Field boundary effects on soil seed banks and weed vegetation distribution in an arable field without weed control (Vaucluse, France)

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Abstract – Studies on the distribution of arable weed species relative to the field boundary have already been performed, although most of these studies have been realised in north-western Europe on intensively managed arable fields. Nevertheless, it is important to examine arable weed communities in more extensive cropping systems to increase our knowledge on how arable plant communities are constructed. Plant composition and seed bank of an arable weed community were sampled in an arable wheat field in Vaucluse (south-eastern France) at 1-m intervals along five 25-m perpendicular transects from the herbaceous field boundary. The results showed that seed bank distribution and plant composition are primarily influenced by distance from the field boundary in the crop edge rather than soil characteristics or wheat density. (© 1999 Inra/Éditions scientifiques et médicales Elsevier SAS.)

field boundary / crop edge / arable weeds / seed banks

Résumé – Effets de la lisière sur la distribution du stock semencier et des mauvaises herbes d'un champ cultivé sans désherbage (Vaucluse, France). De nombreuses études ont été réalisées sur la distribution des mauvaises herbes en relation avec la lisière du champ mais la plupart de ces travaux ont été menés dans les cultures intensives du nord-ouest de l'Europe. Cependant, il est également important d'étudier les communautés de mauvaises herbes dans des écosystèmes cultivés plus extensivement afin d'accroître nos connaissances sur les modalités de mise en place de ces communautés. La végétation et le stock semencier d'une communauté de mauvaises herbes ont été échantillonnés dans un champ de blé du département de Vaucluse (sud-est de la France) tous les mètres le long de cinq transects perpendiculaires à une lisière herbacée. Les résultats montrent que, dans les premiers mètres en bordure du champ, la distribution du stock semencier et la composition botanique sont en premier lieu influencées par la distance à la lisière herbacée plutôt que par les caractéristiques du sol ou la densité de blé. (© 1999 Inra/Éditions scientifiques et médicales Elsevier SAS.)

lisière / bord du champ / mauvaise herbe / stock semencier

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1. Introduction

In the last few decades, species diversity of arable fields in western Europe has decreased substantially [1, 4, 5, 14, 24, 35, 39]. Currently, vegetation in most arable fields is homogeneous and vast areas, or even countries, are characterised by a few dominant species, e.g. *Galium aparine* or *Bromus sterilis* [13, 33]. The main reasons for decreased species richness in arable fields are likely to be herbicide treatments for weed control and the increased use of fertilisers in recent decades [15, 28, 37].

The field boundaries are commonly perceived by landowners to be a haven for weeds, pests and disease [32, 42]. However, informal observations suggest that crop edges (headlands and corners of arable fields) tend to be areas with high botanical diversity and previous surveys have also supported this view [31, 45]. Most of these surveys were performed in intensive farming systems in north-western European countries (England, Denmark, Germany, Netherlands), and little information is available about the effects of field boundaries on arable weed distribution in the Mediterranean basin. Nevertheless, agricultural practices between north-western and south-eastern Europe are quite different especially with the persistence in the Mediterranean basin of traditional extensive arable management [6].

In this study, arable weed distribution according to distance from the field boundary was surveyed in an arable field located in the Vaucluse (south-eastern France). This region is well known for its species-rich arable weed communities containing rare species [19, 20, 23]. The aims of this survey were primarily to examine the relationship between the distribution of arable weeds and distance from the field boundary as well as to understand the importance of soil conditions and seed banks in the spatial variability of soil surface vegetation. We compared our results with those obtained in intensive farming systems in north-western Europe.

2. Materials and methods

An arable field was chosen which had been drilled with a winter wheat crop in October 1997. This field

was located in a farm in the Vaucluse (5° 26' E, 43° 55' N). The soil was calcareous with a large amount of clay. The field has always been cultivated with cereals (winter wheat in 1995 and barley in 1996) and has never received any herbicide treatments since the first ploughing of an old field several decades ago. This management is typical for a lot of fields in this area [18].

2.1. Analysis of soil surface vegetation

Five 25-m transects were laid out perpendicularly from the field boundary to the middle of the crop, with sampling points located at 1-m intervals along each transect (125 quadrats). The direction of ploughing was parallel to the field boundary and the crop edge investigated was not a headland following the definition of Greaves and Marshall [22]. The transects were positioned away from the corner of the field to avoid any possible variation when compared with the other sides of the field. In May 1998, all dicotyledonous and grass weed species were identified at each point in a 1-m² quadrat and their seedlings were counted in a 400-cm² quadrat positioned in a corner of the 1-m² quadrat. Wheat density in the 400-cm² quadrats was estimated by counting the individuals. Jauzein [27] was used when necessary to help identify rare arable weeds. Nomenclature follows Tutin et al. [41].

