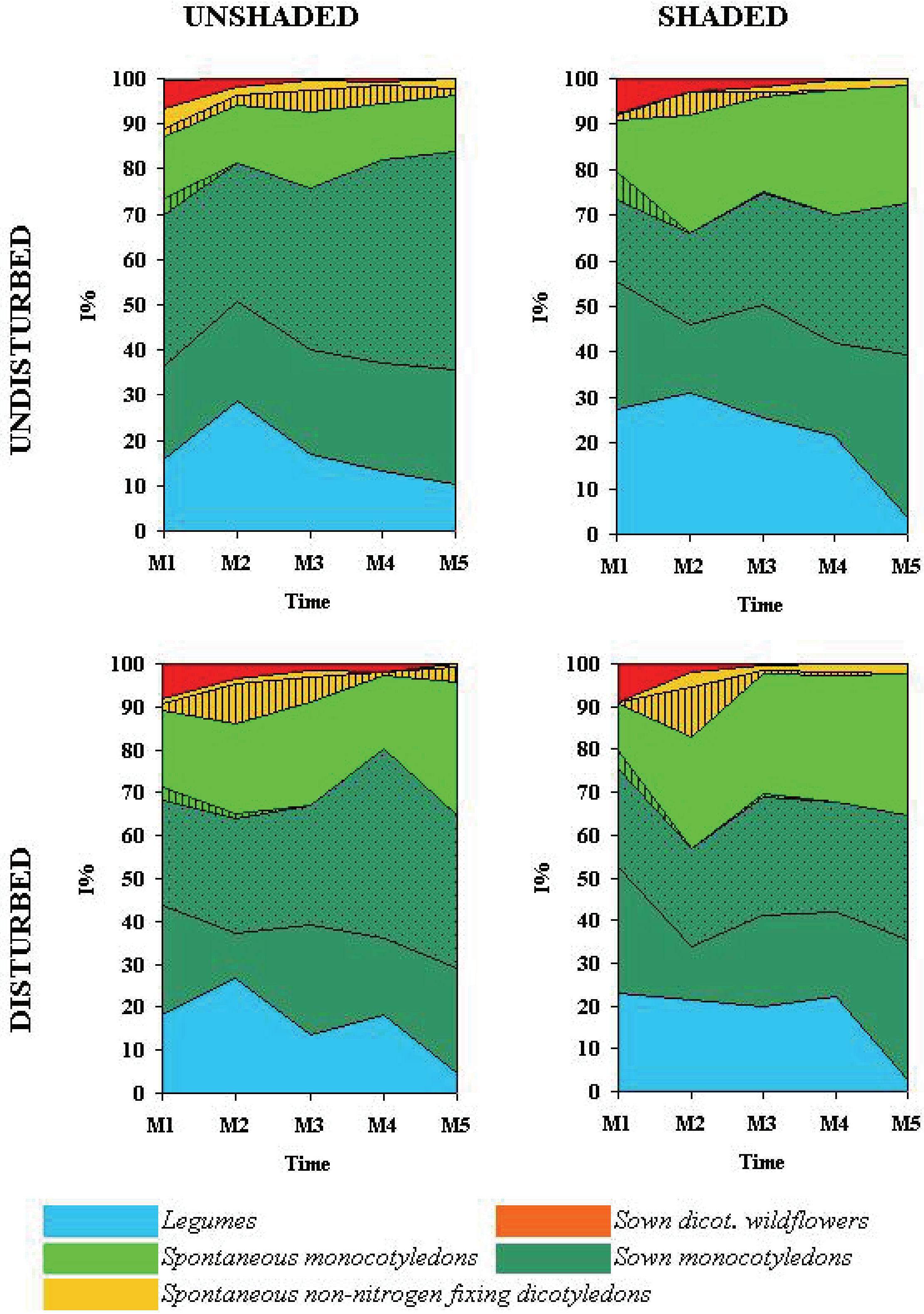
Questions might arise concerning the representativeness of the single rotocultivation event for disturbances in common agricultural practice. Indeed, these disturbances vary in frequency and in intensity. Multiple passes might cause severe soil compaction altering soil chemical and physical properties. Although the passage of heavy vehicles will usually cause significant soil compaction, the soil surface is sheared or broken primarily when a vehicle turns or makes repeated passes (Milchunas et al., 1999). Furthermore, field margins are not uniformly disturbed over their complete area. So, changes in the vertical and horizontal structure of plant communities may probably occur thus creating a mosaic of plant communities.

Nevertheless on the shorter term, the single disturbance in this experiment, simulates well the amount of bare ground created during multiple vehicle passes but not the occurring soil compaction. Timing of the disturbance event is also comparable since field margins will usually be significantly damaged when used as turning headlands at harvest time in autumn.

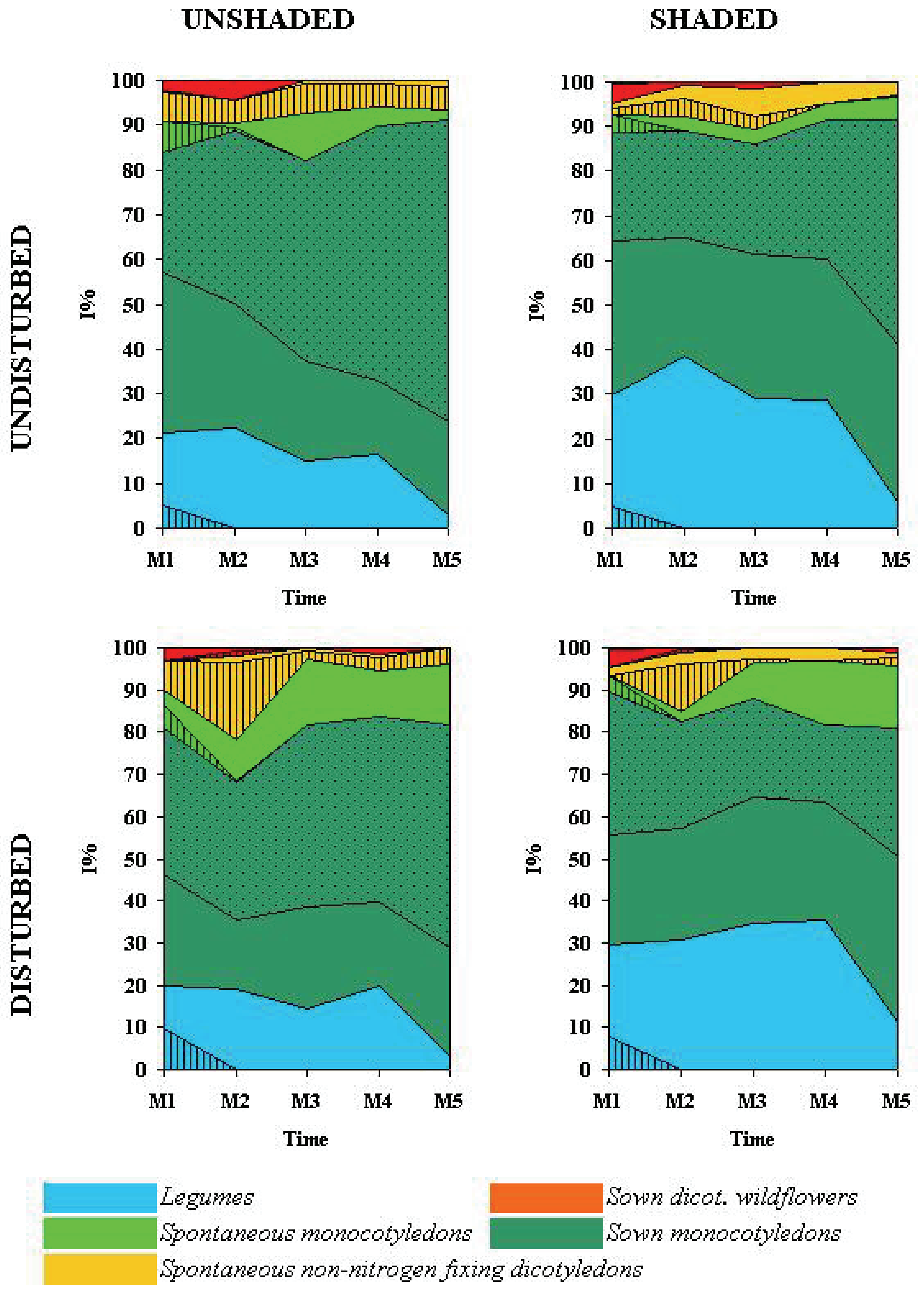
Our research revealed that the species richness on the longer term was not significantly affected by disturbance despite significant temporary effects shortly after the disturbance event. On the contrary, vegetation composition in terms of importance of functional groups changed after disturbance: the share of spontaneous species within functional groups increased resulting in higher similarity between sown and unsown vegetation. The risk of invasion was highest in the disturbed unsown community on the unshaded side of a tree lane.



Appendix 4.1. Mean changes in importance (I%) of functional groups over time (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004) for a disturbed and undisturbed unsown community, on the shaded and unshaded side of a tree lane: vertical hatched=annuals; non hatched=perennials; dotted=invaders. A single disturbance occurred on 19 september 2002



Appendix 4.2. Mean changes in importance (I%) of functional groups over time (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004) for a disturbed and undisturbed community sown to indigenous species, on the shaded and unshaded side of a tree lane: vertical hatched=annuals; non hatched=perennials; dotted=invaders. A single disturbance occurred on 19 september 2002



Appendix 4.3. Mean changes in importance (I%) of functional groups over time (M1, July 2002; M2, October 2002; M3, July 2003; M4, October 2003; M5, July 2004) for disturbed and undisturbed community sown to commercially available species, on the shaded and unshaded side of a tree lane: vertical hatched=annuals; non hatched=perennials; dotted=invaders. A single disturbance occurred on 19 september 2002

Chapter 5

The effect of light and botanical species richness on insect biodiversity nearby arable field margins

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Chapter 5

The effect of light and botanical species richness on insect biodiversity nearby arable field margins

5.1 Introduction

During the last decades, regular mechanical disturbance, increased chemical weed control and pesticide use, drift of agrochemicals into remnant field boundary habitats, field enlargement and the general simplification of crop rotations have directly or indirectly contributed to the impoverishment of many insect groups on arable land (Sotherton & Self, 2000; Morris & Webb, 1987). Consequently organisms downstream the food web are affected, as e.g. the chicks of farmland birds like the partridge (*Perdix perdix*) (Campbell et al., 1997).
In many countries, support mechanisms have been installed to encourage farmers to buffer remaining boundaries and to install new habitats by means of botanically diverse margin strips. A species rich flowering margin vegetation with a high structural diversity, has been shown to increase the associated family richness (Fussell & Corbet, 1992; Lagerlof & Wallin, 1993; Kirkham et al., 1994; Thomas et al., 1994; Huusela-Veistola, 1998; Frank, 1999; Thomas & Marshall, 1999; Marshall & Moonen, 2002; Meek et al., 2002). In particular, field margins may play an important role in conserving pollinators (Mänd et al, 2002) and generalist predators and parasitoids allowing a natural control of agricultural pests in adjacent field crops (e.g. Thomas et al., 1992; Collins et al., 2002; Meek et al., 2002).

However the impact of field margin type and more in particular field margin composition on insect fauna remains poorly documented despite the increased interest to use field margin strips as a management instrument to attract antagonists for biological pest suppression. Meek et al. (2002) demonstrated that the numbers of insects were more than twice as high within arable field margins than in cropped areas adjacent to the edge. According to Meek et al. (2002) different seed mixtures or types of margin management encouraged different colonising insect faunas. Perennial rather than annual flower species, particularly *Asteraceae* are said to encourage the abundance of butterflies (Smith et al., 1993) and bumblebees (Fussell & Corbet, 1992). The presence of perennial herbs promoted numbers of *Hemiptera*, *Hymenoptera* and *Araneae* which may colonize margins very quickly, usually within twelve months (Thomas et al., 1994). Tussocky grasses such as cocksfoot (*Dactylis glomerata* L.), yorkshire fog (*Holcus lanatus* L.) and timothy (*Phleum pratense* L.) are often promoted to attract animals like carabid and staphylinid beetles and spiders because these animal species thrive in a dense vegetation with a shelter offering structure (Marshall & Moonen, 1998). Spontaneously revegetating field margins with a lot of bare ground at early successional stage, may stimulate the development of insect fauna since Kirby (1992) highlighted the importance of bare ground for hunting, basking, burrowing or nesting. Web-spinning spiders require a rigid vegetation structure (Curry, 1994). There is some evidence that more than annual sources, perennial nectar sources are a better energy source, explaining their differential use by butterflies (Corbet, 1995). A vegetation which includes sown native flower species can lead to increased numbers of pollen- and nectar-feeding insects during the flowering season, especially if the margin occupies a sunny, sheltered position (Warren & Stephens, 1989; Dover, 1996). However, on arable land, many field margin strips are installed along tree rows and hedges, because crops growing in these areas are less productive due to the decreased availability of light and water and due to a potential higher weed and disease pressure (Brenner, 1996; Nuberg, 1998; Kleijn, 1997).

This research studies the impact of field margins installed along the shaded and unshaded side of a tree lane and characterized by different plant communities. In particular the following questions are adressed. (1) What is the effect of light regime and plant community on insect number, insect composition and insect diversity both in the margin strip and in the adjacent field crop? (2) Is there a relation between herbivorous insects and generalist predators and parasitoids?

5.2 Specific material and methods

5.2.1 Experimental field site and treatments

The research was based on trial 2 (Chapter 2, Section 2.1). Since insects were monitored prior to the addition of seed rich roadside herbage, MIXT3 was not considered as different from MIXT2 in this study. So, insect monitorings nearby MIXT3 were not considered in this Chapter. Effects of light regime can not be confounded with field effects since fields on both sides of the tree lane were very similar: on both sides of the tree lane, the crop adjacent to the field margin strips was a mixture of red clover (*Trifolium pratense* L.) and Italian ryegrass

(*Lolium multiflorum* Lamk.) During the monitoring period of flying insects the grass/clover vegetation did not flower.

5.2.2 Abiotic conditions

Abiotic conditions were characterized by measurement of the soil water status and light availability. During the period from 27 June to 6 September 2002, soil moisture content of 3 soil profiles (0-10 cm; 10-20 cm; 20-30 cm) was assessed every two weeks within the centre of every plot. For the first sampling, undisturbed soil samples were taken in soil sample rings of known volume (100 cm³). After drying the samples for 24h at 105°C, the volumetric moisture content (vol%) and the apparent specific gravity (i.e. dry weight of soil (g) divided by the ring volume) was calculated. The next samplings were taken with an auger with a diameter of 3 cm. The volumetric soil moisture content was calculated by multiplying the gravimetric moisture contents with the apparent specific gravity of the soil.

On two complete sunny days (9 August and 3 September 2002) photosynthetic active radiation (P.A.R., in $\mu mol.m^{-2}.s^{-1}$) above the field margin canopy (i.e. incident P.A.R.) and P.A.R. within the field margin canopy (i.e. transmitted P.A.R.) was measured every hour and a half with the Sunscan Canopy Analysis System SS1 (Delta-T Devices).

5.2.3 Botanical analysis

Botanical analysis of margin strips followed the methodology described in Chapter 2, Section 2.2. The Sunscan Canopy Analysis System SS1 (Delta-T Devices) calculated the canopy leaf area index (L.A.I.) of the plant communities on 3 September 2002.

5.2.4 Monitoring mobile flying insects nearby field margin strips

The insect fauna was monitored during a four week period from 7 August to 3 September 2002. Fauna was caught on yellow biosignal sticky traps (BUGSCAN-BIOBEST) sized 20 cm x 40 cm. These sticky traps were made of recyclable plastic with a long-lasting water repellent adhesive. The yellow color is highly attractive to insects due to its high reflection properties (Bernays & Chapman, 1994). The trapping method with yellow traps is particularly representative for mobile canopy dwelling insects. Traps were installed on both shaded and unshaded side along twelve transects perpendicular centered to the field margin community plots. Along each transect, traps were placed verticularly 30 cm above the crop canopy at five monitoring positions: 4 m inside the margin strip, upon the edge between margin strip and crop and at three positions in the crop 4, 8 and 16 m away from the margin edge. These positions are further indicated as –4 m, 0 m, 4 m, 8 m and 16 m. The traps were replaced weekly. Prior to determination of trapped insects, collected traps were temporarily stored in a refrigerator at 2°C. Captured insects were determined according to Elseviers insect Guide (Chinery, 1982) using a trinocular microscope (120X). Per trap, all insects were determined to family level, some to superfamily or order level and counted per family, superfamily or order. Total number of insects (hereafter called insect number) in the period from 7 August to 3 September 2002 was calculated by adding the weekly counts per position. Family richness was expressed as the number of occurring insect families.

Shannon diversity index (Magurran, 1988) was used to determine the biological diversity of insects in the margin strips. The Shannon index is related to species richness but is also influenced by the underlying proportional abundances of species and evenness. In this study Shannon index was calculated as $-3p_i\ln p_i$: p_i is the proportion of individuals found in the *i*th family devided by total number of trapped insects. The Berger-Parker index (Berger & Parker, 1970) was used to determine whether there was any change in the dominance of insect families in the plant communities. The Berger-Parker index as a dominance measure expresses the proportional importance of the most abundant species and was calculated as the number of trapped insects in the most abundant family divided by the total number of trapped insects. In this paper the reciprocal form of the Berger-Parker index (hereafter simply called Berger-Parker index) was used; an increase in the value of the index accompanies a reduction in dominance and an increase in diversity (Magurran, 1988).

Insect families were classified according to their predominant feeding habit, according to Elseviers insect Guide (Chinery, 1982) and Borror et al. (1989), and divided into herbivorous insects (plant damaging insects except insects chiefly feeding on pollen and nectar), entomophagous insects (antagonists: predators and parasitoids) and flower visiting insects (insects feeding on flowers, nectar, pollen,...). This classification is rather arbitrary and of limited value since both entomophagous species as well as herbivorous species may occur within some families. Many insects are also rather varied feeders or show different feeding behavior depending for example on their developmental stage (adult, larval or nymphal stages). Some entomophagous or herbivorous insect families were also classified as flower visiting families in case they also feed to a large extent on nectar, pollen or flowers during certain developmental stages. The family of *Miridae* was classified as both entomophagous and herbivorous. Insect families which are predominantly saprophagous (scavengers,...) or which have extremely varied feeding habits were not considered.

5.2.5 Statistical computations

To determine preferential presence of insect families at either the shaded or unshaded side or preferential presence within either the margin strip or the adjacent field crop, independent t-tests (SPSS10.0 programm for Windows) were used at a significance level of 5%. Similar t-tests were used to compare differences in insect composition of sown and unsown margin strips. Family richness and insect numbers were statistically analysed with S-plus 2000 for Windows according to a strip split plot design (Gomez & Gomez, 1984) with three factors (light regime, plant community and monitoring position). Abiotic factors were analysed according to a strip plot design with two factors (light regime and plant community).

5.3 Results

5.3.1 Soil water status and P.A.R. availability

Averaged over the monitoring period from 27 June to 6 September 2002, the soil moisture content in the profile 0-10 cm, was significantly determined by light regime ($p=0.000$). The unshaded side revealed a significantly higher soil moisture content in the profile (unshaded, 32.3 vol% versus shaded, 37.3 vol%; LSD = 2.4 vol%). The impact of plant community on soil moisture content was not significant despite the slightly higher soil moisture content in CONTR compared to sown communities. The fluctuations in soil moisture content (profile 0-10 cm) during the monitoring period are shown in Figure 5.1. Spells of drought occurred around 30 July and 6 September. With increasing depth, differences in soil moisture between plant communities became smaller irrespective of light regime (data not shown).

On 9 August 2002, average incident P.A.R. above the canopy at the unshaded side (1261.5 µmol.m^{-2}.s^{-1}) was significantly higher than incident P.A.R. at the shaded side (637.3 µmol.m^{-2}.s^{-1}; LSD=198.1 µmol.m^{-2}.s^{-1}) (Figure 5.2). The average transmitted P.A.R. revealed a significant interaction between light regime and plant community (p=0.002). Transmitted P.A.R. under the canopy was significantly higher in CONTR (unshaded, 460.7 µmol.m^{-2}.s^{-1}; shaded, 301.5 µmol.m^{-2}.s^{-1}) than in sown communities (unshaded 235.9-253.7 µmol.m^{-2}.s^{-1}; shaded 222.9-226.6 µmol.m^{-2}.s^{-1}) irrespective of light regime (LSD within light regime=55.1µmol.m^{-2}.s^{-1}). CONTR revealed significantly higher transmitted P.A.R. at the unshaded side (460.7 µmol.m^{-2}.s^{-1}) than at the shaded side (301.5 µmol.m^{-2}.s^{-1}; LSD otherwise = 70.4 µmol.m^{-2}.s^{-1}).

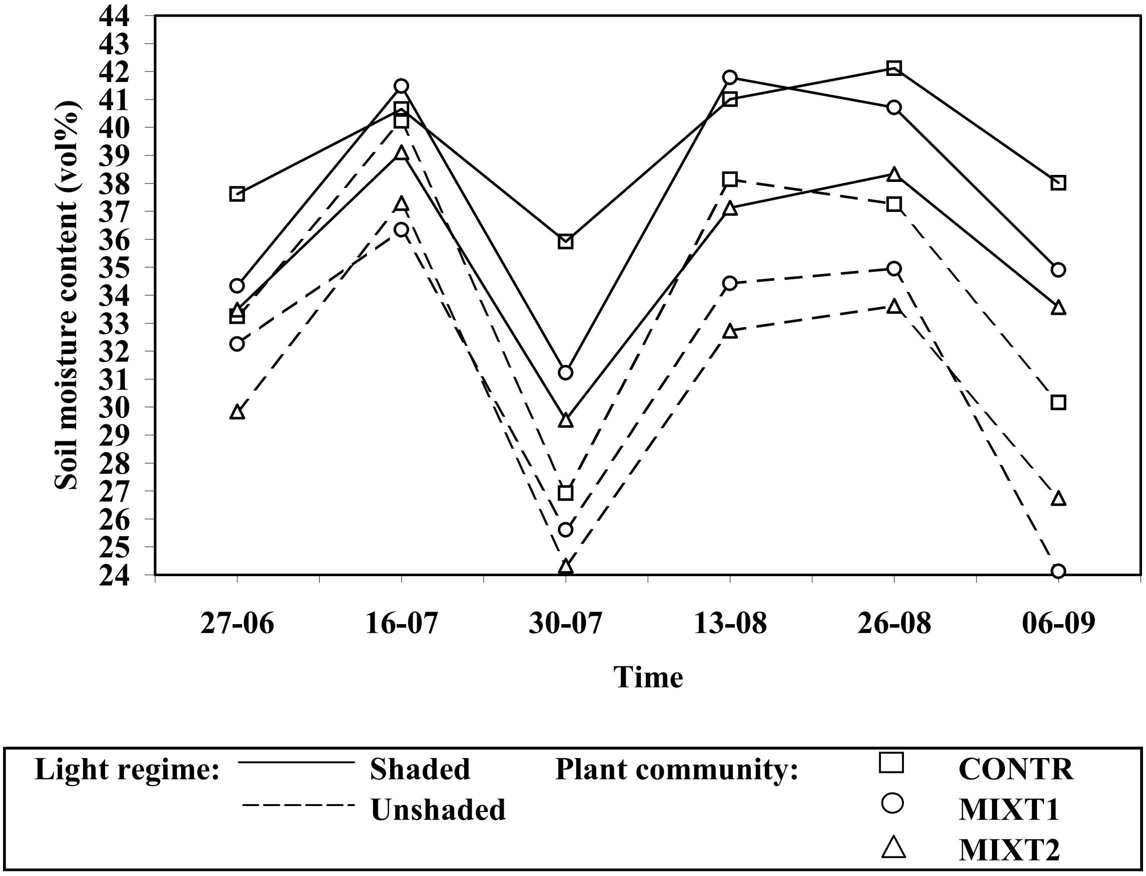

Figure 5.1. Evolution of soil moisture content (vol%) in a soil profile 0-10 cm over time for sown/unsown communities at the shaded and the unshaded side of a tree lane. Monitoring period: 27 June to 6 September 2002. Abbreviations cf. Section 2.1

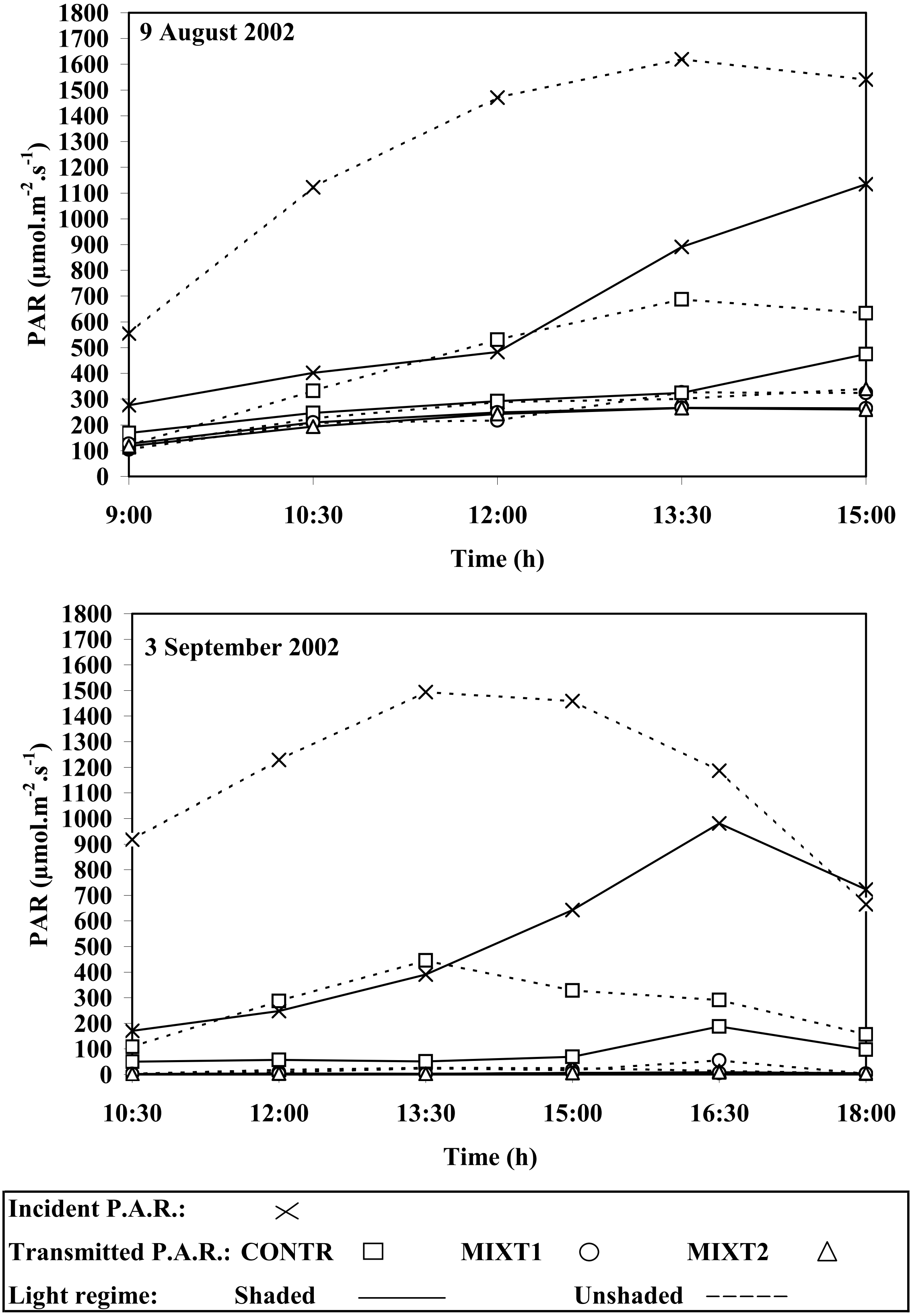

Figure 5.2. Day profile (9 August and 3 September 2002; sunny days) of incident and transmitted P.A.R. (µmol.m^{-2}.s^{-1}) above and under the canopies of sown/unsown communities at the shaded and the unshaded side of a tree lane. Abbreviations cf. Section 2.1

Similar results were found for incident and transmitted P.A.R. on 3 September 2002. Average incident P.A.R. above the canopy at the unshaded side (1158.3 $\mu mol.m^{-2}.s^{-1}$) was significantly higher than incident P.A.R. at the shaded side (526.1 $\mu mol.m^{-2}.s^{-1}$; LSD=174.7 $\mu mol.m^{-2}.s^{-1}$). Transmitted P.A.R. under the canopy was significantly higher in CONTR (unshaded, 269.4 $\mu mol.m^{-2}.s^{-1}$; shaded, 85.4 $\mu mol.m^{-2}.s^{-1}$) than in sown communities (unshaded 15.2-18.4 $\mu mol.m^{-2}.s^{-1}$; shaded 3.7-5.4 $\mu mol.m^{-2}.s^{-1}$) irrespective of light regime (LSD within light regime=38.7 $\mu mol.m^{-2}.s^{-1}$). CONTR revealed significantly higher transmitted P.A.R. at the unshaded side (269.4 $\mu mol.m^{-2}.s^{-1}$) than at the shaded side (85.45 $\mu mol.m^{-2}.s^{-1}$; LSD= 97.0 $\mu mol.m^{-2}.s^{-1}$). P.A.R. light profile on 3 September 2002 is shown in Figure 5.2.

5.3.2 Botanical composition of plant communities

Abundance of occurring species within plant communities at both the unshaded and shaded side of the tree lane is shown in Appendix 5.1. Species composition was clearly affected by light regime. The shaded side revealed several plant species associated to humid conditions such as *Glyceria fluitans* R. Br., *Ranunculus lingua* L., *Juncus effusus* L., *Juncus bufonius* L., *Myosotis palustris* L., *Ranunculus repens* L.. Contrary to the sown communities with many tall growing grasses, mearly low growing plant species occurred in CONTR: the most abundant species were *Alopecurus geniculatus* L. and *Agrostis stolonifera* L. at the unshaded side and *Poa trivialis* L. and *Glyceria fluitans* R. Br. at the shaded side. Contrary to the unsown community, sown communities revealed a high abundance of *Trifolium* spp.. The most abundant species in the sown communities, both at the unshaded and shaded side, were the sown legumes *Trifolium pratense* L., *Trifolium repens* L. and the sown grasses *Arrhenatherum elatius* J. & C. Presl, *Lolium perenne* L., *Phleum pratense* L. and *Dactylis glomerata* L..

Botanical diversity in August 2002 was significantly determined by plant community ($p=0.002$) and not by light regime: no significant interaction was found. CONTR had a higher diversity compared to the sown communities (CONTR, 20.6 spp. versus MIXT1, 14.1 spp. and MIXT2, 15.2 spp.; LSD= 3.6 spp.). Species diversity was comparable at both sides of the tree lane (unshaded, 16.5 spp. versus shaded, 16.7 spp.).

The percentage uncovered area at the end of July, showed a significant interaction between plant community and light regime ($p=0.001$). At the shaded side CONTR revealed a significantly higher percentage uncovered area than sown communities (CONTR, 35.2 % versus MIXT1, 7.9 % and MIXT2, 8.1 %; LSD within light regime=5.6 %). At the unshaded side no significant differences were found. Within CONTR, percentage uncovered area was significantly higher at the shaded side (unshaded, 14.2 % versus shaded, 35.2 %; LSD otherwise= 10.3 %).

L.A.I. on 3 September 2002, was significantly determined by plant community ($p<0.001$) and not by light regime; no significant interaction was found. L.A.I. of CONTR (2.3) was significantly lower than L.A.I. of sown communities (7.6-7.7) (LSD=0.7). These results correspond with the significantly higher transmitted P.A.R. in CONTR compared to sown communities.

5.3.3 Analysis of flying insects

Insect composition:

The distribution of total numbers of trapped insects over their corresponding insect families is shown in Table 5.1. The insect orders with the highest number of trapped insects were the order of *Diptera*, order of *Thysanoptera* and *Hymenoptera*. The order of *Diptera* accounted for half the total number of trapped insects (185 288 insects). Within this order no less than 32 insect families were represented. Some representatives of insect families which can hardly fly (*Nepidae, Psyllidae)* were trapped. *Nepidae*, an aquatic family usually inhabiting bottoms of freshwater ponds, must have accidentally flown onto the traps at night. *Psyllidae* must have jumped onto the sticky traps.

The preferential presence of insect families on either the unshaded or shaded side of the tree lane is shown in table 5.2. Some families were exclusively trapped on either the unshaded or shaded side. However, most families occurred on both sides. Aside from 45 indifferent families (not shown) and with the exception of the families of *Cecidomyiidae* and *Ectopsocidae*, all the other insect families were trapped in significantly higher numbers on the shaded side. Among the insect families showing preference to the shaded side, many families are generally associated to water or moist conditions such as *Haliplidae*, *Dolichopodidae*, *Dryomyzidae, Empididae*, *Lauxaniidae* and superfamily of *Dascilloidea* (Chinery, 1982). Others like *Asilidae*, *Calliphoridae*, *Otitidae, Sepsidae*,... are generally associated to decaying materials.

