Biologia
https://doi.org/10.1007/s11756-024-01804-4

ORIGINAL ARTICLE

Which soil properties could affect the floristic composition of weed communities in saffron fields

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Received: 7 January 2024 / Accepted: 27 September 2024

Abstract

This two-year research was conducted to study the relationship(s) between the soil properties and the species diversity of weed community in saffron (*Crocus sativus*) fields in production poles of Afghanistan, including the Karukh, Injil, and the Ghoryan Districts, during 2020–2021 and 2021–2022 cropping seasons. The saffron fields (one-, two-, and larger than two-hectare fields) were selected based on the saffron cultivated area in each district. Weed sampling from the fields was done using a 0.25-m^2 quadrat depending on the field area, between 5 (one-hectare fields) and 13 times (larger than two-hectare fields), through a W-shaped pattern within fields. The functional diversity of weeds (life cycle and vegetative form) was determined, and diversity indices were used to calculate the abundance, density, and dominance of weed species in each district. Also, soil properties of fields were investigated from the depths of 0–25 and 25–50 cm. The results showed that six variables, including electrical conductivity, absorbable potassium, carbon/nitrogen ratio, pH, moisture, and organic carbon percentage, had the highest effect on weed diversity. In conclusion, changing these factors might be a sustainable method for weed management in saffron fields in a way that these conditions negatively affect weed growth and establishment.

Keywords Homogeneity index · Population dynamics · Shannon-Wiener Diversity Index · Simpson Dominance Index · Simpson Index

Introduction

Saffron (*Crocus sativus* L.) is one of the most valuable and expensive cultivated perennial crops (Kothari et al. 2021). The crimson stigma of saffron is used as a spice and for medicinal purposes. The global production of dried saffron is estimated to be approximately 418 tons annually (Cardone et al. 2020). Presently, about 30 countries of the world cultivate saffron; Iran is in first place with the production of 336 tons of saffron, followed by India in second place with the production of 22 tons, and Afghanistan in third place with the production of 20 tons (Cardone et al. 2020). The saffron plants have grown in the same field for several years in a row, and as a result, various weeds have appeared in the field that compete with saffron. Due to its short stem and narrow leaves, this crop has little competitive ability, and if weeds are not controlled, the saffron plant is easily overpowered by weeds.

On the other hand, since saffron is a perennial plant, both annual and perennial weed species will be present in saffron fields. Therefore, weeds are considered one of the most limiting factors in the cultivation of this crop. In managing and controlling saffron weeds, the most critical and vital step is to know the vegetation and population structure and patch distribution of weeds (Cardone et al. 2020). The existing weed vegetation in an area changes due to the emergence of new species and genera, the adaptations observed within the species, and various agricultural operations. Obtaining information and knowledge of them is one of the primary concerns of weed management in fields. Weed management in the abroad scene is critical in that determining the vegetation

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cover, and the geographical distribution of the weed population provides essential information in this field. In other words, to recommend the management of weeds in fields, it is necessary to know the distribution map of weeds (Krähmer et al. 2020). Soil type had the most significant effect on species distribution and weed community structure, and other factors included crop type, crop stability, prevailing climate, and urbanization, respectively (Mahgoub 2019b). Still, an ecological factor may always be dominant in determining the vegetation structure. In a particular region, the simultaneous effect of available natural resources and the amount of human intervention may be the common factor affecting the structure of the weed community (Mahgoub 2019b).

By determining the factors affecting the expansion and growth of the weed populations and applying preventive management, it is possible to prevent their geographical distribution from weed-infested areas to weed-free areas. Floristic studying at the regional level aids in addressing the influence of various factors on the health of vegetation (Ullah et al. 2023), and especially for saffron fields, the flora of weeds affects the wild flower-visiting insects (Aviron et al. 2023).

Although saffron production in Afghanistan has made significant progress in recent years, few studies have been conducted to identify the flora and weed populations in saffron fields. This research's first objective was to study the composition and diversity of the weed community in saffron fields in the production poles of Afghanistan (including the Karukh, Injil, and Ghoryan Districts). The second aim of this study was to check whether the distribution of weed species in the fields of these districts is affected by soil factors. Also, if the distribution of weeds in saffron fields is influenced by soil factors, which soil characteristics significantly impact the distribution and population of weeds?

Materials and methods

Experimental sites

Herat province, located in the west of Afghanistan, bordering Iran and Turkmenistan, is one of Afghanistan's economic and agricultural poles between 34°20'31'' north latitude and 62°12'11'' east longitude (Fig. 1). Its altitude is 920 m and has a cold winter and hot and dry climate during summers and annual precipitation of 240 mm.