2.2. Analysis of soil seed bank

The soil seed bank was sampled in January 1998. Soil cores were taken using a cylindrical steel tube with a 2-cm radius (cross-sectional area $1.25 \times 10^{-3} \text{ m}^2$) to a depth of 30 cm, representing approximate ploughing depth. A total of 125 (5 × 25) soil samples and quadrats was examined (total surface area investigated: 16 dm²). This is comparable with the optimum numbers of 100 $1.66 \times 10^{-3} \text{ m}^2$ cores proposed by Barralis et al. [9].

The number of seeds in the soil samples was determined by allowing viable seeds to germinate [38]. Each soil core was broken down, placed on a 2 cm layer of sterile coarse sand in separate trays (45 × 30 × 8 cm), kept in an unheated greenhouse for 6 months and watered as necessary. Each tray was stirred at 2-week intervals and emerging seedlings were counted and removed or replanted for later identification. Mamarot et al. [29] and Muller [34] were used when required for identification. The trays were moved around the greenhouse each week to minimise the effects of any non-uniform conditions. After 2 months, each sample was

sprayed with gibberellic acid ($1 \text{ g} \cdot \text{L}^{-1}$), based on Barralis and Chadoeuf's method [7, 8].

2.3. Environmental variables

Spatial variability in the weed seed bank was compared with the following environmental variables.

2.3.1. Physical and chemical characteristics of the soil

In January 1998, three soil samples were taken at 20 cm deep for each of the five transects. The first soil core was located near the field boundary (a, 0 m), the second in the middle of the transect (b, 13 m) and the third in the middle of the crop (c, 25 m). In April 1998, at the same points, soil porosity was measured by burying three cylinders of 300 cm^3 at 20 cm deep for each of the five transects. After drying at 105°C , the soil cores were weighted and the apparent density calculated (D). The porosity (P) was calculated following the formula:

$$P\% = (2.6^* - D) / 2.6$$

(* 2.6 is a constant for the real density of soils).

Soil pH was determined in a slurry with water using a glass electrode. Organic nitrogen and carbon were analysed using the Kjeldahl and Anne methods, respectively. Analysis of extractable major ions (K^+ , Mg^{2+} , PO_4^{3-} , Ca^{2+}) was performed by atomic absorption spectrophotometry after extraction with ammonium acetate and EDTA ($\text{pH} = 4.65$).

2.3.2. Profiles of photosynthetically active radiation (PAR) through the wheat canopy

In May 1998, PAR was measured at 1-m intervals along the five transects through the wheat canopy on the soil surface. Measurements were made on the same day during similar sunny hours between 11.00 a.m. and 13.00 p.m. using a sensor with a light sensitive surface of $95 \times 1 \text{ cm}$ (EMS 7A, University of Provence, Marseille, France). The reference PAR sensor ($18 \times 1 \text{ cm}$) was placed above the wheat canopy using a standard tripod socket to measure incident radiation. PAR values from the line sensor were calculated to percentages of incident radiation.

2.4. Statistical analyses

Several multivariate analyses were performed using ADE software. i) A principal component analysis (PCA)

was performed on a [8 variables $\times$ 15 samples] matrix to identify the main soil gradients involved in the distribution of arable weed communities. ii) Two correspondence analyses (CA) were performed on the [25 quadrats $\times$ 67 species] matrix of the soil surface vegetation and the [25 quadrats $\times$ 42 species] matrix of the soil seed bank after pooling the data of the five different transects for each distance. This was in order to compare the composition and structure of the arable weed community according to distance from the field boundary.

To compare the relationships between species composition in the soil seed bank and on the soil surface with different environmental variables, a canonical correspondence analysis (CCA) was used (ADE Software). A pair co-structure analysis was also used to compare the differences between the distribution of soil seed banks and the soil surface vegetation [40]. Sorensens similarity indices (Cs) were calculated to compare seed bank composition with soil surface vegetation. Species richness, density, diversity (Shannon index) and evenness for the seed bank and soil surface vegetation (arable weeds, segetal species group and individual species) were analysed according to distance from the arable field boundary using the Anova test. Comparison of these dependent variables with the environmental variables was made using simple linear regressions (Statview software).

