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Effect of landscape structure on agrobiodiversity in western Iran (Gilan-E Gharb)

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ABSTRACT
The widespread transition into intensive agroecosystems has led to a considerable decline in plant biodiversity especially for organisms in the field boundaries. The aim of this study was to survey the vegetation of fields and field boundary types located in an agricultural landscape. We provided the structural map of the landscape and classified it into field boundary types nested in three main groups of natural and seminatural elements. Species recorded in all habitat types were categorized into two emergent groups based on their response to land use intensification: 1) agrotolerant species (AT) and 2) high nature-value species (NV). We analyzed the effect of landscape structure and soil physicochemical properties on species richness of these groups. We found both landscape structure and soil properties significant in explaining variation among AT and NV species richness both at 2-m-×-2-m and landscape scales. The most overall species richness was recorded for agricultural fields (43 species) followed by non-crop field edges (37). Woody green veins and permanent ditches were the elements providing high NV species richness clearly, while fields and other field boundary types were mostly supporters of AT species richness. Diversity of AT species increased along nitrogen and clay content gradients of the soil, while NV species benefited where phosphorus and soil moisture content were high. We recommend agricultural landscapes to be more specified with (semi-)natural habitats which embed high a proportion of rare weeds as nature-value plant species.

KEYWORDS
Agrotolerant species; field boundary types; nature-value species; green veining; soil physicochemical properties

1. Introduction

Since the last century, traditionally low intensive agroecosystems have been changed into intensively exploited landscapes, with minimum area of natural habitats available (Kuussaari et al. 2009; Tschartke, Tylianakis, and Rand et al. 2012). In spite of environmental damages including water and air pollution (Liu, Wu, and Zhang 2005) and loss of biodiversity (Perrings et al. 2006), agricultural landscapes are potentially a good choice for conserving biodiversity

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due to a high diversity of habitat types (Waide et al. 1999). Landscape features that are not commonly utilized for agricultural production, like field margins, road edges, wooded banks, hedgerows, and ditch banks with linear shape, and also natural and seminatural patches that are considered as nonlinear elements, form a network of veins and nodes arranged around agricultural ecosystems known as "green veining" (Grashof-Bokdam and Langevelde 2004; Opdam, Grashof, and Van Wingerden 2000). The linear elements make connections among the different parts of the network, while the patch elements are nodes within or beneath the network. Providing nonhomogenous landscape structure in the form of green veins is among options suggested and recently experienced as a policy to improve biodiversity in European agroecosystems (Kleijn et al. 2006; Kleijn and Sutherland 2003; Marshall, West, and Kleijn 2006). Such a heterogeneity, as a factor relating to landscape structure, may influence species richness and biodiversity patterns both at the local and landscape scale (Cook et al. 2002; Fahrig et al. 2011). Another factor influencing biodiversity in an agricultural landscape is the level of connectivity among different linear spatial elements as a network. Connectivity and distance of natural linear elements among so called green veinings, are factors determining the function of veins to support patterns of flora distribution through all field boundary types in an agricultural landscape (Burel and Baudry 1990; Peterson, Allen, and Holling 1998), which has been fully described by the "metacommunity" concept, and a niche-based hypothesis referred to as the "species sorting effect" (Holyoak et al. 2005). These networks of natural and seminatural habitats have been considered as refuges for specialized, endangered, and sensitive species against disturbances caused by intensive agricultural operations (Duelli 1997; Kozakiewicz and Grotat 1994; Paoletti 1999). On the other side, from a point of view regarding species reaction to nonsustainable environmental conditions, responses of different species to habitat availability or, on the contrary, habitat loss and deterioration, depends on specialization degree and stress-tolerance of species experiencing frequent agricultural disturbances (Lirra et al. 2008). To evaluate species success in agricultural landscapes with a negligible amount of green veining habitats, an optimal methodology to classify species into emergent functional groups is needed. There are many proposed classifications relying on the concept of rarity (Clergue et al. 2005; Weibull and Ostman 2003), habitat generalists versus specialists (Krauss et al. 2004) and some others (see also Aavike and Lirra 2009). These classifications each have deficiencies because of a lack of reflection on how functional groups respond to agricultural disturbances. Depending on the degree of response to agricultural land use, a flexible emergent classification has been proposed by Aavik et al. (2008); in which based on frequency of species presence-absence in field observations two emergent agrotolerance groups, including agrotolerant (AT) and nature-value (NV) species are suggested. High loads of fertilizers and pesticides, as well as tillage operations, are obvious indicators of land use intensification (Flohre et al. 2011;

Tscharntke et al. 2005) and are critical determinants of these classes of emergent groups (i.e., AT and NV species). Species enduring high land use and able to occupy vacant niches left by tillage operation, along with high efficiency in taking soil nutrients (DiTomaso 1995; Evans et al. 2003; Weaver, Kropff, and Groenevled 1992), such as nitrogen, are categorized as agrotolerant species; on the other hand, species that are rare or absent in agricultural fields but present in wild or seminatural habitat features are referred to as nature-value species (Falinski and Canullo 1985; Grashof-Bokdam and Langevelde 2004; Jauni and Hyvonen 2010). The aim of our study was to evaluate the influence of landscape structure, in terms of different linear seminatural habitat availability, and edaphic properties of the landscape as a consequence of proximity to agroecosystems, on AT and NV species richness. We expected linear habitats with more connectivity to natural habitats and less impacts from agricultural practices to be a refuge for nature-value species, while habitats highly disturbed by intensive agricultural activities to be supporting of agrotolerant species. For this purpose, the specific study questions that were asked were:

a) What is the level of agricultural intensification of the study landscape? It is useful to obtain an overall picture of the study site?
b) Do the various habitat types of the landscape consist of distinguishable vegetation composition?
c) Considering the concept of plant functional group composition, which habitats support agrotolerant and which support nature-value species richness?
d) The networks of the linear habitats of the landscape are mostly detached and in some parts connected to the neighboring natural habitats of the landscape. If we presume that such habitats experience low levels of disturbance, can such connections play a role as buffer zones around agricultural fields and be the supporters of sensitive species to agricultural practices (so called nature-value species)?
e) In a case in which the landscape is managed intensively, the soil and structure of the landscape and also AT and NV species richness will be affected. How are plant functional group composition affected?

2. Materials and methods

2.1. *Study area*

The study area was located in Gilan-e Gharb County, Kermanshah Province, Iran, along the Zagros Mountains hillsides, a 700-ha landscape with the latitude of 34°20′159″N and longitude of 45°52′865″E. The altitude is 550 m above sea level, mean summer and winter temperature of 32.5 and 11°C, respectively, along with mean annual precipitation of

385 mm (which occurs mostly from November to June), have resulted in a Mediterranean climate with temperate winters and dry warm summers. This area is classified as a semiarid and warm climate according to the Koppen climatic classification and the Embereger method (Milady 1995). The length of the dry season is from mid-May to December based on ambrotermic (precipitation and temperature) meteorology records; and other months are humid. Shallow to moderately deep loamy soil originated from calcic parent materials are characteristic of the study area (Amiri Nejad and Bagher Nejad 1999). The main agricultural crops are wheat with an average yield of 1.94 t/ha, corn 7.97 t/ha, barley 1.66 t/ha, and rice 1.39 t/ha (Kermanshah Agri-Jahad 2010). Zagros forests are mainly covered by *Quercus brantii* L., however, it is not a dense type of forest, and rather occurs as clumps and scattered patches of trees because of negative effects of climate change and dust storms entering the west of Iran in recent decades (Baaghideh et al. 2013; Pourreza et al. 2014). Rangelands of the region are exploited traditionally by the local people. Agricultural fields are mostly found at the foothills of the mountains. Agriculture in the region dates back as far as more than 9000 BC, and are thought to be areas of the origin of some cereal cultivation and also domestication of goats (*Capra hircus*) (Riehl, Zeidi, and Conard 2013; Zeder and Hesse 2000). From ancient times, this region has been the home of peoples from different civilizations who periodically invaded and replaced each other. But there is no sign of erosion of civilization caused by land degradation or any form of deterioration in this 130-centuries-old forest area (Al-Soof 1970; Eidem and Laessoe 2001). However, changing the natural habitats like rangelands and forest areas into arable lands has become a major concern during the last decades. Forest retrogression at the foothills of this area has been mainly caused by expanding bordering arable lands. However, there are still many signs of natural patches and linear elements in the agricultural fields. These natural elements, which are remnants from the forest area, mainly can be found in the form of wood banks, ditch banks, tree lines and solitary trees, and some other non-cropped patch elements like woodlots and ponds.

