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Impact of crop management on weed species diversity and community composition of winter wheat fields in Iran

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The aim of this study was to assess the effects of crop management practices on the diversity, structure, and composition of weed communities. A total of 30 fields (15 fields each) in low-input and conventional farming systems were surveyed in north-eastern Iran. In the conventional cropping system, both mineral fertilizers and herbicides were applied, while in the low-input cropping system, the fertilizer was mainly manure and herbicides were avoided. The results showed that the pool of species, species richness, number of unique species, and Shannon's diversity index were greater in the low-input system than in the conventional system. Both cropping systems had more broad-leaved species than grasses and more annual species than perennial species. All the multivariate methods of analysis that were applied revealed that the weed community composition was significantly different between the two management types. The low-input cropping favored herbicide-susceptible broad-leaved weeds, legumes, and weeds with biodiversity value, whereas a high proportion of herbicide-tolerant grasses was found in the conventional fields. The results suggest that low-input cropping can sustain high weed diversity and abundance.

Key words: biodiversity, farming system, herbicide, species richness, weed diversity.

Arable weed species play a key role in supporting biodiversity within agro-ecosystems. They are primary producers and are of central importance to the arable system's food web. The weeds serve as immediate food sources for herbivores and support prey species at higher trophic levels (Marshall *et al*. 2003; Hyvönen & Huusela-Veistola 2008). In addition to providing food for species at higher trophic levels, the weeds within fields have other ecosystem functions, including nutrient cycling and soil preservation (Tilman & Downing 1994; Altieri 1999). At the same time, weed control per se can be facilitated by weed species diversity. Accordingly, a reserve of weed diversity within fields can be of benefit for sustainable agriculture.

The introduction of intensive agriculture in the mid-20th century led to vital changes in arable communities (McCloskey *et al*. 1996). Intensive agriculture is based on a greater use of mineral fertilizers and herbicides, leveling and draining, intensive tillage of the soil, and the introduction of crop varieties that are sown at high densities. In the long run, the application of such farming methods has been detrimental for the biodiversity of arable habitats (Hyvönen & Salonen 2002). This is especially true for arable weed communities because several cropping measures are directed specifically towards reducing weed diversity and abundance (Hyvönen & Huusela-Veistola 2008). Besides a decline in weed diversity, intensive cropping practices change the weed community composition. The long-term application of herbicides in cereal production reduces the abundance of broad-leaved species and weeds that are susceptible to herbicides, instead supporting more herbicide-resistant species and grass weeds (Moreby *et al*. 1994; McCloskey *et al*. 1996; Hyvönen & Salonen 2002). Many of these species, such as wild barley (*Hordeum spontaneum* C.Koch), now are considered to be serious agricultural pests in the wheat

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(*Triticum aestivum* L.) fields of Iran. A higher rate of N fertilization favors nitrophilous species, such as common lambsquarters (*Chenopodium album* L.), catchweed (*Galium aparine* L.), and chickweed (*Stellaria media* L.) (Rydberg & Milberg 2000; Van Elsen 2000; Murphy & Lemerle 2006). In addition, N fertilization promotes the growth of crops, resulting in closed crop stands and light limitation for the undergrowing weed communities. Thus, N fertilization favors shade-tolerant, climbing, and competitive weed species, but suppresses the others and results in a decrease of weed species diversity (Pyšek & Lepš 1991; Bengtsson *et al.* 2005).

The above findings have encouraged attempts to apply less-intensive cropping measures, such as low-input management, to support weed diversity within agro-ecosystems. Low-input cropping favors methods that replace artificial fertilizers with organic fertilization and that use less or no herbicides. Such cropping practices can be expected to increase the diversity of weed species and to change the composition of weed communities (Hyvönen & Salonen 2002).