3. Results

Seventy-six species were identified during the study: 62 in soil surface vegetation, 40 in soil seed bank and 26 species in both (*table I*). Sixteen species could be considered to have segetal species characteristics (species with their optimal distribution in cereal crops) for south-eastern France based on Guende and Olivier [23]. Most of these species are included in the phytosociological order of Secalinetalia Br. Bl. 1952, and Secalinion-mediterraneum Tx 1937 alliance following Barbero et al. [6].

Sorensens index value ($\text{Cs} = 0.46$) and the pair co-structure analysis (similarity: 3.2 %) revealed that composition and distribution of the soil seed bank was significantly different from that of soil surface vegetation. The pair co-structure analysis also revealed that total inertia (Ti) of the soil seed

Table I. Mean numbers per m² of seedlings recorded in the seed banks and soil surface vegetation * = segetal species of Provence based on Guende & Olivier [23].

Species	Soil seed banks (seedlings/m ²)	Soil surface vegetation (seedlings/m ²)	Species	Soil seed banks (seedlings/m ²)	Soil surface vegetation (seedlings/m ²)
<i>Acinos arvensis</i>	55.01	–	<i>Lolium rigidum</i>	1.14	0.22
<i>Adonis annua</i> *	–	0.24	<i>Lotus hispidus</i>	1.14	–
<i>Agrimonia eupatoria</i>	–	0.03	<i>Medicago lupulina</i>	–	0.01
<i>Ajuga chamaepitys</i>	15.46	–	<i>Melilotus officinalis</i>	77.57	5.52
<i>Ammi visnaga</i>	126.83	–	<i>Muscari comosum</i>	–	0.11
<i>Anagallis arvensis</i>	295.46	10.12	<i>Myagrum perfoliatum</i> *	–	0.17
<i>Anchusa italica</i>	–	0.14	<i>Neslia paniculata</i> *	–	0.01
<i>Asperula arvensis</i> *	–	0.76	<i>Ornithogalum umbellatum</i>	1.14	0.42
<i>Avena sativa</i>	–	0.07	<i>Papaver argemone</i> *	–	0.21
<i>Bifora radians</i> *	–	0.02	<i>Papaver rhoeas</i> *	30.8	0.36
<i>Bromus sterilis</i>	–	0.02	<i>Phleum pratense</i>	1.14	–
<i>Bupleurum subovatum</i>	3.3	0.9	<i>Picris echioides</i>	19.78	0.02
<i>Carex flacca</i>	4.43	–	<i>Picris hieracioides</i>	–	0.02
<i>Caucalis platycarpus</i> *	–	0.02	<i>Plantago major</i>	4.43	–
<i>Centaurea scabiosa</i>	–	0.03	<i>Polygonum arviculare</i>	193.05	9.33
<i>Centaurea solstitialis</i>	–	0.71	<i>Potentilla reptans</i>	45.45	0.5
<i>Chenopodium vulvaria</i>	333.73	1.83	<i>Ranunculus arvensis</i> *	3.3	1.15
<i>Cirsium arvense</i>	3.3	2.46	<i>Rapistrum rugosum</i>	202.75	2.32
<i>Conringia orientalis</i> *	–	0.03	<i>Rubus sp.</i>	–	0.28
<i>Convolvulus arvensis</i>	3.3	1.69	<i>Rumex obtusifolius</i>	2.27	0.18
<i>Coronilla scorpioides</i>	–	0.3	<i>Sanguisorba minor</i>	4.43	0.16
<i>Daucus carota</i>	3.3	–	<i>Senecio erucifolius</i>	–	0.3
<i>Dipsacus fullonum</i>	4.43	–	<i>Setaria viridis</i>	21.02	0.22
<i>Echinops ritro</i>	–	0.19	<i>Sideritis hirsuta</i>	112.29	2.8
<i>Elytrigia repens</i>	–	0.43	<i>Silene vulgaris</i>	–	0.01
<i>Eryngium campestre</i>	–	0.02	<i>Sonchus asper</i>	9.89	0.18
<i>Euphorbia falcata</i>	9.89	1.72	<i>Torilis arvensis</i>	90.41	9.66
<i>Fallopia convolvulus</i>	40.87	3.6	<i>Trifolium campestre</i>	3.3	–
<i>Fumaria officinalis</i>	–	0.74	<i>Trifolium medium</i>	4.43	–
<i>Galeopsis ladanum</i> *	13.18	7.68	<i>Trifolium pratense</i>	3.3	–
<i>Galium tricornerum</i> *	1.14	7.21	<i>Trifolium repens</i>	–	0.02
<i>Geranium dissectum</i>	–	0.01	<i>Triticum aestivum</i>	–	32.35
<i>Gladiolus italicus</i> *	–	2.4	<i>Turgenia latifolia</i> *	–	0.06
<i>Hypericum perforatum</i>	5.57	–	<i>Tussilago farfara</i>	–	0.01
<i>Iberis pinnata</i> *	–	0.01	<i>Verbena officinalis</i>	9.89	–
<i>Kickxia spuria</i>	147.51	1.67	<i>Veronica praecox</i> *	–	0.28
<i>Lathyrus hirsutus</i>	–	0.07	<i>Vicia sativa</i>	–	0.15
<i>Linum usitatissimum</i>	43.98	2.04	Unidentified dicotyledons	11.02	0.11
<i>Lithospermum arvense</i>	–	0.06	Unidentified grass	24.21	0.01