2.2. *Agricultural intensification index*

Agricultural intensification (AI) was measured through an operational definition of agricultural intensity (Herzog et al. 2006) by interviewing farmers and relying on variables that are considered as drivers of biodiversity, soil and water quality. Levels of AI among study sites were determined by the self-reported tillage and agrochemical application practices of farmers interviewed in the five regions. For this purpose, as the method was based on investigating at least 10% of the studied landscape (Herzog et al. 2006), the

landscape was divided into five equal sections, and then an average of 14 ha were investigated from each. Since the fields from each 14 ha belonged to 3–6 farmers, the criteria for determining the number of interviews was based on the area investigated, and not the number of farmers; as the result 22 farmers were interviewed from the whole parts of the landscape. Data on tillage operations, mechanical weed control, and pesticide and fertilizer application were gathered as indicators determining the level of agricultural intensity; these data were for the main crops existing in common crop rotations including wheat, corn, barley and rice. The effect of chemical fertilizers on biodiversity, and tillage operations on the fauna and flora combination in an ecosystem have been well investigated (Gruber and Claupein 2009; Reich 2009; Thorbek and Bilde 2004). Pesticides that affect non-target organisms in addition to weeds and pests are criticized frequently by biology researchers (Greig-Smith et al. 1995). The values on these indicators were weighted for each unit area (ha) based on utilization frequency by each farmer. The percentage of nitrogen contained in organic manure was estimated through averaging the values proposed in research done previously (Akbarinia et al. 2004; Daneshian, Rahmani, and Alimohammadi 2012; Sharifi, Mirzakhani, and Sajedi 2012). An AI value was calculated for the whole landscape as follows: Three main agricultural operation groups including chemical and organic fertilizers (Kg N/ha/year), pesticide input (utilization frequency of herbicides, insecticides, and fungicides), and, finally, the number of tillage operations and mechanical weed control, were entered into the following equation (Flohre et al. 2011):

$$\mathrm{AI} = \frac{\sum_{i=1}^{n}(y_i - y_{imin})/(y_{imax} - y_{imin})}{n} \times 100$$

(Herzog et al. 2006).

Where AI is abbreviation for overall agricultural intensification index, y_i is the observed value, y_{min} the minimum observed value, y_{max} the maximum observed value and n is the number of individual indicators.

2.3. *Landscape structure and boundary type*

2.3.1. *Providing landscape maps using GIS*

In order to provide the landscape map, Deereh area sheets were provided from the National Geographic Center of Iran (NCC). To display all the required features, information was obtained through georeferencing the topographic maps (1:25,000) using a remote sensing method (RS). Finally, each part of the study site was visited to ground truth the accuracy of the landscape features.

2.3.2. *Boundary type*

Three main groups of separable spatial elements (later subdivided into seven subgroups) with respect to differences in their structure and the way they provided special ecological conditions, were determined (Boutin, Baril, and Martin 2008; Holzschuh, Steffan Dewenter, and Tscharntke 2010; Milsom et al. 2004; Tscharntke et al. 2005). These main groups were: 1) agricultural fields; and 2) green vein elements, including linear elements (mostly bordering agricultural fields), and 3) natural and seminatural linear habitats. Considering a habitat's form and function in the landscape, we classified all habitat types into seven subgroups. Group 1 was subdivided into 1) arable and horticultural fields. Group 2 was subdivided into 2) linear elements adjacent to the fields, within field edges, 3) linear elements adjacent to the fields with non-crop field edges (Ma et al. 2012); 4) roads and ditches, 5) permanent ditches, and 6) nonpermanent ditches. Group 3 consisted of 7) woody green vein elements.

The criteria we applied to define some of discrete elements of the landscape included the following:

- All the features with maximum width of 5 m (0.5–5 m) were considered as linear elements bordering fields from one or two sides (Aavik and Liira 2009).
- Permanent earthen channels and drainage ditches utilized for irrigation, in which the presence of water is confined to the time of irrigation, were defined as nonpermanent ditches; as a result, channels built up temporarily during a growing season were not considered.
- Long field boundaries with small numbers of trees were not taken into account except those comprised of acceptable tree density assumed to have a shadow effect.
- Both dirt and asphalt road surfaces were defined as roads.
- Boundary elements within crop fields were referred to as within-field edges, and those between crop fields and non-crop lands, referred to as non-crop field edges.

Spatial dispersion of the landscape features including settlements and constructions, fields, roads, rangelands, forest area and all boundary habitats are presented in Figure 1. In addition, some information on the linear habitats of the landscape is presented in Table 1. Within field edges consisted of 301 linear elements with the most length and area among all boundaries of the landscape. On the other hand, non-crop field edges constituted the least length and area of the landscape while having the most connectivity to the natural habitats. The selected within-field edges, roads and permanent ditches had no connectivity to the natural habitats.

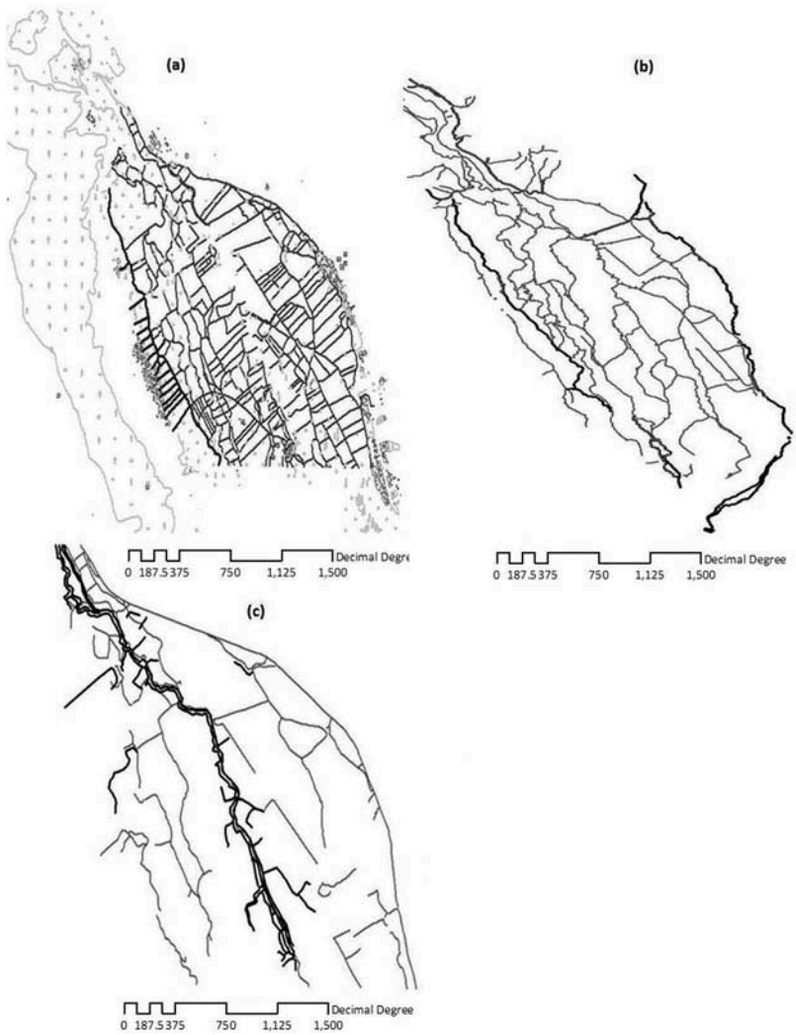

Figure 1. Maps of spatial distribution of different boundary types (1:25,000) depicted in a) non-crop field edges (dark black lines), within-field edges (black), and rangelands, forest and rural settlements (gray); b) permant ditches (black) and nonpermanent ditches (gray); and c) woody green veins (black) and roads (gray).

2.4. *Vegetation data*

To avoid neglecting any part of the landscape being sampled, and as all the parts of the landscape had generally the same climatic and topographic conditions, the whole landscape was divided into the same six sampling units with respect to area (each 116.7 ha). Since there are many bordering linear elements, quadrilateral plots were applied. The "minimal area" method was applied to determine the optimal size of sample plots (Barbour, Burk, and Pitts 1999). Following the Braun–Blanquet method,

Table 1. Number, length, and area of field boundary types of the landscape and their connectivity measures.

