COST-BENEFITS OF UNSPRAYED CROP EDGES IN WINTER WHEAT, SUGAR BEET AND POTATOES.

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ABSTRACT

In winter wheat, potatoes and sugar beet unsprayed crop edges were established on which no herbicides or insecticides were used. The yield (quantity and quality) from the unsprayed crop edges was compared with that from the sprayed edges and the centre of the field. In every crop the yield at the field centre was much greater (by 14%) than at the sprayed field edge. Relative to the sprayed crop edges the reduction in yield on the unsprayed edges (3 metres wide) was about 30% in sugar beet and 2% in potatoes. In winter wheat the reduction in yield was 13% average for the outer 3 metres and 11% for the outer 6 metres of the unsprayed crop edge. The quality of the harvests was unchanged, with the exception of potato size in one year. Balancing the yield losses against the benefits, *viz.* reduced pesticide costs, it is concluded that with winter wheat and potatoes, unsprayed field margins can be well adopted in agricultural practice. In sugar beet, however, the cost is too high.

INTRODUCTION

From an agricultural point of view field margins are economically less valuable than field centres. Management of crop edges often requires additional effort - in the case of wedge-shaped fields, for example - which does not benefit operational efficiency. The yield from crop edges is also often lower, for a variety of reasons (cf. Boatman & Sotherton, 1988): less favourable crop site factors (e.g. fertilizer and water regime, soil structure), competition from off-plot vegetation (tree shade, infestation by perennial weeds), increased feeding damage by pheasants, wild boars, mice and other animals and finally, direct crop damage due to more intensive machinery use on field margins (turning tracks on headlands, and tracks resulting from ditch bank management).

Over the past ten years, in many West European countries there has been a growing interest in establishing unsprayed crop edges for the purpose of nature conservation, biological pest control or reducing pesticide drift to surrounding areas. It has been demonstrated that the creation of unsprayed crop edges has a positive impact on the abundance of rare weed species, invertebrates, birds and mammals (Schumacher, 1984; Rands, 1985; Hald *et al.*, 1988; Tew *et al.*, 1992; De Snoo *et al.*, these proc.). This practice has also been shown to help reduce pesticide drift to surrounding areas (Cuthbertson & Jepson, 1988). There is still little research data available on the costs associated with establishment of unsprayed field margins, however. Boatman & Sotherton (1988) have calculated the cost of maintaining unsprayed cereal crop edges. In the present study the cost has also been calculated for potato and sugar beet crops. The study forms part of the Dutch Field Margin Project being undertaken in the Haarlemmermeerpolder. The aim of this project is to develop a management strategy for promoting nature conservation in arable fields and reducing pesticide drift to non-target areas. Effects on weeds, invertebrates, vertebrates, pesticide drift and costs to the farmer are being studied.

METHODS

Research area

The study was carried out in the Haarlemmermeerpolder (clay soil) during the period 1990-1993 in winter wheat, sugar beet and potato fields (Table 1). Yields were determined on crop edges 100 m long and 3 m wide left unsprayed with herbicides or insecticides and these were compared with yields from sprayed crop edges in the same fields as well as from the field centres. In 1992 and 1993 yields were also measured on 6-m unsprayed edges in winter wheat fields. Because of proliferous weed growth in some plots, in 1990 weeds were cleared by hand on 4 and in 1991 on all sugar beet field margins over a length of 85 m. In the winter wheat crop, too, some of the weeds (*Matricaria recutita* only) were cleared on several farms to prevent seeding; in 1991 on 3 edges, and in 1992 and 1993 on 2 edges. Because of rampant weed growth in the sugar beet crop, in 1991 the scope for differentiated spraying of this crop was considered on a limited scale (strips 25 m long), varying from zero to three herbicide treatments.

TABLE 1. Number of fields investigated. In every field an unsprayed crop edge, a sprayed crop edge and the field centre were investigated.

	winter wheat 3 m wide	winter wheat 6 m wide	potatoes	sugar beet	sugar beet 0-3 sprayings
1990	-	-	5	6	-
1991	6	-	5	8	4
1992	7	5*	7	-	-
1993	5	4**	-	-	-

* = no field centre investigated; ** = incl. 2 spring wheat fields

Yield measurements

In the potato plots, in 1990 the crop was dug up by hand along the crop edge and in the field centre over an area measuring 12 m² (4 x 3 m²), and in 1991 and 1992 over 18 m² (6 x 3 m²). On the edges the samples were taken alternately on the 2nd and 3rd potato ridges and in the centre on the 21st and 22nd ridges. The potatoes were sorted into three size classes: <40 mm, 40-50 mm and >50 mm. In processing the data for the class <40 mm, half of the aggregate weight was taken, as machine harvesting leaves a large proportion of these potatoes behind on the land. The dry-matter content was calculated by determining, for each sample, the underwater weight of the potatoes in the >40 mm fraction (Ludwig, 1972).

In the sugar beet plots, in both years an area measuring 12 m² was manually harvested on each strip (in 1990 4 x 3 m², in 1991 6 x 2 m², including the trial with differentiated spraying). Along the field edges the samples were taken on the 2nd, 3rd and 4th beet rows, and in the centre on the 21st and 22nd rows. In 1990, in the unsprayed, uncleared section (15 m long) an area of only 1 x 3 m² was harvested. In 1990 and 1991 the sugar content as well as the potassium, sodium and alpha-aminonitrogen content of respectively 2 and 4 samples were determined by the Dutch Institute for Rational Sugar Production and the results employed to calculate the sugar extractability index using Van Geyn's formula.