Wheat has been cropped for >100 years and is still the most important winter crop in Iran. Since the early 1970s, cereal cropping systems in Iran have moved towards intensification and specialization, with the development of effective selective herbicides (especially the phenoxy acids, such as 2-methyl 4-chloro phenoxy acetic acid [MCPA] and 2,4-D), the increased use of N fertilizers, monoculture farming rather than traditional mixed systems, the abandonment of rotations, and the use of new cereal varieties that grow at higher densities and shade out the weeds. Along with these, direct subsidies have been allocated to agricultural inputs, such as pesticides and fertilizers, as a result of government-accelerated agricultural intensification. This increasing agricultural intensification has led to dramatic changes in the composition and diversity of weed communities in croplands. In the past decade, however, an outbreak of "problem" weeds that are resistant to the applied herbicides, as well as mounting concern over the economic and ecological sustainability of conventional agricultural management practices, has led to an interest in developing alternative cropping systems and agri-environmental schemes, like low-input systems that are less reliant on synthetic chemical inputs. Although most of the current low-input fields in the region under study are young, it can be expected that the composition and diversity of their weed communities will alter from those that were present when the fields were subjected to intensive conventional cropping practices. The documentation of the effects of a farming system on the vegetation's diversity is an important step towards understanding the whole ecosystem's functioning in agricultural landscapes (Petersen *et al.* 2006). Therefore, in each region, before drawing conclusions about whether or not weed diversity is beneficial for the agro-ecosystem's functioning and sustainability, we need knowledge about the actual weed diversity in the agro-ecosystem under study. Although synchronic studies on weed diversity in two low-input and conventional cropping systems have been carried out in many countries (Hald 1999; Rydberg & Milberg 2000; Hyvönen *et al.* 2003; Weibull *et al.* 2003; Bengtsson *et al.* 2005; Hole *et al.* 2005; Gabriel *et al.* 2006; Clough *et al.* 2007; Boutin *et al.* 2008; Romero *et al.* 2008), this is the first study to evaluate and compare the weed diversity of the two aforementioned cropping systems and to assess their effects on the weeds with biodiversity value in wheat-farming systems in Iran.

MATERIALS AND METHODS

Study site

The study was conducted in the Shirvan region (37°28′–37°31′N and 57°34′–58°13′E), which is located in the north-east of Iran. The annual average precipitation is 290 mm and the mean annual temperature is 12.5°C. The soils are mostly Aridisol.

Weed sampling

A total of 30 fields was surveyed, with 15 fields for each of the low-input and conventional cropping systems. The selection of the fields was based on a paired design. The low-input fields were selected first and then paired with a conventional field. The field pairs within the region under study were located between 4 km and 30 km away from each other. The fields within a pair were of approximately similar size and they were located near each other (<800 m). This selection pattern ensured that both the low-input field and the conventional field were distributed evenly within the study area and also that the soil type, land use, and landscape features were similar between the two cropping systems. The information on cropping practices was obtained by interviewing the farmers (Table 1). The low-input fields had been under this type of management for 5 years, on average (range: 2–10 years), while the conventional fields had been under conventional farming for at least 10 years. Therefore, in the low-input fields, the application of herbicides had been stopped completely for at least 2 years after their conversion to low-input cropping. Insecticides had been applied in some of the conventional fields for some years prior to sampling, but not in the year of the study. In the Shirvan region, conventional farmers use mold board-plowing to a 30 cm depth ~2 weeks before sowing and

Table 1. Characterization of the low-input and conventional wheat cropping practices in the fields under study

Characteristic	Conventional	Low-input
Field area (ha)	1.52 ± 0.40 (1, 2.5)	1.37 ± 0.38 (1, 2)
Fertilization		
N (kg ha^{-1})	153 ± 10.46 (130, 180)	54 ± 3.38 (50, 60)
P (kg ha^{-1})	89 ± 5 (80, 100)	35 ± 4 (30, 40)
Manure (t ha^{-1})†	0.93 ± 0.80 (0, 2)	11 ± 0.85 (10, 12)
Weed control		
Broad-leaved herbicide (L ha^{-1})‡	1.5 ± 0.38 (1, 2)	No
Sowing density (kg ha^{-1})	374 ± 14 (350, 400)	260 ± 8 (250, 270)

Values are the average ± SD; the minimum and maximum values are given in parentheses. † The manure was bovine or sheep manure; ‡ the broad-leaved herbicide was 2, 4-D + 2-methyl 4-chloro phenoxy acetic acid.

disk-harrowing to a 15 cm depth, along with a roller several times on the day of sowing. Similarly, the low-input producers apply such practices for soil preparation, but with a lower intensity. While the low-input farming system uses crop rotation that includes a diversity of crops, such as cereals (e.g. corn, barely, and winter wheat) and legumes (e.g. clover, alfalfa, and bean), the conventional farming system is based solely on cereal cropping. The application time of the postemergence herbicides in the conventional cropping system is in early April and the herbicides are applied only once. The sowing of the crops is carried out from the middle of October to the end of November in both farming systems.