bank matrix ($T_i = 9.212$) showed a higher variability than the soil surface vegetation matrix ($T_i = 1.848$). This result indicates that distribution of species in the soil surface vegetation is more homogeneous than in the soil seed bank.

The PCA performed on the environmental matrix revealed which soil characteristics influence soil fertility from the field boundary and between the five transects (figure 1). The first two axes accounted for almost 60 % of total variation, with

Figure 1. PCA performed on the soil characteristics data sampled at the beginning (a, 0 m), middle (b, 13 m) and end (c, 25 m) of the five transects (1–5).

41.7 % for axis 1 (variance: 3.33) and 18.9 % for axis 2 (variance: 1.51). Axis 1 is strongly influenced by pH (contribution: 22.6) and soil samples with a high pH (5a, 5b, 5c). However, axis 1 is also influenced by K (23.3), C (17.95) and Mg (14.9) concentrations and soil samples 1b, 1c are characterised by high contents of these elements. Axis 1 illustrates fertility gradient for soil samples from the first transect, taken from the left-hand side of the crop, to the fifth transect, taken from the right-hand side of the crop. However, no fertility gradient could be identified from the field boundary to the middle of the crop (figure 1). These results were confirmed by the Anova tests which showed significant differences only for phosphorous, whose values increased from the field boundary to the middle of the crop (table II). Significant differ-

ences were also found for pH and porosity between the five transects (table II).

The first axis for the two CA performed on soil surface vegetation (figure 2a) and soil seed bank (figure 2b), respectively, accounted for 23 and 13.3 % of total variation, respectively. Axes 1 were strongly influenced by species which occurred only in the samples located at 1 and 2 m from the field boundary. Particularly, *Agrimonia officinalis*, *Geranium dissectum*, *Lolium rigidum*, *Medicago lupulina*, *Lathyrus hirsutus*, *Picris echioides* and *Eringyrum campestre* for soil surface vegetation (figure 2a) and *Phleum pratense*, *Dipsacus fullonum*, *Carex flacca* and *Hypericum perforatum* for soil seed bank (figure 2b).

Total inertia of the two CCAs performed on environmental variables by soil surface vegetation matrix and seed bank matrix were 0.12 and 0.09,

Table II. Soil characteristics of samples taken at three points (a, 0 m), middle (b, 13 m) and end (c, 25 m) of the transects (n = 5) (significance : * p < 0.005)

	pH	Porosity	C ‰	N ‰	P ‰	K ‰	Ca ‰	Mg ‰
(n = 5)								
a	8.25	0.550	28.16	0.838	0.004*	0.406	10.52	0.220
b	8.23	0.544	31.97	0.878	0.007	0.440	10.71	0.180
c	8.27	0.536	27.18	0.816	0.006	0.400	10.61	0.156
(n = 3)								
1	8.14*	0.550*	35.25*	0.847	0.007	0.433	10.59	0.200
2	8.23*	0.533	34.84*	0.867	0.006	0.437	10.42	0.210
3	8.26*	0.580*	27.46	0.840	0.005	0.427	10.87	0.203
4	8.29*	0.560*	26.64*	0.907	0.006	0.393	10.70	0.160
5	8.33*	0.493*	21.31*	0.760	0.006	0.387	10.48	0.153

respectively. Inertia of axis 1 CCA and axis 1 CA were quite low, 0.26 and 0.29, respectively. Thus, no clear correlation was apparent between environmental variables, soil surface vegetation or seed bank distribution in the arable field even when wheat density was considered as an environmental variable.

