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Research article

Effect of margin strips on soil mineral nitrogen and plant biodiversity

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Abstract – We studied the effects of two- to three-year-old unfertilized field margin strips, installed between the pre-existing field boundary and the field crop, on soil ammonium N and nitrate N, and on the botanical composition of the adjacent semi-natural vegetation in the field boundary. Margin plots were regenerated spontaneously or were sown to grass/forb mixtures and were managed under a cutting regime with removal of cuttings. In general, soil nitrate N, soil ammonium N and soil mineral N losses were significantly affected by distance from the field crop edge and not by plant community type. The further away from the crop edge, the lower soil nitrate (up to fivefold lower than in the crop) was found in the margin strip, but soil ammonium N was approximately 50% higher close to nearby trees and shrubs. Inside the margin strip, total soil mineral N as well as N loss during winter was minimal at a distance of 5 m from the crop edge. The reduction of soil nitrate N near the boundary by the presence of a margin strip was responsible for the increase in abundance of less competitive species and for an up to 20% higher species-richness within the field boundaries. In summary, our results show clearly that margin strips both decrease N pollution of groundwater and increase botanical diversity. A minimal margin width of 5 m is recommended.

buffer strip / boundary / species diversity / nitrogen loss / nitrate / ammonium

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 habitats 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 (Hald, 2002). According to Rew et al. (1992) and Tsiouris and 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). The remaining plant species are associated with eutrophic and productive biotopes (Hald, 2002). Weed problems in boundary strips are worsened by herbicide drift or herbicide use in ditch banks or hedge bottoms (de Snoo and de Wit, 1993) favoring strong rhizomatous species.

Sown or unsown nature conservation strips installed between an arable crop and pre-existing boundary may buffer flora in the pre-existing boundary, as shown by many authors (Hegarty et al., 1994; Moonen and Marshall, 2001; Hald, 2002). Margin strips may reduce nitrate leaching to surface waters (Hefting, 2003) or function as a filter preventing runoff of sediments and agrochemicals from reaching nearby habitats with susceptible or vulnerable organisms such as ditches or nature reserves (Mander et al., 1997; 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). However, information is not abundant concerning mineral N rates and losses in soil horizons under field margin strips during winter months, or concerning the optimal width of field margin strips for reducing mineral N content in soil. Most studies mainly deal with forested buffer strips (Haycock and Pinay, 1993; Schultz et al., 1995; Mander et al., 1997; Verchot et al., 1997). Grass strips were found to reduce soil nitrate nitrogen concentrations by approximately 50% (Verchot et al., 1997). Nor are there many data about the optimal dimensions of margin strips to function as a buffer against drift of agrochemicals. Tsiouris and Marshall (1998) recommended a margin width of 5 m to protect adjacent boundary vegetation against drift of granular fertilizers deposited by disk spinners. According to Marrs et al. (1989), a strip of 6 m offered a very safe distance for preventing lethal effects from

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herbicides sprayed by a tractor-mounted sprayer; for most herbicides 2-m-wide strips were sufficient.

Over the long term the reduction of agrochemical drift and soil nitrogen content in the boundary might benefit the development of a species-rich less nitrophilous vegetation, thus reducing costs of maintenance of the boundary.

Our study examines the effects of 2–3-year-old sown and unsown grassy 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 addressed: (1) Can sown/unsown grassy 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 recommended to minimize soil mineral N content and loss near the pre-existing boundary? (4) Is species richness and botanical composition of the semi-natural vegetation in the boundary positively affected by the presence of the margin strip?

2. MATERIALS AND METHODS

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), three mowing regimes (subplot) and three blocks. The plant communities were randomized within the blocks and the mowing regimes were randomized within the plant communities. The split-plot design was installed on two contrasting soil types in Belgium, in the province of West Flanders; namely, in Poperinge (SITE1: 50° 52' N, 2° 45' E, drained sandy loam, pH-KCl 6.8, 1.5% C) and in Beernem (SITE2: 51° 09' N, 3° 20' E, humid sandy soil, pH-KCl 5.7, 3.3% C). Analysis of the topsoil (0–30 cm) (June 2001) of SITE1 showed that extractable P and K were 27 mg per 100 g soil and 31 mg per 100 g soil, respectively, and total mineral N was 43 $kg \cdot ha^{-1}$. Analysis of the topsoil (0–30 cm) of SITE2 showed that extractable P and K were 75 mg per 100 g soil and 31 mg per 100 g soil, respectively, and total mineral N was 113 $kg \cdot ha^{-1}$. The experimental sites (360 × 20 m at SITE1 and 360 × 10 m at SITE2) were ploughed with 7-month-old Italian ryegrass in May 2001 and divided into 36 plots (10 × 20 m at SITE1 and 10 × 10 m at SITE2) arranged along an east-west-oriented watercourse at SITE1 and an east-west-oriented tree row along a ditch at SITE2. The pre-existing semi-natural boundary (hereafter called field boundary), encompassing the barrier between fields, constituted a watercourse bank with an 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. The experiments were conducted on a conventional farm at SITE1 and on an organic farm at SITE2. So, no agrochemicals were used in the adjacent crops at SITE2.