In order to survey the weeds, five 0.25 m^2 quadrats were distributed randomly in each field. The field margins and negative topographic positions were avoided because they might represent different habitats (e.g. different soil conditions). Furthermore, the surveys were restricted to those field areas that had homogeneous crop cover (Teresa-Mas *et al.* 2007). The sampling was conducted in all the fields from 16 May to 30 May 2009 after the postemergence herbicide application. The weed species were cut at the soil surface, sorted by species, and counted. Each species was classified into functional groups by its life cycle (annual or perennial) and morphotype (monocotyledonous: grasses; dicotyledonous: broad-leaved species). Also, some of the species were classified according to their biodiversity value from a list of weeds that are valuable in supporting the biodiversity of arable fields, provided by Marshall *et al.* (2003), who listed the main arable weeds with biodiversity value, in terms of their importance for farmland invertebrates and birds' diet.

Data analyses

Shannon's diversity index and species richness were used as the measures of species diversity. The level of species richness was calculated as the number of plant species per field, using the pooled data of the five quadrats that had been established in each field. Shannon's diversity index was calculated as follows: $H' = (N \log N - \Sigma n \log n) N^{-1}$, where N is the total number of individuals per field and n is the number of individuals per species per field (Magurran 1988). The comparison of the means for Shannon's diversity index, the species richness, and the density of the weed species between the cropping systems was carried out by the paired student's *t*-test. Where necessary, the data were transformed to meet the assumptions of parametric analysis. The analyses were carried out by using the SAS Statistical Package (SAS Institute 2003).

A principal components analysis (PCA) from the CANOCO 4 package (ter Braak & Smilauer 1998) was used to identify the overall variation patterns in the species composition across fields. The species abundances were the square roots and were centered by the species. Prior to the ordination analyses, the species with only one occurrence in the database were excluded from the analyses because rare species might have an unduly large influence on such an analysis (ter Braak & Smilauer 1998).

A multiresponse permutation procedure (MRPP), based on the squared Euclidean distance, was used to test the null hypothesis of no difference between the floristic composition of the low-input cropping system and the conventional cropping system. The MRPP is a non-parametric approach for testing the hypothesis of no difference between two or more groups and the estimation of the *P*-value is based on permutation procedures (McCune & Mefford 1999; Mielke & Berry 2001).

The indicator value (IndVal) approach, after Dufréne & Legendre (1997), was applied to find the typical species of the two cropping systems. The IndVal of a species is the product of its group specificity (A_{ij}) and its group fidelity (B_{ij}): $IndVal_{ij} = A_{ij} \times B_{ij} \times 100$. A_{ij} is the mean number of occupied plots of species *i* across sites in group *j* divided by the sum of the mean number of occupied plots of species *i* over all groups, while B_{ij} is the number of sites in group *j*, where species *i* is present, divided by the total number of sites in group *j* (Dufréne & Legendre 1997). The IndVal is maximum (100%) when all the plots that are occupied by a species are found in one group and when that species occurs in all the plots of that group. The index is expressed as a percentage. For each species, the significance of the highest IndVal (corresponding to the cropping system with which it was most associated) was tested with a Monte Carlo procedure (1000 permutations). PC-ORD version 4 (McCune & Mefford 1999) was used for the MRPP and IndVal analyses.

RESULTS

A total of 40 plant species was identified in the 30 inventoried fields (Table 2). The pool of species that was surveyed in the low-input fields (34 species) was 1.3-fold larger than that of the conventional fields (26 species). Both the low-input and conventional systems had more broad-leaved species (32 and 19 species, respectively) than grasses (two and seven species, respectively) and more annual species (27 and 17 species, respectively) than perennial species (seven and nine species, respectively). The conventional fields had a higher proportion of grass species in the species pool (27%) than did the low-input fields (6%). Furthermore, the proportion of perennial species in the species pool of the conventional fields (35%) was higher than in that of the low-input fields (20%). Altogether, 14 species were detected as being exclusively in the low-input fields, while only six species were unique to the conventional fields. The number of joint species (i.e. in both systems) was 20. In the low-input fields, the most numerous family was *Brassicaceae* (11 species), while in the conventional system, it was *Poaceae* (seven species). In the low-input system, seven species with biodiversity value were recorded, of which five species occurred in more than half of the surveyed fields. The number of valuable species in the conventional system was six species and only three of them were recorded in more than half of the surveyed fields.