Type of field boundaries	No. of elements	Total length (m)	Total area (m^2)	Length adjacent to natural habitats (m)	Length adjacent to the fields (m)
W.F.E	301	63248	36,683.83	—	63248
R	52	22185	41,042.25	—	22185
P.D	4	8873	15,705.21	—	8873
N.P.D	67	25016	14,759.44	93	24923
N.F.E	15	6965	12,188.75	6965	6965
W.Gr	5	9635	32,084.55	1183	8452

W.F.E: within field edges. R: road verges. P.D: permanent ditches. N.P.D: nonpermanent ditches. N.F.E: non-crop field edges. W.Gr: woody green viens.

we used a nested-plot design and arranged the subsequent plot sizes (0.25 m^2, 0.50 m^2, 1 m^2, 2 m^2, 4 m^2, 8 m^2), then a species-area curve was fitted based on the cumulative number of species recorded in each sample plot and plot area; as a result 2 m × 2 m sample plots were chosen. The same method was applied to determine the number of plots required for vegetation data. In total, 87 sample plots (2 m × 2 m) were recorded in all elements (fields and linear habitats which were categorized into seven subgroups) so that vegetation data from fields were recorded using 18 sample plots; woody green vein 19 sample plots; and within-field edges, non-crop field edges, permanent ditches, nonpermanent ditches and roads, 10 sample plots each. Sampling was done based on a systematic-randomized method in which equal proportions of sample plots were located in each of the six homogeneous landscape units. For this purpose, and to avoid presumptive spatial autocorrelation of sample plots within an element, we determined a criterion by which the sample plots had to be at least 200 m distance from each other. To follow this criteria easily, we applied 400-m transects along which imaginary vertical lines were given and sample plots were situated along them randomly. In linear elements with more than 2-m width (i.e., roads), we placed our vegetation sample plot right at the center of element. For linear elements with narrow formation, nearly all the within field edges and most of the permanent and nonpermanent ditches were sampled using 1 × 4 m plots (Aavik and Liira 2009). Non-crop field edges were sampled right next to the edge of agricultural fields (0.5 m distance), preserving field-edge-effect comparability among different field boundaries (Aavik and LiIra 2010). In addition to recording the presence of all species existing in the sample plots, the abundance of plant species were also measured by plant cover, that is, the relative area covered by different plant species in the sample plots following standard methods (Coker and Coker 1992; Damagaard 2009). Sampling started at the beginning of July, where it coincided with the after-juvenile phase of the plant species, making identifying them more possible.

Sample plot scale (2 m × 2 m (was considered to assess the species diversity taking into account species agrotolerance. Vegetation data on agricultural fields was used to classify the species into the emerging groups including agrotolerant and high nature value species. The species with presence frequency of 10% or more in the sample plots were considered as agrotolerant species, and other species were classified as nature value or rare weed species (Aavik et al. 2008; Aavik and Liira 2009).

2.5. *Evaluating soil physicochemical properties*

To survey the effect of differences in soil physicochemical properties (edaphic properties) on variation in biodiversity of plant species, composite soil samples at the depth of 0–30 cm were brought to the soil testing laboratory. Five points (four from the corners and one at the center) in each vegetation plot (2 m × 2 m) were sampled using a soil sampling auger. Soil samples were brought to the lab immediately to avoid changes in soil properties, in particular soil pH and moisture. The results of soil analyses is presented in Table 2.

2.6. *Data analysis*

As the number of sample plots in different landscape elements was unequal, a rarefication method was conducted according to Hurlbert (1971) and Simberloff (1978). Species richness variance was checked following Heck et al. (1975), in which there was no significant difference among species richness of various sample sizes according to the determination of the coefficient of the regression between species richness variance and changing the size of samplings (R^2 = 0.0016).

Detrended correspondence analysis (DCA) was conducted to ordinate plant species distribution in response to diversity in existing habitat types, and on the other hand, canonical correspondence analysis (CCA) to ordinate plant species according to differences in edaphic properties in the studied landscape. First, vegetation data from 2 m × 2 m sample plots were classified according to the Van der Maarel method (Faryabi et al. 2012), and then introduced to PC ORD for Win Ver 4.17 software. As it was mentioned, all habitat types existing in the studied landscape were classified into three main groups; because of the large number of diagrams needed for presenting all the paired comparisons of species richness among habitat types, we selected these three main groups to be compared initially. After that, all the field boundary types were categorized into an emergent classification based on their homological aspects regarding structure, function, spatial characteristics, and special ecological conditions. As a result, there were: field boundary type 1 (FBT1) consisting of within-field edges and nonpermanent ditches; permanent ditches as FBT2; non-crop field

Table 2. Summary of analysis of variance (ANOVA) for physicochemical characteristics (0–30 cm depth) of the landscape soil.

	Soil properties										
Habitat Type	N (ppm)	P (ava.) (ppm)	K (ava.) (ppm)	O.C* (%)	C/N	PH	EC** ($ds.m^{-1}$)	Moisture (%)	Sand (%)	Silt (%)	Clay (%)
Fi	16.627^{d}	17.56^{a}	119.5	0.55^{a}	13.37^{bc}	6.94^{ab}	1.91^{a}	2.41^{a}	48.22^{a}	29.6^{bc}	23.2^{b}
W.Gr	9.8^{a}	24.38^{cd}	114.36	1.022^{b}	14.5^{c}	7.21^{b}	2.82^{bc}	10.07^{b}	55.05^{c}	26.8^{abc}	18.05^{a}
N.F.E	11.99^{b}	23.65^{bcd}	116.20	1.15^{b}	12.67^{abc}	7.31^{b}	4.05^{d}	1.84^{a}	54.4^{bc}	24.4^{a}	21.2^{b}
W.F.E	14.17^{c}	21.31^{b}	115.90	0.46^{a}	10.84^{a}	6.94^{ab}	1.85^{a}	1.6^{a}	52.5^{abc}	26.1^{ab}	21.4^{ab}
P.D	10.61^{a}	22.49^{bc}	116.4	1.024^{b}	12.87^{abc}	6.6^{a}	3.47^{cd}	37.8^{c}	49.9^{abc}	30.3^{c}	19.8^{ab}
N.P.D	15.13^{c}	25.88^{d}	113.20	0.73^{a}	11.74^{ab}	6.96^{ab}	3.76^{d}	3.69^{a}	49.5^{ab}	30.5^{c}	20.00^{ab}
R	10.71^{a}	16.54^{a}	113.50	0.47^{a}	13.7^{bc}	7.13^{b}	2.24^{ab}	1.29^{a}	54.2^{bc}	24.7^{a}	20.20^{ab}

Notes. Results in a column followed by a different letter are significantly different ($p \leq 0.05$, according to Duncan multiple range test). W.F.E: within field edges. Fi: fields. R: road verges. P.D: permanent ditches. N.P.D: nonpermanent ditches. N.F.E: non-crop field edges. W.Gr: woody green viens.

*Organic matter.

**Electrical conductivity of the saturated soil-paste extract.

edges as FBT3; and roads as FBT4. Data on species richness were tested regarding normality and then a one way ANOVA was conducted to compare effect of habitat types on the species richness of AT and NV species. A Tukey's multiple comparison test was used to assess the significance of differences between mean values of species richness at the plot level (2 m × 2 m). Differences were considered significant for p values < 0.05. SPSS Ver. 18, Minitab 17, and Sigmastat 3.5 were used to run all the statistic performances.

3. Results and discussion

3.1. *Agricultural intensification index*

According to the calculated AI index (49.56), land use intensity in the agricultural landscape was at the range of highly intensified agricultural utilization (High AI). The minimum and maximum nitrogen inputs were 100.12 and 300.75 kg N per ha, respectively. The number of tillage operations and pesticide applications ranged between 1 and up to 4 and 5 times, respectively. A study on agricultural intensification throughout Europe showed that the overall mean of high value of AI for nine European countries was 28.57 ± 0.70 (Flohre et al. 2011). In this study, the AI index of the landscape was more than what was expected; it was caused by high fertilizer and pesticide applications, frequent tillage operations and mechanical weed management in order to gain the highest level of crop yield. Therefore, ecologically based management plans are necessary to reduce the land use intensity in this agricultural landscape as much as possible.