Species richness (number of species found per m²), diversity (Shannon index) and evenness of the seed bank and soil surface vegetation showed no significant differences between the plots located near the field boundary (1 and 2) and the others plots (3–25). Only the soil surface vegetation density of plot 1 was significantly lower than the others. Nevertheless, species richness, diversity, density and evenness showed significant differences between each transect (table III).

Individual species densities were significantly higher in the crop edge compared to the others plots with a probability of error of $P < 0.05$ for only four species: *Anagallis arvensis*, *Bupleurum subovatum*, *Galium tricorutum* and *Polygonum ariculare* (table IV). Only *Galium tricorutum* is considered by Guende and Olivier [23] as a typical segetal species of the Luberon regional park.

Simple linear regression analyses were performed for species richness, diversity, density and evenness of the seed bank, soil surface vegetation and environmental variables (soil characteristics, PAR values). Wheat density showed a positive significant relationship only with the arable weeds of

Figure 2. (a) CA performed on the main composition of soil surface vegetation plots and (b) CA performed on the main composition of soil seed bank data. ○ = species, ◆ = plots. Only the species and samples showing a significant correlation with axis 1 have been written out in full. In (a), co-ordinates of *Agrimonia eupatoria* are the same as *Geranium dissectum*, *Medicago lupulina* and *Prunus spinosa*.

Figure 3. Simple linear regression between diversity (a) and evenness (b) of the soil surface vegetation and wheat density (wheat/m²).

soil surface vegetation diversity and evenness (figure 3a, b), with a probability of error of $P < 0.0001$. No positive relationship or significant difference has been found between wheat density and the distance from field edge (table III) or wheat density and species richness, density, diversity and evenness for the group of segetal species.

Significant differences of PAR values through the wheat canopy could be observed between the first three points (1–3) situated in the crop edge near the field boundary and the others points, with a probability of error of $P < 0.05$ (table III). Nevertheless, no positive relationship has been found between PAR values and wheat density or PAR values and species richness, density, diversity and evenness for the group of segetal species.

4. Discussion

Multivariate analysis (AFC) showed that some species were restricted to the outer 3 m of the field boundary for soil surface vegetation and 2 m for soil seed bank. Most of these species are boundary non-arable species present in the old field situated near the crop (e.g. *Agrimonia officinalis*, *Lolium*

rigidum, *Medicago lupulina*, *Lathyrus hirsutus*, *Picris echioides*, *Eringyrum campestre*, *Phleum pratense*, *Dipsacus fullonum*, *Carex flacca*, *Hypericum perforatum*, etc.). Similar distributions were found by Marshall [31] and Wilson and Aebischer [45] for typical boundary species and shady ruderal sites in the arable fields in north-western Europe (*Anthriscus sylvestris*, *Heracleum sphondylium*, *Urtica dioica*, *Galium aparine*, *Cirsium arvense*, *Lapsana communis*, *Silene alba*). It is possible that seedlings of boundary species in the crop edge may originate from parent plants of the field boundary. A previous study of seed spread from a weedy area into an adjacent cultivated field indicated that seed dispersal for most species was limited [26].

Other reasons must therefore be found to account for the distribution of arable weeds. Farming operations on the field headland differed considerably from those practised on the rest of the arable field. Farming machinery often turns on the headland, resulting in lower crop yields. Boatman and Soherton [11] and Wilson [44] have already demonstrated differences between crop yields near the field edge and yields in midfield, and implying lower competitive effects near the crop edge. Kleijn and van der Voort [28] also support this

Table III. PAR values, wheat density, species-richness (R), density (D), diversity (H) and evenness (H') of soil seed banks and surface vegetation sampled at one meter intervals along the transects (n = 5) (p * < 0.05).