The species richness (mean ± standard error, SE) was significantly higher ($P < 0.001$) in the low-input system (14.33 ± 0.75) than in the conventional system (8.66 ± 0.44) (Fig. 1). Also, the result showed that Shannon's diversity index (mean ± SE) was significantly higher ($P < 0.001$) in the low-input system (2.13 ± 0.04) than in the conventional system (1.86 ± 0.06) (Fig. 1).

The MRPP indicated that the weed communities of the two management systems were significantly different from one another ($T = 14.15$, $P < 0.0001$). This was seen also in the PCA ordination of the studied wheat fields, on the basis of their weed communities (Fig. 2).

On the basis of the PCA analysis, 45% of the total variation in the species data was explained by the first two axes. Axis 1 explained 36% of the variation and clearly separated the two management systems. The conventional fields clustered together, whereas the low-input fields were dispersed along axis 2, which explained 9% of the total variation (Fig. 2a). The PCA diagram also demonstrates some of the weed species associations with the two management systems (Fig. 2b). These associations between each farming system and certain weed species were reflected in the indicator species analysis that is shown in Table 3.

The species that showed a strong association with the conventional system were: *H. spontaneum* (IndVal = 81.7, $P = 0.001$), knotweed (*Polygonum aviculare* L.) (IndVal = 71, $P = 0.004$), *C. album* (IndVal = 69.5, $P = 0.004$), wild oat *(Avena fatua L.)* (IndVal = 46.7, $P = 0.007$), and camel-thorn (*Alhagi persarum*) (IndVal = 45.8, $P = 0.009$). All of these species were positioned at the left side of axis 1, where the conventional fields were placed (Fig. 2). In contrast, *S. media* (IndVal = 84.2, $P = 0.001$), *Vicia hyrcania* (IndVal = 78.9, $P = 0.001$), Iranian knapweed (*Centaurea depressa* M.B.) (IndVal = 66.7, $P = 0.001$), corn buttercup (*Ranunculus arvensis* L.) (IndVal = 66.7, $P = 0.001$), wild mustard (*Sinapis arvensis* L.) (IndVal = 53.3, $P = 0.002$), African rocket (*Malcolmia africana* [L.] R.Br.) (IndVal = 53.3, $P = 0.002$), roemer poppy (*Roemeria refrecta* D.C.) (IndVal = 53.3, $P = 0.002$), and hare's ear mustard (*Conringia orientalis* [L.] Dumort.) (IndVal = 53.3, $P = 0.002$), positioned at the right side of axis 1, were associated strongly with the low-input system (Fig. 2).

DISCUSSION

As expected, the low-input cropping system, as a result of a lack of agricultural intensification, yielded a greater weed species diversity and number of valuable species than did the conventional cropping system, a finding that is consistent with the results of other studies (Hald 1999; Rydberg & Milberg 2000; Hyvönen *et al.* 2003; Bengtsson *et al.* 2005; Hole *et al.* 2005; Gabriel *et al.* 2006; Storkey 2006; Clough *et al.* 2007; Boutin *et al.* 2008; Romero *et al.* 2008). There also was a clear difference in the functional groups between the two cropping systems. The high proportion of grasses that was recorded in the conventional cropping system was related to the extended use of auxin herbicides, such as 2, 4-D and MCPA, to control broad-leaved weeds (Kudsk & Streibig 2003; Romero *et al.* 2008). Perennial weeds rely not only

Table 2. Mean density of the weed species that were recorded in a survey of 30 wheat fields, corresponding to 15 conventional fields and 15 low-input fields in Shirvan, Iran