In the winter wheat plots, in 1991 a reed mower was employed to reap a swath 50 m long and 1.20 m wide along the edges and at the centre of the fields, and the harvest was removed and then threshed using a plot combine (Deutz-Fahr M660, type 2116). In 1992 and 1993 a plot combine (Claas, type Cosmos) was used to combine (reap and thresh) a single swath 100 m long and 2.20 m wide. On the 6 m wide strips the outer 3 m and inner 3 m of the crop edges were combined separately. Data on the strips partly cleared of weeds were also processed, and there was found to be no difference in crop yield. On each strip the dry crop weight was determined by drying a 5 x 1 kg sample at 100 °C and reweighing.

RESULTS

Potatoes

Table 2 shows the yields from the various strips for potatoes. Comparison of the sprayed and unsprayed edges indicates a lower yield on the unsprayed edges in 1990 and 1992 (by 3.5% and 8.6%, respectively). This yield loss was significant in 1992 only. In that year there was a lower yield of large potatoes (>50 mm), especially. In 1991, however, on 4 of the 5 farms the yield from the unsprayed crop edges was higher than from the sprayed edges (by 5.8% on average). In 1990 and 1991 no significant effects on potato size were found. In all three years there were significant differences, of about 10.0-12.6%, between yields from the field centre and from the sprayed crop edge. In the field centre the yield of large potatoes (>50 mm), particularly, was significantly higher than on the edges. At the field centre there were fewer potatoes in the class <50 mm. No difference in dry weight was found between potatoes from sprayed and unsprayed crop edges (Table 3). In 1992 potatoes from the field centre generally contained more water.

TABLE 2. Potato yield (kg/m²)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1990 (n=5)								
<40 mm	0.44	± 0.12	0.50	± 0.24	n.s.	0.32	± 0.11	***
40-50 mm	1.56	± 0.18	1.51	± 0.29	n.s.	1.47	± 0.40	n.s.
>50 mm	1.95	± 1.33	1.81	± 1.51	n.s.	2.70	± 1.59	***
total	3.96	± 1.22	3.82	± 1.28	n.s.	4.49	± 1.12	**
1991 (n=5)								
<40 mm	0.57	± 0.15	0.54	± 0.10	n.s.	0.46	± 0.12	***
40-50 mm	1.98	± 0.46	2.14	± 0.38	n.s.	1.59	± 0.24	***
>50 mm	1.79	± 1.03	1.92	± 0.64	n.s.	2.77	± 1.02	***
total	4.34	± 0.93	4.59	± 0.67	n.s.	4.82	± 0.75	**
1992 (n=7)								
<40 mm	0.27	± 0.09	0.31	± 0.12	*	0.24	± 0.10	*
40-50 mm	1.71	± 0.32	1.74	± 0.39	n.s.	1.59	± 0.49	n.s.
>50 mm	2.64	± 1.25	2.18	± 1.04	**	3.45	± 1.31	***
total	4.62	± 0.92	4.22	± 0.68	**	5.28	± 0.85	***

Legend: av. = average; s.d. = standard deviation between fields; n = no. of fields; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; n.s. = not significant; T = two-way, two-tailed ANOVA.

TABLE 3. Percentage dry matter in potatoes (>40 mm)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1990 (n=5)	21.8	± 0.6	21.8	± 0.8	n.s.	21.0	± 1.2	n.s.
1991 (n=5)	22.4	± 1.2	22.3	± 0.9	n.s.	21.6	± 2.1	n.s.
1992 (n=7)	19.4	± 2.1	19.3	± 1.9	n.s.	18.2	± 2.3	*

Legend: see Table 2; T = one-way, two-tailed ANOVA

Sugar beet

Because by many of the farmers the unsprayed strip is partly weeded, which meant that in the worst case (1990) only one sample could be taken per plot, it was decided to test the average yields from the individual plots non-parametrically. Compared with the sprayed crop edges, the average sugar beet yield from the unsprayed edges was 20.6% lower in 1990 and 39.1% lower in 1991 (Table 4). This reduction in yield was significant in 1991 only. In both years there was found to be a significant difference between the sprayed edges and the field centre (16.4 and 16.0% average yield reduction on the edges).

No significant differences in sugar content were found between beets from the sprayed and unsprayed crop edges, nor between beets from the sprayed edges and the field centre. Although the sugar content in the field centre was slightly lower than on the sprayed edges (Table 5), the difference was not significant (P = 0.054, Wilcoxon matched pairs, in 1991). There was also no difference in sugar extractability index between beets from the sprayed and unsprayed edges. This index was much lower for beets from the field centre than for those from the sprayed edges (P = <0.05, Wilcoxon matched pairs).

TABLE 4. Sugar beet yield (kg/m^2)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1990 (n=6)	7.34	± 1.57	5.83	± 2.26	n.s.	8.78	± 0.52	*
1991 (n=8)	5.97	± 1.32	3.63	± 1.74	**	7.11	± 0.94	*

Legend: see Table 2; T = one-tailed Wilcoxon matched pairs.

TABLE 5. Sugar content (%) and extractability index (%) of sugar beet

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
sugar content								
1990	17.15	± 1.07	17.03	± 0.98	n.s.	16.47	± 1.29	n.s.
1991	15.82	± 0.78	15.47	± 1.42	n.s.	15.16	± 0.77	n.s.
winning index								
1990	91.90	± 2.41	92.22	± 3.35	n.s.	87.96	± 6.61	*
1991	92.54	± 2.19	93.13	± 3.86	n.s.	88.26	± 4.74	*

Legend: see Table 2; T = two-tailed Wilcoxon matched pairs

The results of the experiment with differentiated spraying are shown in Table 6. There was a significant difference in yield between the unsprayed (36.3% loss) or once-sprayed strip (9.6% loss) and the fully-sprayed strip (3 treatments). Although there was little difference the double spraying gave a significant increase in yield (8.5% loss).