	Soil seed banks				PAR	Wheat density	Soil surface vegetation			
	R/m ²	D/m ²	H	H'	(%)	wheat/m ²	R/m ²	D/m ²	H	H'
(n = 5)										
1	3.2*	1267*	1.56	0.717	74.2*	0*	23.6*	55.8*	3.80*	0.370*
2	2.4*	830*	1.13*	0.606	73.0*	360	23.2*	107.3*	3.43	0.334*
3	4.0	1491*	1.70*	0.426	61.4*	390*	22.0	124.5*	3.38	0.335*
4	3.6	1543*	1.67*	0.664	48.4*	370*	23.2*	130.6*	3.42	0.333*
5	4.2*	1821	1.86*	0.626	42.0*	375*	19.6*	133.7*	3.22*	0.333*
6	3.4	1847	1.45	0.441	36.2*	381*	21.4	135.9*	3.25*	0.327*
7	5.0*	3339*	1.98*	0.492	33.0*	470*	20.2*	134.0*	3.14*	0.323*
8	4.2*	1849	1.66*	0.480	33.0*	305	20.6	103.3*	3.36*	0.342
9	5.4*	2605	2.15*	0.484	32.2*	365*	22.4*	143.5*	3.26*	0.321*
10	3.6	2526	1.33*	0.533	32.2*	230*	21.2	128.7*	3.18*	0.323*
11	4.8*	3432*	1.75*	0.436	32.2*	490*	21.8	129.8*	3.10*	0.314*
12	4.2*	2972*	1.59	0.375	38.8*	440*	19.0*	127.1*	3.18*	0.331*
13	3.8	2284*	1.55	0.409	48.6*	275	22.4*	117.5*	3.32*	0.332*
14	5.6*	2863*	2.29*	0.501	40.0*	345	22.2*	128.5*	3.46	0.344
15	4.0	2009	1.81*	0.574	36.6*	450*	20.4*	124.3*	3.19*	0.329*
16	4.6*	2998	1.89	0.577	44.4*	265	23.0*	107.4*	3.56	0.351*
17	2.4*	1236	1.05*	0.358	42.4*	140*	21.2	90.8*	3.74*	0.376*
18	4.4*	2870*	1.82*	0.490	47.6*	345	21.4	122.3*	3.40	0.343
19	3.2*	1360*	1.36	0.498	45.8*	405	21.2	115.5*	3.23*	0.324*
20	2.6*	1404	1.07*	0.368	47.2*	335	19.8*	110.6*	3.34*	0.343
21	3.6	1571	1.59	0.426	44.6*	245	20.8	89.0*	3.37*	0.341*
22	3.2*	1414	1.40	0.504	43.2*	220	20.6	96.4*	3.50	0.358*
23	1.8*	935*	0.70*	0.538	39.0*	256	19.0*	100.1*	3.36*	0.351*
24	3.0*	1432*	1.40	0.360	39.6*	290	22.6*	94.2*	3.43	0.341*
25	4.0	1787	1.87	0.638	42.8*	340	20.8	107.8*	3.37*	0.340*
(n = 25)										
1	3.2*	658*	1.45	0.569	38.2*	315	19.5*	11.1	3.26	0.336
2	3.8	1742*	1.54	0.515	41.7	299	21.2*	107.2	3.32	0.333
3	3.6	2109*	1.56	0.490	48.5*	318	23.1*	120.3	3.55	0.347
4	4.0	2835*	1.67	0.516	42.9	361	22.2*	121.2	3.35	0.334
5	4.3*	2600*	1.72	0.413	48.3*	324	20.7*	111.9	3.33	0.342

assertion and found that, even in non-headland crop edges, light penetration is higher in the outer metres of the crop and that in fertilised crop edges these light levels determine species richness and individual plant performance. Their results are confirmed by our study because the cover of the wheat measured by the PAR values (*table III*) was significantly higher in the first 3 m in the crop edge near the field boundary than the other plots even with no gradient in the distribution of wheat density in the arable field (*table III*). Then, the presence of

typical grassland species and high seedling density in the crop edge could be explained by this availability of light. Another explanation could be the effects of crop competition, which increase across the arable field, creating more opportunities for these species to develop near the field boundary than in sites located further away [21].