Species	Abbreviation	Life cycle	Morphotype	Density (number of shoots per m^2)		
				Low-input	Conventional	*P*-value
Acroptilon repens	ACRE	P	D	–	2.80	–
Adonis orientalis	ADOR	A	D	2.20	0.13	*
Agropyrum pectinatum	AGPE	P	M	–	3.20	–
Alhagi persarum	ALPE	P	D	0.13	7.00	**
Asperugo procumbens	ASPR	A	D	0.80	0.20	NS
Avena fatua	AVFA	A	M	–	8.53	–
Brassica sp.	BRSP	A	D	0.67	–	–
Bromus tectorum	BRTE	P	M	6.60	14.67	**
Bunium cylindricum	BUCY	P	D	0.93	–	–
Capsella bursa-pastoris†	CABP	A	D	1.73	–	–
Cardaia draba	CADR	P	D	0.47	0.33	NS
Centaurea depressa	CEDE	A	D	13.27	–	–
Chenopodium album†	CHAL	A	D	2.53	16.67	***
Cirsium arvense†	CIAR	P	D	2.60	0.60	*
Conringia orientalis	COOR	A	D	5.87	–	–
Consolida orientalis	CONO	A	D	1.40	0.13	NS
Convolvulus arvensis	COAR	P	D	1.27	7.53	**
Descurainia sophia	DESO	A	D	1.40	–	–
Cryptospora falcata	CRFA	A	D	1.80	0.13	NS
Fumaria vaillantii	FUVA	A	D	0.27	6	**
Galium aparine†	GAAP	A	D	9.00	1.40	**
Goldbachia laevigata	GOLA	A	D	0.13	–	–
Hordeum spontaneum	HOSP	A	M	1.47	24.00	***
Lactuca serriola	LASE	P	D	1.13	7.73	**
Lamium amplexicaule	LAAM	A	D	0.80	8.80	**
Lolium sp.	LOSP	A	M	–	0.07	–
Malcolmia africana	MAAF	A	D	2.13	–	–
Melilotus officinalis	MEOF	A	D	4.87	0.13	**
Neslia paniculata	NEPA	A	D	4.80	–	–
Poa bulbosa	POSP	P	M	–	2.47	–
Polygonum aviculare†	POAV	A	D	2.40	18.87	***
Ranunculus arvensis	RAAR	A	D	4.13	–	–
Rapistrum ragosum	RARA	A	D	2.40	0.47	*
Roemeria refracta	RORE	A	D	6.60	–	–
Secale cereale	SECE	A	M	–	0.53	–
Sinapis arvensis†	SIAR	A	D	9.33	–	–
Stellaria media†	STME	A	D	29.07	0.87	***
Vaccaria oxyodonta	VAOX	A	D	1.33	–	–
Veronica persica	VEPE	A	D	1.60	–	–
Vicia hyrcania	VIHY	A	D	19.47	0.27	***

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$, NS, not significant. † Weed species with a biodiversity value (they have value for invertebrates and are important for seed-eating birds) (from Marshall *et al.* 2003). A, annual; D, dicotyledon; M, monocotyledon; P, perennial.