Apart from an unsown spontaneously evolving plant community (CONTR.), three different sown communities (MIXT1, MIXT2 and MIXT3; mixtures sown in June 2001) were studied (Tab. I). MIXT1 was established with a seed mixture of 63 species comprising native seeds of local provenance, and for MIXT2 a commercially-available seed mixture of 77 species comprising species completely unrelated to the sowing region was used. The initial composition of MIXT3 was identical to that of MIXT2 but once a year, seed-rich herbage originating from neighboring roadsides was added in order to enhance species diversity. Roadsides were cut around the end of September. 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.

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 and 2004) the experimental plots were cut twice per year with cuttings either left or removed, resulting in three different mowing regimes: 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 proportion of the species and to allow the establishment of young seedlings, the first mowing date was postponed until 15 June (first cut). The vegetation was mown a second time around 15 September (regrowth cut).

At SITE1, the semi-natural vegetation in the field boundary was mown twice a year without removal of cuttings. At SITE2, it was mown once a year with removal of cuttings due to the reduced vegetation growth under the tree row. Vegetation succession in the field margin occurred under zero fertilization and no herbicide and pesticide use. For both sites, adjacent crops and their fertilizer, herbicide, fungicide and insecticide inputs are shown in Table II. At SITE1, ammonium nitrate 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 9 m from the field margin edge. Pig slurry was applied by shank-type 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 6 m from the field margin edge. Farmyard manure and farmyard compost (composted farmyard manure) were spread by a rear-beater spreader.

2.1. Assessment

During both the winter periods 2002–2003 and 2003–2004, mineral N content at SITE1 and SITE2 was determined in the REMOV2 plots. Soil samples were taken from 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-cylindrical 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 fixed augering positions along nine transects perpendicularly centered on the MIXT1, MIXT2 and CONTR plots managed under REMOV2. For the winter period of 2002–2003 the augering positions at each site were: one in the field crop area 10 m away from the field margin edge (position 10 m), one right at the border between the field margin and the crop (position 0 m) and three positions in the margin strip; SITE1: 5, 10 and 20 m away from the crop edge (positions –5, –10 and –20 m, respectively); SITE2: 5, 7.5 and 10 m away from the crop edge (positions –5, –7.5 and –10 m, respectively). The outermost positions (position –20 m at SITE1 and position

Table I. Sown seed mixtures: composition, dose of native (MIXT1) and commercial (MIXT2) seed mixture. MIXT3 is identical to MIXT2.

Functional group	MIXT1			MIXT2		
	Dose g ha^{-1}	N[1]	Origin	Dose g ha^{-1}	N[1]	Origin
Non-nitrogen-fixing dicots	6560	45	Pleijboza (NL)	5000	59	Barenbrug (NL)
native wildflowers	6560	45				
commercial wildflowers				5000	59	
Legumes	9200	6		9200	6	
Medicago sativa	1800		Feldsaaten Freudenberger (G)	1800		Feldsaaten Freudenberger
Trifolium incarnatum	1500		Feldsaaten Freudenberger	1500		Feldsaaten Freudenberger
Trifolium pratense	2000		CLO-DvP[2] (B)	2000		Barenbrug
Trifolium repens	1400		CLO-DvP	1400		Barenbrug
Trifolium resupinatum	1500		Feldsaaten Freudenberger	1500		Feldsaaten Freudenberger
Vicia sativa	1000		Pleijboza	1000		Feldsaaten Freudenberger
Monocots	26500	12		26500	12	
Agrostis tenuis	2000		collected[3]	2000		Barenbrug
Anthoxanthum odoratum	600		Pleijboza	600		Feldsaaten Freudenberger
Arrhenatherum elatius	3000		Pleijboza	3000		Feldsaaten Freudenberger
Cynosurus cristatus	1200		Pleijboza	1200		Feldsaaten Freudenberger
Festuca arundinacea	3600		collected	3600		Barenbrug
Festuca pratensis	3000		CLO-DvP	3000		Barenbrug
Festuca rubra	5000		CLO-DvP	5000		Barenbrug
Holcus lanatus	1000		Pleijboza	1000		Feldsaaten Freudenberger
Lolium perenne	3000		CLO-DvP	3000		Barenbrug
Phleum pratense	1400		CLO-DvP	1400		Barenbrug
Poa trivialis	700		collected	700		Barenbrug
Dactylis glomerata	2000		collected	2000		Barenbrug

[1] N = number of species (spp.).
[2] CLO-DvP: Department of Plant Genetics and Breeding, Agricultural Research Center, Merelbeke (Belgium).
[3] Collected in the neighborhood of the trials.