3.2. *Plot and species ordination*

Apart from crop species, a total of 87 vascular plants were recorded in the agricultural landscape. The highest species richness was for agricultural fields (43 species), followed by non-crop field edges (37), woody green veins (32), within-field edges (30), permanent ditches (26), nonpermanent ditches (23), and roads (22). In other words, the highest total species richness was recorded in the existing green vein elements (44 species), while more than 50% of the landscape area was devoted to arable lands (fields). Given the high value of AI in the landscape, the richness of plant species in agricultural fields was surprisingly high. 20.9 % of those were as noxious weeds. We found the use of high levels of chemical fertilizers and pesticides as the main reason for AI being dramatically higher. On the other hand, lack of appropriate management in the application of these off-farms inputs was the reason for low efficiency in weed control. Noticeable amounts of chemical fertilizers and pesticides reach a

destination other than their target species. Also the seeds which farmers use are not formally certified. As a result weed seeds disperse easily.

Using DCA analysis, data on the species recorded in all the plots throughout the landscape were analyzed to determine the distribution pattern of both sample plots and plant species. The first two axis of the DCA explained 52.2% of the total variation in plant species composition; 32.7% by the first and 19.5% by the second axis (Figure 2a). The result of DCA showed that there was an acceptable distinction regarding spatial distribution among plots of different elements in the landscape.

As can be seen, most of the plots from the fields, nonpermanent ditches, roads and within-field edges can be recognized as a group at the left corner of the first axis (square dots). These elements had some characteristics in common with each other; for instance regardless of their usage as channels for irrigation, nonpermanent ditches were very similar to within-field edges both structurally and functionally (in some cases there were nonpermanent ditches that played a role like within-field edges as borders between two agricultural fields). The most frequent species in these plots, known as noxious weeds, were *Amaranthus retroflexus* L., *Cyperus rotundus* L., *Glycyrrhiza glabra* L., *Sorghum halepense* (L.) Pers., and *Xanthium strumarium* L. (Zand et al. 2009), which are light demanding species with high competitiveness ability (Drews et al. 2004; Gaudet and Keddy 1988). Proximity of these elements to the agricultural fields can explain similarity of their species composition.

The second group (near the first one) available in the DCA diagram contained plots mostly from woody green veins and some from roads and within field edges (Figure 2a, solid line). To explain this pattern it is useful to refer to the species composition of sample plots from these elements (Figure 2b). *Tribulus terrestris* L. and *Cardaria draba* L. Desv. Subsp. were mostly recorded in plots from agricultural fields, roads and within-field edges; *Lolium perenne* L. in plots from roads, within-field edges and woody green veins; and *Glaucium* spp. in plots belonging to roads, woody green veins and agricultural fields. Therefore, the reasons for this group being located near the first one were similarity of species composition among plots from this group with the first one, and also the existence of species like *Geranium tuberosum* L. (which was a species exclusive to the woody green veins) and *Alhagi persarum* Bossi. in the woody green vein sample plots. *Geranium tuberosum* L. is a perennial species adapted to a continuum of sandy and clay soils, acidic pH with high moisture content of the soil, and not preferring shaded situations (Polunin and Huxley 1978). It is important because this species and *Alhagi persarum* Bossi., which are usually found among weedy species in most arable lands of Iran (Adim, Sarani, and Moeini 2010), were recorded in the plots dominated by agrotolerant species like *Setaria viridis* (L.)

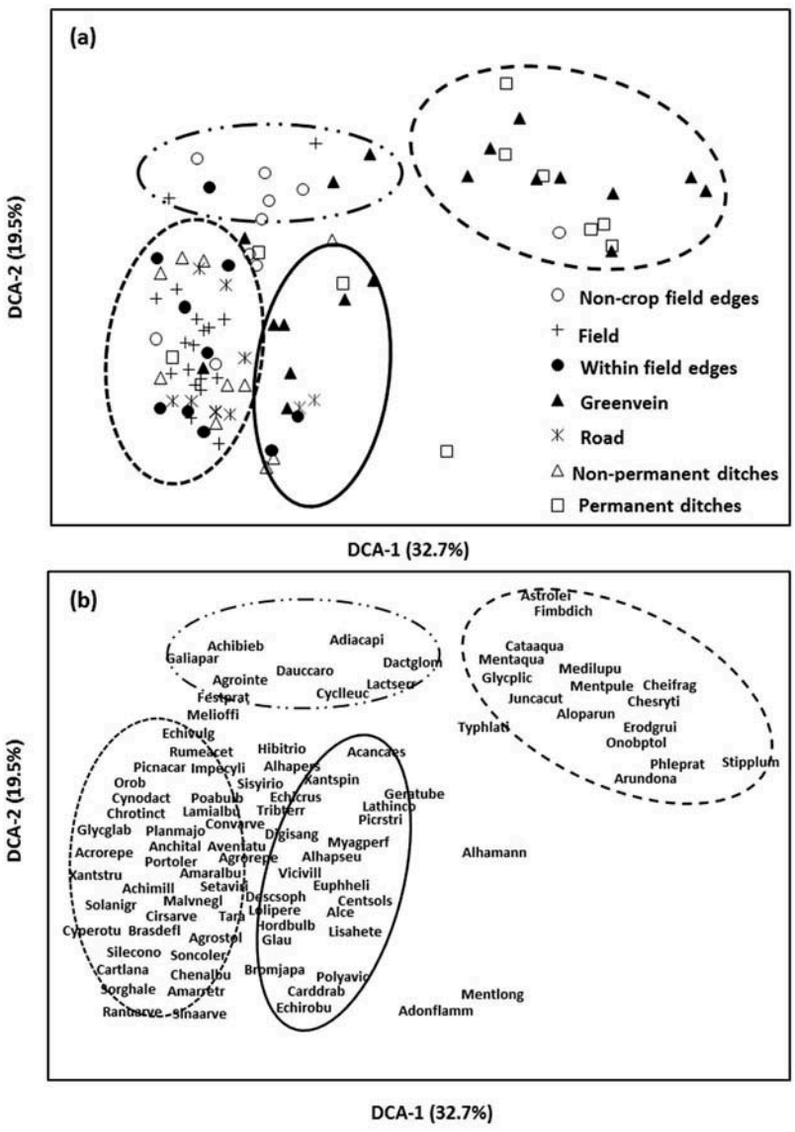

Figure 2. DCA ordination of a) sample plots from fields and different field boundary types and b) recorded species. The four distinct groups are depicted by different types of lines (square dot, solid line, long dash dot dot, dash).

P. Beauv., *Convolvulus arvensis* L., and *Cynodon dactylon* (L.) Pers. The spatial condition of the second group on the DCA diagram indicated the effect of agricultural activities on the soil and micro-environment situation of woody green veins adapted to arable lands. Studies on the effects of agricultural operations on the environmental quality of field boundaries have proven the negative influence of these practices due to agrochemical and agrotechnical disturbances (De Cauwer et al. 2006; Kleijn and

Verbeek 2000; Liira et al. 2008). Not only the structure of linear edge habitats, but also the distance and connectivity of them with agricultural fields and woody habitats, are among the factors explaining flora composition pattern in agricultural landscapes (Baudry 1988; Forman and Baudry 1984).

The third group (Figure 2a; long dash-dot-dot) contained plots mostly from non-crop field edges. The species composition of these plots (Figure 2b) revealed the noticeable presence of nature-value species like *Galium aparine* L., *Adianthum capillius veneris* L., *Cyclotrichium leucotrichum* (Stapf ex Rech. f.) Leblebici., and *Daucus carota* L. which have been reported to be found commonly in rangelands (Pairanj et al. 2011; Soltanipoor and Babakhanloo 2006). According to the metacommunity hypothesis (Leibold et al. 2004), plant species diversity can be affected by species movements from bordering local communities (Bedford and Usher 1994; Holyoak et al. 2005). Therefore, the presence of nature value species in non-crop field edges can be explained by species movement between this element and the neighboring grasslands. As the quantity and quality of so called movements is dependent on spatial position and distance between local bordering habitats (Holyoak et al. 2005), it should be noted that the non-crop field edges in the landscape were mostly adjusted to the rangelands and open forests.