TABLE 6. Sugar beet yield (kg/m²) with various spraying regimes (n=4)

	av. sd.	T	
unsprayed	4.05 ± 1.21	***	(0 vs 3 sprayings)
1 spraying	5.74 ± 0.70	**	(1 vs 3 sprayings)
2 sprayings	5.82 ± 0.56	*	(2 vs 3 sprayings)
3 sprayings	6.35 ± 1.43		

Legend: see Table 2: T = two-way, one-tailed ANOVA

Winter wheat

The yield losses on the unsprayed crop edges are presented in Table 7. The average losses are significant each year: 11.0% in 1991, 11.1% in 1992 and 17.2% in 1993 for the outer 3 m of the strips. In the inner 3 m of the unsprayed 6-m strips, yield losses were 2.7% in 1992 and 7.4% in 1993. In neither year was this difference significant. Over the full 6 m of the strip, the average yield loss was 6.2% in 1992 and 15.2% in 1993, giving a combined loss of 10.7% for the two years. Each year the yield from the sprayed edge was significantly less than at the plot centre; in 1991 this loss was 17.5%, in 1992 11.3% and in 1993 12.1%. There was no significant difference in the moisture content of the grain between the sprayed crop edge, the unsprayed edge and the plot centre.

TABLE 7. Winter wheat yield (kg/m²; 16% grain moisture)

	sprayed edge		unsprayed edge			field centre		
	av.	s.d.	av.	s.d.	T	av.	s.d.	T
1991 0-3 m (n= 6)	0.729	± 0.079	0.649	± 0.076	*	0.883	± 0.087	* 1)
1992 0-3 m (n=12)	0.808	± 0.139	0.718	± 0.120	**	0.952	± 0.154	* 1)
4-6 m (n= 5)	0.872	± 0.093	0.848	± 0.073	n.s.	----		
1993 0-3 m (n= 9)	0.805	± 0.102	0.667	± 0.112	**	0.916	± 0.171	**
4-6 m (n= 4)	0.971	± 0.054	0.899	± 0.091	n.s.	1.054	± 0.056	*

Legend: see Table 2; T = one-tailed Wilcoxon matched pairs; 1) n = 5

DISCUSSION

In making a economic cost-benefit analysis of the unsprayed field margins, yield losses must be offset against savings in pesticide use. In the potato crop, yield losses were only minor (average 2%). The cost of this crop is average Dfl. 0.02 per m² (based on potato price over last six years of Dfl. 0.17 per kg, *cf.* IKC, 1993). Savings on pesticide use (*cf.* IKC, 1993) amount to Dfl. 0.02 per m², giving no nett extra expenditure. In the case of sugar beet, the direct loss of yield is rather greater (average 30%), at a cost of about Dfl. 0.24 per m² (based on 'mixture price' sugar beet of Dfl. 0.11 per kg, adjusted for sugar content and extractability index, *cf.* IKC, 1993). Savings on pesticide use total Dfl. 0.03, giving average Dfl. 0.21 nett extra expenditure per m². The experiment with differentiated spraying shows that the first, pre-emergence treatment is most important for limiting these yield losses. In winter wheat, finally, yield losses are 13% average for the outer 3 m, i.e. Dfl. 0.03 per m² (based on EC price of Dfl. 0.26 per kg). Savings on pesticide use are approximately Dfl. 0.02 per m², giving about Dfl. 0.01 nett extra expenditure per m². For a strip 6 m wide this means about Dfl. 0.005 per m². In England yield losses on 6-m wide unsprayed crop edges have been found to be only 3% for winter wheat and 6% for spring barley. The cost of yield losses in that country, including the cost of separate harvesting, threshing, drying, storage and possibly extra spraying of edges, is about Dfl. 0.04 per m^2 (Boatman & Sotherton, 1988; Boatman, 1990). As a general conclusion it can be said that maintaining unsprayed crop edges is economically viable for crops of potatoes and winter wheat. In sugar beet, however, the cost appeared to be too high.

Besides savings on pesticide use, benefits from establishing unsprayed field margins may also be accrued in the form of extra income from huntsmen, for example. In England the cost of maintaining unsprayed cereal edges is found to be compensated by the increase in revenue resulting from larger populations of partridges and pheasants (Boatman, 1990). This might be tied in with payment for 'nature production'.

The differences in yield between 3-m wide crop edges and field centres are in reasonable agreement for the various years and crops: for potatoes 11% difference, for sugar beet 16% and for winter wheat 15%. Boatman & Sotherton (1988) found that the yield from the edges of cereal fields (6-m wide) was 18% less, on average, than that from the field centre. In establishing compensation measures for arable farmers, therefore, it is important not to base payments on the average yield per hectare but on a yield loss of say 10% to 15% from the field edge.

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RESOURCE USE OF CROPS AND WEEDS ON EXTENSIVELY MANAGED FIELD MARGINS

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ABSTRACT

Many weed species have virtually disappeared from the agricultural landscape in Germany. Encouraged by governmental programmes some farmers try to re-establish a species-rich flora on crop margins omitting fertilizer and pesticides. Biodiversity has increased promisingly on such extensively used boundary strips of fields on sandy soils in the Lower Rhine area. An analysis of weed and crop green area indices, biomass, mineral ion contents and water use patterns gives evidence that the crop nevertheless is superior in the balance of competition. Extensively managed crop margins increase therefore the biotic diversity of a landscape with economic losses remaining at a tolerable level.