The floristic study was conducted in two growing seasons of 2021 and 2022 in three districts of the saffron production poles, which includes the Karukh (34°30'41''N 62°37'39''E, 1320 m a.s.l, and 590 mm long-term averaged annual rainfall, 65 villages were under saffron cultivation, and the total areas were about 200 hectares), the Injil (34°18'00''N 62°15'00''E, 910 m a.s.l., 316 mm long-term averaged annual rainfall, 55 villages under saffron cultivation, and the total areas were about 1000 hectares), and the Ghoryan (34°20'38''N 61°28'47''E, 920 m a.s.l., 296 mm long-term averaged annual rainfall, 115 villages under saffron cultivation, the total areas were about 3000 hectares). The detailed climatic characteristics of Ghoryan, Injil, and Karukh Districts are presented in Fig. 2a to c, respectively.

Fields selection

The selection of saffron fields was based on their abundance percentage of one-hectare fields (type A), two-hectare fields (type B), and more than 2-hectare fields (type C) in three experimental sites. The number of fields for the weed sampling in a district was determined based on the saffron cultivation area. Therefore, the larger the area under saffron cultivation in each district, the more samplings were performed (Tables 1 and 2).

Soil tests

In this research, to investigate the physical and chemical characteristics of the soil in the studied saffron fields, a total of 120 soil samples were taken from two depths of 0–25 and 25–50 cm, and the amount of pH, Electrical Conductivity (E.C.), total nitrogen, phosphorus, potassium absorbable, soil texture and percentage of carbon and organic matter were measured. Nitrogen, phosphorus, and potassium were analyzed according to Jones (2018), and a pH meter was used to measure the soil's acidity (Thomas 1996). E.C. measurement, which indirectly determines the amount of dissolved solutes in the soil, was done by preparing a 1:2 extract from the soil samples, and finally, using an EC-meter, was determined (McLean 1982). The percentage of soil organic matter was determined by the Walkley-Black titration method (Walkley and Black 1934). Finally, the soil texture was determined, and the percentage of silt, clay, and sand in the samples was measured based on the hydrometer method.

Weed sampling method

The weed sampling was done using a 0.25 m^2 quadrat (0.5×0.5 m dimension). After dropping the quadrat, the weeds in each quadrat were identified and counted accurately by genus and species. In perennial weeds, the number of stems in each plant was considered the density (Hajiabaee et al. 2021).