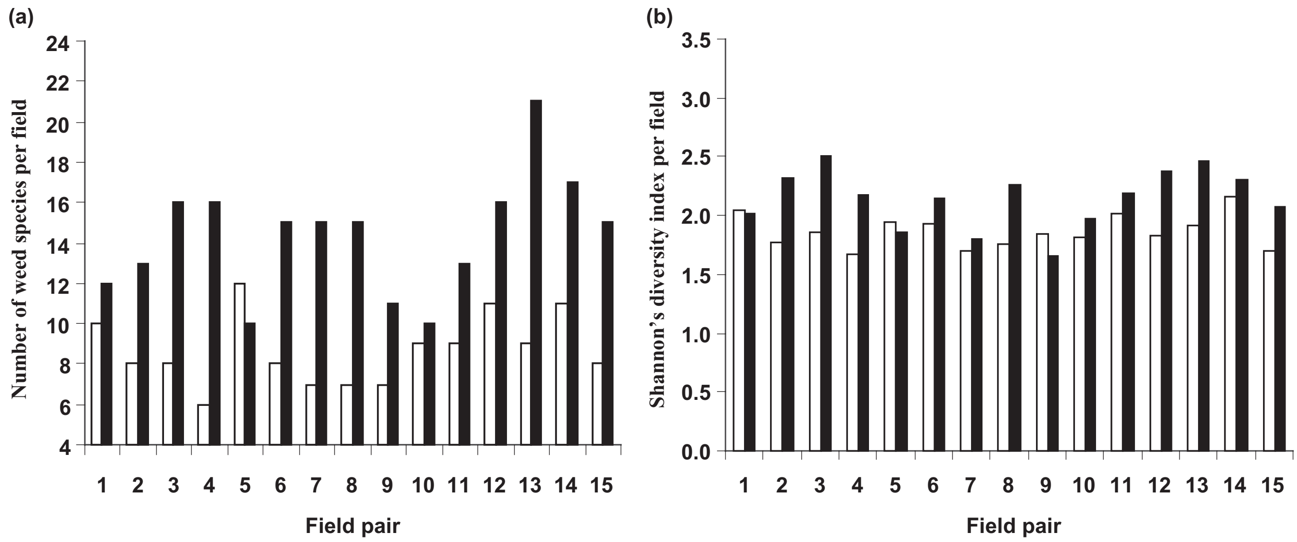

Fig. 1. (a) Species richness (number of weed species per field) and (b) Shannon's diversity index per field on each pair of fields. (□), conventional fields; (■), low-input fields.

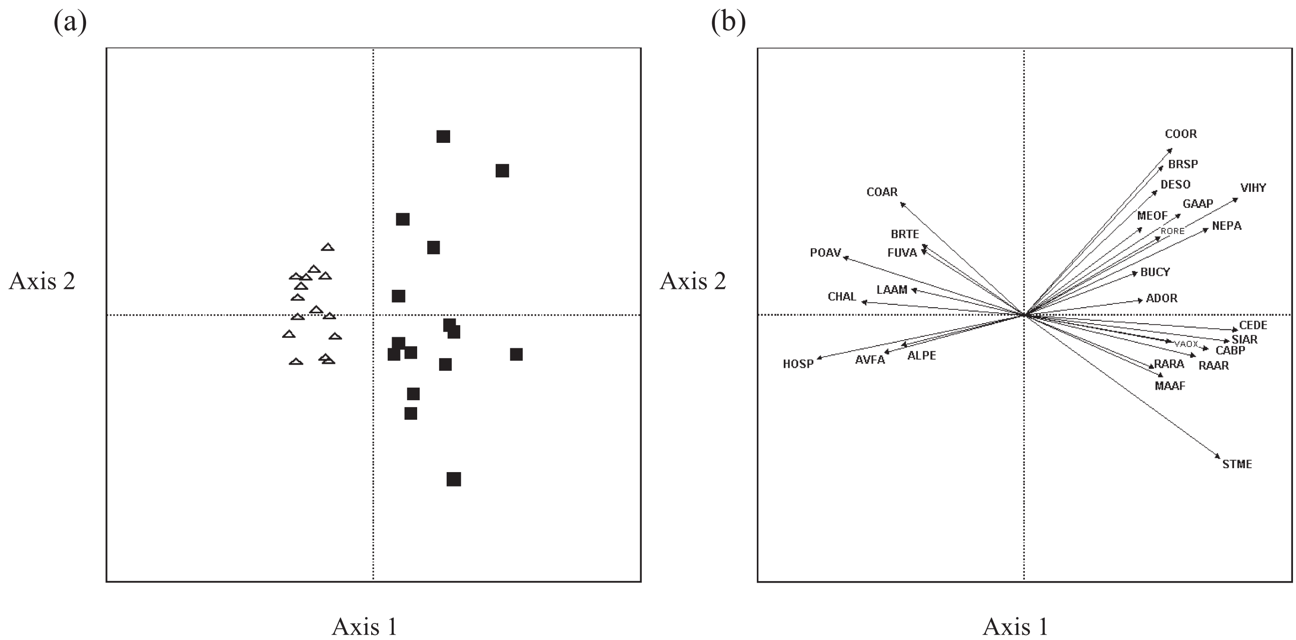

Fig. 2. Principal components analysis ordination diagram for the weed community composition of the wheat fields. Shown are biplots of the (a) fields and (b) species. (△), conventional fields; (■), low-input fields. Only the species with a minimum fit of 18% are shown for clarity. See Table 2 for the abbreviations.

on clonal growth for reproduction but also on abundant seed production. However, they are resistant to most herbicides (Hyvönen & Salonen 2002); thus, an increase in the proportion of perennials per species pool in the conventional fields, compared to the low-input fields, is expected. *Brassicaceae* was the most numerous family that occurred in the low-input fields. All the major wild genera of *Brassicaceae* are very susceptible to most of the herbicides that are used in cereals (Wilson *et al*. 1999), which explains why this family had lower species rich-