–10 m at SITE2) were taken at the edge of the field boundary. For the winter period 2003–2004 augering positions were concentrated more at the border of the field crop area. Augering positions for both sites were: one position in the field crop area (position 2.5 m), one position right at the border between the field margin and the crop (position 0 m) and four positions in the margin strip (positions –1.25, –2.5, –5 and –7.5 m: 1.25, 2.5, 5 and 7.5 m, respectively, from the crop edge). At each augering position three spots (at the center and 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 deep-frozen prior to determination of nitrate N (NO_3-N) and ammonium N (NH_4-N) using continuous flow spectroscopy performed on oven-dried 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} oven-dried soil) with the specific apparent gravity of the soil and volume of the soil within the relevant horizon. 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) were calculated by adding individual amounts in each soil horizon.

Over each winter period Nmin loss (kg N·ha^{-1}) during winter was calculated as a net N change by subtracting the residual Nmin at the end of October from Nmin at the end of February of the next year. This calculation does not take into account airborne N deposition and mineralization/immobilization between the autumn and spring sampling occasions.

Table II. Crops adjacent to the field margin strips (period 2001–2004): crop rotation, fertilizer (fertilizer type + application date), herbicide, insecticide and fungicide application.

		2001	2002	2003	2004
SITE1	Crop	Sugar Beet	Winter Wheat	Silage Maize	Sugar Beet
	Fertilizer	122 N:	220 N:	180 N:	110 N:
	(kg.ha^{-1})	*60 N ammonium nitrate 27% N (22.05)*	*140 N soluble N (80N 11.03 + 60 N 11.04)*	*120 N ammonium nitrate 27% N (23.04)*	*50 N soluble N (12.03)*
		60 N pig slurry 0.25% N (03.04)	*80 N ammonium nitrate 27% N (23.05)*	*60 N pig slurry 0.25% N (27.02)*	*60 N pig slurry 0.25% N (26.02)*
		35 P:	0 P	35 P:	35 P:
		pig slurry 0.33% P_2O_5 (03.04)		*pig slurry 0.33%* P_2O_5 *(27.02)*	*pig slurry 0.33%* P_2O_5 *(26.02)*
		252 K:	0 K	65 K:	173 K:
		187 K muriate of potash, 40% K_2O *(12.05)*		*pig slurry 0.32%* K_2O *(27.02)*	*108 K muriate of potash, 60%* K_2O *(26.02)*
		65 K pig slurry 0.32% K_2O *(03.04)*			*65 K pig slurry 0.32%* K_2O *(26.02)*
	Herbicide[1]	1 × Pyramin (3 L·ha^{-1})	1 × IP flo (3 L·ha^{-1})	1 × Aspect (2 L·ha^{-1})	3 × Pyramin (3, 0.5, 0.75 L·ha^{-1})
		4 × Betanal Progress (1.0, 1.0, 1.2, 1.5 L·ha^{-1})	1 × Hussar (0.2 L·ha^{-1})	1 × Mikado (1 L·ha^{-1})	1 × Betanal Exp. (1 L·ha^{-1})
		3 × Goltix (0.50, 0.25, 0.75 kg·ha^{-1})			2 × Betanal Quattro (1.65, 2 L·ha^{-1})
		2 × Safari (30, 30 g·ha^{-1})			3 × Goltix (0.50, 0.25, 0.25 kg·ha^{-1})
		1 × Fervinal (1.25 L·ha^{-1})			1 × Safari (30 g·ha^{-1})
					1 × Eloge (0.5 L·ha^{-1})
	Fungicide[2]	1 × Opus Team (0.7 L·ha^{-1})	1 × Opus (0.8 L·ha^{-1})		
			1 ×Boscor (0.8 L.·ha^{-1})		
			1 × Allegro (1 L·ha^{-1})		
	Insecticide[3]	1 × Baythroid (0.5 L·ha^{-1})	1 × Karate Zeon (75 mL·ha^{-1})		
	Catch crop		Italian ryegrass		
SITE2[4]	Crop	Potato	Leek	Carrot	2 × Broccoli
	Fertilizer	303 N	258 N	0 N	200 N
	(kg·ha^{-1})	*63 N hair meal 14% N (March)*	*150 N farmyard manure 0.6% N (March)*		*140 N farmyard manure 0.7% N (March)*
		240 N farmyard compost 1.2% N (March)	*108 N organic granules 6% N (April)*		*60 N blood meal 13% N (March)*
		65 P	32 P	0 P	32 P
		farmyard compost 0.8% P_2O_5 *(March)*	*farmyard manure 0.3%* P_2O_5 *(March)*		*farmyard manure 0.3%* P_2O_5 *(March)*
		310 K	320 K	150 K	273 K
		95 K vinasse 40% K_2O *(March)*	*120 K organic granules 8%* K_2O *(April)*	*muriate of potash 30%* K_2O *(April)*	*60 K muriate of potash 30%* K_2O *(March)*
		215 K farmyard compost 1.3% K_2O *(March)*	*200 K farmyard manure 1.2%* K_2O *(March)*		*200 K farmyard manure 1.2%* K_2O *(March)*
					13 K vinasse 38% K_2O *(March)*
	Catch crop	Phacelia	Winter Rye		