The fourth group in the DCA diagram is displayed at the right side of the first axis. This group, which was the most distinguishable group in comparison with others, was prominently occupied by the plants from woody green veins and permanent ditches (Figure 2b). Most of the species available in this group were hydrophyte species, adapted to a continuum of acidic and alkaline soils (*Arundo donax* L. which can tolerate high alkaline conditions, and with low capability to emerge in agricultural fields as weed species (Chiej 1984; Launert 1989; Tran 2013).

3.3. *Vegetation data on agrotolerant and high nature-value species*

Some of the species with the highest frequency in the fields, many of which are classified as agrotolerant species, were as follows: *Sorghum halepense* (L.) Pers. (46.56% of the total frequency of individuals existing in field sample plots), *Cynodon dactylon* (L.) Pers. (11.52%), *Convolvulus arvensis* L. (8.8%), *Echinochloa crus-galli* (L.) P.Beauv. (4.48%), *Cyperus rotundus* L. (4%), *Setaria viridis* (L.) P.Beauv. (2.4%), *Malva neglecta* Wallr. (2.24%), and *Glycyrrhiza glabra* L. (1.76%).

A total of 21 species were recorded as agrotolerant species following the criteria of presence in 10% or more of the field's sample plots, with the highest presence in the sample plots for *Sorghum halepense* (L.) Pers. (existing in 44.44% of the plots in agricultural fields), *Convolvulus arvensis* L. (38.88%), *Xanthium strumarium* L. (27.77%), *Amaranthus retroflexus* L.

(22.22%), *Cynodon dactylon* (L.) Pers. (22.22%), and *Setaria viridis* (L.) P. Beauv. (22.22%).

The most frequent nature-value species, that is, the common species in green vein habitats, were *Mentha aquatica* L. (comprising 20.83% of the total number of individuals recorded in all habitat types of the landscape except agricultural fields), *Arundo donax* L. (4.35%), *Typha latifolia* L. (3.52%), *Phleum pratense* L. (3.17%), *Agrostis stolonifera* L. (2.49%), *Cirsium arvense* (L.) Scop. (1.71%), *Catabrosa aquatic* (L.) P.Beauv. (0.92%), and *Achillea millefolium* L. (0.78%).

3.4. Species richness of AT and NV species

3.4.1. Species richness of AT and NV species among the three main groups of spatial elements

Species richness of agrotolerant and nature-value species were compared within the three main groups of spatial elements including: 1) agricultural fields, 2) linear elements (mostly bordering agricultural fields), and 3) natural and seminatural linear habitats. The highest mean AT species richness belonged to agricultural fields with a mean of 3.66; the lowest score was for natural and seminatural linear habitats at 0.89. The highest mean NV species richness belonged to seminatural linear habitats at a mean of 4.26, and the lowest score was for agricultural fields (1.77) (Figure 3).

There was a significant effect of habitat type on species richness of AT and NV species at the $p < 0.05$ level [$F(5,168) = 10.454$, $p = 0.000$]. A post hoc Tukey test (5%) showed that there was neither significant difference between AT species richness in groups 1 and 2, nor between NV species richness ($p = 0.591$ for comparison of AT richness between groups 1 and 2; and $p = 0.979$ for comparison of NV richness between groups 1 and 2; Figure 3a). The presence of dense woody green veins (group 3) decreased the richness of AT species in comparison with what can be seen in groups 1 and 2 ($p = 0.000$; and $p = 0.000$, respectively); also woody green veins supported significantly the richness of NV species in comparison with groups 1 and 2 ($p = 0.000$; and $p = 0.000$, respectively; Figures 3a and 3b).

Structural properties of woody green veins, in particular connectivity to the natural bordering habitats, as it has been mentioned by Benton, Vickery, and Wilson (2003), gave some advantage for the overall plant species diversity of the landscape and in particular for nature-value species. There are studies that have proven the reverse relationship between internal green veins connectivity and the negative effects of intensified agricultural practices regarding biodiversity; it has been demonstrated that in an agroecosystem with more connectivity of green vein habitats, less area of natural and seminatural patches is needed for reaching the same level of plant diversity found in an agroecosystem with low intensity management practices (i.e., low AI), (Grashof-Bokdam et al. 2009). The

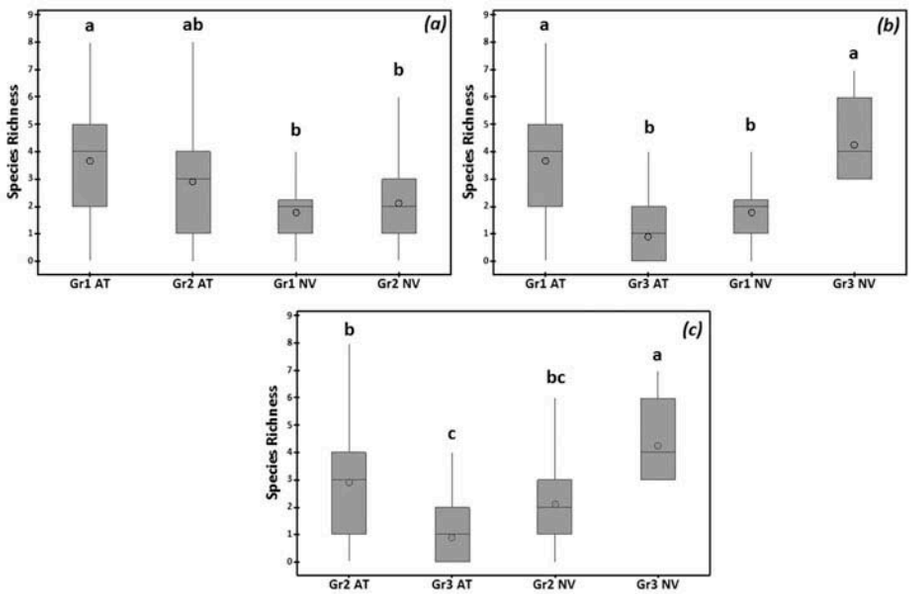

Figure 3. The results of Tukey's multiple comparison test on species richness of agrotolerant (AT) and nature-value (NV) species from three main groups (two paired in boxplots a, b, and c) of the spatial elements (Gr: group) at 2-m-×-2-m scale. *Notes*. Gr1 = agricultural fields; Gr2 = linear elements (field boundaries); and Gr3 = natural and seminatural linear habitats. The circles in the boxes are representative of mean species richness. Error bars represent standard deviation. Different letters indicate significant differences ($p < 0.05$).

result of our study indicated that in spite of the lower proportion of green vein habitats in the landscape structure, they played the clearest role in enhancing plant diversity of the landscape. At the landscape scale, the proportion of natural and seminatural habitats is an effective predictor in evaluating plant diversity; the higher percentage of woody habitats in a landscape can promote species diversity of both AT and NV species at the α level, since this promotion favors NV species twice as much as that for AT species (Aavik and Liira 2009). There are some other studies that have reported the positive relationship between the proportion of area of natural and seminatural patches and the number of plant species existing in a landscape (Kremen et al. 2004; Steffan-Dewenter et al. 2002).

The high diversity of NV species in woody green veins can be explained through ecological adaption and speciation. Woody patches with natural environment may provide a suitable condition for shade-tolerant species (Le Coeur et al. 2002; Petit et al. 2004). For instance, *Adianthum capillius veneris* L. and *Alopecurus arundinaceus* Poir., which were recorded in the woody green veins, are prominent shade-tolerant and high moisture-demanding species found in woody habitats and at the banks of waterways (Akhani 2014; Sim 1915). The total number of plant species may decrease to low levels in the woody edges in comparison with patches without woody

structure, while this decrease is significantly stronger for AT species than that of for NV species (Aavik and Liira 2009). Habitat quality is the second important factor after habitat availability affecting plant distribution in a landscape; vegetation strips along agricultural fields are impacted as non-target places (indirectly, mostly as runoff) and misplaced (directly, e.g., inadvertently when fertilizer application) artificial fertilizers and chemical pesticides (Aavik and Liira 2009; Davidson, Shafer, and Jennings 2002; McCollin et al. 2000; Virtanen et al. 2000). The main reasons by which the woody green veins were distinguishable ecologically from other habitats of the landscape were the dense presence of trees, a distance of more than 10 m radius to the field borders, high availability of moisture provided by a river, and connectivity to the neighboring natural habitats. Such a natural and seminatural element can play a positive role as a buffer zone to reduce the undesirable influence of agricultural operations (Ma, Tarmi, and Helenius 2002) so that high nature-value species can survive in the border of agroecosystems.