INTRODUCTION

In Germany plant species diversity decreased drastically during the past decennia. This is particularly obvious with regard to the arable weed flora where 397 species of a total 581 species are ranked as endangered in their existence (Kaule, 1991). The main reason for this decrease in species diversity is intensive management of fields, viz. increased fertilization and pesticide use. To counteract this undesired trend, programmes for extensive management of crop margins have been initiated designed to re-establish a species-rich field flora from the still existing seed bank. Volunteer farmers are engaged who avoid pesticide and high fertilizer use on 5 m wide crop margins. In the Lower Rhine area of North-Rhine-Westfalia, nutrient-poor cereal fields on light sandy soils are managed in this way.

We investigated the results of these practices under two aspects: The increase in species diversity was assessed and the biomass accumulation, nutrient and water use by some of the most prominent weeds and the crops was quantified in order to obtain information concerning competition for resources between crops and weeds under this field margin management.

MATERIAL AND METHODS

Species diversity and floristic richness were determined for cereal fields in the sandy alluvial plains in the Lower Rhine area near the Dutch/German border. They were managed either according to the regulations of the governmental field margins programme or in the traditional way, with intensive fertilizer and pesticide application. Crop and weed biomass, green area index (GAI) and mineral contents were measured with plants from eight extensively managed fields. Transpiration was measured with *Centaurea cyanus* and two *Papaver* species which all contribute reasonably to the aesthetic value of cereal fields.

The diversity index was calculated according to the Shannon formula, diversity $D = - \Sigma (p_i \ln p_i)$
$[p_i$ = frequency of occurrence of species i].

For the determination of biomass, GAI, and mineral contents above- and below-ground parts of the crop and of the two most abundant weeds were harvested from 20 randomly selected 9 dm^2 plots per field. Green area determinations were done with a LI-3100 area meter (LiCor, USA). For dry matter determinations the harvested material was weighed after complete drying at 80°C. K^+, Mg^{++} and Ca^{++} contents were measured with an AAS (Perkin-Elmer 2280) after six hours wet digestion with 65 % HNO_3 at 180°C.

Transpiration was measured porometrically (Li-1600, LiCor, USA) on plants transferred with the original soil from the field into containers where water supply was controlled.

RESULTS

Species richness

After some years the results of the management program are very promising in terms of increased species diversity. In the study area 100 different species were found, on average 44 per field, which makes up 42% of the local cormophytic flora. Nine species, mentioned by the red data book as highly endangered, recovered in their local occurrence. Most prominent among them are *Arnoseris minima*, *Anthoxanthum aristatum*, *Galeopsis segetum*, *Teesdalia nudicaulis*, *Misopates orontium*,

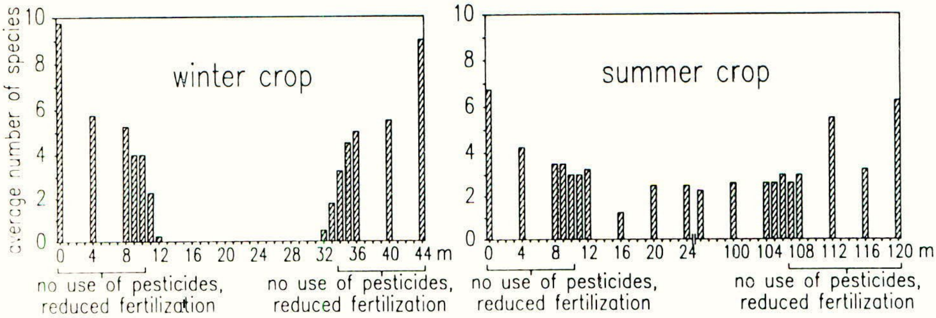

FIG. 1: Species numbers along transects across fields with extensively managed margins and intensively managed centres

and *Gagea arvensis*. Most of them are phytosociological character species of the Teesdalio-Arnoseridetum minimae and the Papaveretum argemonis. Whereas traditionally managed fields had diversity indices around -1 index values of the extensively treated crop margins ranged between -2.1 and -2.4 A steep gradient in species numbers existed between the herbicide- and fertilizer-treated areas and the extensively managed field margins (Fig.1).

GAI and biomass

Maximum GAI values of the crops were measured in June. On extensively managed areas they were between 2 and 4 m^2 m^{-2} for rye, 3 and 7 m^2 m^{-2} for oat and barley, and approx. 3 m^2 m^{-2} for *Triticale*. Maximum GAI values of the weeds ranged between 0.2 and 1.7 m^2 m^{-2} (Fig.2). During spring particularly fall-sown crops showed a much higher GAI than the accompanying weeds. Also biomass productivity of crops was much greater than that of weeds (Fig. 3). Peak values of the above-ground biomass were 1800 g dw m^{-2} soil surface in *Avena*, 1500 g dw m^{-2} in *Triticale*, and 1000 g dw m^{-2} in *Secale*. The highest values of the weeds came to only 200 g m^{-2}. On average, there was a 22 ± 14 % reduction of crop biomass yield on the margins as compared with the intensively managed central parts of the fields. The highest below-ground biomass was 190 g m^{-2} and 25 g m^{-2} for crops and weeds, respectively. This trend is mirrored also by the relationship between crop and weed root surface areas which was in the extreme case of an oat field 2:1 at the start of the season and 27:1 at harvest in July.