[1] Fervinal (120 g·L^{-1} sethoxydim); Hussar (5% iodosulfuron + 15% mefenpyr-diethyl); Aspect (250 g·L^{-1} atrazin + 250 g·L^{-1} flufenacet); Mikado (300 g·L^{-1} sulcotrione); Eloge (108 g·L^{-1} haloxyfop-R-methyl); Betanal Expert (75 g·L^{-1} fenmedifam + 151 g·L^{-1} ethofumesaat + 25 g·L^{-1} desmedifam); Betanal Quattro (60 g·L^{-1} fenmedifam + 100 g·L^{-1} ethofumesaat + 20 g·L^{-1} desmedifam + 200 g·L^{-1} metamitron);
[2] 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);
[3] Baythroid (50g·L^{-1} cyfluthrin); Karate Zeon (100 g·L^{-1} lambda-cyhalothrin);
[4] No use of herbicides, insecticides or fungicides in the organic farming system at SITE2.

Residual Nmin after the growing season (i.e. Nmin amount at the end of October) was 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. This level was established in order not to exceed the 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 (Anonymous, 1991).

During the period 2002–2004, the botanical composition of the vegetation was recorded yearly on 15 July, thirty days after the mid-June cut. Species occurrence was recorded within the central 4 × 4 m area of each 10 × 10 m plot. Species importance was derived from the presence in sixteen randomly-placed quadrats (13 × 13 cm) within the central 4 × 4 m area of each plot according to the combined frequency-rank method of De Vries (De Vries and de Boer, 1959). Species presence was expressed in terms of percentage of importance (I%) based on the ranking of biomass contributed by the various plant species within each quadrat. The botanical composition in terms of importance of functional groups was recorded over time by calculating the percentile contribution of three functional groups to the total importance (= 100%). Species were classified into the following functional groups: legumes (LEG), non-N-fixing dicotyledons (DIC) and monocotyledons (MON). The I% of a functional group was calculated by adding the I% of all contributing species of that group.

Boundary flora was studied to investigate the likely ecological effects of the presence of a margin strip on the adjacent field boundary. The composition of the flora of the field boundary was measured prior to installation (2001) and yearly in June during the period 2002–2004, on a Tansley (1954) scale (r = rare; o = occasional; f = frequent; a = abundant; d = dominant).

ANOVA (SPSS10 for Windows) was used for statistical calculations of Nmin, NO_3-N and NH_4-N amounts and I% of functional groups for plant communities (MIXT1, MIXT2 and CONTR) under REMOV2. In this report the factor mowing regime of the installed split-plot design was not studied since soil augering and Nmin analysis was solely performed on all REMOV2 plots of MIXT1, MIXT2 and CONTR. So, the split-plot design was analyzed as a complete block design. Since soil augering positions and adjacent crops and fertilizer applications differed between locations during both winter periods, statistical analysis was performed per location according to a two-factor experiment (plant community and augering position) in a complete block design with random block effect. The I% of functional groups was analyzed according to a two-factor experiment (plant community and location) in a complete block design with random block effect.

3. RESULTS AND DISCUSSION

3.1. Soil Nmin analysis

Winter 2002–2003

The distribution of residual total Nmin, NH_4-N and NO_3-N as analyzed in samples taken on 29 October 2002 at SITE2 are shown in Figure 1. Data were averaged over the plant communities and are presented for the different soil horizons.

Figure 1. Pre-existing field boundaries: species-rich ditch bank (A); species-poor nitrophilous ditch bank (B).