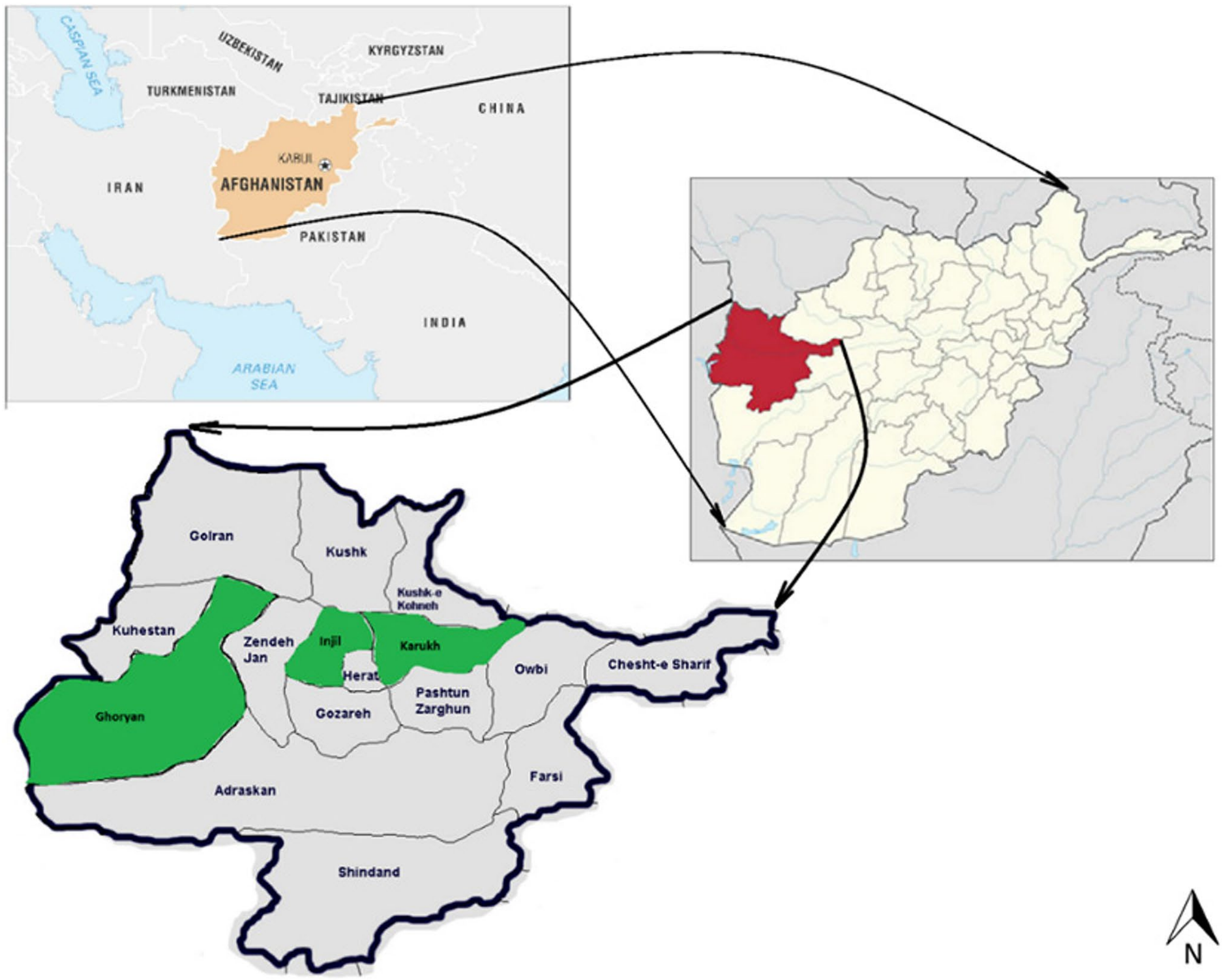

Fig. 1 The geographical locations of three saffron poles in Afghanistan. The light brown area shows Afghanistan, the red area shows the Herat Province, the green area show the Ghoryan, Injil, and Karukh Districts

One-hectare fields

In these fields, a corner of the field was selected, and 20 steps parallel moved to one of the sides from that point, then 20 steps to the field moved by forming an angle with 90-degree sides, and from the first point, the sampling was done (Fig. 3a). Five points were selected according to the W-shaped pattern, so the distance between two consecutive sampling points was 20 steps.

Two-hectare fields

A corner of the field was selected, and 40 steps from that point parallel moved to the field. Then, 40 steps were moved into the field by forming an angle with 90-degree sides and sampling from the first point. Nine points on this pattern were selected based on the W-shaped pattern (Fig. 3b). So, the distance between the two sampling points was 20 steps.

Larger than two-hectare fields

According to Fig. 3c, a corner of the field was chosen, and 60 steps into the field parallel to one of the field sides by forming a 90-degree angle, then 60 steps into the field, and then the first point was selected. Assuming the shape of the letter W, 13 points were chosen, so the distance between both points was 20 steps.

Weeds were sampled via the quadrat inside the fields and at the edge of the field to increase the accuracy of flora identification and evaluation. For this purpose, weeds from the