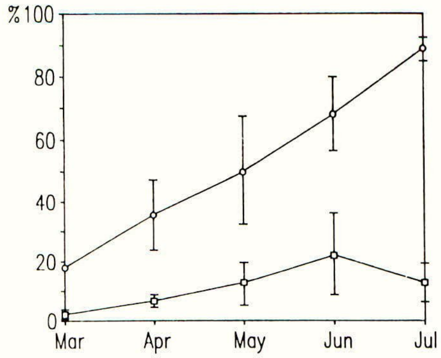

FIG.2: GAI of crops (circles) and weeds (squares) during the season; percentage of average total maximum of the 8 investigated fields.

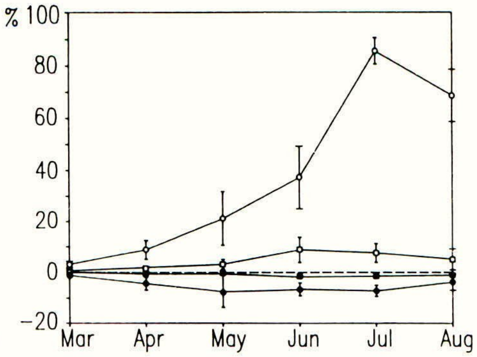

FIG.3: Above-and below-ground biomass (open and closed symbols, respectively) of crops (circles) and weeds (squares) during the season (Percentage of average total maximum biomass of the eight investigated fields).

Water consumption and mineral uptake

Transpirational water loss of *Centaurea* and *Papaver* was considerably high. Even under high leaf-to-air vapour saturation deficits stomata did not close so that high leaf conductances prevailed throughout the day (Fig. 4).

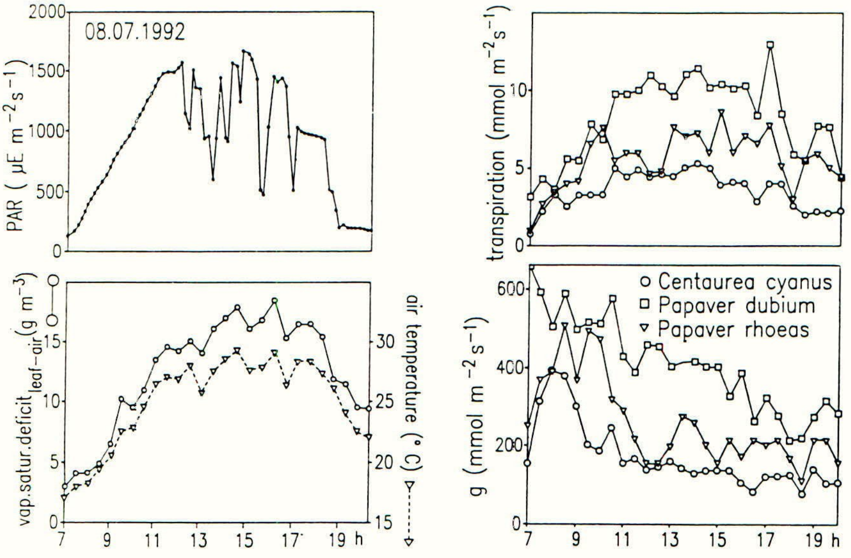

FIG.4: Diurnal courses of microclimate, transpiration and stomatal conductance of well watered poppy and cornflower.

The amphistomatous *Centaurea* leaves (upper epidermis: 85 stomata mm^{-2}, lower: 134 mm^{-2}) had lower total conductances than the hypostomatous leaves of the two *Papaver* species (both: 106 stomata mm^{-2}). Minimum stomatal resistances calculated according to Parlange and Waggoner (1971) are similar in magnitude to those measured porometrically. Taking the data shown in Fig. 4 as representative of sufficiently water-supplied weeds under spring and summer climate conditions, average daily water losses of 4 l are projected. This means daily evapotranspiration rates on account of the weeds of approx. 1 - 6 mm, depending on weed GAI.

Average potassium, calcium and magnesium contents of the crops and the most important weeds as measured in May, June and July are shown in Fig. 5. If related to dry weight, ion accumulation in barley and oat on the one hand and rye and *Triticale* on the other hand are nearly equal. Ion contents of the dicot weeds are, as a rule, higher than those of grasses. However, due to a much higher biomass, the grain crops take up most of the nutrients per soil surface area.

DISCUSSION

Omission of herbicides and reduced fertilizer application increases floristic diversity of cereal fields, and even rare species can be re-established from the soil seed bank. This was evident with the fields on acidic, light sandy soils studied here in the Lower Rhine area, and it has been reported also from calcareous soils (Van Elsen, 1989; Otte, 1990). The weeds compete with the cultivated plants for space, nutrients, and water, so that unavoidably some crop yield reduction occurs. According to Lotz et al. (1990) it will be greater in winter than in summer crops. But generally, the grain crops are rather competitive. As a result, space competition by the weeds, as quantified by the respective GAI and biomass values, is not critical even after 3-4 years extensive management. Nutrient accumulation per dry matter is equal or even higher in weeds as compared with the crops. However, since crop biomass per soil surface area is much bigger than that of the weeds, more than 3/4 of the plant