Given that the NH_4-N data show limited trends and that most of the variation in total Nmin arises from variations in NO_3-N, residual total Nmin was not further statistically analyzed. Augering position significantly determined total NH_4-N (Tab. III) at SITE2 but not at SITE1 at the end of October 2002. Contrary to total NO_3-N, total NH_4-N in the crop area was not significantly higher than NH_4-N in the field margin strip, irrespective of location. However, atSITE2, 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 field boundary, the more NH_4-N.

Focusing on residual total NO_3-N at the end of October 2002 (Tab. III), the Flemish legal threshold value 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. Total NO_3-N at SITE2 was only significantly determined by augering position, with significantly 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.

Compared with 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 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 significantly higher NO_3-N compared with other positions due to the early slurry application.

Nmin loss over the winter period 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.

Table III. Soil NH_4-N and NO_3-N (kg N·ha^{-1}) on 29 October 2002 and on 25 February 2003, and Nmin loss (kg N·ha^{-1}) during winter 2002–2003 along transects perpendicular to margin strips. (Abbreviations cf. p. 5).

		SITE1					SITE2				
COM[1]	POS[1]	29 October 2002		25 February 2003		N loss[2]	29 October 2002		25 February 2003		N loss[2]
		NH_4-N	NO_3-N	NH_4-N	NO_3-N		NH_4-N	NO_3-N	NH_4-N	NO_3-N	
Mean											
	–20	27.2	39.8	57.1	60.8	–50.8	116.0	32.8	160.3	43.9	–55.5
	–10	31.7	46.0	47.6	47.7	–17.6	83.7	46.9	102.5	43.1	–15.0
	–5	33.9	41.9	52.4	42.0	–18.6	84.6	49.8	101.2	46.4	–13.3
	0	34.9	44.3	58.1	51.7	–30.6	99.8	102.5	108.7	45.7	48.0
	10	35.1	62.8	79.8	93.0	–75.0	78.7	143.9	93.2	47.5	81.9
Anova (LSD)[3]:											
COM		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
POS		NS	NS	NS	***	**	**	***	**	NS	*
					(22.4)	(31.8)	(18.1)	(52.4)	(32.9)		(84.1)
COM × POS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] COM, plant community; POS, augering positions: –20, –10 and –5 m within the margin strip, 0 right at the border; between margin strip and crop, 10: 10 m within the crop.

[2] N loss = Nmin on 29 October – Nmin on 25 February.

[3] Significance: NS, not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$. LSD, least significant difference ($P < 0.05$) according to Fisher LSD test.

Winter period 2003 –2004

The distribution of residual total Nmin, NH_4-N and NO_3-N (averaged over plant communities) over the different soil horizons at SITE2 are shown in Figure 2. 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 organic C content in the soil. The installation of a field margin strip, separating the field boundary and the crop area, decreased residual Nmin significantly close to the field boundary. This reduction occurred mainly in the deeper soil horizons 30–60 and 60–90 cm which are more prone to mineral leaching. In the field crop area, Nmin in the horizon 30–90 cm was sixfold higher than Nmin at position –5 m in the margin strip. Half of the total NH_4-N was found in the uppermost horizon, irrespective of position. Total NO_3-N steadily decreased from position 2.5 m up to –5 m. Contrary to positions inside the margin strip, approximately 70% of the total NO_3-N in the field crop area was found in the deeper soil horizons, 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.

Given that the NH_4-N data show limited trends and that most of the variation in total Nmin arises from variations in NO_3-N (Fig. 3), residual total Nmin data was not further statistically analyzed in Table IV. 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 of the crop area. The closer to the tree lane, the higher the total NH_4-N. At SITE 1, total NH_4-N was not affected by augering position. Contrary to NO_3-N, NH_4-N in the margin strip at SITE2 increased with increasing