Table 5.1. Insects along the tree lane: invertebrate number and share (%) of occurring invertebrate families. Monitoring period from 7 August to 2 September 2002

Taxa[1,2]		Number	Share %	Taxa[1,2]		Number	Share %
Order *Coleoptera:*		**1866**	**1.01**				
F. *Anobiidae*		15	0.01	F. *Curculionidae*	H	6	0.00
F. *Cantharidae*	E, F[2]	78	0.04	F. *Haliplidae*		47	0.03
F. *Carabidae*	E	63	0.03	F. *Scarabaeidae*	H	3	0.00
F. *Cerambycidae*	H, F	4	0.00	F. *Staphylinidae*	E	691	0.37
F. *Chrysomelidae*	H, F	40	0.02	SF. *Dascilloidea*		727	0.39
F. *Coccinellidae*	E, F	192	0.10				
Order *Diptera:*		**92114**	**49.71**				
F. *Anisopodidae*		163	0.09	F. *Micropezidae*		270	0.15
F. *Asilidae*	E	61	0.03	F. *Mycetophilidae*		16072	8.67
F. *Bibionidae*	F	1135	0.61	F. *Oestridae*		440	0.24
F. *Borboridae*		4	0.00	F. *Otitidae*		156	0.08
F. *Calliphoridae*		98	0.05	F. *Phoridae*		3532	1.91
F. *Cecidomyiidae*	H	26386	14.24	F. *Platystomidae*		48	0.03
F. *Chamaemyiidae*	E	13	0.01	F. *Psychodidae*		5847	3.16
F. *Chironomidae*		15380	8.30	F. *Ptychopteridae*		149	0.08
F. *Chloropidae*	H	8	0.00	F. *Rhagionidae*	E	6	0.00
F. *Conopidae*	F	5	0.00	F. *Scatopsidae*		4912	2.65
F. *Dolichopodidae*	E	5562	3.00	F. *Sciomyzidae*		130	0.07
F. *Dryomyzidae*		177	0.10	F. *Sepsidae*		442	0.24
F. *Empididae*	E, F	1234	0.67	F. *Stratiomyidae*	F	32	0.02
F. *Heleomyzidae*		417	0.23	F. *Syrphidae*	E, F	193	0.10
F. *Lauxaniidae*		8164	4.41	F. *Tabanidae*	F	29	0.02
F. *Lonchopteridae*		950	0.51	F. *Tipulidae*		99	0.05
Order *Dermaptera*		**3**	**0.00**				
Order *Hemiptera:*		**8706**	**4.70**				
F. *Acanthosomatidae*	H	7	0.00	F. *Nepidae*	E	2	0.00
F. *Aleyrodidae*	H	653	0.35	F. *Piesmatidae*	H	84	0.05
F. *Berytidae*	E	61	0.03	F. *Psyllidae*	H	211	0.11
F. *Cercopidae*	H	41	0.02	F. *Reduviidae*	E	228	0.12
F. *Cicadellidae*	H	3294	1.78	F. *Rhopalidae*	H	24	0.01
F. *Delphacidae*	H	30	0.02	F. *Saldidae*	E	5	0.00
F. *Lygaeidae*	H	6	0.00	F. *Stenocephalidae*	H	6	0.00
F. *Miridae*	E, H	73	0.04	SF. *Aphidoidea*	H	3902	2.11
F. *Nabidae*	E	2	0.00				

Table 5.1. Insects along the tree lane: invertebrate number and share (%) of occurring invertebrate families. Monitoring period from 7 August to 2 September 2002 (continued)

Taxa[1,2]		Number	Share %	Taxa[1,2]		Number	Share %
Order *Hymenoptera:*		**36901**	**19.92**				
F. *Tenthredinidae*	H	489	0.26	SF. *Proctotrupoidea*	E	3947	2.13
SF. *Chalcidoidea*	E	20522	11.08	SF. *Sphecoidea*	E	1	0.00
SF. *Formicoidea*		152	0.08	SF. *Vespoidea*	F	1	0.00
SF. *Ichneumonoidea*	E, F	11789	6.36				
Order *Lepidoptera:*		**75**	**0.04**				
F. *Micropterigidae*	F	66	0.04	F. *Nymphalidae*	H	1	0.00
F. *Notodontidae*	H	7	0.00	F. *Pieridae*	H	1	0.00
Order *Mecoptera*		**60**	**0.03**				
Order *Neuroptera:*		**83**	**0.04**				
F. *Chrysopidae*	E, F	11	0.01	F. *Hemerobiidae*	E	72	0.04
Order *Psocoptera:*		**4967**	**2.68**				
F. *Caeciliidae*		475	0.26	F. *Peripsocidae*		170	0.09
F. *Ectopsocidae*		4310	2.33	F. *Stenopsocidae*		12	0.01
Order *Strepsiptera*	**E**	**1**	**0.00**				
Order *Trichoptera*		**132**	**0.07**				
Order *Thysanoptera*	**H, F**	**40380**	**21.79**				

[1] F., Family; SF., Superfamily

[2] Feeding habit: E, entomophagous (predator, parasitoid); H, herbivorous (plant damaging); F, flower visiting

In Table 5.3 families are classified according to their preference to either the field margin strip (monitoring positions –4 m and 0 m) or to the adjacent crop. A small number of insect families occurred exclusively in either the field margin strip or in the adjacent field crop. However most occurring families were trapped in both areas. At the shaded side, aside from indifferent families (not shown), 13 families were preferentially trapped above the field crop whilst the family of *Phoridae* and order of *Mecoptera* were preferentially trapped above the field margin strip. At the unshaded side, 8 families showed preference to the field margin strip whilst 5 families showed preference to the field crop. Families preferring the field margin strip differed on both side of the tree lane indicating different habitat preferences.

Some families such as *Empididae*, *Chironomidae* and *Cicadellidae* preferred the field crop independently of light regime. Others like the family of *Phoridae* showed preference to the field crop at the unshaded side but preferred the field margin strip at the shaded side. The order of *Thysanoptera* showed preference to the field margin at the unshaded side but was indifferent at the shaded side.

Table 5.2. Distribution profile of trapped invertebrate families according to their preferential presence on either the unshaded or shaded side (indifferent families are not shown) (F= Family, SF= Superfamily, O= Order). Monitoring period from 7 August to 2 September 2002

Solely unshaded side	Unshaded>Shaded[1]	Shaded>Unshaded[1]	Solely shaded side
O. *Dermaptera*	F. *Cecidomyiidae* (D)	F. *Cantharidae* (C)	F. *Nymphalidae* (L)
F. *Acanthosomatidae* (He)	F. *Ectopsocidae* (P)	F. *Carabidae* (C)	F. *Pieridae* (L)
SF. *Sphecoidea* (Hy)		F. *Chrysomelidae* (C)	
SF. *Vespoidea* (Hy)		SF. *Dascilloidea* (C)	
O. *Strepsiptera*		F. *Haliplidae* (C)	
		F. *Staphylinidae* (C)	
		F. *Bibionidae* (D)	
		F. *Mycetophilidae* (D)	
		F. *Asilidae* (D)	
		F. *Calliphoridae* (D)	
		F. *Dolichopodidae* (D)	
		F. *Dryomyzidae* (D)	
		F. *Empididae* (D)	
		F. *Lauxaniidae* (D)	
		F. *Oestridae* (D)	
		F. *Otitidae* (D)	
		F. *Platystomidae* (D)	
		F. *Sciomyzidae* (D)	
		F. *Sepsidae* (D)	
		F. *Reduviidae* (He)	
		F. *Aleyrodidae* (He)	
		F. *Cicadellidae* (He)	
		F. *Psyllidae* (He)	
		SF. *Formicoidea* (Hy)	

[1] Families assigned to either shaded or unshaded side according to the independent t-test

[2] Order: He, *Hemiptera* ; C, *Coleoptera* ; D, *Diptera* ; L, *Lepidoptera* ; Hy, *Hymenoptera* ; P, *Psocoptera*

Table 5.3. Distribution profile of trapped insect families according to their preferential presence in the field margin strip or the adjacent field crop at both sides of a tree lane (F= Family; SF= Superfamily; O= Order). Monitoring period from 7 August to 2 September 2002

	Shaded side		Unshaded side	
Margin strip solely	F. *Chloropidae* (D)[3]	H[2]	F. *Aleyrodidae* (He)	H
	F. *Borboridae* (D)		F. *Lygaeidae* (He)	H
	F. *Nabidae* (He)	E	F. *Stenocephalidae* (He)	H
	F. *Nepidae* (He)	E	SF. *Sphecoidea* (Hy)	E
			SF. *Vespoidea* (Hy)	F
			O. *Strepsiptera*	E
Margin strip > Field crop[1]	F. *Phoridae* (D)		F. *Cantharidae* (C)	E, F
	O. *Mecoptera*		SF. *Dascilloidea* (C)	
			F. *Staphylinidae* (C)	E
			O. *Mecoptera*	
			F. *Ectopsocidae* (P)	
			F. *Caeciliidae* (P)	
			F. *Peripsocidae* (P)	
			O. *Thysanoptera*	H, F
Field crop > Margin strip[1]	F. *Chironomidae* (D)		F. *Chironomidae* (D)	
	F. *Mycetophilidae* (D)		F. *Ptychopteridae* (D)	
	F. *Empididae* (D)	E, F	F. *Empididae* (D)	E, F
	F. *Heleomyzidae* (D)		F. *Phoridae* (D)	
	F. *Lauxaniidae* (D)		F. *Cicadellidae* (He)	H
	F. *Lonchopteridae* (D)			
	F. *Aleyrodidae* (He)	H		
	F. *Cicadellidae* (He)	H		
	F. *Psyllidae* (He)	H		
	SF. *Chalcidoidea* (Hy)	E		
	SF. *Ichneumonoidea* (Hy)	E, F		
	SF. *Proctotrupoidea* (Hy)	E		
	F. *Hemerobiidae* (N)	E		
Field crop solely	F. *Anobiidae* (C)		F. *Curculionidae* (C)	H
	F. *Cerambycidae* (C)	H, F	F. *Scarabaeidae* (C)	H
	F. *Nymphalidae* (L)	H	F. *Conopidae* (D)	F
	F. *Pieridae* (L)	H	F. *Rhagionidae* (D)	E
			F. *Nabidae* (He)	E
			F. *Nepidae* (He)	E
			F. *Saldidae* (He	E

[1] Families assigned to either the field crop or the field margin strip according to the independent t-test at significance level of 5%

[2] Feeding habit: E, entomophagous (predator, parasitoid); H, herbivorous (plant damaging); F, flower visiting

[3] He, *Hemiptera* ; C, *Coleoptera* ; D, *Diptera* ; L, *Lepidoptera* ; Hy, *Hymenoptera* ; P, *Psocoptera* ; N, *Neuroptera*

Within the field margin strip at monitoring position –4 m, insect composition differed between sown and unsown communities at both unshaded and shaded side (Table 5.4). At both light regimes, CONTR showed higher insect number of *Bibionidae*, *Aphidoidea*, *Proctotrupoidea* (significant at both light regimes) and of *Dolichopodidae, Lauxaniidae*, *Mycetophilidae, Oestridae*, *Scatopsidae* and *Psyllidae* (significant at one side). At both light regimes, sown communities showed higher insect number of *Thysanoptera*, *Cicadellidae*, *Chalcidoidea*, (significant at both light regimes) and of *Ichneumonoidea*, *Caeciliidae*, *Aleyrodidae* and *Berytidae* (significant at one side).

Table 5.4. Insect numbers (averaged over replicates) of sown/unsown plant communities monitored in the margin strip (pos. –4 m). Monitoring period: 7 August to 2 September 2002

Taxa^2		**Shaded side**			**Unshaded side**		
		Unsown	**Sown**	**Sig.^{1}**	**Unsown**	**Sown**	**Sig.^{1}**
O. *Coleoptera*	F. *Anobiidae*				0.7	0.3	
	F. *Cantharidae*	1.3	0.8		0.3	1.1	
	F. *Carabidae*	1.3	1.1		0.7	0.2	
	F. *Chrysomelidae*	1.0					
	F. *Coccinellidae*	2.7	1.2		2.0	1.0	
	F. *Haliplidae*		0.9			0.3	
	F. *Scarabaeidae*		0.1				
	F. *Staphylinidae*	11.7	7.0		7.3	6.8	
	SF. *Dascilloidea*	8.7	9.6		4.3	5.7	
O. *Dermaptera*					0.3		
O. *Diptera*	F. *Anisopodidae*	4.7	1.4		3.3	0.6	
	F. *Asilidae*	1.7	0.4	*	0.3	0.4	
	F. *Bibionidae*	38.3	6.7	*	27.0	3.6	*
	F. *Borboridae*		0.1			0.1	
	F. *Calliphoridae*	2.0	0.6			0.2	
	F. *Cecidomyiidae*	287.3	119.8		292.7	214.2	
	F. *Chironomidae*	64.0	43.7		91.3	49.4	
	F. *Chloropidae*					0.1	
	F. *Dolichopodidae*	60.0	41.7	*	30.7	30.0	
	F. *Dryomyzidae*	2.7	1.6		3.0	0.2	
	F. *Empididae*	13.0	6.7		5.3	7.6	
	F. *Heleomyzidae*	1.7	1.7		2.3	2.3	
	F. *Lauxaniidae*	59.0	40.4	*	36.0	30.2	
	F. *Lonchopteridae*	3.7	4.2		7.3	5.0	
	F. *Micropezidae*	1.3	2.1		3.3	1.3	*
	F. *Mycetophilidae*	130.7	82.3	*	151.3	107.4	
	F. *Oestridae*	7.3	2.2	*	2.0	1.0	
	F. *Otitidae*	0.7	3.0		0.7	0.8	
	F. *Phoridae*	19.0	37.7		23.0	18.3	
	F. *Platystomidae*	0.3	0.3			0.1	
	F. *Psychodidae*	35.7	54.0		33.7	46.6	
	F. *Ptychopteridae*	0.7	1.0		0.3	0.4	
	F. *Rhagionidae*		0.1				
	F. *Scatopsidae*	92.0	6.1		10.3	3.8	*
	F. *Sciomyzidae*	0.3	2.7		0.3	0.3	
	F. *Sepsidae*	6.3	2.7		3.7	3.1	
	F. *Stratiomyidae*	0.3	0.6		0.7	0.2	
	F. *Syrphidae*	1.7	0.6		2.7	0.9	
	F. *Tabanidae*	0.7	0.4		0.3	0.2	
	F. *Tipulidae*	0.7	0.7		5.3	0.7	
O. *Hemiptera*	F. *Acanthosomatidae*					0.1	
	F. *Aleyrodidae*		0.4	*		0.1	
	F. *Berytidae*		0.4			0.4	*
	F. *Cercopidae*	0.3	0.7				
	F. *Cicadellidae*	6.7	14.3	*	5.7	10.6	*

Table 5.4. Insect numbers (averaged over replicates) of sown and unsown plant communities monitored in the margin strip (position -4 m). Monitoring period from 7 August to 2 September 2002 (continued)

Taxa[2]		**Shaded side**			**Unshaded side**		
		Unsown	**Sown**	**Sig.**[1]	**Unsown**	**Sown**	**Sig.**[1]
O. *Hemiptera*	F. *Delphacidae*	0.3	0.2		0.3	0.1	
(continued)	F. *Lygaeidae*					0.1	
	F. *Miridae*	0.7	0.8		0.3	0.4	
	F. *Nabidae*	0.3					
	F. *Nepidae*		0.1				
	F. *Piesmatidae*	0.3	1.0		0.7	0.2	
	F. *Psyllidae*	3.3	1.0	*	0.7	0.6	
	F. *Reduviidae*	2.0	2.0		1.0	0.1	*
	F. *Rhopalidae*		0.3			0.2	
	F. *Saldidae*		0.2				
	F. *Stenocephalidae*		0.1				
	SF. *Aphidoidea*	46.3	26.6	*	59.3	29.4	*
O. *Hymenoptera*	F. *Tenthredinidae*	7.7	2.9		4.3	2.7	
	SF. *Chalcidoidea*	90.0	128.8	*	122.7	154.2	*
	SF. *Formicoidea*	2.0	0.8		1.7	0.8	
	SF. *Ichneumonoidea*	59.0	77.4		63.7	94.7	*
	SF. *Proctotrupoidea*	52.0	22.9	*	70.0	14.8	*
O. *Lepidoptera*	F. *Micropterigidae*	1.0	0.4		0.7	1.0	
	F. *Notodontidae*					0.2	
O. *Mecoptera*			1.0		0.7	1.0	
O. *Neuroptera*	F. *Chrysopidae*	0.7			0.3		
	F. *Hemerobiidae*		0.3		1.3	0.4	
O. *Psocoptera*	F. *Caeciliidae*	4.0	4.4		2.0	8.7	*
	F. *Ectopsocidae*	40.0	36.6		99.3	73.6	
	F. *Peripsocidae*	1.7	1.6		2.7	2.3	
	F. *Stenopsocidae*	0.3	0.1			0.2	
O. *Strepsiptera*						0.1	
O. *Trichoptera*		2.0	2.1		1.0	1.4	
O. *Thysanoptera*		137.7	351.6	*	212.0	371.9	*

[1] *= invertebrate number of sown and unsown community is significant different (independent t-test, 5% level of significance)

[2] F., Family; SF., Superfamily; O., Order

Family richness and insect number:

Family richness (Figure 5.3) was significantly determined by light regime (p=0.007) and not by plant community or monitoring position. At the shaded side a significantly higher number of insect families occurred (shaded, 43.5 families versus unshaded, 37.9 families; LSD=1.9 families). At position –4 m within the field margin strip, CONTR showed the highest family richness compared to sown communities irrespective of light regime.

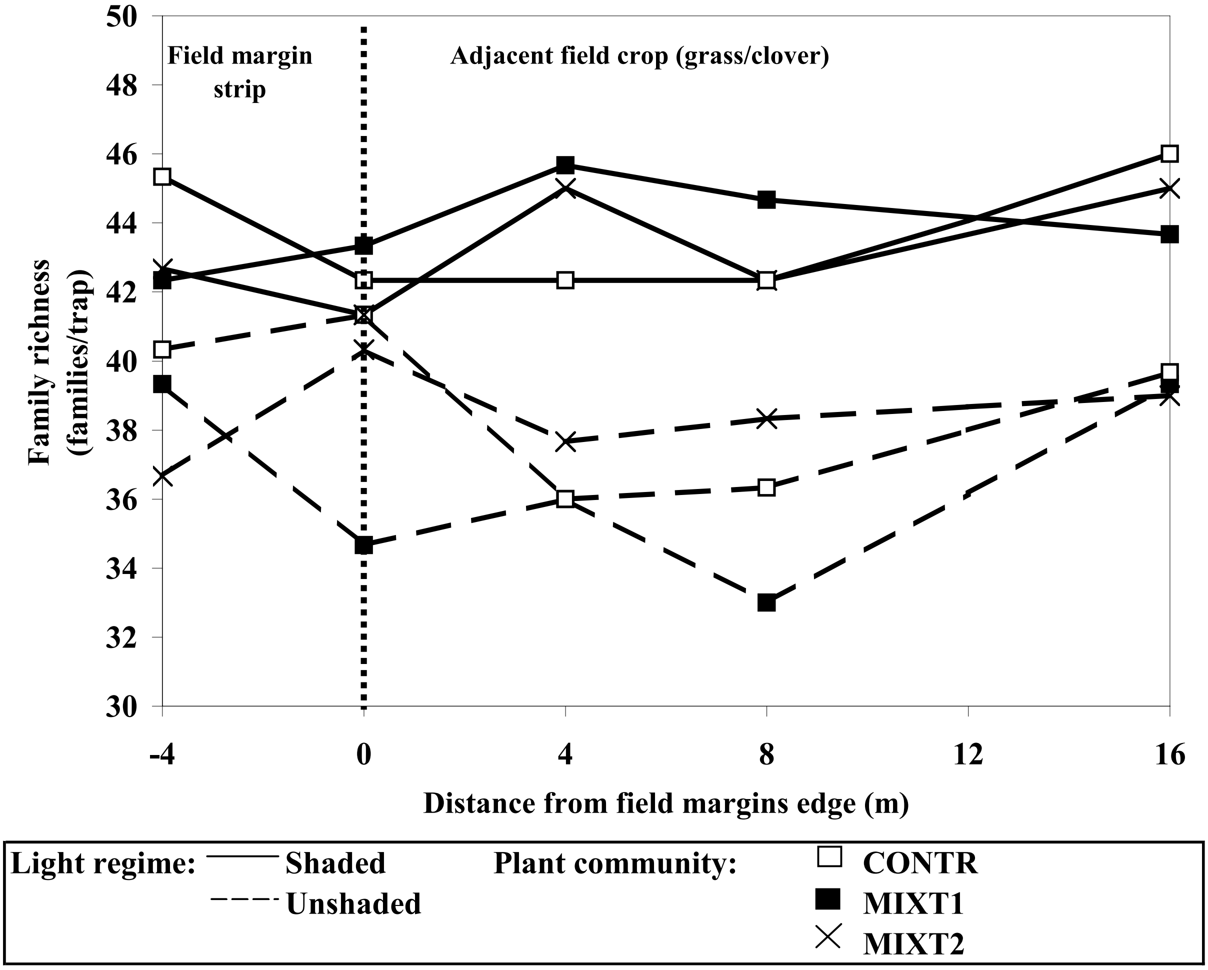

Figure 5.3. Spatial distribution of family richness (families per trap) for sown/unsown communities at the shaded and the unshaded side of a tree lane. Monitoring period from 7 August to 3 September 2002. Abbreviations cf. Section 2.1

The insect number (Figure 5.4) showed a significant interaction between light regime and position (p<0.001), between light regime and plant community (p=0.049) and between plant community and monitoring position (p=0.047). At the unshaded side, significantly higher

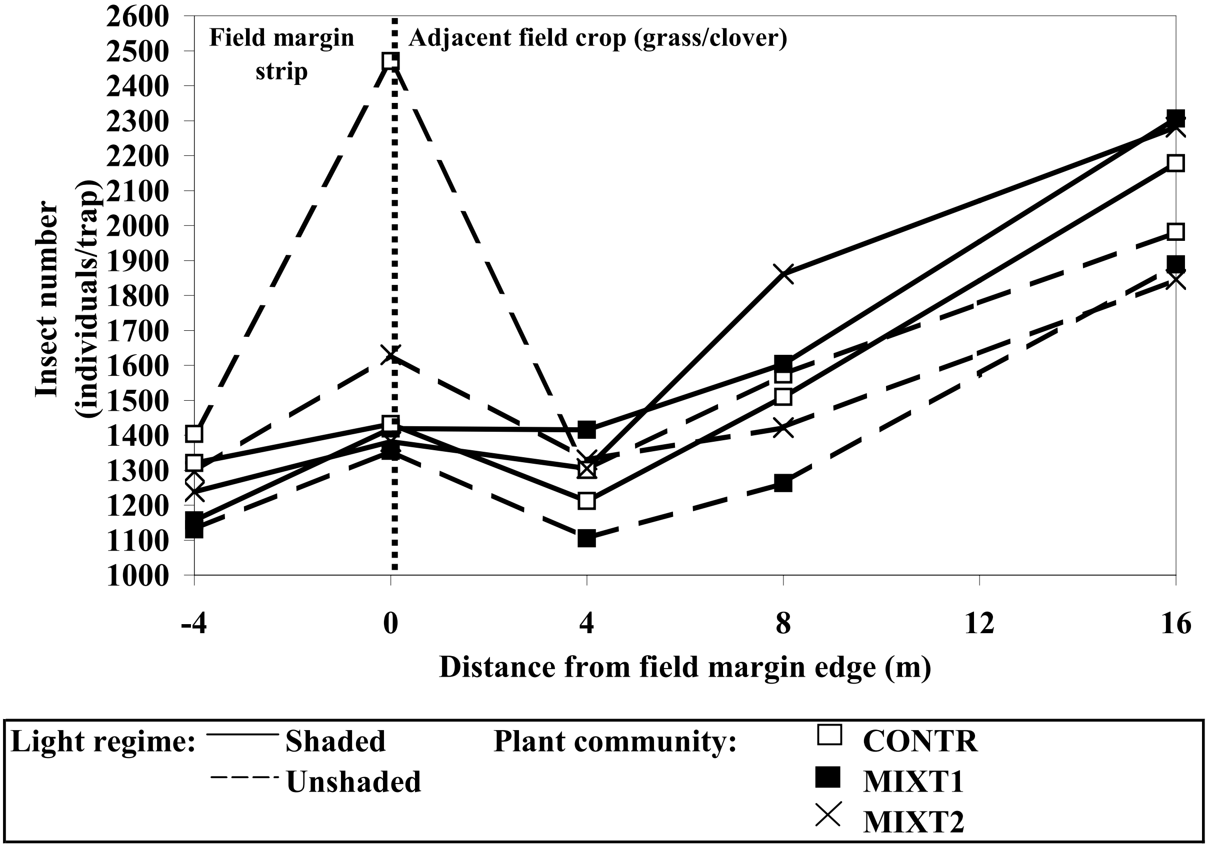

Figure 5.4. Spatial distribution of insect number (insects per trap) for sown/unsown communities at the shaded and the unshaded side of a tree lane. Monitoring period from 7 August to 3 September 2002. Abbreviations cf. Section 2.1

numbers of insects occurred nearby CONTR than nearby sown communities (CONTR, 1746 insects per trap versus MIXT1, 1349 and MIXT2, 1505; LSD=239). At the shaded side, the numbers nearby sown/unsown communities were comparable (CONTR 1531 insects per trap; MIXT1, 1580; MIXT2, 1614; LSD=239). Furthermore within plant community, the insect number was not significantly altered by light regime, although nearby CONTR a higher number was found at the unshaded side (unshaded side, 1746 insects per trap versus 1531 insects at the unshaded side; LSD=327).

The insect number on both sides of the tree lane was significantly determined by monitoring position. Similar distribution patterns over monitoring positions were found at both shaded and unshaded side. In the field margin strip, insect numbers were highest at position 0 m. Within the crop, the numbers increased up to position 16 m. At the shaded side, the significantly highest insect number occured at position 16 m (2255 insects per trap versus 1658 at 8 m, 1311 at 4 m, 1411 at 0 m and 1239 at –4 m; LSD=215). At the unshaded side the insect number at position 16 m and 0 m were significantly higher than the numbers captured at the other positions (1906 insects per trap at 16 m, 1819 at 0 m, 1420 at 8 m, 1245 at 4 m, 1277 at –4 m; LSD=215). Within monitoring positions, insect numbers were not significantly altered by the light regime except at position 0 m (unshaded, 1819 insects per trap versus shaded, 1411; LSD=351).

Compared to sown communities, CONTR revealed higher insect number both at position –4 m (CONTR, 1362 insects per trap versus MIXT1, 1143, MIXT2, 1267) as well as at position 0 m (CONTR, 1952 insects per trap versus MIXT1, 1387, MIXT2, 1506; LSD=295). So, in the field margin strip, CONTR showed both the highest diversity and the highest numbers of insects.

Diversity indices:

The Shannon diversity index was significantly determined by plant community (p=0.02) and revealed a significant interaction between light regime and monitoring position. (p=0.03). The Shannon index nearby CONTR (2.57) was significantly higher than nearby sown communities (2.49 for both MIXT1 and MIXT2) (LSD=0.06). At the shaded side, Shannon indices of all monitoring positions were not significantly different (2.59, 2.59, 2.66, 2.61, 2.70 for position –4, 0, 4, 8, 16 m respectively; LSD within light regime =0.12); At the unshaded side Shannon index of position 0 m was significantly lower than all other positions (2.46, 2.21, 2.48, 2.46, 2.45 for position –4, 0, 4, 8, 16 respectively; LSD within light regime =0.12). Within each monitoring position, Shannon index was significantly higher at the shaded side than at the unshaded side (data above; LSD otherwise=0.13).

The Berger-Parker index revealed a significant interaction between plant community and monitoring position (p=0.02). The Berger-Parker index at position -4 m (CONTR, 5.26; MIXT1, 3.51; MIXT2, 3.36) and at position 0 m (CONTR, 4.42; MIXT1, 3.13; MIXT2, 3.08) was significantly higher for CONTR than for sown communities (LSD within position=1.18). At position 4, 8 and 16 m no significant differences between plant communities were found. Berger-Parker indices at field crop positions 4, 8 and 16 m were significantly higher than at positions –4 and 0 m nearby MIXT1 (3.51, 3.13, 5.25, 5.90, 4.62 for positions –4, 0, 4, 8, 16 m respectively) as well as nearby MIXT2 (3.36, 3.08, 4.84, 4.95, 5.41 for positions –4, 0, 4, 8, 16 m respectively) (LSD within plant community=1.20). Nearby CONTR, no significant differences were found between monitoring positions.

Insect groups:

The number of flower visiting insects showed a significant interaction between light regime and monitoring position ($p<0.001$). Flower visiting insects were caught in larger numbers at positions in the margin strip than at positions in the crop, except for position 16 m. Within the field margin strip insect numbers were highest at position 0 m. Within the crop insect numbers increased up to position 16 m at both sides. Over the monitoring transects the highest insect number was found at position 16 m at the shaded side (position 16 m, 628 insects per trap versus 361, 327, 458, 412 for position 8, 4, 0, -4 m respectively; LSD=115) and at position 0 m at the unshaded side (position 0 m, 806 insects per trap versus 470, 384, 321, 401 for position 16, 8, 4, -4 m respectively; LSD=115).

The number of herbivorous insects showed significant interactions between light regime and plant community ($p=0.02$) and between light regime and monitoring position ($p<0.003$). At the unshaded side the number was higher nearby CONTR than nearby sown communities (CONTR, 767 insects per trap versus MIXT1, 597 and MIXT2, 685; LSD=102). At the shaded side no significant differences between plant communities were found. Nearby CONTR, herbivorous insects were significantly more trapped at the unshaded side (unshaded, 767 insects per trap versus shaded, 546; LSD=106). Sown communities showed no differences between light regimes.

At both light regimes number of herbivorous insects significantly depended on monitoring position. The distribution over monitoring positions was similar at both shaded and unshaded side (Table 5.5). In the field margin strip, numbers were highest at position 0 m. In the crop, numbers increased up to position 16 m. Along the monitoring transects the highest insect number was found at 16 m at the shaded side (position 16 m, 763 insects per trap versus 548, 484, 576, 534 for positions 8, 4, 0, -4 m respectively; LSD=153) and at 0 m at the unshaded side (position 0 m, 970 insects per trap versus 774, 559, 531, 582 for positions 16, 8, 4, -4 m respectively; LSD=153).

Similar to numbers of herbivorous insects, the number of entomophagous insects (Table 5.5) showed a significant interaction between light regime and position ($p<0.001$). At both light regimes the number of entomophagous insects significantly depended on monitoring position. Similar patterns of insect distribution over monitoring positions are found on both sides. Within the field margin strip insect numbers were highest at position 0 m. Within the crop insect numbers increased up to position 16 m at both sides. Over the monitoring transects the highest insect number was found at 16 m from the field margin strip both at the shaded side (position 16 m, 631 insects per trap versus 391, 310, 349, 298 for position 8, 4, 0, -4 m respectively; LSD=61) and at the unshaded side (position 16 m, 415 insects per trap versus 365, 325, 396, 301 for position 8, 4, 0, -4 m respectively; LSD=61).

The similarity in the distribution pattern of numbers of herbivorous insects and entomophagous insects (Table 5.5) clearly indicates that a higher number of herbivorous insects corresponds with a higher number of entomophagous insects resulting in significant positive correlation coefficients irrespective of light regime (unshaded side, 0.60; shaded side, 0.63; p<0.01).

Table 5.5 also shows the family richness of the groups of studied insects. The family richness of flower visiting insects was significantly determined by light regime (p=0.03) and plant community (p=0.03). Family richness was significantly higher at the shaded side (shaded, 7.7 families per trap versus unshaded, 6.5; LSD=1.0). CONTR revealed a significantly higher family richness than sown communities (CONTR, 7.6 families per trap versus MIXT1, 7.0 and MIXT2, 6.7; LSD=0.6).

Family richness of herbivorous insects was significantly higher at the shaded side (shaded, 8.8 families per trap versus unshaded, 7.0; LSD=1.3) and showed a significant interaction between plant community and monitoring position (p=0.007). Within the field margin strip at position 0 m family richness was higher in CONTR than in the sown plant communities (CONTR, 9.0 families per trap versus MIXT1, 7.0 and MIXT2, 8.0; LSD=1.8). At position -4 m, no significant differences between plant communities were found. Within the crop no significant differences were found between plant communities except for position 4 m (CONTR, 7.2 families per trap; MIXT1, 8.2 and MIXT2, 9.3; LSD=1.8).

Similarly, family richness of entomophagous insects was significantly determined by light regime (p=0.01) and plant community (p=0.05). Family richness was significantly higher at the shaded side (shaded, 11.4 families per trap versus unshaded, 10.0; LSD=0.8). Family richnesss was higher nearby CONTR than nearby sown communities (CONTR, 11.1 families per trap versus MIXT1, 10.3 and MIXT2, 10.8; LSD=0.6).