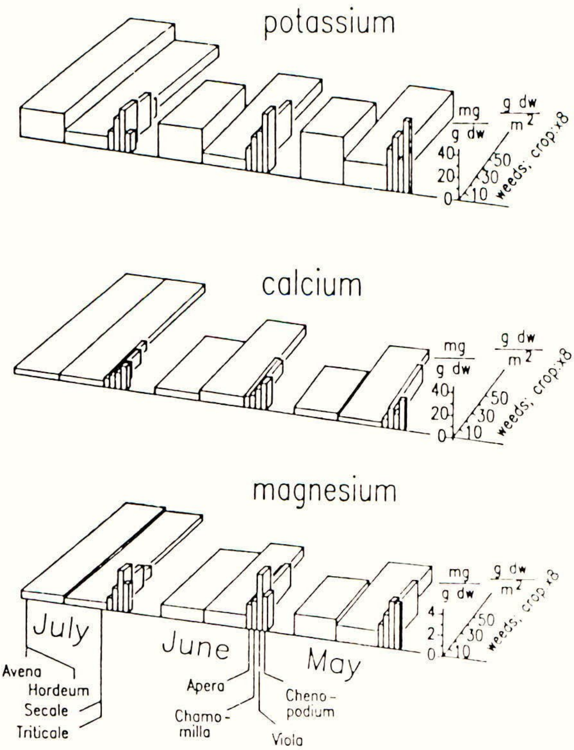

FIG.5: Average potassium, calcium and magnesium contents of grain crops and the most prominent weeds of the fields investigated, *Apera spica-venti*, *Chamomilla recutita*, *Viola arvensis*, and *Chenopodium album*, and average dry matter of these plants per square metre of soil surface area.

nutrient uptake is sequestered in the crop. We did not compare crop and weed transpiration rates directly, but from the measurements with poppies and cornflowers a water loss from weeds under spring and summer fairweather conditions is projected in the order of magnitude of 5 mm day^{-1}. A similar amount has been assessed for densely sown, intensively managed barley under similar edaphic (light sandy soils) and climatic (sub-atlantic) conditions in Jutland (Jensen *et al.*, 1993).

Modern agriculture ceases to be focused simply on yield maximization. Instead, the high costs of agrochemicals and the environmental impact of them, and the benefits for the public of a structured agricultural landscape with high biodiversity are also taken into account. An extensive management of crop margins could be a fair compromise between economic and ecological interests. Yield losses are kept in this case at a tolerable level, particularly if they are compensated to some extent by equalization payment by society. The system may become still improved by further insight into possibilities to promote rare weed species while suppressing undesired "problem weeds" like *Apera spica-venti*.

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THE IMPACT OF NITROGEN FERTILISERS ON FIELD MARGIN FLORA

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ABSTRACT

This paper examines the potential role of misplaced nitrogen fertiliser as a causal factor in the degradation of field margin floras and encouragement of weed species. Evidence from the literature is reviewed and experimental evidence described. The weed species causing greatest concern in relation to field boundaries, *Bromus sterilis, Galium aparine* and *Elymus repens*, are all highly responsive to applied nitrogen. Experiments showed that *B. sterilis* is an effective competitor for nitrogen, but the response of *G. aparine* is inversely related to the competitive ability of competitor species. Application of nitrogen fertiliser to hedge bank vegetation did not alter botanical composition over a three year period, but increased vegetative and reproductive growth of transplanted *B. sterilis*. It is suggested that misplaced nitrogen fertiliser is more likely to affect the herbaceous composition of field boundaries where disturbance maintains a large number of safe sites for germination of annual plant seeds.

INTRODUCTION

It has been suggested that the vegetation of any given habitat is broadly determined by levels of resource availability, or stress, and levels of disturbance (Grime, 1977). Arable field boundaries generally have species-poor floras compared to those adjacent to other land use types, and in recent years there has been a general reduction in the species diversity of the herbaceous vegetation of hedgerows with a shift towards the "arable" type communities (Bunce *et al*, 1994). Disturbance, caused by close cultivation, spray drift, or deliberate herbicide application, and resource augmentation via fertiliser misapplication have been implicated as contributing to the decline in diversity and concomitant increase in weedy species capable of infesting neighbouring crops (Marshall, 1988; Boatman, 1989; Smith & MacDonald, 1989). However, the actual or relative importance of these different factors in field margins have been little studied until recently.

This paper reviews evidence and presents data from some recent studies on the effect of a single nutrient, nitrogen, on the herbaceous vegetation of field margins. Nitrogen fertiliser use has increased dramatically in the last 50 years, nitrogen being the nutrient generally limiting crop growth. For example, the average amount applied to winter wheat increased tenfold from 19 kg/ha in 1943 to 192 kg in 1985 (Church, 1981; Burrell *et al*, 1990). Most of this fertiliser has been applied with broadcast -type distributors, which rely on overlapping bouts to achieve uniform application, though in a questionnaire survey of 120 farmers, 26% used pneumatic or liquid fertiliser applicators, which spread evenly over the whole width (Rew *et al*, 1992a). Broadcasters, whilst capable of accurate application over most of the field, are inherently inaccurate at field margins, and deposit fertiliser outside the cropped area if no measures are taken to prevent this. Various methods of countering this problem are available, but none are totally satisfactory, and often cause uneven application on the outer few metres of crop (Rew *et al*, 1992a).