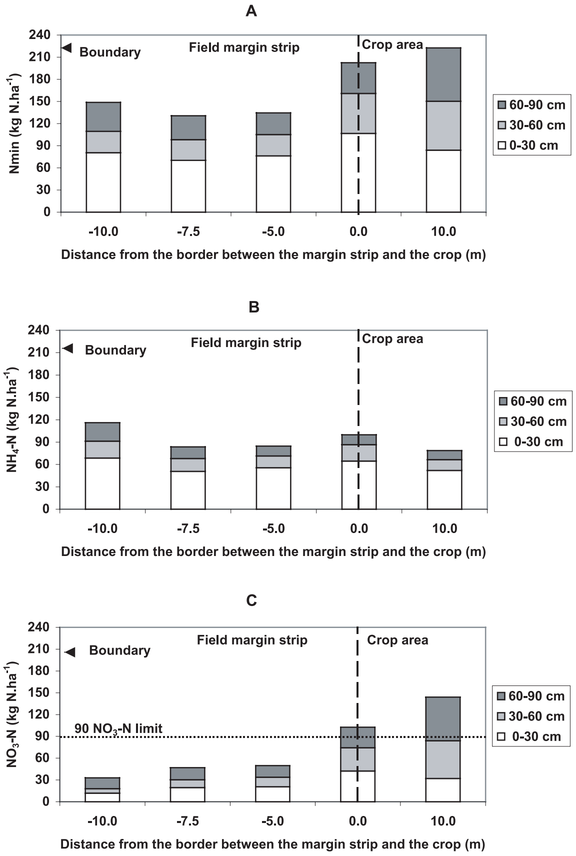

Figure 2. Distribution of total Nmin (A), NH_4-N (B) and NO_3-N (C) in soil horizons 0–30, 30–60 and 60–90 cm related to distance from the border between the margin strip and the crop. SITE2, 29 October 2002.

Table IV. Soil NH_4-N and NO_3-N (kg N·ha^{-1}) on 29 October 2003 and on 1 March 2004, and Nmin loss (kg N·ha^{-1}) during winter 2003–2004 along transects perpendicular to sown/unsown margin strips (Abbreviations cf. p. 5).

COM[1]	POS[1]	SITE1					SITE2				
		29 October 2003		1 March 2004		N loss[2]	29 October 2003		1 March 2004		N loss[2]
		NH_4-N	NO_3-N	NH_4-N	NO_3-N		NH_4-N	NO_3-N	NH_4-N	NO_3-N	
Mean:											
CONTR		29.9	82.3	38.2	46.1	27.8	61.1	120.1	61.6	46.2	73.6
MIXT1		29.3	105.4	39.4	77.1	18.2	67.6	130.3	65.5	49.2	83.1
MIXT2		28.4	72.0	42.8	48.0	9.6	62.6	131.8	58.2	52.9	83.3
	–7.5	29.6	62.8	38.9	40.8	12.7	71.0	61.7	76.3	30.1	26.4
	–5	30.5	62.8	42.5	36.6	14.2	69.4	52.0	63.1	25.5	32.9
	–2.5	31.1	63.3	41.2	35.9	17.3	70.0	61.0	60.9	26.8	43.3
	–1.25	29.3	67.5	41.1	37.6	18.1	62.9	78.0	60.4	43.1	37.5
	0	30.8	80.0	42.3	76.2	–7.7	58.2	199.5	57.2	88.0	112.5
	2.5	23.9	183.0	34.6	115.5	56.9	51.1	312.2	52.8	83.1	227.4
Anova (LSD)[3]:											
COM		NS	*	NS	*	NS	NS	NS	NS	NS	NS
			(26.2)		(25.7)						
POS		NS	***	NS	***	NS	***	***	***	***	***
			(37.1)		(36.3)		(10.9)	(100.1)	(11.8)	(27.8)	(95.3)
COM × POS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] COM, plant community; POS, augering positions: –20, –10 and –5 m within the margin strip, 0 right at the border; between margin strip and crop, 10: 10 m within the crop.

[2] N loss = Nmin on 29 October – Nmin on 1 March.

[3] Significance: NS, not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0001$. LSD, least significant difference ($P < 005$) according to Fisher LSD test.

distance from the crop edge. This was attributable to the presence of a row of fifty-year-old oaks in the field boundary. Near tree rows soil pH is often low due to the acidifying effect of nitrification of leaf litter (Van Breemen et al., 1982). Consequently, during litter decomposition, the organic matter input near tree rows is 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 near the field boundary. Furthermore, nitrification may also be inhibited by tannins and phenolics under deciduous forest trees. So, aside from the adjacent crop area, soil Nmin in the field margin strips was also influenced by the semi-natural vegetation of the field boundary. The positively-charged ammonium ions are absorbed and fixed on the negatively-charged soil particles, thus avoiding leaching.

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. At the end of the growing season, total NO_3-N in the field margin strip never exceeded the Flemish legal threshold value of 90 kg residual NO_3-N·ha^{-1} in the horizon 0–90 cm, contrary to the field crop area. 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 an 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). 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.

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 of the field boundary.

On 1 March 2004, total NO_3-N at both sites was significantly higher in the 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 field boundary. At SITE1, total NO_3-N was significantly higher perpendicular to MIXT1 than perpendicular to CONTR and MIXT2. The patterns of total NO_3-N followed at best the patterns of total Nmin.