Table 5.5. Invertebrate number and diversity of herbivorous, entomophagous and flower visiting insects at all monitored field positions at both unshaded and shaded side of a tree lane. Monitoring period from 7 August to 2 September 2002

Plant community	**Monitoring position**	**Invertebrate number**						**Invertebrate families**					
		Herbivorous insects		**Entomophagous insects**		**Flower visiting insects**		**Herbivorous insects**		**Entomophagous insects**		**Flower visiting insects**	
		S[1]	**U**[1]	**S**	**U**	**S**	**U**	**S**	**U**	**S**	**U**	**S**	**U**
MIXT1	**-4**	508.0	563.3	292.7	276.7	444.3	423.0	9.7	7.7	10.0	10.7	6.3	8.3
	0	628.0	745.7	371.3	326.0	510.7	621.3	8.0	6.0	12.0	10.0	8.3	6.3
	4	514.3	491.7	342.7	274.7	341.0	315.7	9.7	6.7	10.0	8.7	7.3	6.3
	8	520.0	455.3	418.7	354.7	360.7	337.7	8.7	6.0	12.0	8.3	7.7	5.3
	16	851.0	729.0	593.7	444.0	738.3	466.3	8.7	6.3	11.3	10.3	8.0	6.0
MIXT2	**-4**	602.7	606.7	303.3	316.3	533.3	465.7	7.7	6.0	11.7	8.7	6.3	6.3
	0	627.0	863.7	338.7	400.3	542.0	736.0	8.3	7.7	10.0	10.7	7.0	7.7
	4	491.7	605.0	314.7	352.3	328.3	343.7	10.7	8.0	12.7	9.3	7.3	5.3
	8	536.0	613.3	414.7	369.0	335.0	408.0	8.3	7.0	10.7	11.3	7.7	6.0
	16	707.3	737.3	696.3	390.7	594.3	473.7	8.7	7.0	12.0	10.7	7.7	6.0
CONTR	**-4**	491.7	576.0	298.0	308.7	257.3	315.0	8.3	6.7	13.0	9.7	9.7	6.7
	0	472.3	1300.7	336.7	461.7	320.7	1061.7	8.7	9.3	10.7	11.0	7.7	8.0
	4	445.7	497.7	273.7	347.0	313.0	302.7	8.0	6.3	11.0	9.7	8.0	6.0
	8	587.3	607.0	338.3	371.3	387.3	407.3	9.0	6.0	12.3	10.3	8.3	6.3
	16	731.0	854.3	604.0	410.7	550.3	469.7	9.3	7.7	12.3	10.7	8.7	6.7

[1] Light regime; S, shaded side; U, unshaded side

5.4 Discussion and conclusion

During the monitoring period from 7 August to 2 September 2002, 78 insect families were trapped at the shady and sunny side of a tree lane. Half the number of trapped insects belong to the order of *Diptera*. The order of *Diptera* was also the most important order in grassy field margin strips according to findings of Canters & Tamis (1999). This huge diversity might be partly attributed to the structural diversity of the woody landscape at Beernem (see also Chapter 2, Section 2.1). Bommarco (1999) accentuated the beneficial effects of structural diverse surroundings on family richness. However spatial presence and distribution of insect families was significantly affected by light regime. Besides 44 indifferent families, 25 insect families showed preference to the shaded side whilst only 2 families preferred the unshaded side. Families associated with moist conditions or decaying material were caught in larger numbers on the shaded side since soil moisture content was significantly higher at the shaded side of the tree lane. The presence and distribution of insect families over monitoring positions was influenced by light regime. Some insect families preferred the field margin strip whilst others preferred the adjacent crop.

The composition of the caught insects was significantly determined by the field margin type (sown/unsown) irrespective of light regime. Some insect families were more abundant in the unsown margin strip whilst others preferred the sown margin strips. This different distribution pattern between margin types might be explained by the difference in structural diversity and composition of the vegetation. It is suggested that families preferring the unsown community, were probably more attracted by the low growing open vegetation instead of the dense and tall vegetation in the sown communities hampering flying, feeding and hunting. Also the higher soil moisture content in the unsown communities might have attracted some specific families.

Besides the composition, Shannon diversity index, family richness as well as insect number were also greatly affected by light regime. The shaded side was significantly more diverse than the unshaded side as reflected by the significantly higher Shannon diversity indices irrespective of monitoring position. Similarly significantly more insect families were found at the shaded side. Apparently the moist conditions at the shaded side were more attractive to a lot of insect families either directly or indirectly by the impact of shading on the botanical composition of the margin strip. According to Speight et al. (1999) the presence of an insect family could be determined by nearby landscape elements (ditches, animals, hedges, woodlots,...), structure and composition of the vegetation and the microclimate in the vegetation.

At the shaded side of the tree lane, the insect number was lowest at the most shaded positions: at positions –4 m, 0 m and 4 m. Insects are cold-blooded and adopt the prevailing temperature of their environment. All processes such as growth, development and activities of insects are dependent on their surrounding temperature (Speight et al., 1999). Insects attain their optimal body temperature faster under sunny conditions and are thus faster activated (Bernays & Chapman, 1994). The higher the temperature, the higher the activity of insects and thus the higher the chance of being trapped on the sticky traps. Temperature fluctuations are smaller and slower at the shaded side owing to the high fraction of diffuse light: as a result insect activity fluctuates less under shaded conditions.

The diversity and abundance of insects was also clearly affected by the plant community type of the field margin strip. Insect diversity was significantly greater within and in the vicinity of the unsown plant community, as reflected by the significantly higher Shannon diversity index. The unsown margin strip revealed the lowest degree of dominance in insect families (which means the highest evenness of insect families) as reflected in the significant highest Berger-Parker index. The impact of plant community on the numbers of insects was mediated by light regime. Compared to sown communities, the unsown community showed a significantly higher insect number at the unshaded side but not at the shaded side. Probably both insect number and diversity were affected by the botanical diversity of the plant community since highest family richness and number was found in the species richest community (i.e. the unsown community). The lowest diversity and lowest numbers of insects were found in the species poorest community (community sown to native plants). Also Thomas & Marshall (1999) and Lagerlöf & Wallin (1993) found a positive correlation between botanical diversity and invertebrate diversity. In addition to the botanical diversity, insects might show a preference to the open vegetation structure (important share of uncovered soil) of the unsown community characterized by a low L.A.I., an abundance of low growing plant species and a higher P.A.R. transmittance in the canopy offering better opportunities to warm up, fly, feed and hunt. Kirby (1992) highlighted the importance of bare ground for insects for hunting, basking, burrowing or nesting.

A similar insect diversity and family richness was found both within the field margin strip and in the adjacent crop. Insect number on both sides of the tree lane was significantly determined by monitoring position. Similar patterns of insect distribution over monitoring positions were found on both sides. Within the field margin strip, insect numbers were highest closest to the crop edge (position 0 m). Within the crop, insect numbers increased upto position 16 m. Over the monitoring transects the highest insect number was found at 16 m from the field margin strip. The evenness in insect families was significantly higher in the crop than in the sown margin strips. Probably insects preferred the more open vegetation structure of the grass clover crop than the huge sown margin vegetations.

Numbers of caught nectar or pollen feeding insects (for example the superfamily of *Vespoidea)* were small. This experiment is not conclusive whether this is because of low numbers actually present or because of the trapping facilities.

Questions might arise concerning the representativeness of the trapping method. Indeed the yellow sticky traps have been shown to be a representative trapping method for an expanding number of families of insects (Samways, 1986; Muirhead-Thomson, 1991; Heinz et al., 1992; Hoffmann et al., 1997; Kuhar & Youngman, 1998; Badowska-Czubik et., 1999), but we might have caught for example more pollinators by using sticky traps with an aromatic component included. Furthermore, insects (in particular insects which are not attracted by the yellow color) might have flown onto the sticky traps by accident or forced by the wind. Since the sticky surfaces of the traps at the unshaded and shaded side were oriented in opposite directions, we might have caught more insects on traps with their sticky surface oriented opposite to the prevailing wind direction (i.e. north-northeast during the monitoring period). For insects attracted by the yellow color, unshaded traps might have been more attractive than shaded traps.

In general, family richness of flower visiting insects, herbivorous insects and entomophagous insects was highest nearby the unsown community irrespective of light regime. Again this might be explained by the higher floristic diversity in the unsown community or the open vegetation structure. Several authors (Letourneau, 1990; Marino & Landis, 1996; Samu, 2003) reported beneficial effects of structural and floristic diverse plant communities on diversity and presence of predator insects directly by the availability of niches, nectar and pollen and indirectly by the higher availability of prey insects. Distribution patterns of herbivorous insects ran parallel to distribution patterns of entomophagous insects indicating a status of biological equilibrium along field margin strips. Probably the higher availability of prey insects contributed to a higher family richness of their antagonists as also reported by Letourneau (1993), Marino & Landis (1996) and Samu (2003).

Field margin strips installed to enhance floristic diversity might thus be beneficial to overall insect diversity and insect densities. In common agricultural practice many field margin strips are preferentially installed along the shady sides of tree rows and hedges because the area closest to tree rows is less productive. From the viewpoint of nature conservation this practise is no obstacle since faunistic diversity might be benified. For the same reason, unsown margin strips might be preferred to sown communities particularly at the unshaded side because of their open vegetation structure and/or higher botanical diversity. However this might conflict with the agricultural viewpoint that unsown field margin strips might increase the potential risk of weed infestations in both the field margin and adjacent crops (Smith et al., 1999; West et al. ,1997). An argument in favour of the unsown strips is the conclusion that a higher family richness entrains a higher number of entomophagous families which may be useful in biological control of emerging pests in adjacent crops. We have demonstrated (Chapter 6) that the potential risk of weed infestation is low in case of a depauperated seedbank and in case of the absence of aggressive weeds in the vicinity of field margins. Under these circumstances it is highly recommendable to install spontaneously developing field margin strips. Further research is necessary to find out if we are able to design field margins that deliver enough antagonists introgressing far enough in the crop to lean upon them as instruments to manage pests in crops.

In conlusion, our results revealed the positive effect of botanical diversity on insect number and diversity. The effects of botanical diversity on insect number were mediated by light regime. The abundance of some insect families was dependent on the composition of the vegetation. The effects of plant communities were more pronounced at high light availability. Light availability significantly influenced insect diversity as well as the spatial distribution of families. A strong relation was found between the distribution of herbivorous insects and entomophagous families along field margin strips.

Appendix 5.1. Abundance of plant species in sown/unsown plant communities at both the unshaded and shaded side of a tree lane (August 2002). Abbreviations cf. Section 2.1

Plant species	**Unshaded**			**Shaded**		
	CONTR	**MIXT1**	**MIXT2**	**CONTR**	**MIXT1**	**MIXT2**
Non nitrogen-fixing dicots:						
Achillea millefolium	s[1]	o	r			r
Anthriscus sylvestris		s				
Barbarea vulgaris			s			
Borago officinalis			s			
Centaurea cyanus			s			
Chenopodium alba	s					
Cirsium arvense		rl		sl	sl	sl
Cirsium palustre	s					
Coronopus didymus				o		
Epilobium hirsutum	s			o		
Epilobium montanum	s			o		
Erigeron canadensis	s			r		
Galium mollugo				o	s	
Geranium pratense					s	
Gnaphalium uliginosum	o	o		o		
Lamium purpureum	r					
Lathyrus pratensis					s	
Malva sylvestris			s			
Matricaria recutita	s			r		
Myosotis palustris				s		
Pastinaca sativa			s			
Plantago lanceolata		o			o	
Plantago major	r			f		
Polygonum amphibium	r			r		
Polygonum aviculare	o			o		
Polygonum lapathifolium	s	s	s	s		
Polygonum persicaria	o	r		o		s
Prunella vulgaris					s	
Ranunculus lingua	s			o	o	s
Ranunculus repens	o	rl	o	f	o	o
Rorripa sylvestris	o			o		
Rumex acetosa		o	o	r	o	o
Rumex crispus				o	r	
Rumex obtusifolius	o		o	o	r	
Senecio vulgaris	r			o		
Solanum nigra	r		s			
Sonchus arvensis	r			r		
Sonchus oleraceus	s					
Stellaria media	o		o	o		
Tanacetum vulgare	s					
Taraxacum officinale	r	r	r	o		
Urtica dioica	s	rl	rl	rl		rl

Appendix 5.1. Abundance of plant species in sown/unsown plant communities at both the unshaded and shaded side of a tree lane (August 2002). Abbreviations cf. Section 2.1 (Continued)

Plant species	**Unshaded**			**Shaded**		
	CONTR[1]	**MIXT1**	**MIXT2**	**CONTR**	**MIXT1**	**MIXT2**
Legumes:						
Trifolium pratense		c	c		c	c
Trifolium repens	o	c	c	o	c	c
Trifolium resupinatum			s			o
Vicia cracca	s					
Grasses:						
Agrostis stolonifera	a			o		
Agrostis tenuis			o			o
Alopecurus geniculatus	d		o	f	o	
Arrhenatherum elatius		o	a		o	o
Cynosurus cristatus		r	r		r	r
Dactylis glomerata		o	o		o	o
Echinochloa crus-galli	o		r	o		
Elymus repens	o					
Festuca arundinacea						r
Festuca pratensis		r	r		r	
Glyceria fluitans	s			c	o	o
Holcus lanatus	o	o	o	o	o	o
Lolium perenne		f	f		f	f
Phleum pratense		f	o		f	o
Poa annua	o	o		o	o	o
Poa trivialis	f	f	o	c	f	o
Rushes						
Juncus bufonius				o		
Juncus effusus	s			r		

[1] Abundance according to Tansley scale: d(ominant), c(o-dominant), a(bundant), f(requent), o(ccasional), r(are), s(poradic), l(ocal)

Chapter 6

Impact of field margin strip management on ingrowing and anemochorous weeds

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Chapter 6

Impact of field margin strip management on ingrowing and anemochorous weeds

6.1 Introduction

Besides the potential risk of ingrowth of perennials with vigorous underground creeping root or rhizome systems, such as *Cirsium arvense* (L.) Scop*.*, *Elymus repens* (L.) Gould and *Convolvulus arvensis* L. (Boatman & Wilson, 1988; Marshall, 1989; Kleijn,1997; Jacot & Eggenschwiler, 2005), weed problems might be increased by seedrain from field margin species into the adjacent crop since Marshall (1989) reported that the distribution of seed in the seedbank at different distances from the field boundary followed the distribution of the above ground vegetation. Seeds of anemochorous species (wind dispersed) are able to disperse over long distances but the majority of seeds disperse over shorter distances than is often supposed (Feldman & Lewis, 1990). The majority of species with no specialized dispersal structures (barachorous) are dispersed close to the parent plant (Howard et al, 1991). Three studies of seed movement reported only small numbers of seeds moving more than 3 m (Rew et al., 1996), 7 m (Hume & Archibold, 1986) or 12.5 m (Jones & Naylor, 1992) into the field. The majority of seeds of *Bromus sterilis* L. (99%) and of *Anthriscus sylvestris* (L.) Hoffm. (87%) were disseminated within 1 m of the source in the field margin (Rew et al., 1996). Patterns of weed abundance also suggest limited movement of field margin weeds. According to Marshall (1989), field margin weeds have been found to have elevated abundance only within the first 2 to 4 m of the field, and few of these apparent invaders are also important weeds.

In the present study the prevention of occurrence of pernicious problem weeds in field margin strips was considered the best way to reduce risks of weed invasion or infestations in adjacent crops due to ingrowth or seedrain into the adjacent crops, irrespective of the question whether there is a relation between the abundance of weed species in the field margin and in the adjacent crop. If unwanted weed species could be excluded by an appropriate sowing and mowing management, farmers' hesitations concerning the installation of field margin strips might be eliminated. Furthermore the biological diversity of field margin strips and agricultural landscape might be increased when weed problems in field margin could be managed without chemical control. Therefore more research is required concerning weed preventing strategies.

This study quantified and examined the effects of newly created sown and unsown field margin strips on ex-arable land, on potential weed problems in the margin strip and the adjacent crop. The following questions were adressed: (1) What is the best field margin strip management (field margin type and mowing regime) to reduce the abundance of ingrowing and/or specialized anemochorous weeds? (2) Can soil seedbank analysis predict the risk of having problem weeds in the margin strip and in the adjacent crop? (3) And finally, how far in the adjacent crops, seeds of anemochorous field margin species are dispersed?

6.2 Specific materials and methods

This research was based on trial 1 explained in Chapter 2, Section 2.1.

The persistent seedbank was analysed to assess risk of having problem weeds within the adjacent crops and/or the margin strip itself. Particularly specialized anemochorous species (SPAN) with special adaptations to wind dispersal such as wings, parachutes and tufts of hair, and ingrowing species (ING) with rhizomes and creeping roots were considered major risk weeds irrespective of cropping system. The persistent seedbank was sampled after ploughing (end of May 2001) and prior to installation (June 2001) of the trial. Samples were analysed with the seedling emergence method according to the recommendations of Thompson et al. (1997). The method consisted of taking twenty soil cores (end of May) of 7 cm diameter to a depth of 8 cm within the central 4 m x 4 m area of each subplot. To estimate seedbank density of species accurately, this large number of cores was required since there was no knowledge of the spatial distribution of seeds before sampling. The twenty core segments were pooled to give one sample. Each bulked sample was divided in three subsamples which were spread out evenly in a thin layer of 10 mm on sterilized potting soil in seed trays. The trays were than placed in a cage covered with pollen proof tissue (avoiding contamination by wind-born seeds) to allow germination. During a five months period, seedlings were identified (according to Hanf, 1982), counted and removed as soon as possible. The seed density of each species in soil seedbanks was expressed as the number of seedlings in an area of 1 m^2 to a depth of 8 cm and calculated as the number of seedlings in the sample soil volume divided by $20*0.035^2*\pi$. Colonisation type of seedbank species followed Bouman et al. (2000) for generative dispersal and Montegut (1983) for vegetative dispersal (Appendix 6.1).

Specialized anemochorous species within sowing mixtures were *Leontodon autumnalis* L., *Leucanthemum vulgare* Lamk., *Pastinaca sativa* L., *Rumex acetosa* L., and *Tragopogon pratensis* L.. Ingrowing sown species were *Achillea millefolium* L. and *Tanacetum vulgare* L. However these sown species, mainly typical grassland species, were not further examined since they were not considered as pernicious arable weeds for adjacent crops (Montegut,1983).

A botanical analysis of margin strips was performed during succession (2001-2004) to determine species presence particularly of anemochorous and ingrowing species. The botanical analysis followed the methodology described in Chapter 2, Section 2.2. All occurring unsown specialized anemochorous species and ingrowing species in the subplots were classified into the following functional groups: annual unsown anemochorous species (AUSPAN), perennial unsown anemochorous species (PUSPAN) and perennial unsown rhizomatous species (PUING). The I% of these functional groups were calculated by adding the I% of each contributing species of the particular functional group.

The percentage uncovered area (see Chapter 2, Section 2.2.) was estimated to see if the presence of anemochorous and ingrowing weeds was correlated to the percentage uncovered area of the subplots since arable weeds might be favoured in plots with a lower vegetation cover as is the case in arable field conditions.

To determine maximum contamination level by anemochorous species, seed dispersal into adjacent crop was monitored periodically around critical seed dispersal periods between 10 May and 10 June (hereafter May-June) and between 14 August and 9 September (hereafter August-September). Monitoring occurred only when specialized anemochorous species in the margin strip were bearing maturing seeds. As a consequence, the monitoring during August-September was conducted in 2003 and 2004 at SITE1 and in 2002, 2003 and 2004 at SITE2. May-June monitoring was conducted at both locations in 2004 only. At both locations seedrain was sampled on the southern side of the east-west oriented margin strips. Prevailing wind direction during all monitoring periods was north-northeast. So, wind-born seeds were transported into the adjacent crop area. All captured wind-born seeds in the adjacent crop were attributed to the field margins since there was no contamination originating in the surrounding perennial grassy verges or fields (SITE2: grazed grasslands revealing no anemochorous species; SITE1: silage maize, during all monitoring years) or the monitoring area because the arable crops within this area were kept free of weeds by mechanical weeding (SITE2) or by herbicides (SITE1). In 2002, seedrain nearby each main plot was monitored along 12 sampling axes (tree blocks x four main plots) perpendicular centered to the east-west oriented main plots using blue biosignal traps (BUGSCAN-BIOBEST) sized 20 cm x 40 cm with a sticky surface of 0.08 m² faced northward. Sticky seed traps were placed verticularly 30 cm above the leek canopy (50 cm above ground level) at six positions (0, 2, 4, 8, 16 and 32 m from the field margin strip) in the adjacent crop. Sticky seed traps were weekly replaced and captured wind-born seeds were determined and counted. Only filled seeds were counted. In 2003 and 2004 seedrain was monitored nearby each subplot at position 0 m from the field margin strip, using three northward faced sticky traps (sized 20 cm x 40 cm) per east-west oriented subplot. Sticky seed traps were placed verticularly 50 cm above ground level. Positions at higher distance from the field margin were not monitored since overall seed dispersal was very low in both locations. The number of captured seeds per species was expressed as seeds per m² sticky surface.

Regression analysis was used (statistical package SPSS10.0 for Windows) to determine the evolution of I% of species or functional groups over time (time was expressed as days after 15 October 2001). S-plus 2000 for Windows was used to carry out the statistical computations for analysis of variance of a strip split plot design (vertical factor: location; horizontal factor or main plot factor: plant community; subplot factor, mowing regime). SPSS10.0 program for Windows was used to compare differences in seedbank composition of both sites with the independent t-tests (p=0.05) and to correlate parameters.

6.3 Results

6.3.1 Seedbank analysis

The average seed density, colonisation type and seed dispersal period of the soil seedbank species is given in Appendix 6.1. The soil seedbank at SITE2 showed a significant threefold higher total seed density than at SITE1. Both seedbanks contained 59 species and involved indicator species of moist land like *Juncus effusus* L., *Juncus bufonius* L.*, Sagina procumbens* L. and of nutrient rich soil like *Poa annua* L., *Solanum nigrum* L., *Stellaria media* L., *Urtica urens* L.. All seedbank species except *Tanacetum vulgare* L. and *Rumex acetosa* L. were not present in the mixtures, used to install the sown plant communities.

The seedbank analysis indicated the presence of specialized anemochorous species (Al, Ahp, Ah, Aw; for the meaning of the abbreviations see Appendix 6.1) and ingrowing species with long rhizomes (Rhl) or creeping roots (CRl) as possible problem weeds for adjacent crops. More in particular, ingrowing species *Cirsium arvense* (L.) Scop.*, Elymus repens* (L.) Gould, *Sonchus arvensis* L. var. *arvensis*, *Urtica dioica* L. and the anemochorous species *Rumex obtusifolius* L., *Sonchus arvensis* L. var. *arvensis* and *Taraxacum officinale* Wiggers, are known to be pernicious problem weeds for both cropping systems (cf. Table 2.2 in Chapter 2) at both locations.

Species composition of both seedbanks differed in terms of functional groups. Compared to SITE1, the soil seedbank at SITE2 revealed significantly higher seed densities of annual dicotyledons (1569 versus 723 seeds/m²), annual monocotyledons (3892 versus 979 seeds/m²) and perennial monocotyledons (478 versus 45 seeds/m²). At SITE1, total density of perennial dicotyledons was significantly higher (238 versus 132 seeds/m²). Furthermore soil seedbank at SITE2 was unbalanced due to high seed densities of only a few plant species (Appendix 6.1): compared to SITE1, the soil seedbank at SITE2 revealed a (significant) threefold higher seed density of arable nitrophilous competitive annuals *Solanum nigrum* L., *Urtica urens* L. and *Chenopodium album* L.. At SITE2, on a Tansley scale, these species were highly abundant (*C. album*, *U.urens*) or even dominant (*S. nigrum*) during the establishment of the early vegetation prior to the first mowing due to their high seed densities in the seedbank and high soil fertility (high carbon%, mineral N and P content). At SITE1, *Artemisia vulgaris* L. was the most abundant unsown species whilst *U. urens*, *S. nigrum* and *C. album* were only occasionally present in the vegetation.

6.3.2 Vegetation analysis

The percentage uncovered area and significance of individual factors or interactions is given in Table 6.1. In October 2001 a significant interaction was found between plant community

Table 6.1. Uncovered area (%) in margin vegetations during succession (2001-2004) Abbreviations cf. Chapter 2, Section 2.1

LOC[1]	**COM**[1]	**MR**[1]	**Time**[2]							**Slope**[3]		
			M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**			***R²***
SITE1			42.6	33.8	34.9	25.6	26.3	40.3	27.7	-2.22		
SITE2			44.4	29.1	44.3	37.6	36.2	39.6	37.8	-7.68	*	*0.03*
	CONTR		71.8	39.2	30.6	28.5	20.3	37.7	20.2	-3.25	***	*0.26*
	MIXT1		29.2	27.6	31.1	28.6	29.6	34.0	30.1	2.68		
	MIXT2		37.2	27.8	33.5	35.5	32.6	45.2	42.2	9.37	*	*0.04*
	MIXT3		35.7	31.3	63.1	33.8	42.6	43.0	38.5	0.70		
		REMOV0	44.6	50.5	48.8	45.6	41.1	54.9	41.1	-0,75		
		REMOV1	41.2	24.3	43.2	26.4	32.7	34.1	36.3	-2.72		
		REMOV2	44.7	19.7	26.8	22.7	20.0	30.9	20.8	-11.40	**	*0.06*
SITE1	CONTR		84.4	54.3	25.5	32.5	16.2	46.0	20.3	-40.80	***	*0.35*
	MIXT1		13.5	24.6	28.6	22.5	28.9	31.9	23.8	9.28		
	MIXT2		36.3	23.8	25.9	28.5	25.5	43.3	33.4	6.08		
	MIXT3		36.3	32.8	59.4	18.9	34.9	40.1	33.4	-5.27		
SITE2	CONTR		59.3	24.1	35.7	24.4	24.5	29.4	20.1	-24.30	***	*0.19*
	MIXT1		45.0	30.7	33.6	34.7	30.3	36.1	36.4	-3.94		
	MIXT2		38.2	31.9	41.2	42.5	39.7	47.1	51.0	12.56	*	*0.08*
	MIXT3		35.2	29.8	66.8	48.7	50.4	45.8	43.6	6.68		
Anova[4]**:**												
LOC			NS	NS	NS	NS	NS	NS	*			
LSD									10.0			
COM			***	*	***	NS	***	*	***			
LSD			16.5	7.5	8.3		6.1	8.3	6.9			
MR			NS	***	***	***	***	***	***			
LSD				5.1	5.1	4.5	2.4	3.9	5.9			
LOC x COM			*	***	NS	**	NS	*	NS			
LSD within LOC			23.4	10.6		13.6		11.8				
LSD otherwise			80.1	23.3		25.1		13.9				
LOC x MR			NS	NS	NS	NS	*	***	NS			
LSD within LOC							6.8	5.6				
LSD otherwise							21.8	10.8				
COM x MR			NS	NS	NS	NS	NS	NS	NS			
LOC x COM x MR			NS	NS	NS	NS	NS	NS	NS			

[1] LOC, Location; COM, Community, MR, Mowing regime

[2] M1, October 2001; M2, July 2002; M3, October 2002; M4, July 2003; M5, October 2003 M6, July 2004; M7, October 2004

[3] Slope (%.10^{-3}.day^{-1}) of linear regression equation of % uncovered area upon time (days)

[4] NS, non significant; * $p<0.05$, ** $p<0.01$, *** $p<0.001$
LSD, Least Significant Difference ($p<0.05$)

and location. The percentage uncovered area in CONTR was significantly higher than in all sown plant communities at SITE1 and in MIXT3 at SITE2. Inversely, three years later, in October 2004, the actual percentage uncovered area was significantly lower in CONTR than in sown plant communities. Three years after installation, the percentage uncovered area was significantly lower under REMOV2 than under REMOV0. Furthermore, SITE2 revealed a significantly higher percentage uncovered area than SITE1.

During succession the percentage uncovered area in CONTR significantly decreased in time indicated by significant negative slopes of linear regression of uncovered area over time irrespective of location. No significant slopes were found for sown plant communities except for MIXT2 at SITE2. The percentage uncovered area significantly decreased in time under REMOV2. No significant slopes were found under REMOV0 and REMOV1. Within the period 2002-2004, annual percentage uncovered area in October was approximately 10% higher at SITE2 than at SITE1 irrespective of plant community.

At SITE2, the correlation between percentage uncovered area of subplots in October 2001 and summed seed densities of competitive arable annuals *S. nigrum*, *U. urens* and *C. album* in soil seedbank prior to installation was significant with highly positive correlation coefficients of 0.39, 0.67, 0.62 and 0.56 for CONTR, MIXT1, MIXT2 and MIXT3 respectively. At SITE1 no significant correlations were found.

In Table 6.2, I% of AUSPAN and PUSPAN, and significance of their experimental factors are shown for the period 2001-2004. From July 2002 up to October 2004, I% of AUSPAN was solely significantly determined by plant community except for a significant interaction between location and plant community in July 2003. Within this timespan, CONTR revealed significantly higher I% of AUSPAN than the sown communities except for SITE2 in July 2003. During succession, I% of AUSPAN significantly decreased irrespective of location or plant community as indicated by the significant slopes of linear regression of I% over time. The decrease occurred at highest rate in CONTR irrespective of location. Three years after installation, I% of AUSPAN were insignificant irrespective of location, plant community or mowing regime. Correlation between I% of AUSPAN in July 2002, and percentage uncovered area in October 2001 revealed a highly positive and significant correlation of 0.59 at SITE1 and a weak correlation of 0.09 at SITE2.

The I% of PUSPAN showed a significant interaction between plant community and location in the period from October 2001 up to July 2002 with a significantly higher I% in CONTR

Table 6.2. Importance (I%) of unsown anemochorous species over time (2001-2004). Abbreviations cf. Chapter 2 and Section 6.2

LOC[1]	COM[1]	MR[1]	AUSPAN									PUSPAN								
			Time[2]							Slope[3]		Time[2]							Slope[3]	
			M1	M2	M3	M4	M5	M6	M7		*R²*	M1	M2	M3	M4	M5	M6	M7		*R²*
	CONTR		6.3	7.5	6.6	1.1	0.9	0.9	0.1	-7.26 ***	*0.24*	17.8	14.5	9.8	5.9	5.9	5.3	8.9	-9.76 ***	*0.12*
	MIXT1		2.0	1.1	1.4	0.6	0.0	0.0	0.0	-1.92 ***	*0.14*	1.1	0.2	2.4	2.4	2.3	2.3	4.1	2.07 *	*0.05*
	MIXT2		1.8	0.7	0.5	0.1	0.0	0.0	0.0	-1.42 **	*0.07*	1.6	0.7	1.2	0.6	1.5	1.1	1.3	-0.11	
	MIXT3		1.9	0.8	0.1	1.3	0.1	0.2	0.0	-3.73 ***	*0.10*	1.5	1.4	0.4	0.9	1.5	1.4	1.6	0.29	
SITE1	CONTR		4.6	5.2	8.0	1.3	1.2	0.6	0.2			32.9	20.9	12.7	4.7	5.4	7.2	10.2	-20.50 ***	*0.37*
	MIXT1		1.8	1.4	1.3	0.2	0.0	0.0	0.0			1.3	0.4	2.5	3.8	2.0	2.0	2.5	1.25	
	MIXT2		2.9	0.2	0.4	0.0	0.0	0.0	0.0			3.2	0.3	0.3	0.5	1.3	0.7	0.3	-1.46 *	*0.05*
	MIXT3		2.7	0.3	0.0	0.2	0.0	0.0	0.0			2.3	0.7	0.0	0.6	1.3	1.3	0.9	-0.38	
SITE2	CONTR		7.9	9.7	5.3	0.8	0.6	1.3	0.0			2.6	8.2	6.8	7.0	6.5	3.3	7.7	1.03	
	MIXT1		2.2	0.9	1.5	1.1	0.0	0.0	0.0			0.8	2.1	2.3	0.9	2.7	2.7	5.6	2.88 *	*0.09*
	MIXT2		0.6	1.2	0.7	0.2	0.0	0.0	0.0			0.0	1.1	2.2	0.7	1.7	1.5	2.2	1.25	
	MIXT3		1.2	1.3	0.3	2.3	0.3	0.3	0.0			0.6	2.2	0.9	1.2	1.8	1.5	2.3	0.95	
Anova*[4]*:																				
LOC			NS	NS	NS	NS	NS	NS	NS			NS	NS	NS	NS	NS	NS	NS		
LSD																				
COM			NS	***	**	*	**	NS	NS			*	***	***	**	**	*	***		
LSD				2.7	2.9	0.8	0.4					10.7	3.9	3.9	2.8	2.5	3.1	2.8		
MR			NS	NS	NS	NS	NS	NS	NS			NS	NS	NS	NS	NS	NS	NS		
LOC x COM			NS	NS	NS	*	NS	NS	NS			*	**	NS	NS	NS	NS	NS		
LSD within LOC						1.1						15.1	5.5							
LSD otherwise						3.3						16.0	7.7							
LOC x MR			NS	NS	NS	NS	NS	NS	NS			NS	NS	NS	NS	NS	NS	NS		
COM x MR			NS	NS	NS	NS	NS	NS	NS			NS	NS	NS	NS	NS	NS	NS		
LOC x COM x MR			NS	NS	NS	NS	NS	NS	NS			NS	NS	NS	NS	NS	NS	NS		

[1] LOC, Location; COM, Community, MR, Mowing regime

[2] M1, October 2001; M2, July 2002; M3, October 2002; M4, July 2003; M5, October 2003; M6, July 2004; M7, October 2004

[3] Slope ($\%.10^{-3}.day^{-1}$) of linear regression equation of I% of AUSPAN or PUSPAN upon time (days)

[4] NS= non significant, * $p<0.05$, ** $p<0.01$, *** $p<0.001$. LSD = Least Significant Difference ($p<0.05$).

than in sown communities irrespective of location except in October 2001 at SITE2 (Table 6.2). Within this period, the I% of PUSPAN in CONTR was significantly higher at SITE1 than at SITE2. From October 2002 up to October 2004, I% of PUSPAN was solely determined by plant community with a significantly higher I% for CONTR compared to sown communities. Generally, I% decreased over time for plant communities at SITE1 with significantly negative slopes for CONTR and MIXT1, but increased for plant communities at SITE2 with significantly positive slopes for MIXT1 and MIXT2. In July 2002, the most important anemochorous weed species was *S. arvensis* var. *arvensis* revealing a significant interaction between location and plant community. Within both locations, CONTR revealed a significantly higher importance of *S. arvensis* var. *arvensis* than sown communities: 18.2% in CONTR versus 0.2-0.4% in sown communities at SITE1 and, 4.5% in CONTR versus 0-0.8% in sown communities at SITE2 (LSD within location=3.7%). Average I% of *R. obtusifolius* and *T. officinale* was respectively 0.9 and 0.0% at SITE1, and 0.6 and 0.9% at SITE2. No significant factors or interactions were found for both species. Three years after installation (July 2004), *S. arvensis* var. *arvensis* totally disappeared whilst the importance of *R. obtusifolius* and *T. officinale* slightly increased to respectively 1.1 and 0.2% at SITE1 and 0.8 and 1.0% at SITE2. No significant factors or interactions were found for *R. obtusifolius*, whilst *T. officinale* revealed a significantly higher importance in CONTR than in sown communities (1.3% in CONTR. versus 0.3-0.5% in sown communities; LSD=0.8%).