Although very few studies have previously been carried out in field boundaries, there is a wealth of evidence that application of nitrogen fertilisers reduces floristic diversity in grassland communities (e.g. Green, 1972; Tilman, 1982; Mountfield *et al*, 1993). This may be considered undesirable in terms of conservation status, but also important in the context of field boundaries in its effect on the relationship between weedy and non-weedy species. Of particular concern are the species *Galium aparine*, *Bromus sterilis* and *Elymus repens*, which are common in field boundary vegetation and are aggressive and damaging weeds in crops (Boatman & Wilson, 1988; Marshall, 1989; Boatman, 1989). Previous studies have shown that *E. repens* (formerly *Agropyron repens*) increased under high nitrogen conditions in competition with other species (Cussans, 1973; Tilman, 1988; Marshall, 1990). There are also numerous studies which indicate that the growth and competitive ability of *G aparine*, in competition with wheat, is greater at higher levels of nitrogen supply (Mahn, 1984; Rooney *et al*, 1990; Baylis & Watkinson, 1991; Wright & Wilson, 1992). However, the effect of nitrogen on the competitive ability of *G. aparine* in hedgerows has not been investigated. The effect of nitrogen on *B. sterilis* has not been widely studied, but Lintell-Smith *et al* (1991; 1992) observed greater reductions in yield of wheat and greater seed production of *B. sterilis* when grown in competition with wheat at a higher level of nitrogen.

To obtain further information about the effects of misplaced nitrogen fertiliser on plants in field boundaries, we have carried out several pot, semi-field and field experiments.

METHODS

i) Pot experiment

Four grass species, *Bromus sterilis, Poa trivialis, Holcus lanatus* and *Festuca rubra*, were grown in pots in monoculture and 1:1 additive mixtures with *B. sterilis* at two densities and four levels of nitrogen supply (equivalent to 0, 40, 80 and 160 kg N/ha). The growing medium was John Innes No 1 compost (1:1:1 sand:loam:peat), and pots were maintained under glass house conditions. Seeds were sown within the pots in two concentric circles, at densities of eight or sixteen plants per pot in monoculture (16 or 32 in mixture). There were three replicates of each treatment and two harvest dates. Aggressivity (A), a measure of competitive ability (McGilchrist & Trenbath, 1971) was calculated for each species as $A = (W_{ij}/W_{ii})-W_{ji}-W_{jj})$ where W_{ii} and W_{jj} are dry weights per pot of species i and j in pure stands; W_{ij} and W_{ji} are weights of species i and j in mixture with each other. Further details are given in Rew (1993).

ii) Semi-field experiment

Seeds of *B. sterilis, Arrhenatherum elatius, Dactylis glomerata, Aethusa cynapium, Scandix pecten-veneris, Galium aparine, Anthriscus sylvestris* and *Heracleum sphondylium* were sown separately in November 1990 into the central $0.002m^2$ of $0.1m^2$ plots sown at the same time, of winter wheat, *P. trivialis*, or *H. lanatus*, or into unvegetated control plots. There were six replicates of each test species. Nitrogen fertiliser was applied at one of three levels, 0, 80 and 160 kg N/ha in the following spring. Further details are given in Rew *et al* (1992b) and Rew (1993). In autumn 1991, the central portions of plots which had contained annual species were re-sown with *B. sterilis* or *A. sylvestris*, or pot grown *B. sterilis* were transplanted into them in spring 1992. Annual plants were harvested between June and August in 1991 (when seeds were ripe but not shed), and the re-sown annuals and longer lived species in July 1992.

iii) Field experiments

Two experiments were carried out along hedgerows on chalk soil in Hampshire. The study farm had used a pneumatic fertiliser applicator for over ten years prior to the experiment, in combination with one metre wide bare "sterile strips" between crop and field boundary vegetation, so hedge banks had not recently been subject to fertiliser input. Nitrogen fertiliser was applied to 25 metre long plots of herbaceous vegetation next to the hedges at 0, 65 or 130 kg N/ha in March of each year for three years, starting in 1990. There were three replicates of each treatment per experiment. In February 1992, four pot-grown seedlings of *B. sterilis* were transplanted into each plot and marked.

Percentage cover was assessed in May 1990 and 1992, and numbers of naturally occurring *B. sterilis* panicles per unit length of hedge bank counted in all three years. Transplanted *B. sterilis* plants were harvested in June, and various vegetative and reproductive attributes measured. Soil samples were taken in November 1990 and March, April and June 1992 for determination of available nitrate and total nitrogen content.

RESULTS

i) Pot experiment

Bromus sterilis was the most competitive of the four grass species, *Holcus lanatus* being the next most competitive and *Festuca rubra* the least. Applied nitrogen significantly increased the competitive ability of *B. sterilis* at the first harvest (when flowering heads started to appear), but by the time of the second harvest, there was no significant effect (Table 1).

TABLE 1. Mean aggressivity of *Bromus sterilis* at four levels of nitrogen application

	Nitrogen applied (Kg N/ha)					
	0	40	80	160	SED	P
First harvest	0.42	0.55	0.51	0.54	0.04	<0.01
Second harvest	0.48	0.43	0.51	0.50	0.04	NS

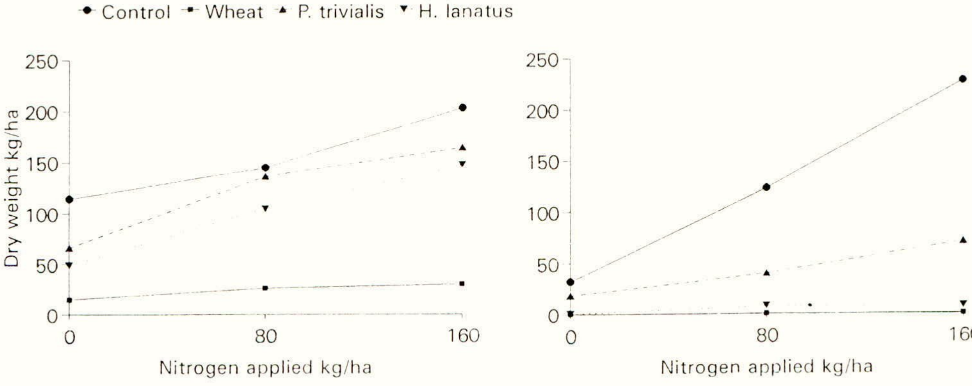
ii) Semi-field experiment

Only *B. sterilis, Galium aparine, Scandix pecten-veneris* and *Arrhenatherum elatius* established successfully in all treatments. *Dactylis glomerata* and the spring-germinating umbellifers *Heracleum sphondylium, Anthriscus sylvestris* and *Aethusa cynapium* did not establish in competition with *Holcus lanatus*, and made very little growth in the other treatments where competitors were present.