Table 3. Indicator species of low-input and conventional wheat cropping, according to the indicator species analysis (*P*-values of <0.05 only)

Species	Relative abundance (%)		IndVal (%)
	Low-input	Conventional	
Adonis orientalis	94	6	37.7
Alhagi persarum	2	98	45.8
Avena fatua	0	100	46.7
Bunium cylindricum	100	0	33.3
Capsella bursa-pastoris	100	0	46.7
Centaurea depressa	100	0	66.7
Chenopodium album	13	87	69.5
Cirsium arvense	93	7	43.3
Conringia orientalis	100	0	53.3
Convolvulus arvensis	14	86	51.4
Descurainia sophia	100	0	33.3
Fumaria vaillantii	4	96	44.7
Galium aparine	87	13	51.9
Hordeum spontaneum	6	94	81.7
Malcolmia africana	100	0	53.3
Melilotus officinalis	97	3	38.9
Neslia paniculata	100	0	44.7
Polygonum aviculare	11	89	71.0
Ranunculus arvensis	100	0	66.7
Rapistrum ragosum	84	16	50.2
Roemeria refracta	100	0	53.3
Sinapis arvensis	100	0	53.3
Stellaria media	97	3	84.2
Vaccaria oxyodonta	100	0	46.7
Veronica persica	100	0	33.3
Vicia hyrcania	99	1	78.9

IndVal, indicator value.

ness in the conventional crops than in the low-input fields in the present study. The establishment of a more similar floristic composition across the surveyed fields in the conventional system is related to the relatively similar management of these fields (Fig. 2a). In contrast, the relatively greater variability in the low-input fields as a result of the diversity of management practices resulted in heterogeneous floristic composition among the low-input fields.

The weed species that depended on the conventional farming system often were herbicide-tolerant or nitrophilous species. Mahn (1984) elucidated that the long-term application of broad-leaved herbicides encourages tolerant grasses due to their resistance to these herbicides. This also was seen in this study, in which *A. fatua* and especially *H. spontaneum*, two grass species that are tolerant to the herbicides that were applied, accounted for a higher proportion of the total weed density in the conventional fields than in the low-input fields. In addition, high N rates favored nitrophilous weeds, such as *C. album*, and species with an ability to climb into more favorable light conditions, like field bindweed (*Convolvulus arvensis* L.) (Rydberg & Milberg 2000; Van Elsen 2000; Blackshaw *et al.* 2003; Murphy & Lemerle 2006). The partly high density of non-nitrophilous species, like *P. aviculare*, in the conventional system is interesting. This might be related to a lack of coincidence between the herbicide application time and the date of *P. aviculare* emergence in the region under study. Whereas, most herbicides are applied in early April, the surveys of the fields showed that *P. aviculare* emerges after mid-April. Apparently, in the low-input system, the density of *P. aviculare* has decreased due to the high densities of early-emerging species, which have reduced the abundance of *P. aviculare* by competitive suppression.

Likewise, some species were closely associated with low-input farming. Besides the non-use of herbicides, which promotes weed diversity in general, other factors contributed to this association. For example, Van Elsen (2000) believed that the high density of species, like *V. hyrcania*, might be caused partly by their highly competitive ability at lower amounts of mineral N input. This is also the reason for the occurrence of non-nitrophilous species, such as shepherd's-purse (*Capsella bursa-pastoris* [L.] Medicus) and *R. arvensis*, in the low-input fields (Murphy & Lemerle 2006). The low density of wheat in the low-input system favored slower-growing arable weeds, such as *C. depressa* and *S. arvensis*. The high density of the nitrophilous species, *S. media*, in the low-input system is unexpected. The most likely cause of this increase is the cessation of herbicide use (Van Elsen 2000).

CONCLUSION

The level of weed species diversity was higher in the low-input fields than in the conventional cropping system in Iran. Herbicide-tolerant grasses and some nitrophilous species dominated the weed communities in the conventional cropping system, but in the low-input cropping system, the herbicide-susceptible broad-leaved weeds and non-nitrophilous species were dominant. The low-input farming system supported a greater number of weed species that have biodiversity value in relation to the birds and invertebrates that inhabit farmlands (Marshall *et al.* 2003).

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