The correlation between I% of PUSPAN in July 2002, and percentage uncovered area in October 2001 and between I% of PUSPAN in July 2003 and percentage uncovered area in October 2002 showed a highly significant and positive correlation of respectively 0.76 and 0.43 at SITE1 and 0.53 and 0.54 at SITE2.

Three years after installation, the I% of PUING was significantly determined by location ($p<0.05$), plant community ($p<0.01$) and mowing regime ($p<0.001$). The I% was significantly higher at SITE2 than at SITE1 (SITE2, 10.8% versus SITE1, 2.9%; LSD=7.8%). CONTR showed a significantly higher I% than the sown communities (CONTR, 14.5% versus MIXT1, 5.4%, MIXT2, 4.3% and MIXT3, 3.1%; LSD= 6.6%). REMOV0 showed a significantly higher I% than REMOV1 and REMOV2 (REMOV0, 12.4% versus, REMOV1, 5.0% and REMOV2, 3.2%; LSD=3.8%). Under REMOV0, the I% significantly ($p<0.01$) increased over time (2001-2004) at a rate of 0.007%.day^{-1} ($R^2=0.10$). I% of PUING significantly increased over time at SITE2 (slope, 0.008%.day^{-1}; $R^2=0.12$; $p<0.001$) but significantly decreased at SITE1 (slope, -0.004%.day^{-1}; $R^2=0.09$; $p<0.001$). Table 6.3 shows

Table 6.3. Importance (I%) of rhizomatous margin species during succession (2001-2004). Abbreviations cf. Chapter 2, Section 2.1

			Cirsium arvense				*Elymus repens*				*Urtica dioica*			
			Time[2]			Slope[3]	Time			Slope	Time			Slope
LOC[1]	COM[1]	MR[1]	M3	M5	M7		M3	M5	M7		M3	M5	M7	
SITE1			0.1	0.5	1.5		0.0	0.0	0.9		0.0	0.0	0.3	
SITE2			0.1	0.1	0.4		5.1	8.1	7.7		0.2	0.8	2.7	
	CONTR		0.3	1.0	2.9		5.5	9.3	8.2		0.2	0.7	3.1	1.9**
	MIXT1		0.0	0.2	0.8		1.8	4.1	2.2		0.2	0.8	2.4	1.5*
	MIXT2		0.0	0.0	0.0		1.2	1.3	4.1		0.0	0.0	0.2	0.2*
	MIXT3		0.1	0.0	0.0		1.7	1.4	2.7		0.0	0.0	0.4	0.4*
		REMOV0	0.0	0.1	1.2	0.9**	2.6	5.7	7.9	7.6***	0.1	0.7	3.0	2.0***
		REMOV1	0.0	0.2	1.1	1.2**	2.8	3.3	2.9	2.2*	0.1	0.4	1.0	0.8*
		REMOV2	0.3	0.5	0.5	0.4	2.2	3.2	2.1	1.6	0.0	0.0	0.5	0.2
SITE1	CONTR		0.6	1.9	5.8	5.5**	0.0	0.0	0.3		0.0	0.0	0.7	
	MIXT1		0.0	0.0	0.0		0.0	0.0	0.9		0.0	0.0	0.7	
	MIXT2		0.0	0.0	0.0		0.0	0.0	1.0		0.0	0.0	0.0	
	MIXT3		0.0	0.0	0.0		0.0	0.0	1.4		0.0	0.0	0.0	
SITE2	CONTR		0.0	0.0	0.0		10.9	18.6	16.0	14.3**	0.4	1.4	5.4	
	MIXT1		0.0	0.4	1.7	1.3*	3.7	8.3	3.5	4.7	0.4	1.7	4.1	
	MIXT2		0.0	0.0	0.0		2.3	2.7	7.3	5.2*	0.0	0.0	0.3	
	MIXT3		0.3	0.0	0.0	-0.1	3.4	2.8	4.0	3.5	0.0	0.0	0.9	
SITE1		REMOV0	0.0	0.0	1.7		0.0	0.0	2.7		0.0	0.0	0.6	
		REMOV1	0.0	0.4	1.6		0.0	0.0	0.0		0.0	0.0	0.0	
		REMOV2	0.4	1.0	1.0		0.0	0.0	0.0		0.0	0.0	0.4	
SITE2		REMOV0	0.0	0.3	0.6		5.3	11.4	13.1		0.3	1.4	5.5	
		REMOV1	0.0	0.0	0.6		5.5	6.6	5.7		0.3	0.9	2.0	
		REMOV2	0.2	0.0	0.0		4.4	6.3	4.3		0.0	0.0	0.6	
Anova[4]:														
LOC			NS	NS	NS		NS	NS	NS		NS	NS	NS	
COM			NS	NS	NS		NS	**	NS		NS	NS	*	
LSD													2.2	
MR			NS	NS	*		NS	*	*		NS	NS	*	
LSD					0.6				4.1				2.1	
LOC x COM			NS	*	*		NS	**	*		NS	NS	NS	
LSD within LOC				1.2	3.6			2.8	7.2					
LSD otherwise				1.4	3.9			5.2	13.1					
LOC x MR			NS	NS	NS		NS	*	NS		NS	NS	NS	
LSD within LOC								3.3						
LSD otherwise								19.6						
COM x MR			NS	NS	NS		NS	NS	NS		NS	NS	NS	
LOC x COM x MR			NS	NS	NS		NS	NS	NS		NS	NS	NS	

[1] LOC, Location; COM, Community, MR, Mowing regime

[2] M3, October 2002; M5, October 2003; M7, October 2004

[3] Slope ($\%.10^{-3}.day^{-1}$) of linear regression equation of I% upon time (days)

[4] NS= non significant; * $p<0.05$, ** $p< 0.01$, *** $p<0.001$
LSD= Least Significant Difference ($p<0.05$)

annual I% of most pernicious rhizomatous species. One year after installation, in October 2002, no significant factors were found for *E. repens*, *C. arvense* and *U. dioica* (Table 6.3). However three years after installation, the situation had changed completely. The I% of *C. arvense* was significantly determined by mowing regime with significantly lower I% under REMOV2 than under REMOV1 and REMOV0. The I% of *E. repens* was significantly determined by mowing regime with significantly lower I% under REMOV1 and REMOV2 than under REMOV0. CONTR revealed a significantly higher I% of *E. repens* than sown communities at SITE2 while no significant differences were found at SITE1. The I% of *U. dioica* was significantly determined by plant community and mowing regime. The I% was significantly lower under REMOV2 than under REMOV0 and REMOV1. CONTR and MIXT1 showed a significantly higher I% than MIXT2 and MIXT3.

Correlation between I% of PUING in October 2004 and percentages uncovered area in July 2004 and July of preceding years revealed in general significant and positive correlation coefficients in sown communities irrespective of location (Tabel 6.4). Dissimilar to sown communities, correlation coefficients in CONTR were low and not significant.

Table 6.4. Correlation coefficients (r) between importance (I%) of PUING in October 2004 and % uncovered area in July of preceding years. Abbreviations cf. Chapter 2, Section 2.1

		r_a[1]	r_b[2]	r_c[3]
SITE1	CONTR	-0.53	0.31	0.61 *
	MIXT1	0.77 *	0.57 *	0.69 *
	MIXT2	0.44	0.58 *	0.67 *
	MIXT3	0.68 *	0.45 *	0.58 *
SITE2	CONTR	-0.40	-0.06	-0.03
	MIXT1	0.77 *	0.46 *	0.59 *
	MIXT2	0.50 *	0.35	0.53 *
	MIXT3	0.84 **	0.35	0.06

[1] r between I% of PUING in October 2004 and % uncovered area in July 2002

[2] r between I% of PUING in October 2004 and % uncovered area in July 2003

[3] r between I% of PUING in October 2004 and % uncovered area in July 2004

*, **, *** significant at $p<0.05$, $p<0.01$ and $p<0.001$ respectively

6.3.3 Seed dispersal into adjacent crop

One year after installation, in August-September 2002, the total number of captured seeds in the adjacent crop at SITE2 was not significantly determined by plant community. This was due to the patchy and variable pattern of seed dispersal resulting in a high standard deviation of means (Table 6.5). Nevertheless seedrain (expressed as seeds per m² sticky surface) into the adjacent crop was a factor 4 to 8 times higher perpendicular to CONTR than perpendicular to sown communities. Nearby sown communities, a lower number of captured seeds in the adjacent crop were found perpendicular to MIXT1 than to MIXT3 and MIXT2. At SITE1, no monitoring of seed dispersal was performed since no anemochorous species bearing maturing seeds were present in August-September 2002.

Table 6.5. Total number of seeds (seeds/m² sticky surface) of disseminating plant species in the adjacent crop, captured perpendicular to sown/unsown plant communities within 32 metres from the field margin strip (SITE2; 14 August to 9 September 2002). Abbreviations cf. Chapter 2, Section 2.1

Plant community	Plant species [1]						Total seed dispersal
	SONOL	SONAR	ERICA	GASCI	ECHCG	ARREL	
CONTR	840 ± 929	1148 ± 831	1481 ± 2566	2 ± 4	19 ± 17	75 ± 94	3565± 3019
MIXT1	33 ± 31	96 ± 113	0 ± 0	0 ± 0	0 ± 0	271 ± 127	400 ± 127
MIXT2	25 ± 33	633 ± 1001	0 ± 0	0 ± 0	0 ± 0	96 ± 62	754 ± 1057
MIXT3	42 ± 72	554 ± 949	0 ± 0	0 ± 0	0 ± 0	225 ± 176	821 ± 1185

[1] *Sonchus oleraceus* (SONOL), *Sonchus arvensis* var. *arvensis* (SONAR), *Erigeron canadensis* (ERICA), *Galinsoga parviflora* (GASCI), *Echinochloa crus-galli* (ECHCG), *Arrhenaterium elatius* (ARREL)

Seed dispersal decreased exponentially with increasing distance into the field. Averaged over all plant communities, the total number of captured seeds was significantly higher at 0 m (536 seeds/m²) from the field margin than at elevated distances into the crop which showed no significant differences (at 2 m, 358; at 4 m, 295; at 8 m, 129; at 16 m, 54 and at 32 m, 13 seeds/m²). Most seeds were captured within 4 m from the field margin (Table 6.6). In sown

Table 6.6. Cumulative percentage of seed dispersal (seeds/m² sticky surface) in the adjacent crop with increasing distances (m) from the field margin strip nearby sown/unsown plant communities (SITE2; 14 August to 9 September 2002). Abbreviations cf. Chapter 2, Section 2.1

Plant community	Distance from field margin strip (m)						Total seed dispersal
	0	2	4	8	16	32	(100%)
CONTR	44.2	67.7	81.3	93.6	99.1	100.0	3565
MIXT1	90.6	97.9	99.0	99.0	100.0	100.0	400
MIXT2	11.6	31.5	90.1	97.8	97.8	100.0	754
MIXT3	14.7	65.5	95.9	98.0	100.0	100.0	821

communities from 90% to 99% of all captured seeds were disseminated within 4 m from the field margin. In the unsown community CONTR, a lower proportion (82%) was found due to the higher occurrence of anemochorous species which disseminated over higher distances. Nearby sown communities, seed dispersal within 2 m from the field margin was mainly due to seed dispersal of the grass *Arrhenatherum elatius* (L.) J. & C. Presl with heavy seeds.

Seed dispersal distance (Figure 6.1) was determined by plant species (seed density between brackets): seeds of *Echinochloa crus-galli* (L.) Beauv. (3.75 seeds/m²), *Galinsoga parviflora* Cav. (2.5 seeds/m²) and *Arrhenaterium elatius* J. & C. Presl. (2.5 seeds/m²) were disseminated within 4 m adjacent to the field margin; *Sonchus oleraceus* L. (3.75 seeds/m²) and *Sonchus arvensis* L. var. *arvensis* (2.5 seeds/m²) were detected within 16 m from the field margin. *Erigeron canadensis* L. showed the highest seed dispersal distance (32 m) at a seed density of 33.7 seeds/m². It is very probable that these seeds spread beyond this distance, but this was not monitored. One year after installation, in August-September 2002, number of captured seeds of SPAN at 0 m from the field margin (Table 6.7) was significantly higher nearby CONTR than nearby sown communities. Two years after installation (2003) seed dispersal of SPAN into adjacent crops in the same period was similar for all plant communities. Compared to the preceding year, seed dispersal at 0 m from the margin strip was low. Three years after installation in May-June 2004 solely seeds of *T. officinale* (PUSPAN) were captured at 0 m from the margin strip. Number of captured seeds was significantly higher nearby CONTR than nearby sown communities.

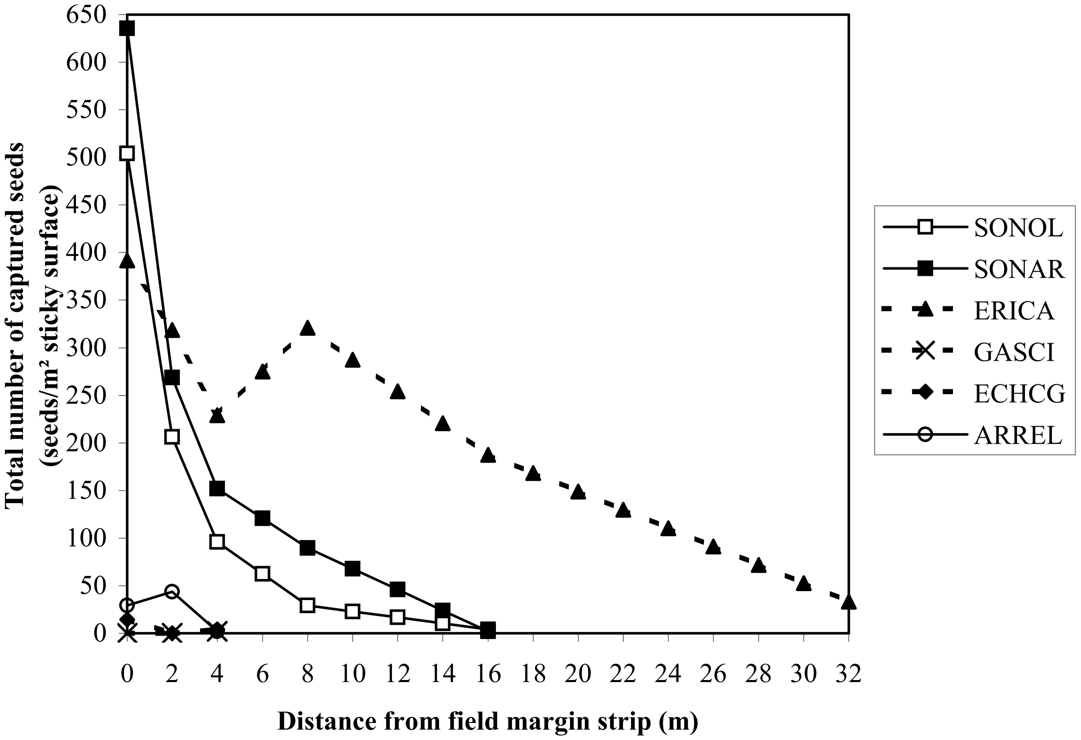

Figure 6.1. Seed dispersal (seeds/m² sticky surface) of *Sonchus oleraceus* (SONOL), *Sonchus arvensis* (SONAR), *Erigeron canadensis* (ERICA), *Galinsoga parviflora* (GASCI), *Echinochloa crus-galli* (ECHCG), *Arrhenaterium elatius* (ARREL) into the adjacent crop at increasing distances from CONTR (SITE2, from 14 August to 9 September 2002)

Numbers of captured wind-born seeds of AUSPAN, PUSPAN, SPAN in August-September 2002 were significantly positively correlated with their I% in July 2002 with correlation coefficients of 0.89, 0.53, 0.94 respectively. Similar significantly positive correlations were found for individual disseminating species with correlation coefficients of 0.61, 0.86 and 0.91 for *S. arvensis* var. *arvensis*, *S. oleraceus* and *E. canadensis* respectively.

No significant correlation coefficients were found in 2003. In 2004 correlation between I% of *T. officinale* prior to seed monitoring (October 2003) and its number of captured seeds revealed a significantly positive correlation coefficient of 0.59 and 0.27 at SITE2 and SITE1 respectively.

Table 6.7. Captured wind-born seeds nearby plant communities at 0 m from margin strip (Period 2002-2004). Abbr. cf. Section 2.1, 6.2

Location	Plant Community	August-September								May-June
		AUSPAN		PUSPAN		Total SPAN		GRASSES		PUSPAN
		2002	2003	2002	2003	2002	2003	2002	2003	2004
SITE1	CONTR	-	6 ± 7	-	12 ± 33	-	18 ± 39	-	93 ± 186	19 ± 19
	MIXT1	-	0 ± 0	-	9 ± 23	-	9 ± 23	-	0 ± 0	3 ± 7
	MIXT2	-	0 ± 0	-	4 ± 10	-	4 ± 10	-	9 ± 18	1 ± 3
	MIXT3	-	10 ± 17	-	14 ± 17	-	24 ± 26	-	4 ± 9	2 ± 2
SITE2	CONTR	896 ± 1327	7 ± 20	635 ± 757	4 ± 13	1531 ± 1261	11 ± 33	44 ± 27	0 ± 0	73 ± 65
	MIXT1	21 ± 19	0 ± 0	71 ± 112	0 ± 0	92 ± 116	0 ± 0	271 ± 253	2 ± 7	6 ± 9
	MIXT2	8 ± 7	0 ± 0	38 ± 45	7 ± 14	46 ± 38	7 ± 14	42 ± 29	4 ± 9	2 ± 4
	MIXT3	13 ± 22	0 ± 0	4 ± 7	23 ± 70	17 ± 19	23 ± 70	104 ± 83	0 ± 0	2 ± 2
Anova[1](Sign./LSD)										
Location		-	NS	-	NS	-	NS	-	NS	NS
Community		NS	NS	NS	NS	*/519	NS	NS	NS	*/29
Cutting treatment		-	NS	-	NS	-	NS	-	NS	NS
2-and 3 way interaction		-	NS	-	NS	-	NS	-	NS	NS
Species[2]		SONOL ERICA GASCI	SONOL CRCA	SONAR	SONAR HESP	SONOL ERICA GASCI SONAR	SONOL CRCA SONAR HESP	ECHCG ARREL	ARREL DAG AGR LM	TAROF

[1] Significance: NS, non significant; *, significant p<0.05. LSD, least significant difference (p<0.05)

[2] *Sonchus oleraceus* (SONOL), *Sonchus arvensis* var. *arvensis* (SONAR), *Erigeron canadensis* (ERICA), *Galinsoga parviflora* (GASCI), *Crepis capillaris* (CRCA), *Heracleum sphondylium* (HESP), *Taraxacum officinale* (TAROF), *Agrostis spp.* (AGR), *Dactylis glomerata (DAG), Lolium multiflorum* (LM), *Arrhenaterium elatius* (ARREL), *Echinochloa crus-galli* (ECHCG)

6.4 Discussion and conclusions

Farmers are reluctant to margin strips because they fear weed invasion and seed dispersal into adjacent crops. In this study, importance of ingrowing species significantly increased over time under mowing regime without removal of cuttings. Three years after installation, the importance of ingrowing species in field margin strips significantly quadrupled when cuttings were not removed and tripled or were multiplied by five in the unsown margin strip. According to Naylor (2002) the worst perennial weed species which have the largest impact on crop yields of many crops in northern Europe are the nitrophilous ingrowing species *E. repens*, *C. arvense* and *S. arvensis*, which were found actively adjusting root and shoot growth into locally resource-rich zones (Kleijn, 1997; Campbell et al., 1991) such as the crop area. In our plots these species significantly increased over time under mowing regimes without removal of cuttings except for *S. arvensis* which disappeared three years after installation of the margin strip. Three years after installation, the importance of *E. repens*, *C. arvense* and *U. dioica*, was significantly higher when cuttings were not removed. Mowing with removal of cuttings enhanced mineral depletion of soil thus taking away optimal growing conditions for ingrowing species. Indeed, Marshall (1990) found for *E. repens* that fertilizer use doubled the amount of rhizomes. Mowing with removal of cuttings also significantly reduced the percentage uncovered area over time, thus reducing gaps prone to colonization by ingrowing species. In general, importance of *E. repens*, *C. arvense* and *U. dioica* significantly increased over time in the unsown community, resulting in significantly higher importance of these species in the unsown community compared to sown communities. Similar results were reported by Bokenstrand et al. (2004) and West et al. (1997) who found *E. repens* increasing over time in unsown boundary strips. So, ingrowing species apparently invaded faster in poorly revegetated, unproductive margin strips. The low species competitiveness of unproductive (see Chapter 7) low-growing species in the unsown community is likely to be responsible for the increase of the ingrowing species. In conclusion, ingrowing species are better suppressed by sown margin strips than by unsown margin strips; their presence remaining low in sown communities.

The importance of ingrowing species such as *E. repens*, *U. dioica* and *C. arvense* in the field margin strips could not be explained by their seed densities in the soil seedbank since species importance was not linked to seed density in soil seedbank (*E. repens*); at SITE2 *U. dioica*, *C.*

arvense were even not present in soil seedbank despite their presence in the margin strip. This unlinkage between seed density and species importance in the margin strip might be explained by contamination of soil by vegetative propagules of these rhizomatous species. Pieces of rhizomes offer strong opportunities for the species to quickly spread or invade into field margin strips when conditions are beneficial. Unfortunately, pieces of rhizomes were not appropriately quantified by seedbank analysis. Furthermore, according to Dessaint et al. (1996) and Naylor et al. (2002) no seedbank sampling design can be expected to sample 100% of species to a high precision: in particular, species at low seed densities may not be accurately estimated. This might be the case for *E. repens*: it is well known that its seed production is often poor (Kleijn, 1997).

Three years after installation, importance of ingrowing species was significantly higher at SITE2 than at SITE1. This was attributed to the significantly higher percentages uncovered area at SITE2. This was probably a long-term effect caused by choking of sown margin species by competitive arable annual weeds *Solanum nigrum*, *Chenopodium album* and *Urtica urens* which overgrew the initial vegetation at SITE2, leaving a less competitive vegetation. The choking by these nitrophilous weeds was enhanced by the high nutrient richness of the soil at SITE2. The importance of choking nitrophilous competitive annuals in the margin vegetation before the very first cutting could be linked to their seed density in the soil seedbank prior to installation. Furthermore high summed seed densities of *S. nigrum*, *U. urens* and *C. album* were significantly correlated with high percentages uncovered area in the vegetation after the first cutting. This knowledge offers opportunities to predict the potential risk of species ingrowth into adjacent crops.

Besides the potential risk of ingrowth of rhizomatous species into the adjacent crop, weed problems might be increased by seedrain from anemochorous margin species into the adjacent crop. Seed monitoring from 14 August to 9 September at SITE2 revealed that 4 to 8 times more wind-born seeds of specialized anemochorous species, mainly disseminated by annuals, were captured nearby the unsown community than nearby sown communities. So, unsown field margin strips, contrary to sown communities, were hot spots for specialized anemochorous species. This might be explained by the higher initial percentage uncovered area in the uncompetitive unsown vegetation, resulting in a higher importance of anemochorous annuals during the first two successional years compared to sown communities. Moreover, the importance of specialized anemochorous margin species (mainly annual arable weeds) was significantly and highly positively correlated to the percentage uncovered area. This result is in accordance with Smith et al. (1999) who found field margin strips very unlikely to affect weed levels within the crop, especially where they contain, or are sown to non invasive perennial species. West et al. (1997) also found that sowing a grass/clover mixture reduced weed pressure compared with options that left the sward more open.

The highest influence of seed dispersal from the unsown margin strip into the adjacent crop, mainly occurred one year after its installation on ex arable land since the seedrain significantly decreased over time. This might be explained by the significant decrease in importance of annual and perennial specialized anemochorous species during succession and the decrease in invadable gaps over time. Three years after installation there was no more wind-born seed dispersal by annual species irrespective of plant community. Seeds of typical arable anemochorous perennials such as *S. arvensis* var. *arvensis* were also lacking three years after installation. Future anemochorous seed dispersal will greatly depend on the importance of perennial anemochorous species typically found in grasslands such as *T. officinale.*

Contrary to ingrowing species seed dispersal by specialized anemochorous species was not significantly determined by mowing regime despite the significantly higher percentage uncovered area when cuttings remained on the margin strip. Probably low light penetration below the remaining litter hampered seed germination of anemochorous species but enhanced colonisation of gaps by ingrowing species

Seed dispersal decreased exponentially with increasing distance into the adjacent crop: 82-99% of all dispersed seeds were disseminated within 4 m from the field margin strip. However seed dispersal distance depended on plant species with a high dispersal distance (up to 32 m) for *E. canadensis* and a low distance for *G. parviflora* and the grasses *A. elatius*, *E. crus-galli*, lacking specialized wind dispersal systems. In our study, seed dispersal distance nearby margin strips exceeded seed dispersal distances reported by Rew et al. (1996) (3 m), Hume & Archibold (1986) (7 m), Jones & Naylor (1992) (12.5 m).

The risk of seed dispersal might be lower when field margin strips are sown in autumn since West et al. (1997) found more weeds in field margin strips after spring-cultivation than after autumn-cultivation. Sowing in autumn might avoid germination of thermophilous competitive annuals like *S. nigrum* and *C. album* (Chancellor, 1985*)* thus avoiding choking of vegetation in the installation year and hence leaving little space for autumn-germinating annual weeds to introgress.

In conclusion, the risk of weed infestation due to newly installed field margins might be controlled by appropriate field margin management without the need for chemical control.
The analysis of the soil seedbank gives an idea of the potential risk of weed invasion into adjacent crops. If this risk is substantial, it is recommended to avoid a spontaneous development and to install the margin strip by sowing. According to the seed species present in the seedbank, one may choose a spring or an autumn sowing.
A mowing regime with removal of cuttings is a good practice to diminish the risk of species ingrowth into adjacent crops by creeping roots and rhizomes. Seed dispersal was only problematic one year after installation of the field margin strips particularly nearby the unsown margin strip and wind-borne seeds were dispersed over limited distances, mainly within 4 m of field margins. Knowing this, one might tighten the management during the first year after installation in order to prevent plants from flowering during this first year.

Appendix 6.1. Seed densities (seeds/m^2) and colonisation type of soil seedbank species at SITE1 (Poperinge) and SITE2 (Beernem) (June 2001)

	Seed density (seeds/m^2)			**Colonisation type** [2]
	SITE1	**SITE2**	**T**[1]	
Annual dicots:				
Arabidopsis thaliana (L.) Heynh.	0.4 ± 2.2			*AS*
Atriplex prostrata DC.	1.1 ± 4.8	1.1 ± 3.7		*A, H*
Bidens tripartita L.	2.6 ± 7.5			*H, Zp*
Capsella bursa-pastoris Med.	2.9 ± 5.5	40.8 ± 53.9	***	*AS, H*
Cardamine hirsuta L.	14.8 ± 25.7	15.9 ± 24.7		*A, AUT*
Chenopodium album L.	61.0 ± 133.2	192.4 ± 157.5	***	*A, H, Ze*
Coronopus didymus (L.) Sm.	0.4 ± 2.2	174.0 ± 689.8		*H*
Erigeron canadensis L.	0.4 ± 2.2	10.5 ± 19.6	**	*Ahp*
Galeopsis tetrahit L.		0.8 ± 3.1		*H, Zp*
Galinsoga parviflora Cav.	25.3 ± 129.7	3.7 ± 7.4		*Asp, H*
Gnaphalium uliginosum L.	4.7 ± 8.9	31.8 ± 30.7	***	*Ahp, H*
Lamium amplexicaule L.	5.8 ± 22.5	1.9 ± 7.1		*Zm*
Lamium purpureum L.		78.0 ± 180.9		*Zm*
Matricaria recutita L.	15.6 ± 18.1	34.3 ± 24.5	***	*AS, H, Ze, Zp*
Mercurialis annua L.	9.8 ± 28.6			*AUT, Zm*
Phacelia tanacetifolia Bentham	0.4 ± 2.2			
Polygonum aviculare L.	4.4 ± 9.9	138.6 ± 162.7	***	*H*
Polygonum convolvulus L.	26.4 ± 39.6	0.4 ± 2.2	***	*H*
Polygonum lathifolium L. subsp. *pallidum* Fries	2.6 ± 8.2			*H*
Polygonum persicaria L.	84.1 ± 359.4	15.9 ± 21.1		*H*
Portulaca oleracea L.				*Al, AS*
Ranunculus sceleratus L.	10.5 ± 18.4			*A, H, Ze*
Senecio sylvaticus L.		1.5 ± 5.2		*Ahp, H*
Senecio vulgaris L.	11.9 ± 27.2	9.1 ± 15.2		*Ahp, H*
Sinapis arvensis L.	0.4 ± 2.2	1.1 ± 4.8		*AS*
Solanum nigrum L.	110.5 ± 100.2	344.7 ± 301.3	***	*Ze*
Solanum tuberosum L.	2.6 ± 11.6			
Sonchus asper (L.) Hill	7.6 ± 11.8	2.6 ± 6.1	*	*Ahp, H*
Sonchus oleraceus L.	9.1 ± 23.0	0.4 ± 2.2	*	*Ahp, H*
Stachys arvensis L.		1.1 ± 4.8		*H, Zp*
Stellaria media L.	163.5 ± 232.0	209.4 ± 114.9		*B, H*
Urtica urens L.	145.1 ± 288.7	252.0 ± 354.3	*	*A*
Veronica arvensis L.		2.2 ± 3.7		*AS, H, Ze, Zm*
Viola arvensis Murray		2.6 ± 6.1		*AUT, Zm*
Perennial dicots:				
Apium graveolens L.	0.4 ± 2.2			*H*
Arctium minus (Hill) Bernh.	2.2 ± 5.9			*Zp*
Artemisia vulgaris L.	37.9 ± 34.5			*AS, Zp*
Calluna vulgaris (L.) Hull		1.5 ± 5.2		*Al, AS*
Cerastium fontanum B. subsp. *vulgare* Greuter& Burdet	2.2 ± 5.9	15.9 ± 25.7	**	*AS*
Cirsium arvense (L.) Scop.	5.5 ± 11.4			*Ahp, CRl, Rhl, Zm*
Epilobium angustifolium Holub		6.5 ± 16.3		*Ah, H, Rhs*
Epilobium hirsutum L.	82.3 ± 63.6	0.4 ± 2.2	***	*Ah, H, Rhs*

Appendix 6.1. Seed densities (seeds/m^2) and colonisation type of soil seedbank species at SITE1 (Poperinge) and SITE2 (Beernem) (June 2001) (continued)

	Seed density (seeds/m^2)			**Colonisation type** [2]
	SITE1	**SITE2**	**T**[1]	
Perennial dicots:				
Epilobium montanum L.	27.5 ± 54.5	25.7 ± 41.4		*Ah, H, Rhs*
Equisetum palustre L.	0.4 ± 2.2			*Rhl*
Hypericum perforatum L.		11.2 ± 26.1		*Al, AS*
Ornithopus perpusillus L.		1.9 ± 4.6	*	*A*
Oxalis fontana Bunge		0.4 ± 2.2		*AUT, Zp*
Plantago major L.	6.2 ± 10.6	25.0 ± 40.3	*	*H, Zp*
Ranunculus repens L.	7.6 ± 14.1	1.1 ± 4.8		*A, H, Ze, Zp, Zm*
Rorripa sylvestris (L.) Besser		1.9 ± 6.4		*AS, CRs, H, Z*
Rubus arcticus L.	0.8 ± 3.1	2.2 ± 5.9		*Ze*
Rumex acetosa L.	1.5 ± 5.2			*Aw, H, Zp*
Rumex acetosella L.		2.6 ± 6.9		*Aw, H, Zp*
Rumex obtusifolius L.	0.4 ± 2.2	3.3 ± 9.6		*Aw, H, Zp*
Sagina procumbens L.	20.6 ± 110.2	1.9 ± 5.6	*	*AS, H*
Salix alba L.	21.0 ± 35.2	5.5 ± 18.3	*	*Ah, H*
Sonchus arvensis L. var. *arvensis*	7.6 ± 23.0	7.6 ± 10.5		*Ahp, H, CRl*
Tanacetum vulgare L.	0.8 ± 3.1			*AS*
Taraxacum officinale Wiggers	1.1 ± 3.7	6.9 ± 12.7	*	*Ahp*
Teucrium scorodonia L.		1.5 ± 4.2		*A, H*
Trifolium repens L.	2.2 ± 7.3	9.8 ± 13.0	**	*A, AUT, H, Zp*
Urtica dioica L.	10.5 ± 13.2			*A, Rhl*
Veronica beccabunga L.	0.4 ± 2.2			*AS, H, Ze, Zm*
Annual monocots:				
Echinochloa crus-galli Beauv.	1.1 ± 3.7	5.5 ± 19.8		*Zp*
Juncus bufonius L.	36.1 ± 32.5	2590.6 ± 1763.8	***	*AS, Zp*
Poa annua L.	942.0 ± 1604.0	1295.3 ± 981.0		*A, Zp*
Setaria viridis (L.) Beauv.		0.4 ± 2.2		*A*
Perennial monocots:				
Agrostis stolonifera L.	1.9 ± 7.1	79.1 ± 82.2	***	*A, Zp*
Carex hirta L.		0.4 ± 2.2		*A, Rhs, H, Zp, Zm*
Dactylis glomerata L.	1.5 ± 5.2			*A*
Elymus repens (L.) Gould	3.3 ± 11.4	0.8 ± 3.1		*A, H, Rhl*
Festuca arundinacea Schreber	1.1 ± 4.8			*A, Rhs, H*
Holcus lanatus L.	0.4 ± 2.2	7.3 ± 22.3	*	*H, Rhs, Zp*
Juncus effusus L.	35.1 ± 28.8	368.2 ± 334.3	***	*AS, Zp*
Lolium perenne L.	0.4 ± 2.2	0.4 ± 2.2		*A, H, Zp*
Poa trivialis L.	2.6 ± 9.3	22.1 ± 91.3		*A, Zp*
TOTAL SEED DENSITY	1986.1 ± 2217.3	6070.3 ± 2107.3	*	

[1] T: Independent t-test between SITE1 and SITE2; *** $p<0.001$, ** $p<0.01$, * $p<0.05$

[2] Generative dispersal: *A, Anemochory (addition of minuscules for specialized wind-born spp.: l, light seeds; hp, hairy pappus; h, hairy seed; w, wings); B, Barochory; AS, Semachory; AUT, Autochory; H, Hydrochory; Z, Zoochory + addition of minuscules: e, endozoochory; p, epizoochory; m, myrmecochory .*
Vegetative dispersal: *Rhl, long rhizomes; Rhs, short rhizomes; CRs, short creeping roots; CRl, long creeping roots*

Chapter 7

Dry-matter yield and herbage quality of field margin vegetations as a function of botanical evolution and management regime

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Chapter 7

Dry-matter yield and herbage quality of field margin vegetations as a function of botanical evolution and management regime

7.1 Introduction

Field margin strips aimed to protect wildlife and environment, are usually managed according to management agreement prescriptions as agreed upon by farmers and a governmental organization. Contrary to intensively managed grasslands, field margin strips usually are unfertilized since fertilizer use is incompatible with the objective of creating or maintaining a species–rich vegetation (Peeters & Janssens, 1998). Low nutrient availability and, in particular, low extractable soil phosphorus appears to be a key factor to maintain a botanically rich vegetation (Marrs, 1993; Janssens et al., 1997). In order to accelerate mineral depletion of the soil, many management agreements prescribe to cut the vegetation once or twice per year with removal of the cuttings. The first cutting date is scheduled around mid June or even later in order to allow seed set of some valuable species. Around mid June many grass species reach maturity. It is well known that the forage quality of mature grass is low due to a low leaf/stem ratio, a high cell wall content and an increased lignification in cell walls, all resulting in a low digestibility of the fodder (Korevaar, 1986; Kirkham & Tallowin, 1995; NIAB, 1996; Bruinenberg et al., 2002). Protein content is low and mineral concentrations may drop below animal needs (Armstrong et al., 1986; Tallowin & Jefferson, 1999). Moreover, during the transition period, the succession patterns in the vegetation are expected to result in an ever changing botanical composition of the vegetation, the resulting fodder having a fluctuating value (Korevaar et al., 2004; Korevaar & Geerts, 2004).