3.4.2. *Species richness of AT and NV species among the linear field boundary types*

Species richness of all field boundary types was compared using an independent-sample *t* test (5%). The species richness of AT species was recorded in FBT3 (mean richness of 4.4) as the highest, and FBT2 as the lowest (1.1). The species richness of NV species was recorded in FBT2 (3.3) as the highest, and FBT4 as the lowest (0.7) (Figure 4).

There was a significant effect of field boundary type on species richness of AT and NV species at the $p < 0.05$ level [$F(7, 92) = 5.508$, $p = 0.000$]. A post hoc Tukey test (5%) showed that the permanent ditches decreased richness of AT species even though not significantly ($p = 0.07$). It did not significantly favor the richness of NV species, in spite of a high mean score ($p = 0.621$, Figure 4a). There was no significant effect of FBT1 on AT and NV species richness in comparison with FBT3 and 4 (Figure 4b and 4c). FBT3 increased the richness of AT species in comparison to FBT2 ($p = 0.001$; Figure 4d).The difference between AT and NV diversity in permanent ditches and roads (FBT 2 and FBT4) was one of the most obvious differences indicating the selection preference for a particular habitat. Roads were the habitats which supported the diversity of AT species even though not statistically significant ($p = 0.178$), while NV species diversity was promoted significantly by permanent ditches ($p = 0.015$; Figure 4e). NV species diversity increased significantly in FBT3 in comparison to FBT4, while there was no difference regarding AT species in these two types of habitats ($p = 0.021$ and $p = 0.105$, respectively; Figure 4b).

The negative effects of agricultural operations on field boundaries have been abundantly demonstrated (Macdonald and Johnson 2000; Cousins

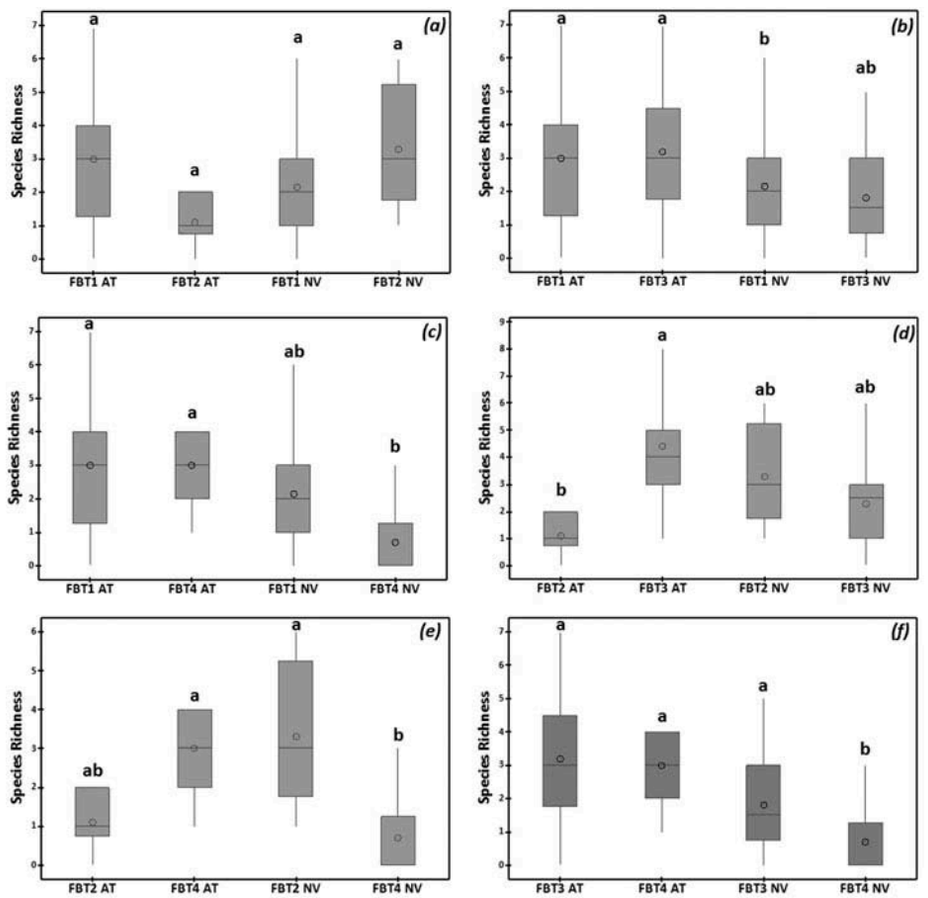

Figure 4. The results of Tukey's multiple comparison test on species richness of agrotolerant (AT) and nature-value (NV) species from different field boundary types (FBTs; two paired in boxplots a, b–f) at 2-m-×-2-m scale. *Notes*. FBT1: within field edges and nonpermanent ditches; FBT2: permanent ditches; FBT3: non-crop field edges; FBT4: roads. The circles in the boxes are representative of mean species richness. Error bars represent standard deviation. Different letters indicate significant differences ($p < 0.05$).

2006; Oreszczyn and Lane 2000) emphasizing the importance of habitats with acceptable quality needed to conserve high nature-value species. We expected the field boundaries with more disturbance, as a result of proximity to the agricultural fields, to be a desirable habitat for stress-tolerant species. As it was mentioned, the richness of AT species was higher in elements like within-field edges, nonpermanent ditches and roads. These elements, in particular within-field edges and nonpermanent ditches, had a great similarity to the agricultural fields of the landscape with respect to structure and habitat quality. Leakage and misplaced agrochemical inputs such as pesticides and fertilizers have been reported as factors changing species composition and community structure of field boundary types (Boutin and Jobin 1998;

Kleijn and Verbeek 2000). The habitats experiencing continuous disturbance, along with high nutrients and availability of sunlight, mostly support noxious and invasive weeds (Milbau and Nijs 2004; Pysek et al. 2009). As a result, in this study the high AT species richness in such habitats, which are often nitrophyle species (plants of places rich in available nitrogen) and heliophyle species (light-demanding species) with high competitive ability (Calster et al. 2008), is not unusual. It is also reported that proximity to agricultural fields can expose the field boundaries to shading from a tree layer, which combined with high levels of disturbances can negatively affect crop yield production (Sparkes et al. 1998). There have been some efforts to remove or make these boundaries as thin as possible (Blois, Domon, and Bouchard 2002).

In this study, roads had clear difference regarding functional plant composition; as richness of AT species was considerably higher (mean species richness of 3.0), with the richness of NV species having the minimum score. It has been demonstrated that disturbance-tolerant species, in particular those adapted to intensive agricultural management, are commonly found in the road edges (Cale and Hobbs 1991; Tyser and Worley 1992). In addition to reducing the total species richness, transportation and mowing plant species along the road edges can enhance the richness of invasive and exotic species (Hansen and Clevenger 2005; Panetta and Hopkins 1991; Ross 1986). Community structure in and along the roads can be understood by considering the unsustainable condition common to this type of habitat element because of fertilizers and pesticides deposition coming from agricultural fields or even inadvertent spilling of these materials from agricultural machinery, mechanical disturbance caused by foot and vehicle traffic. Dry and dusty conditions are among the factors that mostly favor tress-tolerant species by affecting soil pH and mineral nutrient levels on the road edges (Angnold 1997; Ibanga, Umoh, and Iren 2008; Ross 1986; Santelman and Gorham 1988; Farmer 1993).

Non-crop field edges (FBT3) showed no significant effect on richness of AT species in comparison with FBT 1 and 4; whereas their NV species richness was significantly higher than that for FBT4. By considering the DCA analysis and plant species of non-crop field edges (Figures 2a and 2b), we observed some differences among plant composition of this element with the other existing habitat types of the landscape. This might be due to the more ideal environmental conditions provided by non-crop field edges for some nature-value species including *Achillea biebersteinii* Afan., which is also a valuable medicinal plant (Mazandarani et al. 2015), *Adianthum capillius veneris* L., and *Cyclotrichium leucotrichum* (Stapf ex Rech.f.) Leblebici. On the other hand, in this boundary habitat of the landscape some common weed species can also be found like *Dactylis glomerata* L., *Chrozophora tinctoria* (L.) A.Juss., *Sisymbrium irio* L., and *Silene conoidea* L., which are not considered to be AT species. Non-crop field edges, in particular those neighboring forest areas, are key habitat elements for

conserving plant species diversity in agricultural landscapes (Ma et al. 2012). This type of habitat, in contrast with that of within-field edges, creates a transitional environmental gradient along marginal habitats of agricultural fields (like grasslands and rangelands and forest areas). There are some studies emphasizing the positive effect of non-crop field edges on plant biodiversity through species transitions from natural habitats to field boundaries (Euskirchen, Chen, and Bi 2001; Jansson 2009). In our study, although the total species richness of non-crop field edges was high, contrary to what was expected, the diversity of AT species was also considerably higher.