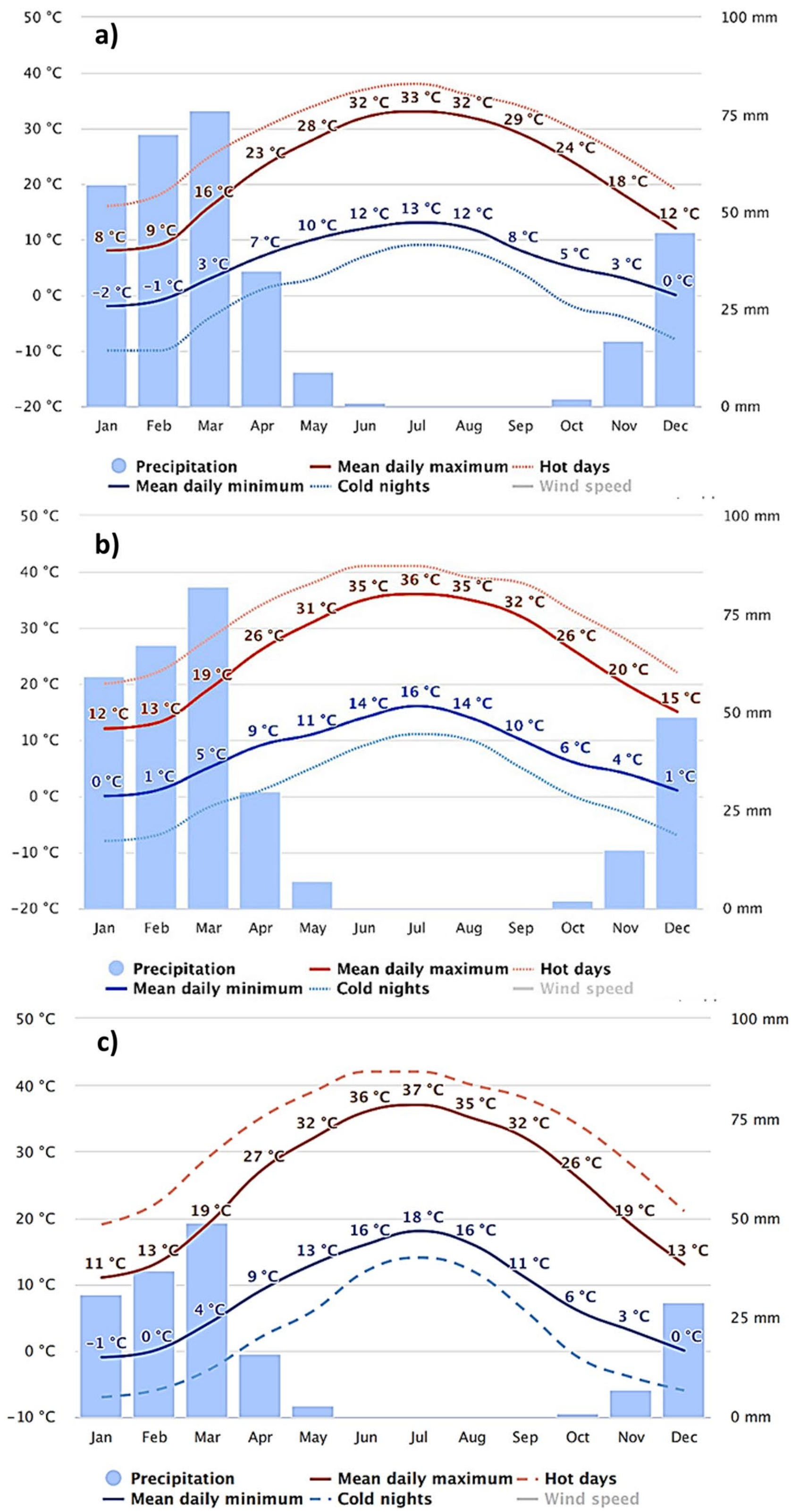

Fig. 2 Climatic characteristics of (**a**) Karukh district, (**b**) Injil district, and (**c**) the Ghoryan district (30-year long-term average of temperature (°C) and precipitation (mm), 1990–2020 period)

Table 1 Number of Saffron fields assessed in each district based on the saffron cultivated area

The saffron cultivation area	Number of selected saffron fields (district)
Less than 100 hectares	2 fields (Karukh)
101 to 150 hectares	3 fields (Karukh)
151 to 200 hectares	3 fields (Karukh)
201 to 500 hectares	4 fields (Injil)
501 to 1000 hectares	5 fields (Injil)
1001 to 1500 hectares	6 fields (Ghoryan)
1501 to 2000 hectares	7 fields (Ghoryan)

The total number of selected fields is 30 fields that have been prepared and arranged based on the facilities of Afghanistan

Table 2 Geographical characteristics of selected saffron fields in Afghanistan in two growing seasons of 2021 and 2022

Farm No	Latitude	Longitude	Field area (ha)	District
1	34.351348	62.121325	2	Injil
2	34.352968	62.122008	2	Injil
3	34.353386	62.119780	2	Injil
4	32.353583	62.116999	2	Injil
5	34.353701	62.116578	2	Injil
6	34.355882	62.115693	2	Injil
7	34.357238	62.112637	2	Injil
8	34.361829	62.106760	2	Injil
9	34.358696	62.098208	2	Injil
10	34.513500	62.582000	1	Karukh
11	34.512000	62.581500	1	Karukh
12	34.510200	62.575500	1	Karukh
13	34.509900	62.575100	1	Karukh
14	34.510400	62.574700	1	Karukh
15	34.478000	62.572300	1	Karukh
16	34.477200	62.572000	1	Karukh
17	34.473500	62.564900	1	Karukh
18	34.225100	61.342600	5	Ghoryan
19	34.225100	61.348000	3	Ghoryan
20	34.225300	61.335800	3	Ghoryan
21	34.224300	61.334400	8	Ghoryan
22	34.223800	61.335500	2	Ghoryan
23	34.224300	61.325000	5	Ghoryan
24	34.233000	61.344100	16	Ghoryan
25	34.237000	61.355000	4	Ghoryan
26	34.231300	61.355000	3	Ghoryan
27	34.231500	61.355000	3	Ghoryan
28	34.222400	61.343500	10	Ghoryan
29	34.225100	61.342600	3	Ghoryan
30	34.213500	61.354000	3	Ghoryan

first sampling point of the field up to 20 steps inside the field in one-hectare fields, up to 40 steps in two-hectare fields, and 60 steps in larger than two-hectare fields, which are not calculated in the W pattern, at 5 m from each other and in Equal distances are determined on both sides of the border. To identify weeds, the book of Flora of Iran by Assadi et al. (1989).