This study examines the effects of sown and unsown margin strips on dry matter yield and herbage quality during early vegetation succession of ex-arable land under different mowing regimes. In particular the following questions are adressed: (1) Does the mowing regime and/or field margin type affect dry matter yield over time? (2) What is the impact of field margin type and associated vegetation composition on herbage quality (3) Is herbage quality affected by cutting time (4) How useful is herbage from field margin as an animal feed?

7.2 Specific material and methods

The research was based on trial 1 explained in Chapter 2, Section 2.1. A botanical analysis (according to methodology described in Chapter 2, Section 2.2) was executed in each subplot, in order to determine the impact of vegetation composition on herbage yield and quality.

Herbage yields were determined twice per year around 15 June (hereafter called the first cut) and 15 September (hereafter called the regrowth cut) by cutting the central 4 m x 4 m quadrat of each subplot using an Agria motor cutter at a cutting height of 5 cm. Herbage was weighed on the field to determine fresh herbage yield. Per subplot, herbage samples were taken and dried for 12h at 75°C to calculate dry matter (DM) yield. DM yield of both the first and the regrowth cut were added to determine annual DM yield. Mean annual DM yield over the period 2002-2004 was then calculated by averaging annual DM yields of the three consecutive years. Similarly, mean DM yield of the first cut and the regrowth cut was calculated by averaging their DM yields over the period 2002-2004.

Herbage quality of each plot was determined under REMOV2 in each year. Dried herbage samples were ground in a RETSCH mill with a 1 mm mesh sieve and analysed for crude protein (CP, %), crude ash (ASH, %), crude fibre (CF, %) and organic matter digestibility (OMD, %). ASH content was determined gravimetrically after calcination during 4h at 550°C. Crude fibre content was analysed gravimetrically after calcination of the non-soluble residues that remained after heating in 0.26 $mol.l^{-1}$ H_2SO_4 and 0.23 $mol.l^{-1}$ NaOH successively. CP content was determined as 6.25 x Kjeldahl-N content. OMD (%) was determined *in vitro* according to the pepsine-cellulase method (De Boever et al., 1988). Additionally, phosphorus (P, %) content was analysed spectrophotometrically both in the first cut and the regrowth cut of 2004.

The energy value of the herbage was calculated according to formulas of CVB (1999) using ASH, OMD, CP, CF contents. The energy value was expressed as Dutch Feed Units (VEM, Voedereenheid Melk; De Boer & Bickel, 1988). One VEM unit corresponds with 6.9 kJ Net Energy for Lactation (NEL) per kg DM (Van Es, 1978).

Except for 2002, herbage quality parameters were determined per individual cut. In 2002, herbage quality was determined on a mixed DM sample, bulked according to the proportional share of each cut in the annual DM yield. In 2003 and 2004 herbage quality of the annual yield was calculated as the weighted average of herbage quality of both the first and regrowth cut. Mean herbage quality of annual yield over the period 2002-2004 was then calculated by averaging herbage quality of three consecutive years. Similarly, mean herbage quality of the first cut and the regrowth cut over the period 2003-2004 was calculated by averaging herbage quality of the years 2003 and 2004

Changes in DM yield, I% of individual plant species or functional groups over time were assessed using lineair regression analysis. Analysis of variance of a strip split plot design (vertical factor: location; horizontal factor or main plot factor: plant community; subplot factor, mowing regime) was used to analyse DM yield and I% using S-plus 2000 for Windows. The factor mowing time (i.e. subsub factor) was added in case DM yield was analysed on cut level. SPSS10 for windows was also used for statistical calculations of herbage quality parameters under REMOV2.

7.3 Results

7.3.1 Biomass quantity

Analysis of variance of data of DM yield of individual cuts and of annual DM yield during the period 2002-2004 is shown in Table 7.1. Both annual and mean annual DM yield showed a significant interaction between location and plant community; they were not significantly affected by mowing regime. The sown plant communities outyielded CONTR, irrespective of location. Within plant communities annual and mean annual DM yield were significantly higher at SITE1 than at SITE2 except for CONTR. Within sown plant communities, mean annual DM yield was significantly higher for MIXT1 than for MIXT2 and MIXT3 at SITE1; at SITE2 no significant differences in mean annual DM yield were found.

Mean DM yield per cut (Table 7.2) showed a significant interaction between plant community and location, between plant community and mowing time and between location and mowing regime. Mean DM yield of the first cut was significantly higher than mean DM yield of the regrowth cut, irrespective of plant community. Compared to REMOV1 and REMOV2, mean DM yield per cut was significantly lower under REMOV0 at SITE1 but not at SITE2.

Table 7.1. Annual dry matter yield (kg DM.ha^{-1}) in sown/unsown plant communities at two locations (Abbreviations cf. Chapter 2, Section 2.1)

Location	Plant community	Mowing regime	Year			Mean	Slope[2]		
			2002	2003	2004				*R²*
SITE1	CONTR		4165	8157	10331	7551	3083	***	*0.70*
	MIXT1		14312	16062	16422	15599	1055	*	*0.20*
	MIXT2		13457	14753	15359	14523	951	*	*0.13*
	MIXT3		12874	13845	14259	13659	692	*	*0.12*
SITE2	CONTR		6145	6717	8638	7167	1246	***	*0.32*
	MIXT1		9373	8720	9936	9343	282		
	MIXT2		10830	8998	10975	10267	73		
	MIXT3		11114	7880	10048	9680	-533		
SITE1		REMOV0	10914	12676	13269	12286			
		REMOV1	11316	13315	14643	13091			
		REMOV2	11376	13621	14366	13121			
SITE2		REMOV0	9625	8074	10219	9306			
		REMOV1	9122	7874	9648	8881			
		REMOV2	9349	8288	9831	9156			
Anova[1]									
Location			NS	*	**	*			
Plant community			***	***	***	***			
Location x Plant community			***	***	**	***			
LSD within Location			1424	1286	1336	904			
LSD otherwise			3531	4120	1481	2398			
Mowing regime			NS	NS	NS	NS			
Location x Mowing regime			NS	NS	***	**			
LSD within Location					1252	848			
LSD otherwise					1812	2609			
Plant community x Mowing regime			NS	NS	NS	NS			
Location x Plant community x Mowing regime			NS	NS	NS	NS			

[1] NS, non significant; *= p<0.05; **=p<0.01; ***=p<0.001
LSD, least significant difference (p<0.05)

[2] Slope (kg DM. Year^{-1}) of linear regression equation of annual DM yield upon time (year)

CONTR showed a significantly lower mean DM yield per cut than the sown communities, irrespective of location. At SITE1, MIXT1 revealed a significantly higher mean DM yield per cut than MIXT2 and MIXT3; at SITE2 no significant differences between sown communities were found.

Table 7.2. Dry matter yield per cut (kg $DM.ha^{-1}$) in sown/unsown plant communities: CUT1, 15 June (first cut); CUT2, 15 September (regrowth cut). Abbr. cf. Chapter 2, Section 2.1

Location	**Plant community**	**Mowing regime**	**Mowing time**	**Yield per cut**			**Mean**
				2002	**2003**	**2004**	
SITE1	CONTR			2082	4078	5166	3775
	MIXT1			7156	8031	8211	7799
	MIXT2			6729	7376	7680	7262
	MIXT3			6437	6923	7129	6830
SITE2	CONTR			3073	3359	4319	3584
	MIXT1			4686	4360	4968	4671
	MIXT2			5415	4499	5488	5134
	MIXT3			5557	3940	5024	4840
SITE1		REMOV0		5457	6338	6635	6143
		REMOV1		5658	6658	7321	6546
		REMOV2		5688	6811	7183	6561
SITE2		REMOV0		4812	4037	5109	4653
		REMOV1		4561	3937	4824	4441
		REMOV2		4675	4144	4916	4578
SITE1			CUT1	7120	7860	9022	8001
			CUT2	4082	5344	5071	4832
SITE2			CUT1	4961	6040	6827	5943
			CUT2	4404	2039	3073	3172
	CONTR		CUT1	2571	5233	6414	4739
			CUT2	2584	2204	3071	2620
	MIXT1		CUT1	7290	8257	8771	8106
			CUT2	4553	4134	4408	4365
	MIXT2		CUT1	7011	7756	8816	7861
			CUT2	5133	4119	4352	4535
	MIXT3		CUT1	7292	6554	7697	7181
			CUT2	4702	4309	4456	4489
Anova[1]							
Location				NS	*	**	*
Plant community				***	***	***	***
Location x Plant community				***	***	**	***
LSD within Location				712	643	668	452
LSD otherwise				1765	1628	741	1199
Mowing regime				NS	NS	NS	NS
Mowing time				***	***	***	***
Location x Mowing regime				NS	NS	***	**
LSD within Location						318	391
LSD otherwise						544	854
Plant community x Mowing regime				NS	NS	NS	NS
Location x Mowing time				***	***	NS	NS
LSD within Location				549	439		
LSD otherwise				1723	2036		
Plant community x Mowing time				***	***	***	***
LSD within Plant community				776	620	695	549
LSD otherwise				744	631	681	503
Mowing regime x Mowing time				NS	NS	NS	NS
3-way and/or 4-way interactions				NS	NS	NS	NS

[1] NS, non significant; * $p<0.05$; **$p<0.01$; ***$p<0.001$. LSD, least significant difference

Despite zero fertilization, annual DM yield increased significantly over time at SITE1 as shown by the positive slopes of linear regression equations (Table 7.1). A similar trend was seen at SITE2 except for MIXT3. The difference in DM yield between CONTR and sown communities decreased over time since the increase occurred at a higher rate in CONTR than in the sown communities.

7.3.2 Herbage quality

Annual yield:

Herbage quality of the annual DM yield is shown in Table 7.3 (CF, CP, ASH) and 7.4 (OMD, VEM). Slopes of linear regression equations of annual CF, CP, ASH, OMD and VEM over time are shown in Table 7.5.

The overyears average values of CF showed a significant interaction between plant community and location. Herbage from CONTR had a significantly lower mean CF than herbage from sown communities, irrespective of location. Within sown communities, there were no significant differences in CF at SITE1; at SITE2, MIXT1 had a significantly lower mean CF than the other communities. Within plant communities, MIXT1 showed a significantly lower mean CF at SITE2 than at SITE1.

Mean CP was not significantly affected by location or plant community.

Both mean OMD and VEM were significantly affected by plant community and location. Values were higher at SITE2 than at SITE1; they were higher in CONTR than in the sown communities, which did not differ significantly.

Annual CP as well as ASH and OMD significantly decreased over time; the rate of decrease being higher at SITE1 than at SITE2 for CP and OMD. CF increased over time in all plant communities at SITE1; at SITE 2 changes were influenced by plant communities. Annual VEM significantly decreased over time in sown communities irrespective of location except for MIXT2 at SITE2.

Table 7.3. Contents of CF, CP, ASH (% on DM) of annual DM yield from sown/unsown plant communities at two locations
Abbreviations cf. Section 2.1 and 7.2

		CF				CP				ASH			
Location	**Community**	**2002**	**2003**	**2004**	**Mean**	**2002**	**2003**	**2004**	**Mean**	**2002**	**2003**	**2004**	**Mean**
SITE1	CONTR	30.3	31.4	31.1	30.9	8.4	9.1	9.4	9.0	9.8	8.3	8.0	8.7
	MIXT1	36.0	37.5	38.9	37.5	10.8	9.0	9.2	9.6	8.4	7.0	7.3	7.6
	MIXT2	35.1	35.7	36.9	35.9	11.4	9.5	8.8	9.9	9.4	8.1	7.7	8.4
	MIXT3	35.0	35.9	36.6	35.8	11.4	9.5	8.7	9.9	9.1	7.7	8.2	8.3
SITE2	CONTR	31.2	32.9	31.2	31.8	11.5	11.0	9.1	10.5	9.3	8.4	7.4	8.4
	MIXT1	34.0	35.7	34.8	34.8	11.0	10.4	9.9	10.4	10.2	8.7	7.5	8.8
	MIXT2	38.1	36.7	37.0	37.3	10.0	10.1	8.6	9.6	9.0	8.5	6.9	8.2
	MIXT3	35.8	35.4	36.3	35.8	10.5	10.5	9.2	10.1	9.4	9.1	7.5	8.7
Mean													
SITE1		34.1	35.1	35.9	35.0	10.5	9.3	9.0	9.6	9.2	7.8	7.8	8.3
SITE2		34.8	35.2	34.8	34.9	10.7	10.5	9.2	10.1	9.5	8.7	7.3	8.5
	CONTR	30.8	32.2	31.2	31.4	10.0	10.0	9.3	9.8	9.6	8.3	7.7	8.5
	MIXT1	35.0	36.6	36.8	36.1	10.9	9.7	9.5	10.0	9.3	7.9	7.4	8.2
	MIXT2	36.6	36.2	37.0	36.6	10.7	9.8	8.7	9.7	9.2	8.3	7.3	8.3
	MIXT3	35.4	35.6	36.5	35.8	10.9	10.0	9.0	10.0	9.3	8.4	7.9	8.5
Anova (Sign.[1]/LSD[1]):													
Location		NS	NS	*/1.0	NS	NS	*/1.0	NS	NS	NS	***/0.5	*/0.4	NS
Community		***/2.0	***/1.7	***/1.4	***/1.4	NS	NS	NS	NS	NS	NS	NS	NS
Location x Community		NS	NS	*/1.9	*/2.0	*/1.9	NS	NS	NS	NS	NS	NS	*/0.7

[1] Significance: NS, non significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$. LSD= Least Significant Difference ($p<0.05$)

Table 7.4. OMD (% on DM) and VEM units/kg DM of annual DM yield from sown/unsown plant communities at two locations. Abbreviations cf. Section 2.1 and 7.2

		OMD				**VEM/kg DM**			
Location	**Community**	**2002**	**2003**	**2004**	**Mean**	**2002**	**2003**	**2004**	**Mean**
SITE1	CONTR	60.8	59.2	57.6	59.2	668	663	648	660
	MIXT1	59.1	55.0	51.5	55.2	652	613	567	611
	MIXT2	59.0	57.7	52.7	56.5	647	640	580	622
	MIXT3	59.6	56.4	55.0	57.0	656	626	606	629
SITE2	CONTR	62.8	59.3	62.1	61.4	700	662	705	689
	MIXT1	61.8	55.3	55.7	57.6	677	605	619	633
	MIXT2	59.7	56.8	56.4	57.6	656	628	631	638
	MIXT3	60.7	58.5	56.0	58.4	667	645	621	644
Mean									
SITE1		59.6	57.1	54.2	57.0	656	636	600	631
SITE2		61.2	57.5	57.5	58.8	675	635	644	651
	CONTR	61.8	59.3	59.9	60.3	684	662	677	674
	MIXT1	60.4	55.1	53.6	56.4	664	609	593	622
	MIXT2	59.4	57.3	54.6	57.1	651	634	606	630
	MIXT3	60.2	57.5	55.5	57.7	661	636	614	637
Anova (Sign.[1]/LSD[2]):									
Location		*/1.4	NS	***/1.7	**/1.1	*/16	NS	**/24	**/14
Community		NS	*/2.3	***/2.4	***/1.5	*/23	*/32	***/33	***/20
Location x Community		NS	NS	NS	NS	NS	NS	NS	NS

[1] Significance: NS, not significant; *= p<0.05; **=p<0.01; ***=p<0.001

[2] LSD, least significant difference (p<0.05)

Per cut:

Mean CF per cut was characterized by a significant interaction between plant community and location and between location and mowing time (Table 7.6). Mean CF in CONTR was significantly lower than in sown communities, both at SITE1 as at SITE2. Within sown communities, mean CF was significantly higher in MIXT1 than in MIXT2 and MIXT3 at SITE1), but MIXT1 had a significantly lower mean CF than MIXT2 at SITE2.

CF was significantly lower in the regrowth cut than in the first cut at SITE2; no difference was found between cuts at SITE1.

Mean CP per cut revealed a significant interaction between location and mowing time. At both locations, the regrowth had a significantly higher mean CP than the first cut; mean CP of the first cut was significantly higher at SITE2 than at SITE1.

Table 7.5. Slopes (%. year^{-1}) of linear regression of herbage quality parameters over time (in brackets, R²). Abbreviations cf. Section 2.1 and 7.2

Location	**Community**	**CF**	**CP**	**ASH**	**OMD**	**VEM**
SITE1	CONTR	0.4	0.5	-0.9 *	-1.6 *	-10
				(0.59)	*(0.31)*	
	MIXT1	1.4 *	-0.8 *	-0.6 *	-3.8 **	-42 **
		(0.42)	*(0.51)*	*(0.46)*	*(0.74)*	*(0.71*
	MIXT2	0.9 *	-1.3 **	-0.8 ***	-3.2 ***	-33 ***
		(0.30)	*(0.66)*	*(0.84)*	*(0.88)*	*(0.79)*
	MIXT3	0.8	-1.3 **	-0.4	-2.3 *	-25 *
			(0.64)		*(0.50)*	*(0.43)*
SITE2	CONTR	0.0	-1.2 *	-0.9 *	-0.3	3
			(0.36)	*(0.46)*		
	MIXT1	0.4	-0.6 *	-1.3 ***	-3.1 **	-29 *
			(0.57)	*(0.91)*	*(0.66)*	*(0.52)*
	MIXT2	-0.6	-0.7 *	-1.0 ***	-1.6 *	-12
			(0.32)	*(0.84)*	*(0.31)*	
	MIXT3	0.3	-0.6	-0.9 *	-2.4 **	-23 *
				(0.54)	*(0.71)*	*(0.52)*

[1] Significance: NS, non significant; *= p<0.05; **=p<0.01; ***=p<0.001

[2] LSD, least significant difference (p<0.05)

[3] Slope (%. year^{-1}) of linear regression of quality parameter upon time (year)

Mean ASH per cut was only significantly affected by mowing time with the highest values in the regrowth cut.

OMD was characterized by interaction between location and mowing time and between plant community and mowing time. Unlike SITE 1, the regrowth cut at SITE 2 had a significantly higher OMD than the first cut. Within plant communities, OMD in the first cut was higher in CONTR than in the sown communities. No significant difference in OMD was found between plant communities in the regrowth cut.

Table 7.6. Contents of CF, CP, ASH (% on DM) and OMD% of cuts from sown/unsown plant communities at two locations
Abbreviations cf. Section 2.1 and 7.2

Location	Plant community	Mowing time[1]	CF			CP			ASH			OMD		
			2003	2004	Mean	2003	2004	Mean	2003	2004	Mean	2003	2004	Mean
SITE1		CUT1	36.3	35.5	35.9	7.2	6.9	7.1	7.2	7.1	7.2	54.3	55.4	54.9
		CUT2	33.3	36.7	35.0	12.2	12.5	12.4	8.6	9.0	8.8	61.1	52.0	56.6
SITE2		CUT1	36.8	35.1	36.0	9.4	8.6	9.0	8.2	6.7	7.5	54.6	56.5	55.6
		CUT2	29.5	34.0	31.8	14.5	10.8	12.6	10.2	8.9	9.5	67.1	60.2	63.6
	CONTR	CUT1	33.1	30.7	31.9	8.2	7.7	8.0	7.8	7.3	7.5	58.1	61.9	60.0
		CUT2	28.9	31.7	30.3	14.2	12.3	13.3	9.6	8.8	9.2	63.6	56.6	60.1
	MIXT1	CUT1	38.8	37.1	38.0	8.2	8.2	8.2	7.3	6.7	7.0	51.7	53.5	52.6
		CUT2	31.3	36.1	33.7	12.9	12.2	12.5	9.4	8.8	9.1	63.2	54.5	58.9
	MIXT2	CUT1	37.8	37.0	37.4	8.2	7.3	7.7	7.9	6.6	7.2	53.6	54.0	53.8
		CUT2	32.1	37.2	34.6	13.7	11.2	12.4	9.3	9.0	9.2	66.1	56.1	61.1
	MIXT3	CUT1	36.6	36.4	36.5	8.6	7.8	8.2	7.9	7.2	7.6	54.4	54.6	54.5
		CUT2	33.2	36.6	34.9	12.5	10.9	11.7	9.3	9.1	9.2	63.5	57.2	60.3
Anova (Sign./LSD[2]):														
Location			**/1.2	**/0.9	***/0.9	***/0.9	NS	***/0.6	**/0.8	NS	*/0.5	***/1.3	***/1.7	***/1.3
Plant community			***/1.6	***/1.3	***/1.3	NS	NS	NS	NS	NS	NS	**/1.8	***/2.3	***/1.8
Mowing time			***/1.2	NS	***/0.9	***/0.9	***/0.8	***/0.6	***/0.8	***/0.4	***/0.5	***/1.3	NS	***/1.3
Location x Plant community			NS	***/1.9	*/1.8	NS	NS	NS	NS	NS	NS	NS	NS	NS
Location x Mowing time			***/1.6	*/1.3	***/1.3	NS	***/1.1	*/0.9	NS	NS	NS	***/1.8	***/2.3	***/1.8
Plant community x Mowing time			NS	NS	NS	NS	NS	NS	NS	NS	NS	**/2.6	**/3.3	***/2.6
Location x Plant community x Mowing time			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

---

[1] Mowing time: CUT1, 15 June (first cut); CUT2, 15 September (regrowth cut)

[2] Significance: NS, not significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$. LSD=least significant difference ($p<0.05$)

In 2004, P content was significantly determined by location ($p<0.001$) and by mowing time ($p<0.001$) but not by plant community. No significant two way or three way interactions were found. Average P content of regrowth cut was significantly higher than average P content of the first cut (0.32% versus 0.23%; LSD=0.02%); it was significantly higher at SITE2 than at SITE1 (0.30% versus 0.26%, LSD=0.02%) reflecting higher extractable P content at SITE2. The forage quality of both cuts harvested in the field margin strips was inferior compared to intensively managed grasslands (Table 7.7).

Table 7.7. Mean ASH, CP, CF (% on DM), OMD (% on DM) and VEM units/kg DM per cut compared to quality parameters of cuts from intensively managed grassland. Abbreviations cf. Section 2.1 and 7.2

Quality parameter	Intensively managed grassland[1]	Margin strips[2]			
		SITE1		SITE2	
		First cut	Regrowth cut	First cut	Regrowth cut
ASH	9.7	6.6-7.5	8.2-9.2	7.3-7.7	9.1-10.1
CP	22.5	6.6-7.4	11.4-13.4	8.5-9.3	12.0-13.1
CF	20.0	30.7-39.4	32.3-36.6	31.8-36.7	29.5-37.8
OMD	80.0	51.8-60.2	55.4-58.2	53.3-59.8	62.5-64.8
VEM	997	574-680	613-642	588-673	691-733

[1] According to CVB (1999)

[2] Minimum and maximum values over plant communities

7.3.3 Botanical analysis

Vegetation succession in terms of importance of functional groups was analysed in Chapter 3 (Figure 3.1). In Table 7.8, the I% and significance of the most important species is shown for the year 2004. Plant species which were significantly affected by mowing regime, irrespective of location or plant community, were: *Arrhenatherum elatius*, *Elymus repens*, *Poa trivialis* and *Trifolium repens*. *A. elatius*, *E. repens*, and *P. trivialis* were significantly more important under REMOV0 than under REMOV2. Inversely, *T. repens* was significantly more important under REMOV2. For the legumes *Trifolium pratense* and *Medicago sativa,* the effect of mowing regime was significantly mediated by location irrespective of plant community. While no significant differences were found for these species at SITE2, the I% of *T. pratense* and *M. sativa* at SITE1 was significantly lower under REMOV0 than under REMOV2: as a result, the I% of legumes at SITE1 was significantly lower under REMOV0

Table 7.8. Importance (I%) of the most important species in sown/unsown plant communities under different cutting regimes at two locations, anno 2004. Abbreviations cf. Chapter 2, Section 2.1.

Location	Plant	Mowing	Monocotyledons^2										Legumes^2		
	community	regime	AGR	AREL	DAG	ELRE	FAR	HOL	LM	LP	PHP	PTR	MSA	TPR	TR
SITE1			6.9	8.1	8.6	0.4	1.4	1.1	19.1	0.3	8.0	11.6	13.3	6.0	3.3
SITE2			9.7	11.7	25.2	9.8	2.0	2.5	4.9	0.4	1.3	3.1	9.3	1.7	0.7
	CONTR		16.0	0.6	1.0	11.4	0.2	5.3	31.3	0.6	0.3	5.2	0.0	5.6	4.1
	MIXT1		2.0	19.7	8.4	3.9	1.0	1.1	3.0	0.4	14.8	6.8	17.9	3.4	1.5
	MIXT2		4.3	10.2	33.0	2.8	4.7	0.6	9.2	0.4	1.3	9.3	8.3	2.9	1.8
	MIXT3		10.9	9.2	25.2	2.3	1.2	0.1	4.4	0.2	2.1	8.0	18.9	3.6	0.5
		REMOV0	8.5	15.6	15.4	8.9	0.5	1.8	11.9	0.6	3.6	11.2	8.4	1.1	0.8
		REMOV1	6.9	6.2	17.0	3.2	2.9	1.8	13.5	0.3	4.8	5.5	13.3	4.7	2.0
		REMOV2	9.5	7.9	18.3	3.3	1.9	1.8	10.5	0.4	5.5	5.4	12.1	5.9	3.2
SITE1	CONTR		4.1	0.0	0.0	0.0	0.0	3.7	45.7	0.0	0.3	7.8	0.0	11.3	7.9
	MIXT1		3.1	16.7	2.1	0.4	0.9	0.0	5.3	0.2	25.2	11.2	23.2	4.1	1.0
	MIXT2		2.5	11.3	16.6	0.9	3.4	0.3	16.8	0.8	2.6	15.7	10.5	4.3	3.7
	MIXT3		17.9	4.4	15.7	0.5	1.5	0.3	8.5	0.3	4.0	11.9	19.5	4.5	0.6
SITE2	CONTR		28.0	1.1	1.9	22.9	0.3	6.9	16.9	1.2	0.4	2.6	0.0	0.0	0.2
	MIXT1		0.9	22.7	14.7	7.4	1.1	2.1	0.6	0.6	4.4	2.5	12.7	2.7	2.1
	MIXT2		6.1	9.0	49.3	4.7	5.9	0.9	1.6	0.0	0.0	2.9	6.1	1.6	0.0
	MIXT3		3.9	14.0	34.8	4.2	0.9	0.0	0.3	0.0	0.3	4.2	18.2	2.7	0.4
SITE1		REMOV0	11.2	14.4	4.9	1.3	0.4	1.3	21.2	0.0	5.7	17.6	7.0	1.6	1.4
		REMOV1	4.8	4.3	11.1	0.0	1.6	0.6	19.5	0.4	9.3	8.6	16.5	6.4	3.6
		REMOV2	4.7	5.6	9.8	0.0	2.4	1.3	16.5	0.6	9.1	8.8	16.3	10.1	4.9

Table 7.8. Importance (I%) of the most important species in sown/unsown plant communities under different cutting regimes at two locations, anno 2004. Abbreviations cf. Chapter 2, Section 2.1. (continued)

Location	**Plant community**	**Mowing regime**	**Monocotyledons[2]**										**Legumes[2]**		
			AGR	**AREL**	**DAG**	**ELRE**	**FAR**	**HOL**	**LM**	**LP**	**PHP**	**PTR**	**MSA**	**TPR**	**TR**
SITE2		REMOV0	5.8	16.8	25.9	16.4	0.6	2.3	2.6	0.9	1.6	4.8	9.7	0.5	0.2
		REMOV1	9.0	8.1	23.0	6.3	4.1	3.0	7.5	0.2	0.3	2.5	10.1	3.0	0.4
		REMOV2	14.3	10.3	26.7	6.7	1.4	2.2	4.5	0.2	1.9	1.9	7.9	1.7	1.5
Anova[1]:															
Location			NS	NS	*	NS	NS	NS	*	NS	NS	**	NS	*	NS
LSD									12.0			3.3			
Plant community			*	**	***	***	*	*	**	NS	***	NS	***	NS	*
LSD				9.2			3.1	3.7	15.7				7.0		
Location x Plant community			**	NS	*	***	NS	NS	NS	NS	***	NS	NS	**	**
LSD within Location			11.9		12.3	4.0					4.2			3.4	2.8
LSD otherwise			26.7		12.7	16.7					12.4			4.0	6.0
Mowing regime			NS	***	NS	*	NS	NS	NS	NS	NS	**	**	***	*
LSD				4.4		4.6						2.9			1.5
Location x Mowing regime			**	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	**	NS
LSD within Location			5.5										4.4	3.1	
LSD otherwise			25.9										16.6	3.6	
Plant community x Mowing regime			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Location x Plant community x Mowing reg			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] Significance: NS, non significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$. LSD, least significant difference ($p<0.05$)

[2] AGR, *Agrostis stolonifera* L.; AREL, *Arrhenatherum elatius* J. & C. Presl; DAG, *Dactylis glomerata* L.; ELRE, *Elymus repens* Gould; FAR, *Festuca arundinacea* Schreber; HOL, *Holcus lanatus* L.; LM, *Lolium multiflorum* L.; LP, *Lolium perenne* L.; PHP, *Phleum pratense* L.; PTR, *Poa trivialis* L.; MSA, *Medicago sativa* L.; TPR, *Trifolium pratense* L.; TR, *Trifolium repens* L.

than under REMOV2 (10.0% versus 31.3%, LSD=5.1%). Furthermore I% of all legumes under REMOV2 was significantly higher at SITE1 than at SITE2: 31.3% versus 11.4%, LSD=13.3%.