Permanent ditches were among the linear elements in this study which effectively supported the richness of NV species while decreasing diversity of AT species. Having the special conditions needed by hydrophytic species, permanent ditches provide a suitable environment for high-moisture demanding species such as *Arundo donax* L., *Catabrosa aquatic* (L.) P.Beauv., *Phleum pretense* L., *Typha latifolia* L., and some species of *Mentha*. Absence of mowing and the changing structure of permanent ditches (in contrast to nonpermanent ditches that are mown or removed every year) have provided stable conditions, distinguishable from bordering habitats, in which nature-value species can easily survive. Reducing contaminants coming from agricultural fields, adjusting hydrologic regimes, and enhancing richness of high-moisture demanding species are among positive effects of permanent ditches in agroecosystems (Gavin 2003; Milsom et al. 2004; Walters and Shrubsole 2003); however, there are different reports on the effect of this type of marginal habitat in the landscape. Studying the effect of ditches on plant diversity and species composition in an agricultural landscape, Tao et al. (2008) reported that the highest species richness was at the medium level of disturbance caused by agricultural practices; the minimum score for species richness was for high and low levels of agricultural disturbance. They explained this by using the intermediate disturbance hypothesis (Pollock, Naiman, and Hanley 1998). Agricultural disturbances change the local environment in such a way that various dominant species in different communities can be found and as a result, species composition changes while enhancing species richness. In our study, the level of disturbance was low for permanent ditches and woody green veins, except where the connection to nonpermanent ditches occurred, as was explained in the DCA analysis, causing some variation in species composition of plots from this type of habitat (Figure2 DCA); therefore, according to the intermediate disturbance hypothesis and the results shown by Tao et al. (2008), the total species richness of permanent ditches was not very high. The permanent ditches had the strongest effect in enhancing richness of NV species along with decreasing richness of AT species. Aavik and Liira (2009) reported that among all types

of field boundary types, it was ditches which clearly supported NV species richness. They urged that as ditches experience low levels of disturbance in an agricultural landscape, a disturbance such as mowing once every few years along with reduced nutrient leaching increases the richness of perennial and hydrophyte species.

3.5. *Variation in species richness in response to edaphic properties*

3.5.1. *Sample plot ordination according to the landscape's soil physicochemical properties*

Ordination of sample plots in response to variation in edaphic characteristics was run using Canonical Correspondence Analysis (CCA). The first axis explained 23.5%, the second 7.8%, and the third axis 1.3% of the ordination process (explaining 44.3, 19.3, and 8.5% of the total variance). According to a Monte Carlo test (99 runs), p values were significant just for the first and second axis (0.0100) indicating a recognizable pattern in ordination of sample plots along with changes in soil physicochemical properties. The most changes in species composition was explained by nitrogen content of the soil, phosphorus, organic carbon (O.C), clay and sand percentage, pH, and soil moisture (Figure 5).

There was high correlation with nitrogen (first axis 0.82, second axis 0.3) and clay (first axis 0.63, second axis 0.31), with a considerable number of plots from fields (plots from 1 to 18 were for fields), within-field edges (48–57), non-crop field edges (38–47) and roads (78–87), as observed in (Figure 5. These plots are along the positive part of the first axis with high correlation. In comparison with the plots located at the negative part of the axis, these plots are along nitrogen and clay gradients; that is, they are located in the habitats with a high content of nitrogen and clay. In the other hand, one can find plots of woody green veins (19–37) located on the negative part of the first axis with negative correlation (first axis −0.8, second axis −0.27). These plots are located in habitats rich in phosphorus, and in the poor habitats with respect to nitrogen and clay. Along the soil moisture gradient of the landscape, plots from permanent ditches are mostly found (58–67) with high correlation with the positive part of the second axis (first axis −0.48, second axis 0.73). Other physicochemical factors of the soil did not contribute much in explaining ordination of sample plots; therefore, in order to make the CCA diagram representative, these factors are not presented.

3.5.2. *Model of stepwise regression*

Stepwise (backward) regression was conducted considering AT and NV species richness at the plot level (2 m × 2 m) as dependent variables; and soil physicochemical properties as the independent variables. Nitrogen, clay

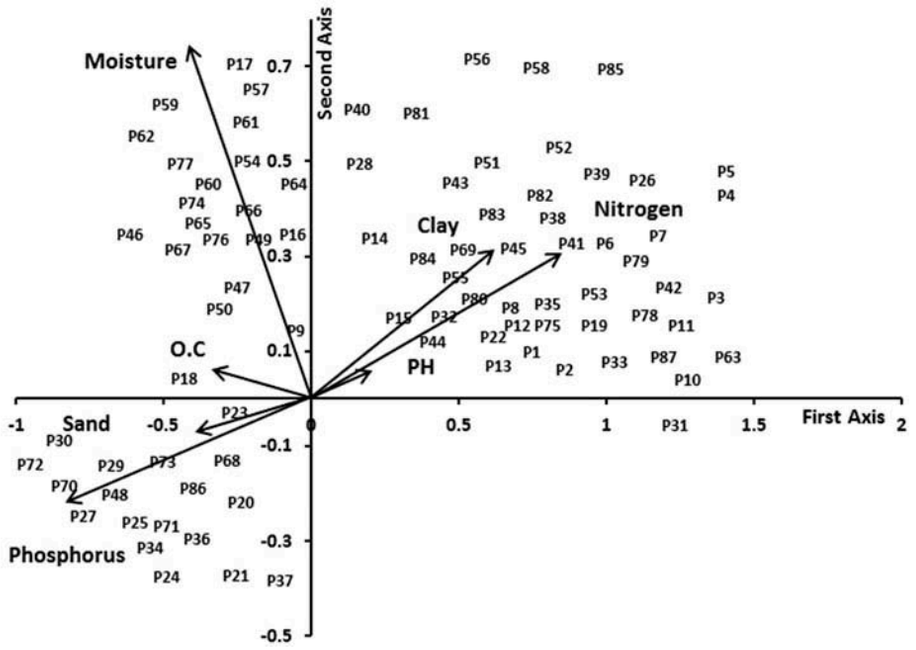

Figure 5. The first two axis of CCA between all sample plots of the landscape and the soil physicochemical variables. The vectors indicate the correlation between sample plots and soil factors. To make the graph more readable, correlation of some of the nonsignificant soil variables are not presented.

content and soil moisture were factors explaining variation in AT species diversity [AT = 0. 903 – (0.053 moisture) + (0.097 clay) + (0.153 nitrogen)]; phosphorus, clay content, and soil moisture were factors explaining variation in diversity of NV species [NV = 1.002 + (.127 P) + (0.038 moisture) – (0.075 clay)]. Other soil factors did not share significantly in developing the model. The regression model to evaluate the variation in the number of AT species as the dependent variable suggested 0.153 and 0.097 increases, as well as 0.053 reductions, in response to a 1.0% increase in nitrogen, clay, and moisture content of the soil, respectively. Also the regression model suggested 0.127 and 0.038 increases, as well as 0.075 reductions, in the number of NV species in response to a 1.0% increase in phosphorus, moisture and clay content of the soil, respectively.