Nmin loss over the winter period 2003–2004 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 of the field crop area. Nmin loss was minimal 7.5 m from the edge of the field crop, irrespective of location. Under the field crop area, extremely high Nmin losses were found,

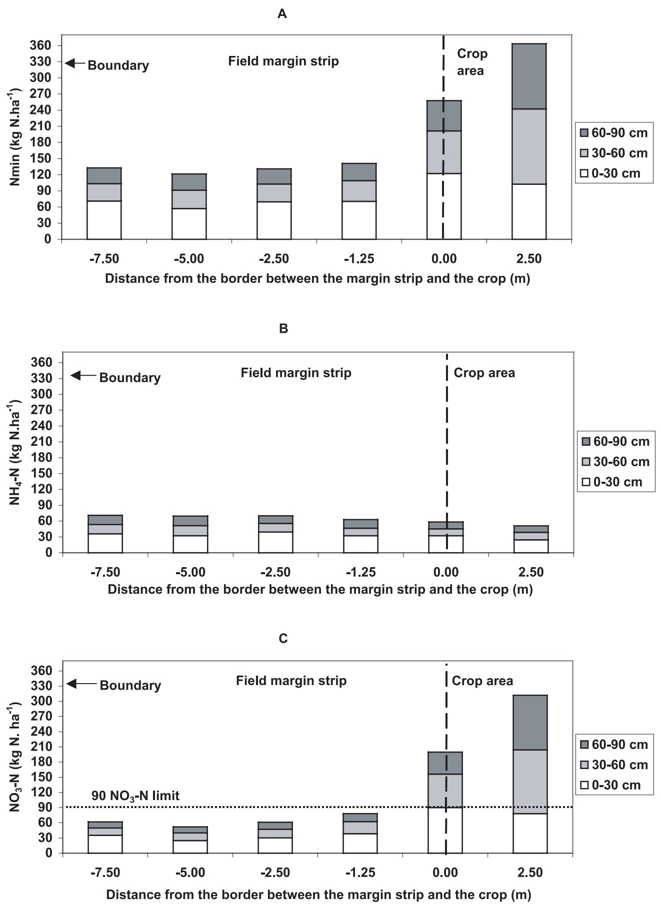

Figure 3. Distribution of total Nmin (A), NH_4-N (B) and NO_3-N (C) in soil horizons 0–30, 30–60 and 60–90 cm related to the distance from the border between the margin strip and the crop. SITE2, 29 October 2003.

particularly at SITE2. 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 horizons 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 ryegrass 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 MIXT1 (at SITE1), as a result of symbiotic nitrogen fixation (results not shown). However, a major part of soil Nmin was found in the uppermost horizon where it is less prone to leaching. Our 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 become increasingly look-alike over time (De Cauwer et al., 2005). Hence, N export in 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, which is also indicated by Lyons et al. (2000) and Sabater et al. (2003), who found no significant difference in N removal between vegetation types. However, N removal by the periodic removal of biomass (N uptake) and N immobilization might be higher in younger vegetations than in older vegetations, irrespective of location. N immobilization might be higher during the first successional years as a result of the relatively rapid and marked increase in soil organic matter stimulating microbial populations which tie up much of the soil nitrogen in an unavailable form (Garwood et al., 1977). Owing to the accumulation of organic matter in the rooting zone and the repeated removal of the cuttings, the high-yielding sown species are expected to be replaced by species with a less abundant nutrient consumption such as *Agrostis* spp. and *Festuca* spp.

Taking into account the asymptotically decreasing pattern of Nmin and NO_3-N, a field margin 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 the margin widths recommended by Marrs et al. (1989), de Snoo and de Wit (1993) and Tsiouris and 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.

3.2. Botanical analysis

Table V shows mean I% and annual I% of functional groups for all installed margin strip vegetations during the succession period 2002–2004. The mean I% of legumes (average I% over the period 2002–2004) was significantly determined by location and plant community. SITE1 revealed a significantly and twofold higher mean I% than SITE2. Compared with SITE2, SITE1 revealed a significantly lower mean I% of monocotyledons and non-leguminous dicotyledons and significantly higher mean I% of legumes than SITE2. MIXT1 revealed a significantly higher mean I% of legumes and lower mean I% of monocotyledons than MIXT2 and CONTR. CONTR showed a significantly higher mean I% of non-leguminous dicotyledons than sown communities, showing no significant difference.