Lolium multiflorum and *P. trivialis* were significantly more important at SITE1 than at SITE2. MIXT1 showed significantly higher I% of *A. elatius* compared to all other plant communities. CONTR showed significantly higher I% of *Holcus lanatus* and *L. multiflorum* compared to sown plant communities. At SITE2, the I% of *Agrostis stolonifera* and *E. repens* in CONTR was significantly higher than in sown plant communities while MIXT2 showed a significantly higher I% of *Dactylis glomerata* compared to other plant communties. At SITE1 the I% of *Phleum pratense* in MIXT1 was significantly higher than in all other plant communities while CONTR had a significantly higher I% of *T. pratense* and *T. repens* than sown plant communities. At SITE1, *D. glomerata* in MIXT2 and MIXT3 was significantly higher than in CONTR or MIXT1 and the I% of *A. stolonifera* was significantly higher in MIXT3 than in other plant communities.

Botanical analysis for REMOV2:

Table 7.9 shows annual I% in the different plant communities at both sites. Following significant evolutions in annual I% over time were found: an increase of *D. glomerata* and *M. sativa* and a decrease of *T. pratense* and *T. repens* in sown communities, irrespective of location; an increase of *A. elatius* in MIXT1, irrespective of location; an increase of *A. stolonifera* and *L. multiflorum* in CONTR, irrespective of location.

Compared to sown communities, CONTR showed a significantly lower mean I% of *A. elatius*, *D. glomerata*, *M. sativa*, *T. pratense* and significantly higher mean I% of *Poa annua* and *L. multiflorum,* irrespective of location (Table 7.10). At SITE2, *E. repens* and *A. stolonifera* were more important in CONTR than in the sown communities. Compared to SITE2, SITE1 revealed a significantly higher mean I% of *Lolium perenne*, *L. multiflorum*, *P. trivialis*, *Phleum pratense*, *M. sativa*, *T. pratense* and *T. repens* and a significantly lower mean I% of *E. repens*, *D. glomerata*, *A. elatius* and *A. stolonifera*.

Table 7.9. Annual importance (I%) of the most important species in sown/unsown plant communities under REMOV2 at two locations. Abbreviations cf. Chapter 2, Section 2.1

Location	Plant community	Year	Monocotyledons[1]											Legumes[1]		
			AGR	AREL	DAG	ELRE	FAR	HOLA	LM	LP	PHP	POAN	PTR	MSA	TPR	TR
SITE1	CONTR	2002	0.0	1.0	0.0	0.0	0.0	1.8	1.6	0.0	0.0	15.8	3.6	0.0	0.0	3.1
		2003	0.7	0.0	0.5	0.0	0.0	5.3	28.5	0.0	0.0	0.0	13.9	0.0	3.8	19.6
		2004	3.0	0.0	0.0	0.0	0.0	4.5	44.1	0.0	0.0	0.0	4.0	0.0	18.4	9.0
		Slope[2]	1.5*						21.3***			-7.9*			9.2**	
		R²	*0.38*						*0.92*			*0.37*			*0.69*	
	MIXT1	2002	0.0	1.3	0.6	0.0	0.6	2.5	0.0	9.3	12.7	0.0	0.9	9.3	31.1	17.8
		2003	0.0	5.9	6.2	0.0	2.4	0.0	0.7	5.7	23.9	0.0	4.9	17.5	17.6	6.8
		2004	0.0	10.7	5.3	0.0	0.9	0.0	4.3	0.7	24.9	0.0	5.9	28.0	9.4	2.3
		Slope		4.7*	2.3*			-1.2**	2.2**	-4.3*				9.3*	-10.8*	-7.8*
		R²		*0.32*	*0.25*			*0.71*	*0.71*	*0.39*				*0.48*	*0.72*	*0.50*
	MIXT2	2002	2.4	4.3	9.8	0.0	0.0	0.5	0.5	1.8	3.9	0.0	11.5	2.8	32.3	15.1
		2003	1.7	5.5	8.8	0.0	3.9	1.9	2.9	0.0	11.1	0.0	18.1	5.6	17.4	17.6
		2004	1.6	8.9	17.9	0.0	6.9	0.0	14.5	0.8	4.4	0.0	11.1	11.7	8.3	7.3
		Slope			4.1*		3.4**		7.0*					4.5*	-12.0*	-4.0*
		R²			*0.24*		*0.75*		*0.42*					*0.60*	*0.76*	*0.27*
	MIXT3	2002	1.4	2.3	5.3	0.7	0.7	0.0	2.9	4.5	0.0	0.0	14.7	5.3	25.0	18.1
		2003	4.7	0.0	8.5	0.0	4.3	0.6	2.2	4.9	2.9	0.0	23.9	12.0	13.6	13.6
		2004	14.2	2.7	16.2	0.0	1.8	0.8	3.2	1.0	6.9	0.0	14.1	25.6	4.2	1.2
		Slope	6.4*		5.5*									10.2*	-10.4**	-8.4*
		R²	*0.51*		*0.56*									*0.43*	*0.69*	*0.55*

[1] AGR, *Agrostis stolonifera* L.; AREL, *Arrhenatherum elatius* J. & C. Presl; DAG, *Dactylis glomerata* L.; ELRE, *Elymus repens* Gould; FAR, *Festuca arundinacea* Schreber; HOL, *Holcus lanatus* L.; LM, *Lolium multiflorum* L.; LP, *Lolium perenne* L.; PHP, *Phleum pratense* L.; POAN, *Poa annua* L.; PTR, *Poa trivialis* L.; MSA, *Medicago sativa* L.; TPR, *Trifolium pratense* L.;TR, *Trifolium repens* L.

[2] Slope (I%. $year^{-1}$) of linear regression of I% of species upon time (year)

Table 7.9. Annual importance (I%) of the most important species in sown/unsown plant communities under REMOV2 at two locations. Abbreviations cf. Chapter 2, Section 2.1 (continued)

Location	Plant community	Year	Monocotyledons[1]											Legumes[1]		
			AGR	**AREL**	**DAG**	**ELRE**	**FAR**	**HOLA**	**LM**	**LP**	**PHP**	**POAN**	**PTR**	**MSA**	**TPR**	**TR**
SITE2	CONTR	2002	13.2	0.0	0.9	14.9	0.0	7.7	1.1	0.0	0.0	6.3	5.8	0.0	0.9	0.0
		2003	26.2	0.0	3.1	15.6	0.0	7.8	6.4	0.0	0.0	0.8	7.0	0.0	1.6	2.1
		2004	35.7	0.0	1.3	20.9	0.0	5.0	16.2	0.0	0.0	0.0	1.0	0.0	0.0	0.0
		Slope[2]	11.2*						7.5*			-3.2*	-2.4*			
		R^2	*0.20*						*0.19*			*0.31*	*0.24*			
	MIXT1	2002	1.5	9.3	2.0	1.9	0.0	8.9	0.0	2.8	4.8	3.2	1.5	7.1	14.4	10.3
		2003	1.2	21.0	17.8	8.6	1.8	1.4	0.0	0.0	3.9	0.0	2.9	5.4	11.2	4.2
		2004	0.9	16.2	16.5	4.5	0.0	2.6	1.9	0.9	6.8	1.8	2.6	12.5	2.1	4.7
		Slope		3.5*	7.2*			-3.1**						2.7*	-6.1*	-2.8*
		R^2		*0.23*	*0.51*			*0.36*						*0.28*	*0.32*	*0.19*
	MIXT2	2002	3.9	8.9	12.6	0.0	2.2	1.4	0.0	3.3	3.2	0.0	10.8	2.6	19.0	5.0
		2003	9.9	16.8	34.3	1.0	5.5	1.6	0.0	0.0	1.6	0.1	7.7	3.2	3.0	0.0
		2004	11.1	6.7	59.1	0.0	2.8	1.3	0.0	0.0	0.0	0.2	2.4	6.0	2.7	0.0
		Slope			23.2**					-1.6*			-4.2*	1.7*	-8.2*	-2.5*
		R^2			*0.67*					*0.43*			*0.42*	*0.22*	*0.59*	*0.51*
	MIXT3	2002	4.6	7.1	21.9	0.0	0.0	5.9	0.0	2.0	1.4	0.3	3.7	4.7	15.9	7.3
		2003	7.5	17.7	16.0	3.5	2.9	0.0	0.0	0.0	1.6	0.4	8.8	7.8	6.2	0.2
		2004	9.6	18.1	29.9	1.4	2.6	0.0	0.0	0.0	0.9	0.5	1.7	13.0	2.2	1.3
		Slope			3.9*		1.3*	-2.9**		-1.0*				4.1*	-6.9***	-3.0*
		R^2			*0.19*		*0.38*	*0.70*		*0.38*				*0.23*	*0.84*	*0.52*

[1] AGR, *Agrostis stolonifera* L.; AREL, *Arrhenatherum elatius* J. & C. Presl; DAG, *Dactylis glomerata* L.; ELRE, *Elymus repens* Gould; FAR, *Festuca arundinacea* Schreber; HOL, *Holcus lanatus* L.; LM, *Lolium multiflorum* L.; LP, *Lolium perenne* L.; PHP, *Phleum pratense* L.; POAN, *Poa annua* L.; PTR, *Poa trivialis* L.; MSA, *Medicago sativa* L.; TPR, *Trifolium pratense* L.;TR, *Trifolium repens* L.

[2] Slope (I%. year^{-1}) of linear regression of I% of species upon time (year)

Table 7.10. Importance (I%) of the most important species in sown/unsown plant communities under REMOV2 at two locations in 2004 Abbreviations cf. Chapter 2, Section 2.1

Location	**Plant**	**Monocotyledonous species**^{2}											**Leguminous species**^{2}		
	community	**AGR**	**AREL**	**DAG**	**ELRE**	**FAR**	**HOL**	**LM**	**LP**	**PHP**	**POAN**	**PTR**	**MSA**	**TPR**	**TR**
SITE1	CONTR	1.2	0.3	0.2	0.0	0.0	3.9	24.8	0.0	0.0	5.3	7.2	0.0	7.4	10.5
	MIXT1	0.0	6.0	4.0	0.0	1.3	0.8	1.7	5.2	20.5	0.0	3.9	18.3	19.4	9.0
	MIXT2	1.9	6.2	12.2	0.0	3.6	0.8	6.0	0.9	6.5	0.0	13.6	6.7	19.3	13.3
	MIXT3	6.8	2.3	10.0	0.2	2.2	0.5	2.8	3.5	3.3	0.0	17.6	14.3	14.3	11.0
SITE2	CONTR	25.0	0.0	1.7	17.1	0.0	6.8	7.9	0.0	0.0	2.4	4.6	0.0	0.8	0.7
	MIXT1	1.2	15.5	12.1	5.0	0.6	4.3	0.6	1.2	5.2	1.7	2.3	8.4	9.2	6.4
	MIXT2	8.3	10.8	35.3	0.3	3.5	1.4	0.0	1.1	1.6	0.0	7.0	3.9	8.2	1.7
	MIXT3	7.2	14.3	22.6	1.6	1.8	2.0	0.0	0.7	1.3	0.0	4.7	8.5	8.1	2.9
Mean															
SITE1		2.5	3.7	6.6	0.1	1.8	1.5	8.8	2.4	7.6	1.3	10.6	9.8	15.1	10.9
SITE2		10.4	10.2	17.9	6.0	1.5	3.6	2.1	0.7	2.0	1.0	4.7	5.2	6.6	2.9
	CONTR	13.1	0.2	1.0	8.6	0.0	5.4	16.3	0.0	0.0	3.8	5.9	0.0	4.1	5.6
	MIXT1	0.6	10.7	8.1	2.5	1.0	2.6	1.2	3.2	12.8	0.8	3.1	13.3	14.3	7.7
	MIXT2	5.1	8.5	23.8	0.2	3.5	1.1	3.0	1.0	4.0	0.0	10.3	5.3	13.8	7.5
	MIXT3	7.0	8.3	16.3	0.9	2.0	1.2	1.4	2.1	2.3	0.0	11.2	11.4	14.3	6.9
Anova (Sign./LSD^1**)**															
Location		*/7.0	**/4.3	***/5.6	*/5.3	NS	NS	**/4.7	*/1.5	**/3.5	NS	***/2.5	*/3.4	***/3.4	***/3.5
Community		NS	*/6.1	***/8.0	NS	***/2.0	NS	***/6.7	*/2.1	***/4.9	*/2.6	***/3.5	***/5.6	**/4.8	NS
Location x Community		*/14.0	NS	NS	*/10.5	NS	NS	NS	NS	*/7.0	NS	*/5.0	NS	NS	NS

[1] Significance: NS, not significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$. LSD, least significant difference ($p<0.05$)

[2] AGR, *Agrostis stolonifera* L.; AREL, *Arrhenatherum elatius* J. & C. Presl; DAG, *Dactylis glomerata* L.; ELRE, *Elymus repens* Gould; FAR, *Festuca arundinacea* Schreber; HOL, *Holcus lanatus* L.; LM, *Lolium multiflorum* L.; LP, *Lolium perenne* L.; PHP, *Phleum pratense* L.; POAN, *Poa annua* L.; PTR, *Poa trivialis* L.; MSA, *Medicago sativa* L.; TPR, *Trifolium pratense* L.; TR, *Trifolium repens* L.

7.4 Discussion and conclusions

Despite zero fertilization, mean annual DM yield of sown/unsown unfertilized field margin strips was quite high during the first three successional years (between 7 360 and 12 470 $kg.ha^{-1}$) reflecting a high nutrient richness of the soil in these plots, formerly used as arable land. Annual DM yield increased significantly over time irrespective of plant community, mowing regime or location. Changes in species composition might explain this increase. Apparently the nutrient stocks were high enough to allow high yields despite a mineral depletion owing to the removal of cuttings, as reflected by significantly decreasing ash contents over time. High nutrient stocks in soil and high yields during the succession period are also reported by other researchers. Marrs (1993) reports very high nutrient levels on arable land in Western Europe as a result of the application of large amounts of inorganic fertilizers over the last 50 years. Soils tend to contain high levels of P and K, while N may be relatively low due to leaching (Sinclair et al., 1992). From a nature conservation viewpoint such soils must be depleted of P. Knowing the P status of the soil, 27 mg P per100 g dry soil at SITE1 and 75 mg at SITE2 the P stock in the uppermost 30 cm of the rooting zone is estimated at 1215 $kg.ha^{-1}$ at SITE1 and 3375 $kg.ha^{-1}$ at SITE2. Under removal of cuttings the P export was calculated as 32.8 kg. ha^{-1} $year^{-1}$ at SITE1 and 25.6 kg. ha^{-1} $year^{-1}$ at SITE2. This corresponds to a theoretical P export during the period 2002-2004 of 0.73 and 0.57 mg P per 100 g dry soil per year. Assuming no loss of P and assuming similar annual yields in the years to come (which is very probable an overestimation) it could take 30 years at SITE1 and 123 years at SITE2 to deplete soil P up to levels of about 5 mg P per 100 g dry soil; the latter concentration being the optimal concentration in order to promote a botanical rich vegetation (Janssens et al., 1997). Similar results were found by Gough & Marrs (1990) and Johnston & Poulton (1977) revealing timespans between 4 and 11 years to >70 years for the initial residual P to decline to levels typical of semi-natural grassland, depending on the amount remaining in soil and the management applied.

Surprisingly, annual DM yield was not significantly affected by mowing regime. Although the removal of the cuttings took away quite a lot of nitrogen, potential DM yield losses due to the depletion of nitrogen, were probably compensated by the yield stimulating effect of nitrogen fixing legumes, which were more important when cuttings were removed than when cuttings remained on the field. This hypothesis is underpinned by the correspondence between higher yields in sown plant communities and higher importance of legumes at SITE1. Annual DM yield of the unsown community was significantly lower than of sown communities irrespective of location. However the difference in annual DM yield between sown and unsown community decreased over time. Initially, the unsown community showed a higher importance of low productive annuals which were quickly replaced by more productive perennial grasses and to a lesser degree by perennial legumes.

Mean digestibility of the forage was extremely low (below 60%) irrespective of plant community or location. Similar low values for digestibility were found by Kirkham & Tallowin (1995) and Kirkham & Wilkens (1994) for semi-natural grasslands with a delayed cutting time. At mid-June most of the grasses and legumes as *M. sativa* are at an advanced stage of phenological maturity, characterized by a high proportion of lignin an structural carbohydrates in the dry matter thus reducing digestibility (Chesson et al., 1995).

The digestibility of herbage from sown communities containing a high proportion of bred grass and legume varieties was significantly lower than the digestibility of herbage from the unsown community.

Differences in digestibility between sown and unsown community were attributable to difference in species composition during succession. Compared to sown communities, unsown communities were characterized by a significantly higher importance of late flowering grasses (e.g. *A. stolonifera*) and dicotyledons. Peeters & Janssens (1998) found that the digestibility of dicotyledonous species such as *Ranunculus repens* and *Rumex acetosa* decreased slower than the digestibility of grasses. Inversely, sown communities had significantly more early flowering grasses such as *D. glomerata* and *A. elatius*, and legumes particularly of *M. sativa* and *T. pratense*. It is well documented that the digestibility of stemmy lucerne, and to a lesser extent of flowering red clover, is very low (Hacker & Minson, 1981; Wilman & Altimimi, 1984; Armstrong et al., 1986; McDonald et al., 1988; Holmes, 1989).

During the monitoring period annual digestibility of the forage significantly decreased at a faster rate in the sown plant communities than in the unsown plant communities. The first cut, taken around mid-June, allowed early flowering grasses, abundantly present in sown communities, to survive and to spread a part of their seeds before the cutting time. As a consequence the importance of these species generally increased over time. The share of these grasses was very low in the unsown plots.

The significantly higher digestibility of the forage harvested at SITE2 compared to SITE1 may be due to the very heavy first cuts at SITE 1.

Annual crude protein content significantly decreased over time in sown communities irrespective of location very probably because of the corresponding decrease in importance of the legumes *T. pratense* and *T. repens*. On the contrary annual crude protein content of the unsown community at SITE1 increased over time and this goes along with an increase of *T. pratense* and *T. repens*.

Mean DM yield and quality differed between the mid-June cut and the regrowth cut in mid September. As expected, the first cut significantly outyielded the second cut with 77-122% depending on the site. Not surprisingly, herbage quality was higher in the regrowth cut than in the first cut, but its digestibility remained below 65% because of leaf senescence and occurrence of flowering species such as *M. sativa* and *L. multiflorum*. For similar reasons discussed above, the unsown community showed a higher mean digestibility, lower crude fibre content and a higher mean crude protein content within each cut.

As indicated in Table 7.10, the quality of the herbage harvested in the field margins is by all means inferior to the quality of herbage produced on intensively managed dairy farms. If one wants to use the harvested material as a forage it is recommended to modify the initial species composition during installation of the field margins. As long as management agreements for field margins prescribe not to mow before mid-June, it might be beneficial to compose initial sowing mixtures with forage species with a late flowering time and maturity or with species which show a slow decrease in digestibility when ageing. The incorporation of *M. sativa* in our mixtures, in order to improve the forage value, was no success.

However it might be beneficial both for agriculture as well as for species diversity to take the first cut earlier in the season, e.g. around half May: digestibility of the mown product will be higher and the mineral export and hence depletion of soil will be maximized as showed by Nevens & Reheul (2002). An earlier cut will offer opportunities to a series of wildflower species to grow and to reproduce during summertime because grass growth in the aftermath will be slowed down. When, after several years of mineral depletion biomass yields have dropped substantially, the first cut might be delayed again in order to allow seed set of early flowering species. From the same viewpoint, sowing productive legume-rich perennial margins are preferable to unsown field margins in order to accelerate mineral depletion of the soil driven by the extra nitrogen input by the legumes: the extra nitrogen input initially provokes the development of a high biomass volume, extracting a lot of P and K. The legumes are expected to decrease over time, which was demonstrated in this research for *T. pratense* and *T. repens*; *M. sativa* did not yet decrease during the the monitoring period.

The removal of cuttings from margin strips, as imposed in many management agreement prescriptions of botanically managed margin strips, is a controversial issue to farmers, who are particularly concerned about the on farm valorisation of the cuttings (Hopster & van de Voort, 2004).

The quality of the harvested produce is too low to be used as a regular forage for highly productive livestock. However herbage or hay from field margins might be used as a source of crude fibre in feeding rations for non lactating cows or heifers. A good solution is to use it as a feed for horses requiring a tasteful energy-low and protein-low hay. An alternative destination is its use as a component in farmland compost. Indeed, quite a lot of the material harvested in our experiments went either to horse feeding or was used for compost making.

However studies by Wilman & Riley (1993) indicated that *in vitro* digestibility does not offer a conclusive indication of the potential feeding value of forages containing wildflower species. The occurrence of dicotyledonous species in field margin strips may therefore have an unexpected positive influence upon the intake of hay and on the digestibility of the entire forage. Furthermore tissues of dicot species are easier to break down in the rumen than those of grasses (Wilman et al. 1997), again boosting a higher intake than forecasted by standard quality analyses.

This research revealed that annual DM yield was not affected by mowing management. DM yield of sown/unsown communities converged over time. Compared to herbage from intensively managed fertilized grassland, the feeding value of herbage from field margins was extremely low, owing to a low crude protein content, a low digestibility and a high crude fibre content. The unsown community delivered a forage with a higher quality than plant communities sown to bred commercially available grassland varieties. Both digestibility and crude protein content decreased over time irrespective of plant community or location, owing to a changing botanical composition. Mid June cuts were more productive than mid

September cuts but their digestibility and crude protein content were lower. The use of herbage from field margins as hay for horses or as a component in farmland compost are good alternatives to the limited use in the rations of ruminants.

Chapter 8

Soil mineral nitrogen under field margin vegetations bordering arable crops

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Chapter 8

Soil mineral nitrogen under field margin vegetations bordering arable crops

8.1 Introduction

Arable field boundaries play an important role in the agricultural landscape since they provide a habitat for a range of perennial plant species as well as food, shelter and movement corridors between hatitats for a multitude of animal species (Kleijn, 1997). However, botanical diversity in semi-natural pre-existing boundaries has declined considerably in recent decades (Bunce et al., 1994) mainly due to disturbances caused by modern agricultural activities on adjacent arable fields such as close ploughing, misplacement of fertilizer or drift of herbicides (Willis, 1963; Marshall, 1987; Freemark & Boutin, 1995; Hald, 2002). The remaining plant species are associated with eutrofic and productive biotopes (Hald, 2002). Furthermore weed problems in boundary strips are worsened by herbicide drift (Boatman, 1992) or herbicide use in ditch banks or hedge bottoms (de Snoo & Wegener Sleeswijk, 1993) favouring strong rhizomatous species such as *Urtica dioica*, *Elymus repens*, *Calystegia sepium* and *Cirsium arvense*. Also fauna in pre boundaries is affected by modern agriculture. Aside from a direct mortal effect (Longley & Sotherton, 1997) on insects , agrochemical drift indirectly affects invertebrates by the loss of host plant species. Web spinning spiders are extremely sensitive to agrochemical spray drift (Samu et al., 1992; Hassall et al., 1992). Consequently organisms downstream the food web are affected, as e.g. the chicks of farmland birds like the partridge (*Perdix perdix*) (Campbell et al., 1997).

However sown or unsown nature conservation strips installed between arable crop and pre-existing boundary may act as a buffer for fauna and flora in the pre-existing boundary as shown by many authors. Compared to reference ecotones bordering permanent natural grassland, border ecotones of arable fields in crop rotation showed poorer botanical species richness (Hald, 2002). Hedges along field crops showed higher species richness when separated from the field crop by a margin strip (Hegarty et al., 1994; Moonen & Marshall, 2001). Seedlings of non-target plants in boundaries were protected from herbicide spray drift when separated from arable field with a buffer strip (Davis, 1990). Mortality rates of butterfly larvae fed on grasses from the boundary with a buffer strip were lower than those on grasses from a boundary without a buffer (Longley et al, 1997; Dover, 1994).

Margin strips may reduce nitrate leaching to surface waters (Marrs et al., 1991; Haycock & Pinay, 1993; Hefting, 2003) or function as a filter preventing runoff of sediments and agrochemicals to reach nearby habitats with susceptible or vulnerable organisms such as ditches or nature reserves (Daniels & Gilliam, 1996; Jenssen et al., 1994; Mander et al., 1997; Mersie & Seybold, 1997; Patty et al., 1997; Schultz et al., 1995; Uusikamppa & Ylaranta, 1992; Van Dijk et al., 1996; Verchot et al., 1997).

Apart from the combined effect of direct N uptake and N incorporation (immobilization) in litter, buffer strip vegetation has a significant indirect role in N removal by stimulating denitrification activity through the supply of organic matter by litter and root exudates (Hefting, 2003). Denitrification causing permanent nitrogen removal in soil was identified as the dominant process of N removal in most riparian zones (Hefting, 2003) particularly under waterlogged conditions. Hanson et al. (1994) calculated that 59% of nitrate N that entered an enriched riparian buffer was removed by denitrification.

However information is not abundant concerning mineral N rates and losses in soil horizons under field margin strips during winter months and concerning the optimal width of field margin strips to reduce mineral N content in soil. Nor are there much data about the optimal dimensions of margin strips to reduce erosion by runoff and to function as a buffer against drift of agrochemicals. Van Dijk et al. (1996) reported reductions of sediment discharge between 50 and 60, 60 and 90, and 90 and 99% for strips of 1, 4-5 and 10 m width respectively. According to Marrs et al. (1989) a strip of 6 m offered a very safe distance to prevent lethal effects from herbicides sprayed by a tractor mounted sprayer; for most herbicides 2 m wide strips were sufficient. De Snoo & de Wit (1993) and de Snoo (1995) demonstrated that the creation of a 3 m wide conservation headland reduced pesticide drift into the adjacent ditch by 95% at wind speeds of 4.5 m/s. No drift was measured in the ditch with 6 m wide buffer strips.

According to Rew et al. (1992) and Tsiouris & Marshall (1998), who studied the patterns of granular fertilizer deposition beside field margins, fertilizer misplacement is likely to occur using spinning disk applicators, the commonest type of fertilizer applicator used on farms: pneumatic applicators would reduce off-field contamination. Regular fertilizer addition in field margins is likely to encourage nitrophilous species to dominate field margin communities and have adverse effects on their botanical diversity (Boatman et al., 1994). On the long term the reduction of agrochemical drift and soil nitrogen content in the boundary might benify the development of a species rich less nitrophilous vegetation, thus reducing costs of maintenance of the boundary.

This study examines the effects of 2-3 years old sown and unsown margin strips between the boundary and the arable crop on soil mineral N content and loss during winter at two locations. In particular the following questions are adressed: (1) Can sown/unsown margin strips bordering arable crops reduce mineral N residues and loss during winter? (2) Is mineral N content and loss affected by plant community type or location? (3) Which margin width is advisable to minimize soil mineral N content and loss nearby the pre-existing boundary? (4) Is species richness and botanical composition of boundary vegetation positively affected by the presence of the margin strip?

8.2 Specific material and methods

The research was based on trial 1 (Chapter 2, Section 2.1.). Total width of the margin strip (i.e. distance from boundary to the crop) was 10 m (i.e. width of the experimental strip) at SITE2, and 20 m at SITE1, including the experimental strip which occupies the outermost 10 metres adjacent to the crop.

During both winterperiods 2002-2003 and 2003-2004, mineral N content at SITE1 and SITE2 was determined seperately in three soil horizons 0-30, 30-60 and 60-90 cm. Mineral N analysis was performed on soil samples taken at the end of the growing season (29 October 2002, 29 October 2003) and before the start of the next growing season (25 February 2003, 1 March 2004) using half-cylindrically augers of 4, 3 and 2 cm diameter for the horizon 0-30, 30-60 and 60-90 cm respectively.

Soil augering was performed at five or six augering positions along nine transects perpendicular centered to MIXT1, MIXT2 and CONTR managed under REMOV2. For the winterperiod 2002-2003, the five augering positions at each site were: one in the field crop area 10 m away from the field margin edge (position 10 m), one in the field margin edge (position 0 m) and three positions in the margin strip; SITE1: at 5, 10 and 20 m away from the margin edge (positions -5, -10 and -20 m respectively); SITE2: at 5, 7.5 and 10 m away from the margin edge (positions -5, -7.5 and -10 m respectively). The outhermost positions (position -20 m, at SITE1 and position -10 m at SITE2) were taken at the edge with the boundary. For the winterperiod 2003-2004, augering positions were concentrated more around the edge with the field crop area. Augering positions for both sites were: one position in the field crop area (position 2.5 m) one position at the margin edge (position 0 m) and four positions in the margin strip (positions -1.25, -2.5, -5 and -7.5 m at 1.25, 2.5, 5 and 7.5 m respectively from the margin edge).

At each augering position three spots (at the centre and at 2 m right and left perpendicular to the augering transect) were augered. Per augering position samples were mixed for each horizon separately. Mixed samples were immediately deepfrozen prior to determination of nitrate N (NO_3-N) and ammonium N (NH_4-N) using continuous flow spectroscopy performed on ovendried soil. Nitrate N was determined according to the cadmium reduction method (ISO/DIS 14256-1, ISO/DIS 13395). Nitrate is reduced to nitrite using cadmium as the reducing agent. The resulting nitrite concentration is then determined colorimetrically. Ammonium N was determined according to the salicylate method (ISO/DIS 14256-1, ISO/DIS 11732): free ammonia reacts with hypochlorite to form monochloramine; monochloramine then reacts with salicylate, in the presence of sodium nitro-ferricyanide, to form 5-aminosalicylate, a green colored complex. Amounts ($kg.ha^{-1}$) of soil NO_3-N and NH_4-N in each soil horizon were calculated by multiplying the laboratory contents ($mg\ N.kg^{-1}$ ovendry soil) with specific apparent gravity of soil and horizon volume. Mineral nitrogen (Nmin, $kg.ha^{-1}$) in each soil horizon was calculated by adding amounts of NO_3-N and NH_4-N. Amounts of Nmin, NO_3-N and NH_4-N in the soil horizon 0-90 cm (hereafter called total Nmin, total NO_3-N and total NH_4-N respectively) was calculated by adding individual amounts in each soil horizon.

Over each winterperiod Nmin loss ($kg\ N.ha^{-1}$) during winter was estimated by subtracting the residual Nmin at the end of October from Nmin at the end of February of the next year.

Residual Nmin after the growing season (i.e. Nmin amount at the end of October) were compared with the Flemish legislative limit: according to this legal prescription no more than 90 kg NO_3-$N.ha^{-1}$ should be present in the soil horizon up to 90 cm of depth (Vlaamse

Regering, 2000). This level was established in order not to exceed maximum concentration of 50 mg nitrate.L^{-1} or 11.3 mg N.L^{-1} in surface and groundwater as stipulated in the European Nitrate Directive (Anonymus, 1991).

The composition of the flora of the adjacent boundary was measured prior to installation (2001) and yearly during the period 2002-2004, on a Tansley (1954) scale explained in Section 2.2 (Chapter 2).

ANOVA (SPSS10 for windows) was used for statistical calculations of Nmin, NO_3-N, NH_4-N amounts under REMOV2.

8.3 Results

8.3.1 Soil Nmin analysis

Winter 2002-2003 (Tables 8.1, 8.2):

At SITE2 residual total Nmin at the end of October 2002 was significantly determined by augering position and not by plant community (Table 8.2). At SITE1 no significant factors were found (Table 8.1). At SITE2 total Nmin was significantly higher in the field crop area (positions 10 m and 0 m) than in the field margin strip. In the field margin strip, total Nmin decreased up to 7.5 m away from the edge with the crop but increased again towards the edge with the pre-existing boundary. Similar results were found at SITE1 but Nmin in the field margin strip continued to decrease with increasing distance from the crop edge. Between sites, total Nmin was two to threefold higher at SITE2 irrespective of augering position. Furthermore MIXT1 revealed a higher, but not significant, total Nmin than MIXT2 and CONTR irrespective of location.

Augering position significantly determined total NH_4-N at SITE2 but not at SITE1 at the end of October 2002. Contrary to total NO_3-N and Nmin, total NH_4-N in the crop area was not significantly higher than NH_4-N in the field margin strip irrespective of location. But at SITE2, total NH_4-N was significantly higher at position -10 m than at any other position. Within the field margin strip at SITE2, total NH_4-N exceeded total NO_3-N : the closer the pre-existing boundary, the more NH_4-N.