B. sterilis was relatively unaffected by competition with *H. lanatus* and *P. trivialis* sown at the same time and showed a pronounced response to nitrogen application in all treatments (Figure 1(a)). For *G. aparine* there was a significant nitrogen x competitive interaction, with response to nitrogen being greater in the absence of competition and declining as the competitive ability of the competitor species increased, in the order *Poa trivialis* < *Holcus lanatus* < wheat (Figure 1(b)). Seeds sown into one year old swards in autumn 1991 did not establish successfully. Transplanted *B. sterilis* seedlings established but made little growth

FIGURE 1. Response of annual weeds of field margins to nitrogen fertiliser in the presence of different competitors

a) *Bromus sterilis* b) *Galium aparine*



iii) Field experiment

Application of nitrogen fertiliser increased the level of available nitrate in the soil, but did not affect the percentage cover of any of the species present in either hedgebank over the three year period during which measurements were made. The number of *B. sterilis* panicles and spikelets per 0.5m of hedgebank was unaffected by fertiliser, but the number of spikelets per panicle was significantly increased by fertiliser application in the second year. Transplanted *B. sterilis* were larger and had more and larger panicles when nitrogen was applied (Table 2), though in this case there were not significantly more spikelets per panicle.

TABLE 2. Mean plant dry weight, number of tillers, tiller length and reproductive parameters (with one standard error) for *Bromus sterilis* transplanted into hedgebank vegetation (combined data from two hedgerows)

	Nitrogen applied			
	0	65	130	P
Plant dry weight (g)	1.79 (0.45)	3.94 (0.93)	5.64 (1.89)	<0.05
No. tillers/plant	2.3 (0.4)	4.0 (0.7)	5.3 (1.7)	<0.05
Tiller length (mm)	832 (87)	922 (31)	953 (12)	<0.01
Spikelets/panicle	15.4 (2.3)	18.0 (0.5)	18.0 (1.8)	NS
Florets/spikelet	5.64 (0.41)	6.05 (0.28)	6.94 (0.55)	<0.05

DISCUSSION

These experiments have shown that *Bromus sterilis* increases growth and reproductive output in response to nitrogen fertiliser when grown with other species in pots or in field plots, or when transplanted into established vegetation. When seeds were sown into established field plots of *Poa trivialis* and *Holcus lanatus* however, none survived to maturity. *Galium aparine* also responded strongly to nitrogen application, but the response was reduced in proportion to the degree of competition from other species.

Treatment of hedgebank vegetation with nitrogen did not affect the relative species composition over the three-year period of the experiments, in contrast to the results reported by Melman & van Strien (1993), who found significant differences in the botanical composition of nitrogen-treated and untreated ditch banks. However, their nitrogen rates were higher that those in our study. In longer term experiments, fertiliser has been shown to influence composition of plant communities similar to those found in field boundaries e.g. Berendse *et al* (1992) showed that *Festuca rubra* increased at the expense of *Arrhenatherum elatius* in unfertilised plots, the speed of replacement being enhanced by cutting, whereas in the fertilised treatment *A. elatius* replaced *F. rubra*. Mahmond & Grime (1976) also found that *A. elatius* eliminated *F. rubra* and *Agrostis tenuis* in a high nitrogen treatment but not a low nitrogen treatment.

The experimental hedgebanks were well vegetated with a more or less continuous sward. In a more open sward, with more opportunity for establishment from seed, the effects of nitrogen on weed species might be more apparent, since the annuals *B. sterilis* and *G. aparine* grew more rapidly from seed and were more responsive to nitrogen than the perennials. These observations conform with previous work showing that annuals tend to have a higher relative growth rate that perennials (Grime & Hunt, 1975; Muller & Garnier, 1990), and that annuals are more responsive to nitrogen than perennials (Muller & Garner, 1990; Wilson & Tilman, 1991).

Once established, *B. sterilis* seems to be a strong competitor, but it cannot establish in the absence of gaps and consequently tends to become marginalised by perennial grasses in undisturbed field boundaries, towards the interface between the boundary vegetation and the cultivated land (Dunkley & Boatman, 1994). It is commonly observed in a strip along this interface. Nevertheless, annual bromes were found to be capable of establishing in smaller gaps than other grassland herbs (Watt & Gibson, 1988), and this may account for the ability of *B. sterilis* to persist at low levels in readily undisturbed hedgebanks. *G. aparine*, establishes readily in bare ground beneath hedgerow shrubs, where *B. sterilis* does not occur, but it may be more susceptible to competition in a perennial sward.

In conclusion, misplacement of nitrogen fertiliser seems unlikely to encourage annual weeds in a dense closed field boundary sward, but where frequent disturbance creates gaps of sufficient size for establishment, nitrogen fertiliser may stimulate weed growth and increase the likelihood of spread into the cropped area. This paper has only considered nitrogen, but misplacement of fertilisers containing phosphorus and potassium may also be important.

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