Our study showed that species richness, diversity and evenness in the seed banks and soil surface vegetation were not higher in plots sampled near

Table IV. Seedling density per m² of 4 species sampled in the surface vegetation at one meter intervals along the transects (n = 5)(p * < 0.05)

	<i>Anagallis arvensis</i>	<i>Bupleurum subovatum</i>	<i>Galium tricornutum</i>	<i>Polygonum arviculare</i>
(n=5)				
1	14.00*	0.40*	1.00*	1.00*
2	9.30*	0.40*	1.80*	2.20*
3	21.50*	0.60*	3.20*	4.20*
4	20.50*	1.00*	2.20*	9.40*
5	18.60*	0.20*	4.00*	15.10*
6	20.00*	0.20*	6.90*	16.00*
7	3.60*	0.40*	9.70*	14.00*
8	5.10*	0.40*	7.80	7.30*
9	5.60*	0.40*	6.30*	25.00*
10	2.20*	0.80*	12.70*	20.00*
11	3.40*	0.00*	14.50*	14.50*
12	7.90*	0.20*	10.20*	7.30*
13	7.90*	0.20*	6.90	17.10*
14	10.30*	0.20*	5.90	15.50*
15	10.70*	0.20*	5.00	14.10*
16	10.70*	1.00*	5.50	7.50
17	8.20*	1.00*	4.40	7.30*
18	9.10*	1.00*	10.90*	6.30*
19	13.70*	1.40*	6.20	3.20*
20	6.00*	1.20*	10.10*	6.60*
21	7.30*	1.20*	6.60	4.60*
22	9.70*	3.40*	11.30*	3.20*
23	13.60*	3.40*	8.70	3.60*
24	6.40*	1.80*	7.30	3.20*
25	7.70*	1.40*	11.20*	5.10*
(n=25)				
1	10.16	0.84*	4.66*	14.44*
2	7.48*	0.44*	7.54	9.66
3	12.30*	0.64*	6.50	8.64*
4	10.12	0.84*	7.68	8.22*
5	10.54	1.72*	9.68*	5.70*

the field boundary than in midfield plots. These results are opposed to those found by Marshall [30] or Wilson and Aebischer [45]. However, the differences could be explained by the absence of herbicide treatment. In spite of the fact that, in their studies, weed seedlings were surveyed before herbicide application, the differences in distribution were nonetheless probably due to the cumulative effects of herbicide and nitrogen applications in previous years (Wilson, pers. Comm.). In an intensive farming system, most weed seedlings in the middle of the field are eliminated by herbicide

treatments and the only plants left are either ones which germinate after cultivation or are resistant to the herbicide used. Because the crop edge is usually cultivated and sprayed using a different pattern from that of the main part of the arable field, it could act as a refuge for most of the arable weed flora which would increase species richness and plant diversity [12, 42, 43].

The positive relationship between wheat density, arable weed diversity and evenness (*figure 3a, b*) could not be explained by the distance from the field margin. Only localised changes that favour

the crop could also favour the diversity and evenness of the arable weeds community. These results are in contrast with those of Kleijn and van der Voort [28] but their work took place in an intensive farming system in Netherlands (pesticide drift, fertilisation, high wheat productivity, etc.). Then, it is difficult to make valuable comparisons with our study site localised in south-eastern France.

The CCA and linear regression analyses between seed bank, soil surface vegetation and the chemical characteristics of the soil showed no significant correlations. These results confirmed those of Albrecht and Pilgram [3] and Palmer and Maurer [36] who found that former management (previous cultivation and farming) is a more significant factor in determining the distribution of arable weed flora than environmental variables in small areas.

No distinct differences between the environmental relationships in the soil seed bank and soil surface vegetation could be observed using the pair co-structure analysis and Sorensens index. These results agree with other studies [2, 10, 17, 45]. In arable soils, the spatial pattern that exists immediately after seed rain is modified by agricultural practices and because farm machinery can transport weed seeds. Combine harvesters, in particular, can carry or concentrate weed seeds [16, 25]. Because the soil surface vegetation is more affected by the mechanical practices than the soil seed bank, the heterogeneity of soil seed bank is higher as revealed by the pair co-structure analysis.

An EEC project for the conservation of species-rich crop edges has recently been initiated. This project includes reducing wheat seedling density on crop edges to increase segetal species richness. This approach was based on previous studies conducted in northern Europe [45]. However, our results showed that this type of action could be more beneficial to the boundary species than to the segetal species of Mediterranean fields. In our case, segetal species are not only limited to field edges in contrast to arable weeds in the intensive crop in northern Europe. In these intensive cropping systems prevailing in northern Europe, field margin management is crucial to conservation of

endangered arable species. But, in southern France, where cereals are grown very extensively without agrochemical inputs, arable plant conservation may need to be approached on a 'whole-field' basis rather than on a field-margin basis as practised in northern Europe.

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