Table 8.1. Nmin loss (kg N.ha^{-1}) during winter 2002-2003 and soil NH_4-N, NO_3-N and Nmin (kg N.ha^{-1}) on 29 October 2002 and 25 February 2003 along transects perpendicular to sown/unsown margin strips at SITE1. Abbreviations cf. Chapter 2, Section 2.1

Community	**Position**	**29 October 2002**			**25 February 2003**			**N loss**[1]
		NH_4-N	**NO_3-N**	**Ntot**	**NH_4-N**	**NO_3-N**	**Ntot**	
CONTR	**-20**	29.9	44.7	74.6	47.5	66.1	113.6	-39.0
	-10	31.1	43.4	74.5	47.9	42.4	90.2	-15.7
	-5	33.1	32.8	65.9	41.7	39.7	81.4	-15.5
	0	29.1	53.1	82.1	44.5	63.7	108.2	-26.0
	10	35.0	55.6	90.5	62.3	98.2	160.4	-69.9
MIXT1	**-20**	29.9	44.3	74.2	63.8	68.0	131.8	-57.6
	-10	34.1	54.7	88.9	51.9	60.4	112.3	-23.5
	-5	32.4	56.2	88.6	64.9	60.5	125.4	-36.8
	0	38.3	48.8	87.1	72.5	48.8	121.3	-34.2
	10	35.4	76.4	111.8	83.6	87.6	171.2	-59.4
MIXT2	**-20**	21.8	30.5	52.2	59.9	48.2	108.1	-55.9
	-10	29.9	39.8	69.7	43.0	40.2	83.2	-13.5
	-5	36.2	36.7	72.9	50.7	25.7	76.4	-3.5
	0	37.2	31.2	68.4	57.2	42.7	99.9	-31.5
	10	35.0	56.3	91.3	93.5	93.3	186.8	-95.5
Mean								
	-20	27.2	39.8	67.0	57.1	60.8	117.8	-50.8
	-10	31.7	46.0	77.7	47.6	47.7	95.2	-17.6
	-5	33.9	41.9	75.8	52.4	42.0	94.4	-18.6
	0	34.9	44.3	79.2	58.1	51.7	109.8	-30.6
	10	35.1	62.8	97.9	79.8	93.0	172.8	-75.0
Anova (Sign./LSD[2])								
Community		NS	NS	NS	NS	NS	NS	NS
Position		NS	NS	NS	NS	***/22.4	*/46.6	**/31.8
Community x Position		NS	NS	NS	NS	NS	NS	NS

[1] N loss=Nmin on 29 October - Nmin on 25 February

[2] Significance: NS, non significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$
LSD, least significant difference ($p<0.05$)

Table 8.2. Nmin loss (kg N.ha^{-1}) during winter 2002-2003 and soil NH_4-N, NO_3-N and Nmin (kg N.ha^{-1}) on 29 October 2002 and 25 February 2003 along transects perpendicular to sown/unsown margin strips at SITE2 Abbreviations cf. Chapter 2, Section 2.1

Community	**Position**	**29 October 2002**			**25 February 2003**			**N loss[1]**
		NH_4-N	**NO_3-N**	**Ntot**	**NH_4-N**	**NO_3-N**	**Ntot**	
CONTR	**-10**	115.4	16.9	132.2	129.2	33.3	162.5	-30.2
	-7.5	82.0	52.5	134.5	99.6	36.2	135.9	-1.4
	-5	78.0	50.9	128.9	96.0	42.9	138.9	-10.0
	0	106.1	80.0	186.2	111.6	35.2	146.8	39.4
	10	74.2	148.1	222.3	84.7	37.0	121.6	100.7
MIXT1	**-10**	115.4	38.0	153.3	202.5	49.0	251.5	-98.2
	-7.5	90.0	40.1	130.1	102.5	42.1	144.6	-14.6
	-5	85.9	57.7	143.6	105.5	50.9	156.4	-12.9
	0	98.9	105.0	203.9	108.7	45.4	154.1	49.9
	10	86.1	153.1	239.2	104.7	65.0	169.7	69.5
MIXT2	**-10**	117.2	43.5	160.6	149.1	49.5	198.6	-38.0
	-7.5	79.0	48.2	127.2	105.4	50.9	156.3	-29.1
	-5	90.0	40.8	130.8	102.2	45.5	147.7	-16.9
	0	94.4	122.6	216.9	105.8	56.5	162.3	54.6
	10	75.7	130.6	206.3	90.2	40.6	130.8	75.5
Mean								
	-10	116.0	32.8	148.7	160.3	43.9	204.2	-55.5
	-7.5	83.7	46.9	130.6	102.5	43.1	145.6	-15.0
	-5	84.6	49.8	134.4	101.2	46.4	147.7	-13.3
	0	99.8	102.5	202.3	108.7	45.7	154.4	48.0
	10	78.7	143.9	222.6	93.2	47.5	140.7	81.9
Anova (Sign./LSD[2])								
Community		NS	NS	NS	NS	NS	NS	NS
Position		**/18.1	***/52.4	**/50.4	**/32.9	NS	NS	*/84.1
Community x Position		NS	NS	NS	NS	NS	NS	NS

[1] N loss=Nmin on 29 October - Nmin on 25 February

[2] Significance: NS, non significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$
LSD, least significant difference ($p<0.05$)

Focusing on residual total NO_3-N at the end of October 2002, the Flemish legal prescription of 90 kg NO_3-N.ha^{-1} was exceeded in the field crop area but not in the margin strip at SITE2. At SITE1 no more than 90 kg NO_3-N.ha^{-1} in the horizon 0-90 cm was found irrespective of augering position. Similar to total Nmin, total NO_3-N at SITE2 was only significantly determined by augering position with significant higher total NO_3-N in the crop area than in the field margin strip. Within the field margin strip total NO_3-N decreased from position 0 m up to position -10 m. Similar results were found at SITE1 but differences were not significant. Total NO_3-N at SITE2 were twofold higher than NO_3-N at SITE1 irrespective of augering position.

The distribution of total residual Nmin, NH_4-N and NO_3-N over the different soil horizons at SITE2 are shown in Figures 8.1A, 8.1B and 8.1C respectively (29 October 2002). Figure 8.1A revealed that total Nmin reduction in the field margin strip occurred mainly in the soil horizons 30-60 and 60-90 cm. In the crop area more than half of total Nmin was found in the horizon 30-90 cm contrary to the field margin strip with approximately 50% of total Nmin in the uppermost horizon 0-30 cm. Nmin in the horizon 30-90 was twice as high in the crop area than Nmin at position -5 m. Figure 8.1B clearly demonstrates the more flattened pattern of total NH_4-N compared to total Nmin and highlights the high value at -10 m. More than 60% of total NH_4-N was found in the upper soil horizon 0-30 cm irrespective of augering position. The steady decrease in total NO_3-N from position 10 m up to -10 m is illustrated in Figure 8.1C. Contrary to the positions inside the margin strip more than 70% of total NO_3-N was found in the deeper soil horizons in the crop area. Similar but less pronounced and more flattened patterns were found at SITE1 (figures not shown).

Compared to the residual total Nmin at the end of October 2002, total Nmin in the margin strip at the end of February 2003 was higher irrespective of location. At the end of February 2003, total Nmin at SITE2 (Table 8.2) was significantly higher at position -10 m than at all other positions except for position 0 m. At SITE1 (Table 8.1) no significant differences along the traject in the margin strip were found. The significantly higher total Nmin in the crop area was due to an early application of slurry at the end of February (cf. Chapter 2, Table 2.2). Compared to the residual total NH_4-N at the end of October 2002, total NH_4-N was higher at the end of February 2003 irrespective of augering position or location. Again position -10 m

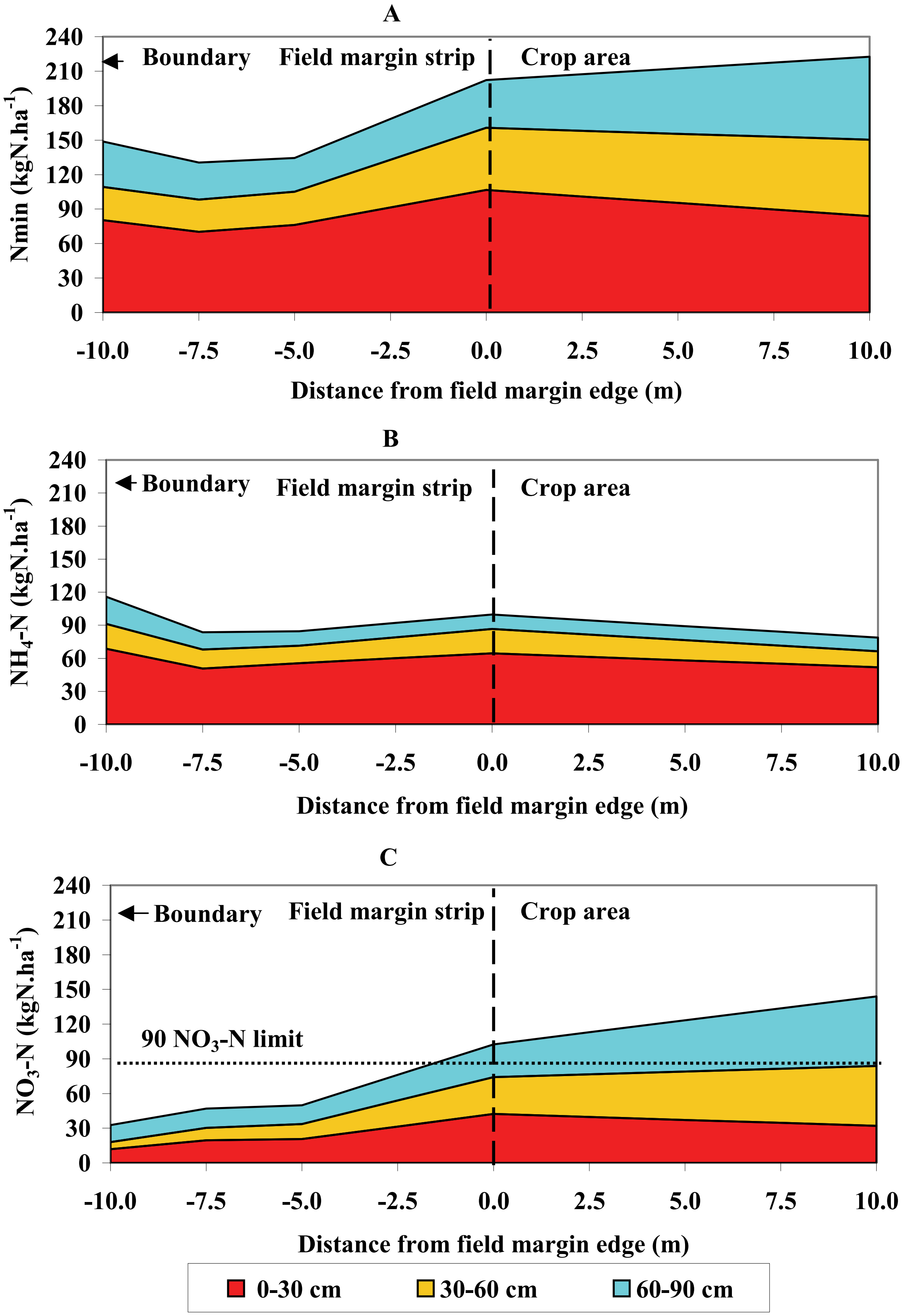

Figure 8.1. Distribution of total Nmin (A), NH_4-N (B) and NO_3-N (C) in soil horizons 0-30, 30-60 and 60-90 cm related to distance from the crop edge. SITE2, 29 October 2002.

at SITE2 showed a significantly higher total NH_4-N than all other positions. At SITE2 total NO_3-N showed no significant differences between augering positions. At SITE1, position 10 m showed a significantly higher NO_3-N compared to other positions due to the early slurry application.

Nmin loss (Tables 8.1 and 8.2) over the winterperiod 2002-2003 was significantly determined by augering position irrespective of location. At SITE2 a significant Nmin loss occurred under the crop area but we monitored a soil Nmin accrual in the field margin strip. At SITE1 no Nmin losses were found irrespective of augering position.

Winterperiod 2003–2004 (Tables 8.3, 8.4):

Compared to SITE1, SITE2 showed significantly higher total Nmin in the crop area but lower total Nmin in the field margin strip. At the end of October 2003 residual total Nmin was significantly determined by augering position at SITE2 (Table 8.4) and by augering position and plant community at SITE1 (Table 8.3).

Total Nmin under the crop area were extremely high. At SITE2 total Nmin was significantly higher at positions 2.5 and 0 m than at positions inside the field margin strip. At SITE1 total Nmin was significantly higher at position 2.5 m than at all other positions towards the crop edge and inside the margin stip. At both sites total Nmin in the field margin strip decreased asymptotically from position 0 m upto position -7.5 m except for a slight increase at position -7.5 m at SITE2. At SITE2, total Nmin averaged over all positions perpendicular to MIXT1 was significantly higher than total Nmin perpendicular to MIXT2 or CONTR.

Residual total NH_4-N at the end of October 2003 was significantly determined by augering position at SITE2. No significant factors were found at SITE1. At SITE2, total NH_4-N inside the margin strip increased with increasing distance away from the edge with the crop area. The closer to the tree lane, the higher total NH_4-N. At SITE 1, total NH_4-N was not affected by augering position.

Similar to total Nmin, residual total NO_3-N at the end of October 2003 was significantly determined by augering position at SITE2 and by augering position and plant community at

SITE1. Total NO_3-N of position 2.5 m (SITE1, SITE2) and 0 m (SITE2) farly exceeded Flemish legal prescription of 90 kg NO_3-N.ha^{-1} in the horizon 0-90 cm. No exceedings occurred inside the field margin strip. Similar to Nmin, at both sites, total NO_3-N in the field margin strip decreased asymptotically from 0 m up to position -7,5 m except for a slight increase at position -7.5 m at SITE2. At SITE1, total NO_3-N averaged over all positions perpendicular to MIXT1 was significantly higher than total NO_3-N perpendicular to MIXT2. Generally total NO_3-N was higher at SITE2 than at SITE1 irrespective of augering position.

Table 8.3. Nmin loss (kg N.ha^{-1}) during winter 2003-2004 and soil NH_4-N, NO_3-N and Nmin (kg N.ha^{-1}) on 29 October 2003 and 1 March 2004 along transects perpendicular to sown/unsown margin strips at SITE1. Abbreviations cf. Chapter 2, Section 2.1

Community	**Position**	**29 October 2003**			**1 March 2004**			**N loss**[1]
		NH_4-N	**NO_3-N**	**Ntot**	**NH_4-N**	**NO_3-N**	**Ntot**	
Mean								
CONTR		29.9	82.3	112.2	38.2	46.1	84.3	27.8
MIXT1		29.3	105.4	134.7	39.4	77.1	116.5	18.2
MIXT2		28.4	72.0	100.4	42.8	48.0	90.7	9.6
	-7.5	29.6	62.8	92.4	38.9	40.8	79.7	12.7
	-5	30.5	62.8	93.2	42.5	36.6	79.1	14.2
	-2.5	31.1	63.3	94.4	41.2	35.9	77.1	17.3
	-1.25	29.3	67.5	96.8	41.1	37.6	78.7	18.1
	0	30.8	80.0	110.8	42.3	76.2	118.5	-7.7
	2.5	23.9	183.0	206.9	34.6	115.5	150.1	56.9
Anova (Sign./LSD[2])								
Community		NS	*/26.2	*/29.3	NS	*/25.7	*/28.9	NS
Position		NS	***/37.1	***/41.5	NS	***/36.3	***/40.8	NS
Community x Position		NS	NS	NS	NS	NS	NS	NS

[1] N loss=Nmin on 29 October - Nmin on 1 March

[2] Significance: NS, non significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$
LSD, least significant difference ($p<0.05$)

Table 8.4. Nmin loss (kg $N.ha^{-1}$) during winter 2003-2004 and soil NH_4-N, NO_3-N and Nmin (kg $N.ha^{-1}$) on 29 October 2003 and 1 March 2004 along transects perpendicular to sown/unsown margin strips at SITE2. Abbreviations cf. Chapter 2, Section, 2.1

Community	**Position**	**29 October 2003**			**1 March 2004**			**N loss**[1]
		NH_4-N	**NO_3-N**	**Ntot**	**NH_4-N**	**NO_3-N**	**Ntot**	
Mean								
CONTR		61.1	120.1	181.3	61.6	46.2	107.7	73.6
MIXT1		67.6	130.3	197.9	65.5	49.2	114.8	83.1
MIXT2		62.6	131.8	194.4	58.2	52.9	111.1	83.3
	-7.5	71.0	61.7	132.8	76.3	30.1	106.4	26.4
	-5	69.4	52.0	121.4	63.1	25.5	88.6	32.9
	-2.5	70.0	61.0	131.0	60.9	26.8	87.7	43.3
	-1.25	62.9	78.0	140.9	60.4	43.1	103.4	37.5
	0	58.2	199.5	257.7	57.2	88.0	145.2	112.5
	2.5	51.1	312.2	363.3	52.8	83.1	135.9	227.4
Anova (Sign./LSD[2])								
Community		NS	NS	NS	NS	NS	NS	NS
Position		***/10.9	***/100.1	***/103.0	***/11.8	***/27.8	***/32.3	***/95.3
Community x Position		NS	NS	NS	NS	NS	NS	NS

[1] N loss=Nmin on 29 October - Nmin on 1 March

[2] Significance: NS, non significant; *= $p<0.05$; **=$p<0.01$; ***=$p<0.001$
LSD, least significant difference ($p<0.05$)

The distribution of total Nmin, NH_4-N and NO_3-N over the different soil horizons at SITE2 are shown in Figures 8.2A, 8.2B and 8.2C respectively. Nmin reduction in the field margin strip occurred mainly in the soil horizons 30-60 and 60-90 cm. Compared to the field crop area, Nmin in the horizon 30-90 cm was eightfold higher than Nmin at position -5 m. Procentile contribution of the horizon 30-90 cm in total Nmin was approximately 70% in the field crop area and 50% in the field margin strip. Half of total NH_4-N was found in the uppermost horizon irrespective of position. The steady decrease in total NO_3-N from position 2.5 m up to -5 m is illustrated in Figure 8.2C. Contrary to positions inside the margin strip approximately 70% of total NO_3-N in the field crop area was found in deeper soil horizons

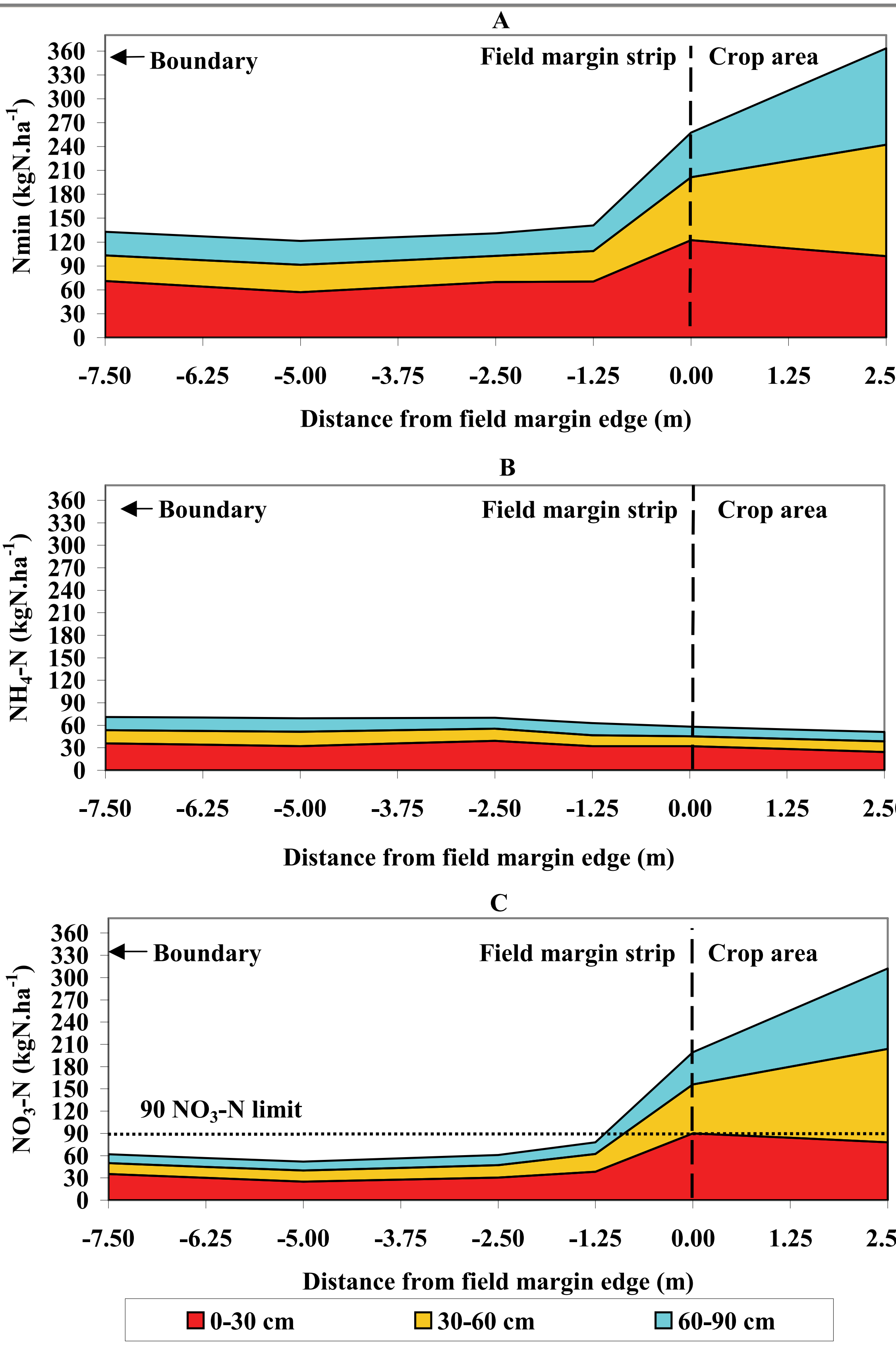

Figure 8.2. Distribution of total Nmin (A), NH_4-N (B) and NO_3-N (C) in soil horizons 0-30, 30-60 and 60-90 cm related to distance from the crop edge. SITE2, 29 October 2003.

30-60 and 60-90 cm. The reduction in NO_3-N inside the margin strip was higher in the deeper soil horizons 30-60 and 60-90 cm than in the uppermost soil horizon. Similar but less pronounced, more flattened patterns were found at SITE1.

On 1 March 2004 total Nmin was significantly determined by augering position at SITE2 (Table 8.4) and by augering position and plant community at SITE1 (Table 8.3). A SITE2, total Nmin amounts in the crop area were significantly higher than at positions inside the field margin strip except for the outermost position -7.5 m. Total Nmin inside the field margin strip decreased upto position -5 m and increased again at position -7.5 m. At SITE1 position 2.5 m was significantly different from all other positions with a minimum Nmin at position -2.5 m; total Nmin perpendicular to MIXT1 was significantly different from total Nmin perpendicular to CONTR. Total Nmin in the field area (position 0 m and 2.5 m) at SITE1 were influenced by early sow slurry application at the end of February 2004 resulting in a underestimation of Nmin loss under the crop area.

Total NH_4-N on 1 March 2004 was not determined by augering position at SITE1 contrary to SITE2. At SITE2 , total NH_4-N increased from the crop area to the edge with the pre-existing boundary.

On 1 March 2004, total NO_3-N at both sites was significantly higher in field crop area than inside the margin strip. In the margin strip total NO_3-N decreased from position 0 to -2.5 m and from position 0 to -5 m for SITE1 and SITE2 respectively and increased again closer to the pre boundary. At SITE1 total NO_3-N was significantly higher perpendicular to MIXT1 than perpendicular to CONTR and MIXT2. Patterns of total NO_3-N followed at best patterns of total Nmin.

Nmin loss over the winterperiod 2003-2004 (Tables 8.3 and 8.4) was solely significantly determined by position at SITE2. No significant factors were found for Nmin loss at SITE1. Inside the field margin strip Nmin loss decreased with increasing distance from the edge with the field crop area. Inside the field margin Nmin loss was minimal at 7.5 m from the edge with the field crop, irrespective of location. Under the field crop area, extreme high Nmin losses were found particularly at SITE2. At SITE1 Nmin loss under MIXT1 was not significantly higher than Nmin under CONTR or MIXT2 despite the significantly higher residual total Nmin at the end of October 2003 under MIXT1.

8.3.2 Botanical analysis

The evolution of the floristic composition of the boundary at SITE2 in 2001 is shown in Table 8.5. Due to the presence of a tree row (50 year old oaks) and a small ditch, boundary vegetation comprised plant species from dry (such as *Teucrium scorodonia*, *Cytisus scoparius*, *Jasione montana*,...) to moist (such as *Polygonum amphibium*, *Juncus effusus*, *Galium palustre*,...) habitats and forbs thriving in nutrient poor (such as *Anthoxanthum odoratum*, *Ornithopus perpusillus*, *Calluna vulgaris*,...) to nutrient rich (such as *Urtica dioica*, *Rumex obtusifolius*, *Elymus repens*,...) soils.

Three years after installation of the margin strip, species diversity was higher compared to the species diversity prior to installation. Slow growing non nitrophilous species such as *Geranium molle*, *Stellaria graminea*, *Veronica chamaedrys*, *Viola arvensis*, *Cerastium fontanum*, *Hypericum dubium* and more in particular leguminous species such as *Ornithopus perpusillus*, *Medicago lupulina* and *Vicia hirsuta* did not occur prior to installation of the margins strip but were present after installation. None of these species originated from sowing mixtures of the margin strip. Aside from changes in species composition, also changes in species abundance occurred over the 4 year period. Some species preferring low soil fertility such as *Calluna vulgaris*, *Anthoxanthum odoratum*, *Rumex acetosella*, *Festuca rubra* and *Cytisus scoparius* already present prior to installation became more abundant after installation. Over the 4 year period abundance of nitrophilous species such *Urtica dioica*, *Rumex obtusifolius* and *Rubus idaeus* was not greatly affected.

Species richness of the boundary at SITE1 remained stable over the period 2001-2004 with 46 species prior to installation and 47 species three years after installation of the field margin strip. The boundary vegetation (data not shown) was highly nitrophilous with high abundance of *Arrhenatherum elatius*, *Urtica dioica*, *Heracleum* spp., *Calystegia sepium*, *Galium aparine* and *Rumex obtusifolius*. Indicator species from moist conditions such as *Arctium minus*, *Bidens tripartita*, *Heracleum mantegazzianum*, *Symphytium officinale*, *Scrophularia auriculata* were present. No clear changes in species composition or abundance occurred over the 4 year period. Nevertheless some wildflower species such as *Hypericum perforatum*, *Torilis japonica* and *Scrophularia auriculata* absent prior to installation, were found three years after installation.

Table 8.5. Composition of the flora (on a Tansley scale) of the boundary at SITE2, prior to and after the installation of sown/unsown margin strips

Group	**Plant species**	**Occurrence on a Tansley scale** [1]			
		Prior to installation	**After installation**		
		June 2001	**July 2002**	**June 2003**	**June 2004**
Forbs	*Achillea millefolium*	o	f	o	o
	Calluna vulgaris	sl	sl	o	o
	Cerastium fontanum			s	s
	Crepis capillaris	o	r	s	o
	Cytisus scoparius	o	f	f	f
	Epilobium angustifolium	o			
	Epilobium montanum	r	r		
	Galeopsis tetrahit	r	r		
	Galium aparine			r	o
	Galium palustre	rl	o	o	o
	Geranium molle			r	o
	Glechoma hederacea			s	
	Hieracium umbellatum	ol	f	fl	o
	Hypericum dubium			s	o
	Hypericum perforatum	f	a	f	f
	Hypochaeris radicata	ol			
	Jasione montana	fl	f	f	f
	Lamium purpureum				o
	Leontodon autumnalis	r			
	Lotus corniculatus	o	o	o	s
	Lysimachia punctata	o	o	o	o
	Medicago lupulina			o	o
	Ornithopus perpusillus		r	o	o
	Plantago major	o	o		
	Polygonum amphibium	ol	r	ol	o
	Polygonum hydropiper	ol	ol	ol	ol
	Polygonum lapathifolium			s	
	Ranunculus repens	o	o	o	o
	Rumex acetosella	r	o	o	o
	Rumex axetosa	o	o	o	o
	Rumex crispus	r	r		
	Rumex obtusifolius	o	ol	o	f
	Sisymbrium officinale				s
	Solidago virgaurea	s	sl		
	Stellaria graminea				s
	Taraxacum officinale	o	o	s	
	Teucrium scorodonia	ol	ol	o	f
	Trifolium repens	o	o		o
	Urtica dioica	f	al	al	f

Table 8.5. Composition of the flora (on a Tansley scale) of the boundary at SITE2, prior to and after the installation of sown/unsown margin strips (continued)

Group	Plant species	Occurrence on a Tansley scale [1]			
		Prior to installation	After installation		
		June 2001	July 2002	June 2003	June 2004
Forbs	*Veronica chamaedrys*				s
	Vicia hirsuta			o	s
	Vicia sativa			f	f
	Viola arvensis				s
Grasses	*Agrostis stolonifera*	o	o	f	d
	Arrhenatherum elatius	o	o	f	f
	Athoxanthum odoratum	fl	fl	al	al
	Bromus sterilis				s
	Dactylis glomerata	o	o	o	o
	Elymus repens	o	o	a	a
	Festuca rubra	r	r	f	f
	Holcus lanatus	f	f	o	o
	Lolium perenne	r	r	s	
	Phalaris arundinacea	ol	ol	ol	ol
	Poa annua			o	
	Poa trivialis	o	o	f	f
Rushes	*Juncus bufonius*				o
	Juncus effusus	o	f	o	f
	Luzula campestris			s	
Schrubs	*Prunus serotina*			o	o
	Rubus idaeus	f	d	f	f
Trees	*Pinus sylvestris*			r	r
	Quercus robur	r	r	r	r
	Quercus rubra	a	a	a	a
	Sorbus aucuparia			s	s
Total species number (spp.)		42	40	48	49

[1] Tansley scale (in order of importance): s=sporadic; r=rare; o=occasional; f=frequent; a=abundant; d=dominant, followed by "l" in case species occurred only locally

8.4 Discussion and conclusions

At the end of the growing season, residual Nmin in the soil horizon 0-90 cm in the crop area was high at SITE2 owing to the high carbon level. The installation of a field margin strip, separating the pre-existing boundary and the crop area, decreased residual Nmin significantly close to the boundary. This reduction occurred in the deeper soil horizons 30-60 and 60-90 cm which are more prone to mineral leaching. At 5 m inside the field margin strip Nmin was reduced by approximately 50% to 70% compared to Nmin under the crop area. At the end of the growing season, NO_3-N in the field margin strip never exceeded Flemish legal prescription of 90 kg residual NO_3-N.ha^{-1} in the horizon 0-90 cm contrary to the field crop area. Within the margin strip, NO_3-N significantly decreased with increasing distance away from the crop edge, irrespective of location or augering year. Similarly Schultz et al. (1995) found in a multi-species riparian buffer strip along a stream in Iowa a reduction in NO_3-N contents from 12 mg.L^{-1} in adjacent arable field to levels never exceeding 2 mg.L^{-1} in the buffer strip. The reduced amounts of residual soil NO_3-N under the margin strip might be attributed to zero fertilization, periodic removal of biomass, N immobilization in decomposing litter and denitrification in winter stimulated by the supply of organic matter by litter and root exudates (Hanson et al, 1994; Lyons et al., 2000; Hefting, 2003).

Contrary to NO_3-N, NH_4-N in the margin strip at SITE2 increased with increasing distance from the crop edge. This was attributable to the presence of a row of fifty years old oaks in the boundary. Nearby tree rows soil pH is offenly low due to the acidifying effect of nitrification of leaf litter (Van Breemen et al., 1982). Consequently during litter decomposition, the organic matter input nearby tree rows was mainly ammonified instead of nitrified under conditions of low pH since the activity of nitrifying bacteria is reduced at pH-KCl below 6.0 (Fenchel et al., 1998). As a result ammonium accumulates in the topsoil nearby the boundary. Furthermore nitrification may also be inhibited by tannins, phenolics under deciduous forest trees (Fenchel et al., 1998). So, aside from the adjacent crop area, soil Nmin in the field margin strips was also influenced by the semi-natural vegetation of the boundary. The positive charged ammonium ions are absorbed and fixed on the negative charged soil particles thus avoiding leaching.

In the margin strips Nmin losses during winter were, if any, significantly lower than in the crop area. This is attributable to the lower amounts of residual Nmin and NO_3-N particularly in the soil horizon 30-60 and 60-90 cm. So, a perennial vegetation at the edges of fields might reduce nitrogen leaching into watercourses. This is in agreement with Marrs et al. (1991) who demonstrated that rates of nitrogen loss were higher on arable soils left fallow than on arable land sown with perennial rye-grass or under grassland.

Field margin type did not significantly determine Nmin loss despite the significantly higher residual Nmin and NO_3-N under the clover-rich sown community (MIXT1 at SITE1) as a result of symbiotic nitrogen fixation (see also Chapter 3, Figure 3.1 and Chapter 7, Table 7.9). However, a major part of soil Nmin was found in the uppermost horizon where it is less prone to leaching.

Recently installed field margin types showed only small differences in mineral nitrogen. These small differences will presumably not increase during further succession since vegetation compositions of sown/unsown plant communities becomes increasingly look-alike over time (De Cauwer et al., 2005; Chapter 3 and 4). N export through the removed biomass will be comparable over time owing to the converging biomass production of sown/unsown plant communities over time and similar N contents of the harvested produce (see also Chapter 7). Also other studies (Lyons et al., 2000; Sabater et al., 2003) indicated no significant difference in N removal between vegetation types.