Species richness and the composition of boundary vegetation evolved positively after installation of a margin strip between the field boundary and field crop. At SITE2, three years after installation of the margin strip, the botanical species diversity of the field boundary was higher compared with the species diversity prior to installation (49 spp. in 2004 versus 42 spp. in 2001). Slow-growing non-nitrophilous species such as *Geranium molle*, *Stellaria graminea*, *Veronica chamaedrys*, *Viola arvensis*, *Cerastium fontanum* and *Hypericum dubium* and more particularly, leguminous species such as *Ornithopus perpusillus*, *Medicago lupulina* and *Vicia hirsuta* did not occur prior to installation of the margin strip but were present after installation. None of these species originated from the sowing mixtures of the margin strip. Aside from changes in species composition, changes in species abundance also occurred over

Table V. Annual and mean importance (I%) of functional groups for sown/unsown plant communities at two locations under REMOV2 (Abbreviations cf. p. 5).

LOC[1]		Functional group											
		Non-leguminous dicotyledons				Legumes				Monocotyledons			
	COM[1]	2002	2003	2004	Mean	2002	2003	2004	Mean	2002	2003	2004	Mean
Mean													
SITE1		25.7	9.9	9.1	14.9	41.0	36.4	31.3	36.2	33.3	53.8	59.6	48.9
SITE2		29.1	22.9	17.8	23.3	23.0	11.2	11.4	15.2	47.9	65.9	70.8	61.5
	MIXT1	18.8	14.4	16.4	16.6	45.1	31.3	29.5	35.3	36.1	54.2	54.1	48.1
	MIXT2	17.0	9.9	6.9	11.3	40.1	23.4	18.0	27.2	42.9	66.7	75.1	61.6
	MIXT3	19.6	17.0	13.8	16.8	39.9	26.7	23.7	30.1	40.5	56.3	62.5	53.1
	CONTR	54.2	24.3	16.8	31.8	3.0	13.5	14.2	10.2	42.8	62.2	69.0	58.0
Anova (LSD)[2]:													
LOC		NS	***	*	**	***	***	***	***	**	**	*	***
			4.7	7.7	4.8	5.5	7.7	7.2	3.8	8.5	6.5	10.2	5.8
COM		**	**	NS	***	***	*	*	***	NS	*	*	*
		10.8	6.6		6.8	7.7	10.8	10.2	5.4		9.2	14.5	8.2
LOC × COM		*	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
		15.3				10.9							

[1] LOC, location; COM, plant community.

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

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 the abundance of nitrophilous species such as *Urtica dioica*, *Rumex obtusifolius* and *Rubus idaeus* was not greatly affected. 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*, etc.) to moist (such as *Polygonum amphibium*, *Juncus effusus*, *Galium palustre*, etc.) habitats and forbs thriving in nutrient-poor (such as *Anthoxanthum odoratum*, *Ornithopus perpusillus*, *Calluna vulgaris*, etc.) to nutrient-rich (such as *Urtica dioica*, *Rumex obtusifolius*, *Elymus repens*, etc.) soils. Owing to the organic farm management we are sure that the beneficial evolution in species diversity and composition was not due to a buffering effect for agrochemicals of the margin strip. So, species richness and abundance of less competitive species was increased directly owing to the reduction of nutrient input from the adjacent arable field. Marshall and Moonen (1998) and Tsiouris and Marshall (1998) demonstrated the competitive growth of nitrophilous species in fertile soils, limiting the development of slower-growing species. So, an impoverished adjacent margin strip might offer better opportunities for slow-growing species to develop in the field 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. 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 (Campbell et al., 1991; Kleijn, 1997).

The species richness of the field 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 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* and *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. At SITE1 the timescale of the experiment was probably too short to discourage the highly nitrophilous vegetation growing on this heavy soil type. Also, Boatman et al. (1994) found no major changes in species composition of hedge banks fertilized over a 3-year period.

4. CONCLUSION

Our results show that field margin strips, separating a field boundary and field crop, offer opportunities to buffer the semi-natural vegetation in the field boundary and watercourses against cropped areas loaded with high levels of mineral nitrogen. The semi-natural vegetation became less competitive and species-richer by the presence of a margin strip. In the long term, the presence of a margin strip between the crop edge and the field boundary might restore the semi-natural vegetation in the field boundary, creating a non-nitrophilous, weed-free and species-rich plant community. This might result in lower costs for maintenance of boundary vegetation. Margin strips reduced the mineral nitrogen content of the soil and mineral nitrogen loss during winter months. The field margin type showed only small effects on mineral N. Mineral nitrogen loss was not affected by field margin type but by distance from the field crop. So, designing margin strips to reduce N input in watercourses should predominantly focus on the factor width than on the factor plant community type. A minimal width of 5 m is necessary to reach an optimal reduction in mineral soil N and N losses.

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