Following the evaluation of the effect of changes in soil gradient properties on AT and NV species richness, significant variables above were entered into continuous bivariate linear regressions (i.e., followed by entering two-paired variables). Changes in richness of AT species had a negative relationship with the soil moisture content, and a stronger positive relationship with the clay content of the soil [AT = 0.716 + (0.0.119 × clay) – (0.0542 × moisture)]. Nitrogen had a more efficient effect on AT species richness than that of soil

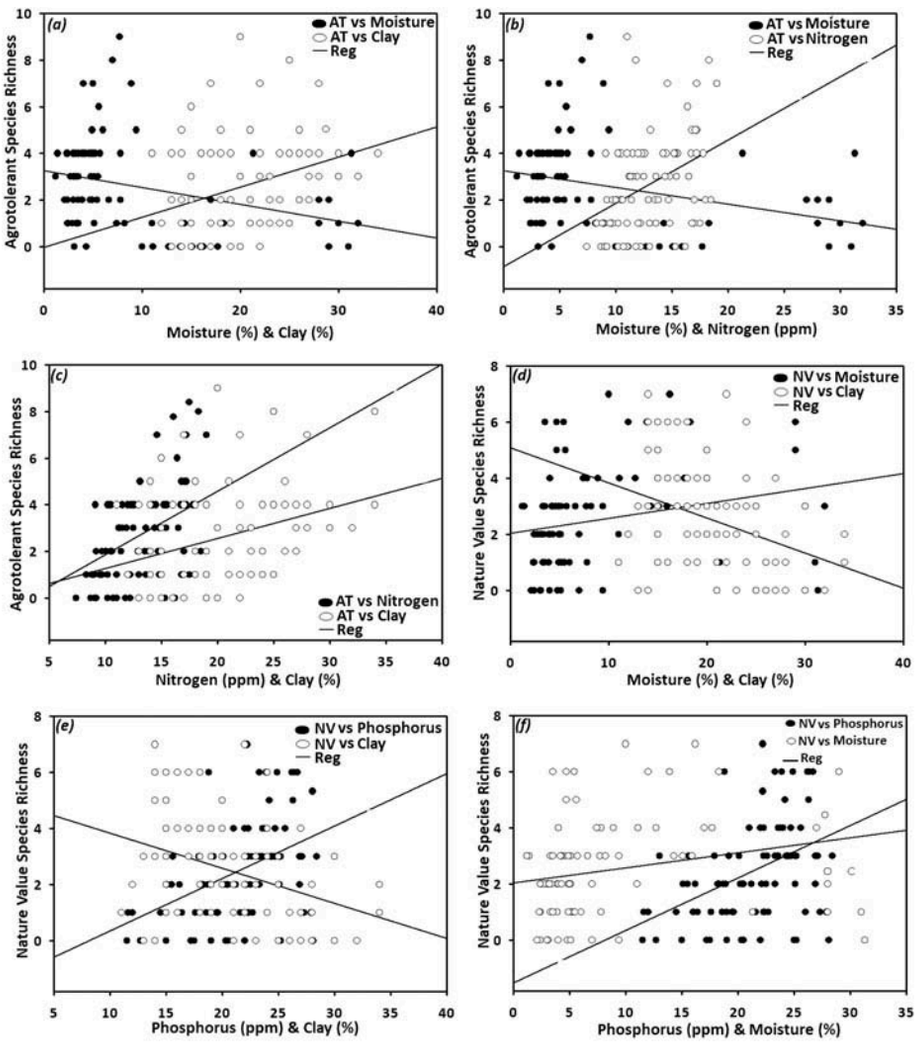

Figure 6. The results of bivariate regressions of two paired edaphic variables and agrotolerant (a, b, and c)/nature-value species (d, e, and f). Significant soil variables were detected in stepwise regression heretofore.

moisture (AT = 0.102—(0.0379 × moisture) + (0.226 × nitrogen)], and clay content [AT = −2.393 + (0.231 × nitrogen) + (0.100 × clay)] (Figures 6a–6c).

NV species richness were affected negatively by the clay content of the soil; and less positively affected by the soil moisture (NV = 4.537 + (0.0395 ×moisture) − (0.117 × clay)]. Phosphorus had a higher positive effect on NV species richness in comparison with the negative effect of the clay content [NV = 0.967 + (0.146 × Phosphorus) − (0.0778 × clay)], and the positive effect of the soil moisture [NV = −1.481 + (0.171 × phosphorus) + (0.0313 × moisture)] (Figures 6d–6f).

Applying high loads of agrochemicals and fertilizers induces direct and indirect effects (e.g., positive relationship between plant diseases and nitrogen content) on plant diversity of a given area (Joyce 2001; Wolf, Rötter, and Oenema 2005). Low levels of soil nutrient content at the local scale can favor plant biodiversity (Janssens et al. 1998; Kleijn and Snoeijing 1997). According to the investigation of AI index in this study, the effect of intensification of agricultural operations and its nondesirable consequences are promoted by an increase in clay percentage of the soil (Ziyaee and Roshani 2012), a reduction in soil pH (Benbi and Brar 2009), and nitrogen leakage and deposition into soil and water resources (Aude, Tybirk, and Bruus 2003). A high content of nitrogen and clay enhanced the richness of AT species, which are also known as nitrophyles and disturbance-tolerant species in agricultural fields. Phosphorus and soil moisture supported the richness of NV species; it is important to indicate that the positive effect of moisture on the diversity of NV species was not necessarily because of a higher water use efficiency of these species, but due to providing habitats (like permanent ditches) containing enough moisture for high moisture-demanding hydrophytic species. Positive effect of ditches and habitats with high moisture content on NV species was reported by Aavik and Liira (2009); they also indicated the effect of fertilizer application, nitrogen in particular, on enhancing richness of AT species. There have been some studies investigating the effect of phosphorus on plant diversity and species composition at the landscape scale (Farrukh, Shaheen, and Durrani 1994; Jensen 1990; Mi et al. 1996). There are a range of studies on the relationship between soil nutrient supply and plant diversity. An increase in the proportion of N:K and N:P has a negative effect on species diversity, and in particular endangered species (Roem and Berendse 2000). Taleshi and Akbarinia (2011) reported a positive relationship of soil pH and species richness; in addition they found a significant negative relationship between species richness and nitrogen and potassium content of the soil. Species diversity can decrease because of the high application of N fertilizers which induces a competition for light absorption as a result of an increase in biomass production (Oerlemans, Boberfeld, and Wolf 2007). These results were partly supported by our findings. In some studies a reverse relation between plant diversity and soil nitrogen and phosphorus availability has been reported; phosphorus can enhance the amount of biomass produced by the plants which are more effective in nutrient absorption and as a consequence reduce overall diversity (Carroll et al. 2003; Young-Mathews et al. 2010). This is not completely in agreement with our results. In a different point of view, we can argue that the positive relationship between phosphorus content of the soil and NV species richness must have been due to the lack of this nutrient in agricultural fields of Iran, and not necessarily because of high amount of this nutrient in the seminatural habitat.

Phosphorus content of 71.8% of that found in the agricultural fields in Iran is less than the critical level needed for crop production (Shahbazi and Besharati 2013) in the landscape, soil phosphorus content of woody green veins, non-crop field edges, and permanent ditches was high because of the absence of tillage operation and water erosion of soil particles from the agricultural fields. Frequent tillage operations and, as a consequence, an increase in clay percentage of the soil texture from increased soil erosion, are the factors inducing phosphorus shortage in agricultural fields.

4. Conclusion

DCA analysis indicated that dispersion of flora in the landscape showed a recognizable pattern. Fields, nonpermanent ditches, roads and within-field edges constituted a group in which richness of agrotolerant species was higher than most other habitat types. Plots from woody green veins and permanent ditches were found predominantly in a high separable group in which richness of hydrophytic nature-value species was noted. In an overall view, woody green veins, as representative of seminatural woody habitats, were able to support diversity of nature-value species along with decreasing agrotolerant species richness. Woody green veins were highly connected to the natural habitats in the surrounding landscape. Among field boundary types, non-crop field edges had the most overall species richness, which was not surprising as proximity of these boundaries to the neighboring natural rangelands was highest; however, in spite of what was expected, richness of agrotolerant species in this type of marginal habitat was considerably higher as well. After that, road edges, nonpermanent ditches and within-field edges were boundary types with high richness of agrotolerant species. Permanent ditches were the most supportive of nature-value species, particularly high-moisture demanding plants; however, the overall species richness was not very high. Evaluating the relationship of agrotolerant and nature-value species with the physicochemical characteristics of the landscape revealed that nitrogen, phosphorus, clay content, and soil moisture were the edaphic factors explaining the most variation in agrotolerant and nature-value species richness. Nitrogen and phosphorus were the most effective soil factors enhancing species richness of agrotolearnt and nature-value species, respectively. In total, we recommend the agricultural landscapes be modified structurally in a way in which the proportion of well-connected linear seminatural networks is increased. Such an agricultural landscape is sustainable, mostly self-sufficient, and also environmentally friendly by supporting a vast range of plant species beyond the agricultural crops.

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