Taken into account the asymptotically decreasing pattern of Nmin and NO_3-N, a field margin strip of 5 m width sufficiently reduced soil Nmin and Nmin losses. At greater width no extra reduction in soil Nmin or Nmin loss occurred. A margin width of 5 m corresponds with margin widths recommended by Marrs et al. (1989), De Snoo & de Wit (1993) and Tsiouris & Marshall (1998) for drift of herbicides, pesticides and granular fertilizers (deposited by disk spinners) respectively.

However for waterlogged margin strips adjacent to water streams, wider margins might be preferred to increase subsurface removal of nitrates by denitrification. During winter residual soil nutrients are transported towards watercourses by lateral groundwater flow. Before reaching the watercourse this lateral transport must pass through the margin strip were nitrates become partly removed by denitrification (Knowles, 1982). The longer the passage time, as determined by width, and the higher the groundwater tables, the more denitrification of nitrates is expected to occur (Hefting, 2003). However, denitrification may cause a shift from groundwater pollution with nitrates towards air pollution with nitrous oxide in case nitrate concentration is high (Hefting, 2003).

Species richness and composition of boundary vegetation evolved positively after installation of a margin strip between boundary and field crop. Prior to the installation, slow growing or small plant species were poorly present. Three years after installation of the margin strip species diversity was enriched at SITE2 by plant species of conservation interest in particular slow growing wildflower species. Furthermore these forb species and more in particular leguminous species became more abundant after installation of the margin strip. At SITE1 only minor changes in species richness or composition of the boundary occurred probably because time scale of the experiment was too short to discourage the highly nitrophilous vegetation growing on this heavy soil type. Boatman et al. (1994) found no major changes in species composition of hedge banks fertilized over a 3 year period.

Owing to the organic farm management we are sure that the beneficial evolution in species diversity was not due to a buffering effect for agrochemicals of the margin strip. It is possible that species richness and abundance of less competitive species was increased directly owing to the reduction of nutrient input from the adjacent arable field. Marshall & Moonen (1998), Tsiouris & Marshall (1998) and Mountford et al. (1993) demonstrated the competitive growth of nitrophilous species in fertile soils, limiting the development of slower growing species. So, an impoverishing adjacent margin strip might offer better opportunities for slow growing species to develop in the pre-boundary. Aside from the reduction of fertilizer drift, the presence of a margin strip might eliminate root foraging by tall competitive species thus discouraging nitrophilous species. Campbell (1991) found species to contrast in their scale of root foraging. Tall dominant plant species such as *Urtica dioica* were found to actively adjust root and shoot growth into locally resource-rich zones such as edges with arable crops while low-growing species rather depended on capturing pulses of resources in nutrient-poor environments more efficiently. Kleijn (1997) found that biomass production in a zone within 1 m from the arable field was significantly higher than at more distant zones in the margin strip due to the presence of tall, competitive species which concentrated biomass production in a zone within 1 m from the arable field.

This research revealed field margin opportunities to buffer boundary vegetation and watercourses against cropped areas loaded with high levels of mineral nitrogen. Margin strips reduced mineral nitrogen content of the soil and mineral nitrogen loss during wintermonths. Mineral nitrogen loss was not affected by field margin type but by distance from the field crop. A minimal width of 5 m is necessary to reach an optimal reduction in mineral soil N and N losses.

Summary and general conclusions

Men mag Amphion zijn, en rots en muur ontroeren, ook met het grootste vernuft weerlegt men nimmer boeren

Man mag Amphion sein und Fels und Wand bewegen, deswegen kann man doch nicht Bauern widerlegen

GELLERT, Fabeln

Summary and general conclusions

The presented multidisciplinary study investigated agro-ecological functions (nature conservation, agriculture, environment) and implications of newly created, unfertilized, permanent field margin strips installed on ex-arable land to increase biodiversity. Margin strips were mown twice a year with a late first cut on 15 June and a regrowth cut on 15 September to meet nature conservation purposes.

From **conservational concern**, margin management techniques (sowing or not, removal of cuttings or not, addition of roadside herbage or not) were evaluated *(research questions 1 to 5, Section 1.2*) on two soil types in order to increase botanical species richness. Investigated factors were: location, plant community and mowing regime.

During the first three successional years, botanical species diversity of sown and unsown communities converged over time, irrespective of mowing regime or location. So, species diversity on the long term seemed unaffected by the type of plant community that was installed.

The decrease in species diversity, number and density of sown wildflowers was more pronounced under a mowing regime without removal of cuttings. On nutrient-rich ex-arable land, the introduction of costly wildflower species at installation of permanent margin strips or at early successional stage is not recommendable. After several years of depletion of soil minerals, the introduction of wildflower species might be reconsidered in case of impoverished soil seedbank.

The annual addition of mown roadside herbage significantly enhanced botanical species richness and the importance of dicotyledons in the margin strips, particularly after three successional years. This offers opportunities to valorise seed-rich roadside herbage in field margins provided that the herbage is free of waste and weed seeds, in particular of clonal, rhizomatous species such as *Cirsium arvense L.*. Aside from wildflower seeds, a lot of associated invertebrates might also be introduced in the margin strips by the addition of roadside herbage.

Early succession of sown/unsown margin strips, managed with/without removal of cuttings, was characterised by the replacement of annuals in favour of perennials, a steady increase in the importance of monocotyledons and a decrease in non N-fixing dicotyledons. Mowing with removal of cuttings delayed this succession pattern.

Convergence in vegetation composition between sown and unsown plots occurred in terms of species importance, as assessed by Sorenson's quantitative index, but was delayed on nutrient-rich soils. Similarity in species importance was significantly enhanced by cutting with removal of cuttings.

Besides margin management, species diversity and vegetation development might be affected by disturbance and shading. Indeed, many field margin strips are preferentially installed along tree rows and hedges and are likely to be disturbed by wheeled or tracked machinery although not allowed in many management agreement prescriptions.

Effects of light and disturbance on species diversity, botanical composition and invasion were assessed during early succession of newly created sown and unsown field margins strips installed along the sunny and shady side of a tree lane *(research questions 6 and 7, Section 1.2)*. One year after installation of the margin strips, a single disturbance by a rotor cultivator was applied. Simultaneously, invader species were inserted to assess invasibility of margin vegetations.

One year after the disturbance event, species richness was not significantly determined by light regime or disturbance. However, shortly after the disturbance event, species richness increased temporarily at the unshaded side due to introgression by annual species in created gaps. At the shaded side species richness was significantly lower in disturbed plots.

Disturbance caused a temporary increase in importance of spontaneous annuals which were quickly replaced by perennial sown and unsown monocotyledons and to a lesser extend to perennial unsown non-fixing dicotyledons. The share in importance of spontaneous species within functional groups increased, resulting in significantly higher similarity between sown and unsown vegetation. Similarity between sown and unsown vegetation was significantly higher at the shaded side and in disturbed vegetations.

Risk of invasion was highest in the disturbed unsown community at the unshaded side of a tree lane. From an agronomical viewpoint, it is therefore recommendable to install field margins by sowing at unshaded field sites in order to minimize the risk of botanical invasion. Sown field margin strips do not conflict with nature conservation purpose since our results show that shortly after installation, the perennial sown vegetation became increasingly look-alike to the spontaneous vegetation leaving opportunities for spontaneous introgression.

Composition and diversity of flying insects was assessed along both the shaded and unshaded side of an old lane of beeches *(research questions 8 and 9, Section 1.2)*. Investigated factors were light regime, plant community and monitoring position.

Both insect composition and spatial preference of insect families were strongly dependent on light regime, field margin type and monitoring position. The number of insect families preferring the shaded side greatly exceeded families preferring the unshaded side. Particularly, insect families associated to moist conditions were preferably or exclusively found at the shaded side characterized by higher soil moisture content. Some families showed higher abundance in the unsown field margin whilst others preferred the sown field margins. Similarly, some families occurred exclusively in the field margin strip whilst others preferred the adjacent field crop. Differential habitat preference might be explained by differences in botanical composition and structure of the vegetation.

Insect diversity was significantly higher nearby the botanically species richest margin strip, namely the unsown margin strip, than nearby sown margin strips. Furthermore insect diversity was significantly higher at the shaded side, irrespective of monitoring position. At the unshaded side insect number was significantly higher in the unsown plant community. Within the shaded strip, insect activity and hence insect number were lower close to the trees owing to the lower temperature. Within the field margin strip (shaded and unshaded), family richness of flower visiting insects, herbivorous insects and entomophagous insects was highest in the unsown community. Spatial distribution patterns of insect numbers of herbivorous insects and entomophagous insects were closely linked, indicating a status of biological equilibrium along the field margin habitat: higher numbers of herbivorous insects entrained higher numbers of entomophagous insects irrespective of the distance from the field margin edge. Field margin strips installed to enhance floristic diversity might thus be beneficial to overall insect diversity and insect densities.

From **agricultural concern** the risk of weed infestation nearby margin strips was studied *(research questions 10 to 12, Section 1.2).* Field margin species, particularly species with rhizomes and creeping roots, and anemochorous species are oftenly considered as potential problem weeds for adjacent crops due to their ingrowing ability or wind dissemination.

Three years after installation, the importance of economically important weeds *Elymus repens* (L.) Gould, *Cirsium arvense* L. and *Urtica dioica* (L.) Scop. was significantly higher when cuttings were not removed and in the unsown community.

Seed dispersal into the adjacent crop was only of importance one year after installation of the margin strips and decreased with increasing distance from the margin strip. Seedrain was significantly 8 times higher nearby the unsown community than nearby sown communities. Approximately 82-99% of the captured seeds were disseminated within 4 m from the margin strip.

Soil seedbank analysis prior to installation of margin strips can be useful to predict potential risk of weed invasion into adjacent crops. If this risk is substantial, it is recommended to avoid a spontaneous development and to install the margin strip by sowing. A mowing regime with removal of the cuttings is an accurate management instrument for sustainable weed control, limiting the expansion of problem weeds, thus creating a weed free ánd species rich margin strip. A cutting management fits into farmers' perception of 'clean' fields. Hence the promotion of field margins might be more successful if farmers are advised to use a seed mixture upon installation of the margin and if they are advised to cut the margin twice a year. Furthermore removal of the cuttings will accelerate mineral depletion of the soil, promoting the development of a botanically species richer vegetation.

To assess the potential agricultural valorisation of herbage from margin strips dry matter (DM) yield and herbage quality of mown field margin strips was studied during their first three successional years *(research questions 13 to 16, Section 1.2)*. Investigated experimental factors were: location, plant community and mowing regime. For each cut, herbage quality was determined by analysis of *in vitro* digestibility, crude ash, crude fibre and crude protein content.

DM yield averaged over the first three years was not significantly determined by mowing regime and generally significantly increased over time irrespective of plant community or mowing regime. Initially sown margin strips outyielded unsown margin strips significantly but differences in DM yield converged over time.

Herbage from the unsown margin strip had a significantly higher mean digestibility and a significantly lower mean crude fibre content than herbage from sown margin strips. Within the monitoring period, digestibility and crude protein content significantly decreased over time while crude fibre content increased irrespective of location or plant community. Changes in digestibility and DM yield were explained by varying species composition and importance over time.

The mid June cut was significantly more productive than the regrowth cut but the herbage of the former had a significantly lower digestibility and crude protein content and a significantly higher mean crude fibre content

The feeding value of herbage from field margin strips was low compared to the feeding value of herbage harvested in agricultural managed fertilized grassland, limiting its use in rations for highly productive livestock. The shift of the first cut to the end of May however might improve the nutritive value ánd enhance nature conservation on the long term owing to an accelerated depletion of soil minerals.

From **environmental concern,** effects of unfertilized sown and unsown field margin strips, installed between the field boundary and the field crop, on soil mineral N and botanical species composition of the boundary vegetation were studied *(research question 17 to 20, Section 1.2)*. Investigated factors were: location and plant community type.

Soil mineral N was significantly affected by distance from the field crop edge and not by plant community type. Starting from the crop edge, soil mineral N decreased in the margin strip up to 5 m inwards. The presence of a tree row in the boundary enhances mineral N close to the trees. The further away from the crop edge, the lesser soil nitrate was found in the margin strip, but soil ammonium N was high close to nearby trees and shrubs. Total soil mineral N as well as N loss during winter was minimal at a distance of 5 m inside the margin strip. So, a minimal width of 5 m is necessary to reach an optimal reduction in mineral soil N and N losses.

The reduction of soil mineral N nearby the boundary by the presence of a margin strip was responsible for the increase in abundance of less competitive species and enrichment of species diversity within the semi-natural boundary. Abundance of slow growing less competitive species was enhanced. So, on the long term, boundaries might be ‘restored’ and develop into weed free and species rich boundaries by the presence of a margin strip separating crop edge and boundary. Together with the regular removal of cuttings this might result in lower costs for maintenance.

Questions might arise whether the obtained results for permanent botanically managed margin strips might be influenced by the choice of the experimental sites, of the wildflower mixtures, of the mowing time and frequency. The margin strips were installed on nutrient-rich arable land and are therefore representative for the margin strips installed in practice. Indeed, most arable land in Flanders is nutrient-rich. Under nutrient-rich soil conditions, the impact of the choice of the wildflower mixture on agricultural, conservational and environmental parameters is probably much less than the impact of the choice of mowing time or mowing frequency. Indeed most sown species will be choked in tall growing productive vegetations except for some persisting species (mostly roset-like or clonal species). However, mowing time and frequency might significantly influence both agronomical, conservational and environmental parameters during early succession. The mowing time and frequency in our experiment follow the legal prescriptions but are probably not the most suitable under conditions of high fertility, particularly when used during early succession. Firstly the margin management should focus on the fast mineral depletion of the soil by (1) chosing simple, productive grass/clover mixtures (2) increasing mowing frequency and (3) by taking the first cut earlier in the season (e.g. around half May). At a later stage mowing time might be postponed again and/or mowing frequency decreased to further increase or maintain species richness. So, for the successful development of permanent species rich margin strips, mowing time and frequency should follow the successional stage of the vegetation and the fenological stages of some target species. Under such a management regime, the negative botanical aspects (e.g. weed risk) of margin strips might decrease whilst the positive aspects (floristic diversity, Nmin reduction) might increase or occur faster.

Finally, although the experiments described in this thesis increase our knowledge of agro-ecology of botanically managed permanent margins, new research questions were generated. From conservational concern more information is needed with respect to the timespans required for optimal ‘restoration’ of nutrient-rich field boundaries, the optimal application time and application frequency of seed-rich roadside herbage in margin strips to enhance botanical diversity. Sowing mixtures need to be optimized in order to accelerate depletion of soil minerals during early succession of margin strips without limiting spontaneous recolonisation on the long term.

From agronomical concerns owing to the low feeding quality of the herbage, more information is required concerning both low cost removal techniques (for example deposition and incorporation of herbage in the crop edge, after crop harvest...) and alternative use (for example, compost making on farm, fermentation,...) of margin herbage. Better quantification of the effects of margin strips on crop performance through their influence of pest predators, parasites and pollinating insects. Optimalisation of sowing mixtures and management techniques in order to attract on a sustainable way beneficial target invertebrates, taking into account their botanical, faunistical and structural needs.

Owing to a growing interest in minimum cultivation techniques in agricultural practice, the risk of weed infestations in crops growing nearby field margins and managed under minimum tillage or shallow cultivation, should be evaluated. Furthermore an answer should be given whether noxious species growing in the margin strip might be different in their reaction on herbicides, from the same species growing in the crop area due to selective pressure by sublethal doses of herbicides drifting into the margin strip.

The mowing regime might be diversified within the margin strip itself according to the existing gradient in vegetation productivity with highest productivity closest to the crop edge owing to root foraging into the crop area and nutrient input. So, the mowing frequency might be increased nearby the crop edge and decreased nearby the boundary. This mowing regime probably might optimally reduce weed invasion in adjacent crops and optimize floristical, faunistical and structural diversity.

Samenvatting en algemene conclusies

Samenvatting en algemene conclusies

De agro-ecologische functies en implicaties van onbemeste en onbespoten permanente soortenrijke akkerranden werden onderzocht in jong successief stadium (2001-2004). De akkerranden werden aangelegd op akkerland en botanisch beheerd met 2 maaibeurten per jaar: een late eerste snede rond 15 juni en een hergroeisnede op 15 september.

Vanuit **natuurtechnisch oogpunt** werd op 2 bodemtypes bestudeerd hoe de botanische soortendiversiteit in akkerranden verhoogd kan worden door verschillende manieren van aanleggen (al dan niet inzaaien), mengselkeuze (commercieel verkrijgbaar mengsel of mengsel van streekeigen aanwezige soorten), maaibeheer (al dan niet afvoeren van het maaisel) en al dan niet aanbrengen van zadenrijk maaisel van lokaal aanwezige wegbermen *(onderzoeksvragen 1 t.e.m. 5, Sectie 1.2)*. Onderzochte proeffactoren waren: proeflocatie (bodemtype), plantengemeenschap en maairegime.
Drie jaar na installatie werd de botanische diversiteit niet significant bepaald door het type plantengemeenschap. De botanische diversiteit van spontane en ingezaaide akkerranden convergeerde immers in de tijd ongeacht het type plantengemeenschap of de locatie.
Zowel de botanische diversiteit als het aantal ingezaaide wildbloemsoorten van ingezaaide randen nam versneld af in de tijd onder een niet verschralend maaibeheer (maaibeheer zonder afvoer van maaisel). Op nutriëntenrijk akkerland is het gebruik van dure wildbloemsoorten bijgevolg af te raden bij de installatie van permanente akkerrandstroken evenals een eventuele inbreng ervan tijdens de prille vegetatieontwikkeling. Na enkele verschralingsjaren kan de inbreng overwogen worden in geval van een soortenarme zaadbank.
De botanische diversiteit en het aandeel dicotylen in de vegetatie namen toe na het jaarlijks aanbrengen van een zadenrijk bermmaaisel. De valorisatie van zadenrijk bermmaaisel in akkerrandstroken is bijgevolg mogelijk op voorwaarde dat het maaisel afvalvrij is en geen hardnekkige onkruidsoorten bevat zoals van clonale soorten als *Cirsium arvense* L. e.a..
De prille akkerrandvegetaties waren onderhevig aan een gestage vervanging van éénjarigen door meerjarigen, een gestage toename van monocotylen en een afname van niet-vlinderbloemige dicotylen. Verschralend maaien vertraagde dit successie-patroon. Ingezaaide en spontaan evoluerende akkerranden leken steeds meer op elkaar qua soortensamenstelling zoals aangetoond door Sorenson's quantitatieve index. Dit proces verliep vertraagd op een nutriëntenrijke bodem. Verschralend maaien versterkte dit nog.

Akkerranden worden in de praktijk preferentieel aangelegd langs waterlopen of langs bomenrijen of hagen (vooral dan langs de schaduwzijde) en zijn vaak onderhevig aan machinale berijding bij slootreitings- of oogstwerkzaamheden. Daarom bestudeerden we het effect van licht en verstoring op de vegetatie-ontwikkeling en op biologische invasie (succesvol installeren en uitbreiden van ongewenste soorten) *(onderzoeksvragen 6 en 7, Sectie 1.2)*. Daartoe werden dezelfde plantengemeenschappen als hierboven vermeld, aangelegd langsheen de zonne- en schaduwzijde van een bomenlaan. De verstoring werd gesimuleerd door een éénmalige bewerking met een rotoreg gevolgd door het overzaaien met invasieve grassoorten.

Eén jaar na het verstoringstijdstip werd de botanische diversiteit niet significant beïnvloed door het lichtregime of de verstoring. Desondanks was er kort na de aangebrachte verstoring een tijdelijke toename in botanische diversiteit in de onbeschaduwde akkerrand teweeggebracht door spontane introgressie van éénjarigen in de tijdelijk ontstane openingen in de vegetatie. De botanische diversiteit in de beschaduwde akkerrand nam tijdelijk af na verstoring.

Verstoring veroorzaakte tevens een tijdelijke toename in de belangrijkheid van spontane éénjarigen die echter snel vervangen werden door spontane en ingezaaide meerjarige monocotylen en in minder mate door spontane meerjarige niet-vlinderbloemige dicotylen. Het aandeel spontane soorten binnen de functionele groepen nam toe in de tijd waardoor ingezaaide en spontane akkerrandvegetaties - vooral de vegetaties aan de schaduwzijde van de bomenlaan en in verstoorde vegetaties- steeds beter op elkaar leken.

Botanische invasie was het hoogst in de verstoorde, spontaan evoluerende plantengemeenschap, langsheen de zonnezijde van de bomenrij. Vanuit landbouwkundig oogpunt is het daarom aangewezen om akkerranden in te zaaien om het risico op biologische invasie te beperken, zeker op onbeschaduwde plaatsen. Het inzaaien van akkerranden botst geenszins met natuurbehoudsdoelen: immers in de meerjarige ingezaaide rand ontstaat er vlug introgressie van spontane soorten waardoor een ingezaaide en een spontane rand steeds meer op elkaar gelijken.

Naast de botanische diversiteit werd tevens de faunistische diversiteit en samenstelling opgevolgd langsheen beide zijden van de bomenrij *(onderzoeksvragen 8 en 9, Sectie 1.2)*. Onderzochte factoren waren: lichtregime, plantengemeenschap en waarnemingspunt.

Zowel de samenstelling als de ruimtelijke voorkeur van de gevangen insectenfamilies werd sterk bepaald door het lichtregime, de plantengemeenschap en het waarnemingspunt. Insectenfamilies geassocieerd met vochtige condities werden preferentieel of uitsluitend gevangen langsheen de schaduwzijde, gekenmerkt door hogere bodemvochtgehaltes. Sommige insectenfamilies waren exclusief aanwezig in de akkerrand terwijl andere vooral het aanpalend gewas bezochten. Deze voorkeurspatronen waren waarschijnlijk te wijten aan verschillen in botanische samenstelling en structurele diversiteit van de vegetaties.

Nabij de botanisch soortenrijkste plantengemeenschap, in casu de spontane vegetatie, werden significant meer insectenfamilies gevangen dan nabij ingezaaide plantengemeenschappen. Het aantal gevangen insectenfamilies was tevens significant hoger aan de schaduwzijde van de bomenlaan, onafgezien van het waarnemingspunt. In de onbeschaduwde akkerrand was het aantal gevangen insecten significant hoger in de spontane plantengemeenschap dan in ingezaaide plantengemeenschappen. Langsheen de schaduwzijde werden lagere aantallen insecten gevangen als gevolg van de lagere insectenactiviteit. Binnen de spontane plantengemeenschap werden er zowel significant meer herbivore, entomofage en bloembezoekende insectenfamilies gevangen dan binnen ingezaaide plantengemeenschappen. De ruimtelijke distributie van entomofage insecten was duidelijk positief gerelateerd aan het voorkomen van herbivore insecten m.a .w. langsheen de akkerrand stelde zich een biologisch evenwicht in. De installatie van botanisch diverse akkerranden draagt aldus bij tot een hogere insectendiversiteit en –densiteit.

Vanuit **landbouwkundig oogpunt** werd het risico op veronkruiding in en nabij akkerranden nagegaan *(onderzoeksvragen 10 t.e.m. 12, Sectie 1.2)*. Soorten met kruipende wortels en rhizomen en anemochore soorten worden vaak beschouwd als potentiële risico-onkruiden voor aanpalende gewassen vanwege hun ingroeivermogen of windverspreiding in het aanpalend gewas.

Gedurende de vegetatieontwikkeling nam de belangrijkheid van ingroeiende soorten significant toe onder niet verschralend maaibeheer en in de spontane plantengemeenschap. Drie jaar na installatie was de belangrijkheid van de economisch belangrijke onkruiden *Elymus repens*, *Cirsium arvense* en *Urtica dioica* significant hoger onder niet verschralend maaibeheer en in de spontane plantengemeenschap.

Anemochore zaadverspreiding in het aanpalend gewas was alleen van betekenis één jaar na installatie en nam af met toenemende afstand tot de akkerrand. De zaadregen was ongeveer 8 keer hoger nabij de spontane plantengemeenschap dan nabij ingezaaide plantengemeenschappen. 82 à 99% van de gecapteerde zaden streken neer binnen de eerste 4 m naast de akkerrand.

Het inzaaien van akkerranden én het toepassen van verschralend maaibeheer is aan te raden om ingroeiende onkruiden en zaadverspreiding te beperken. Een analyse van de zaadbank vóór de installatie van de akkerrand, kan bruikbaar zijn ter voorspelling van onkruidproblemen nabij akkerranden. Is dat risico groot dan is het aangewezen de akkerrand in te zaaien en niet spontaan te laten evolueren. Verschralend maaien (maaien met afvoer van het maaisel) is bijgevolg een belangrijk management instrument in duurzame onkruidbeheersing resulterend in een onkruidvrije én soortenrijke akkerrandstrook. Bovendien past dit maaien van akkerranden in de perceptie van 'propere velden'. De promotie van akkerranden bij landbouwers is wellicht meer succesvol wanneer zij geadviseerd worden de akkerrandstroken in te zaaien en twee snedes per jaar toe te passen. Dergelijk advies past in hun 'proper veld' perceptie. Bovendien zorgt verschralend maaien voor een versnelde afvoer van bodemmineralen hetgeen uiteindelijk resulteert in een soortenrijkere vegetatie.

Om te bestuderen in welke mate het akkerrandmaaisel bruikbaar is als veevoeder, werd de drogestof (ds) opbrengst en voederkwaliteit bepaald *(onderzoeksvragen 13 t.e.m. 16, Sectie 1.2)*. Onderzochte factoren waren: locatie, plantengemeenschap en maairegime. De voederwaarde van elke snede werd bepaald door analyse van ruwe celstof, ruw eiwit, ruwe as en *in vitro* verteerbaarheid.

De gemiddelde jaarlijkse ds-opbrengst werd niet significant bepaald door het maairegime. De jaarlijkse ds-opbrengst nam zelfs toe onafgezien van de plantengemeenschap of maairegime. De gemiddelde ds-opbrengst van de spontane akkerrand was significant lager dan die van de ingezaaide randen, maar de opbrengstverschillen namen af in de tijd. De voederkwaliteit van het maaisel van de spontane rand was significant beter dan die van het maaisel van ingezaaide randen. Over de jaren heen namen de verteerbaarheid en het ruw eiwitgehalte significant af terwijl het ruwe celstofgehalte significant toenam, onafgezien van plantengemeenschap of locatie. De veranderingen waren te wijten aan de variërende soortensamenstelling en soortenbelangrijkheid in de tijd.

Gemiddeld over de jaren was de half-juni snede significant productiever dan de hergroeisnede (half-september) maar de voederwaarde van de eerste snede was slechter. Door de slechte verteerbaarheid is het gebruik van maaisel uit akkerranden maar beperkt bruikbaar in rantsoenen van hoogproductieve dieren. Vroeger maaien (bv. half mei) bevordert de voederwaarde van het maaisel maar ook de natuurwaarde van de rand a.g.v. een versnelde uitputting van bodemmineralen.

Vanuit **milieu-oogpunt** wilden we weten wat het effect was van een akkerrand op de botanische samenstelling van de akkerzoom en op de stikstofhuishouding in de rand *(onderzoeksvragen 17 t.e.m. 20, Sectie 1.2).* Onderzochte factoren waren: plantengemeenschap en afstand tot het gewas.

De hoeveelheid minerale bodemstikstof in de rand werd uitsluitend beïnvloed door de afstand tot het gewas en niet door de plantengemeenschap.

De hoeveelheid minerale residuele stikstof in het bodemprofiel nam af vanaf de gewasrand tot 5 m randinwaarts; nog verder in de akkerrand nam de minerale stikstof opnieuw toe a.g.v. de nabijgelegen bomenrij. Hoe verder van het akkergewas, hoe minder nitrische stikstof in het bodemprofiel. Zowel de residuele hoeveelheid minerale bodemstikstof als het stikstofverlies tijdens de winter waren minimaal 5 m randinwaarts. Een minimale akkerrandbreedte van 5 m is bijgevolg nodig voor een optimale reductie van minerale bodemstikstof en stikstofverlies.

De reductie in minerale bodemstikstof nabij de zoomvegetatie was verantwoordelijk voor de toenemende abundantie van traaggroeiende, minder competitieve soorten en botanische diversiteit in de semi-natuurlijke perceelszoom. Op lange termijn kunnen perceelszomen aldus ‘gerestaureerd’ worden en ontwikkelen tot onkruidarme, soortenrijke vegetaties a.g.v. de bufferende werking van de aanpalende akkerrandstrook. Dit in combinatie met een verschralend maaibeheer resulteert uiteindelijk in verminderde onderhoudskosten van zoomvegetaties.

Men kan zich de vraag stellen in welke mate de bekomen resultaten beïnvloed kunnen zijn door de keuze van de locaties, de keuze van de wildbloemenmengsels, de maaitijdstippen en maaifrequentie. De akkerranden werden geïnstalleerd op nutriëntenrijk akkerland en zijn bijgevolg representatief voor de in de praktijk aangelegde akkerranden aangezien akkerland in Vlaanderen nutriëntenrijk is. Onder nutriëntenrijke condities, is de impact van de keuze van het wildbloemenmengsel op agronomische, natuurtechnische en milieuparameters waarschijnlijk veel lager dan de impact van de keuze van het maaitijdstip en -frequentie. Immers de meeste ingezaaide soorten worden op uitzondering van enkele rozetvormende of clonale soorten, verstikt in hoogopgroeiende, productieve vegetaties. Maaitijdstip en maaifrequentie kunnen echter op significante wijze de agronomische, natuurtechnische en milieu- parameters van akkerranden in een jong successief stadium beïnvloeden. De maaitijdstippen en de maaifrequentie zoals aangehouden in deze thesis, volgen de wettelijke voorschriften maar zijn wellicht niet de meest geschikte onder condities van hoge bodemvruchtbaarheid. In eerste instantie zou het akkerrandenbeheer afgestemd moeten zijn op de snelle verschraling van de bodem door (1) te kiezen voor eenvoudige, productieve gras/klaver mengsels en/of (2) een hogere maaifrequentie of (3) de eerste snede te vervroegen naar bv. half mei. Pas in een later stadium kan het eerste maaitijdstip opnieuw verlaat worden en/of de maaifrequentie afnemen om de verdere toename of instandhouding van de botanische soortendiversiteit te bewerkstelligen. Een succesvolle ontwikkeling van permanente soortenrijke akkerranden vereist m.a.w. een beheer waarbij maaitijdstip en -frequentie aangepast worden aan de successiestadia en aan de fenologisch stadia van enkele ‘target’ soorten. Onder een dergelijk beheer kunnen de negatieve botanische aspecten (zoals veronkruidingsrisico) van akkerranden (sneller) afnemen terwijl de positieve aspecten (botanische diversiteit, reductie van minerale bodemstikstof,…) toenemen of sneller opduiken.

Tenslotte genereren de besproken experimenten met betrekking tot botanisch beheerde permanente akkerrandstroken nog een aantal bijkomende onderzoeksvragen.

Vanuit natuurtechnisch oogpunt is er meer kennis vereist betreffende de tijdsduur vereist voor de ‘restauratie’ van nutriëntenrijke perceelszomen en betreffende het optimaal toedieningstijdstip en toedieningsfrequentie van zadenrijk bermmaaisel op akkerrandstroken ter verhoging van de botanische diversiteit. Zaadmengsels vereisen optimalisatie ter versnelling van de bodemverschraling gedurende de prille vegetatieontwikkeling, zonder evenwel de kansen op spontane introgressie op lange termijn te hypothekeren.

Vanuit landbouwkundig oogpunt is er, gezien de lage voederwaarde van het maaisel, meer kennis vereist omtrent goedkope afvoermethoden (bijvoorbeeld na de oogst van het gewas, akkerrandmaaisel in gewasrand blazen en inploegen, …) en alternatief gebruik (boerderijcompostering, vergistingsinstallatie,…) van akkerrandmaaisel.

Er is tevens nood aan kwantificatie van de effecten van akkerrandstroken op de gewasopbrengst, meer bepaald de invloed van predatoren, parasieten en bestuivende insecten enerzijds, en ziekten en plagen anderzijds. Zaadmengsels en akkerrandbeheer dienen

geoptimaliseerd te worden om specifieke, nuttige doelinsecten duurzaam aan te trekken, rekening houdend met hun botanische, faunistische en structurele behoeften.
Anderzijds is er, gezien de toenemende interesse in minimale grondbewerkingstechnieken, nood aan kennis omtrent het onkruidrisico in aanpalende gewassen die een minimale grondbewerking hebben ondergaan bij de installatie. Bovendien dient een antwoord gegeven op de vraag of schadelijke plantensoorten in de akkerrand verschillend reageren op herbiciden dan diezelfde plantensoorten aanwezig in het gewas. Mogelijks zijn onkruiden afkomstig uit de akkerrand minder gevoelig voor herbiciden dan de soortgenoten afkomstig uit de gewasrand dit a.g.v. de selectieve druk heersend in de akkerrand onder invloed van overgewaaide sublethale herbicidedosissen.

Bovendien is er meer informatie gewenst omtrent diversificatie van het maaibeheer binnen de akkerrand met de hoogste maaifrequentie nabij het gewas en de laagste nabij de perceelszoom rekening houdend met de toenemende productiviteitsgradiënt van de vegetatie gaande van zoom naar gewasrand. Zo’n complex maairegime onderdrukt mogelijkerwijze optimaal de onkruidproblemen nabij de gewasrand en optimaliseert mogelijkerwijze zowel floristische, faunistische als structurele diversiteit.

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  From October 1998 to April 2001 as researcher in a corn breeding project
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- Department of Biology, University of Antwerp (3/2005-2/2006): project assistant

PUBLICATIONS

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