Floristic composition indices

Frequency index

This index shows the percentage of fields with the desired weed species on the total number of studied fields. This index is about the presence or absence of a weed species in a square, field, or area under investigation and does not refer to the number or density of the species (Thomas 1985).

$$Fk = \frac{\sum Yi}{n} \times 100 \quad (1)$$

Fk indicates the abundance of weed species K, Yi indicates the absence (0) or presence (1) of weed species K in saffron field number i, and n indicates the number of saffron fields investigated.

Uniformity Index (UI)

This index shows the percentage of field contamination by the investigated weed species, which shows the area occupied by a specific weed in an estimated form (Thomas 1985).

$$Uk = \frac{\sum_1^n \sum_1^m Xij}{\sum_1^m m} \times 100 \quad (2)$$

Uk indicates the uniformity of weed species K in a saffron field, Xij indicates the presence (1) or absence (0) of weed species K in quadrat number i in saffron field number j, n indicates the number of saffron fields visited, and m represents the number of quadrats (Thomas 1985).

The Mean frequency index (MFD)

This index shows the average number of weeds per square meter in the studied saffron fields.

$$MDF_{ki} = \frac{\sum_1^n D_{ki}}{n} \quad (3)$$

MFDk indicates the average density of weed species K, Dki indicates the density of weed species K in saffron field number i, and n indicates the number of saffron fields investigated (Thomas 1985).

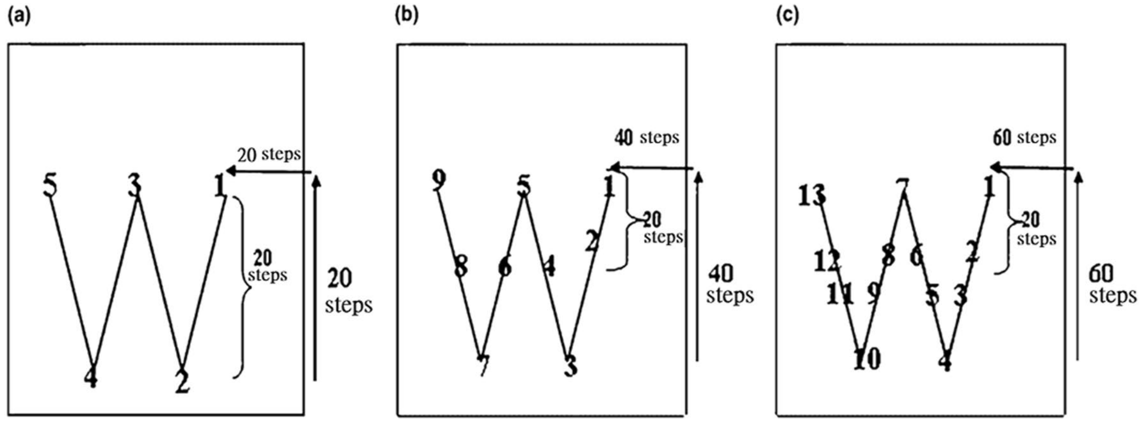

Fig. 3 The weed sampling method in saffron fields; **a** one-hectare fields, **b** two-hectare fields, **c** larger than 2-hectare fields (the numbers show the points where the 0.25 m^2 sampling quadrat were placed)

Dominance index

This index includes the sum of uniformity, frequency, and average weed density indicators.

$$AI_k = F_k + U_k + MFK_k \tag{4}$$

AI_k represents the dominance index of species K (Moeini et al. 2008).

Shannon-Wiener Index (H′)

This index is used to study the diversity of weed species in a field and region and the diversity of weed species over consecutive years (Shannon and Wiener 1963).

$$H' = -\sum \left[P_i(\ln P_i)\right] \tag{5}$$

P_i represents the relative frequency of the ith specific weed species, which is determined through the relationship $Pi = n_i/N$, and ln is equal to the natural logarithm (Shannon and Wiener 1963).

Simpson index (D)

This index determines species diversity in a plant population (MacDonald et al. 2017).

$$D = \sum \frac{ni(ni-1)}{N(N-1)} \tag{6}$$

D is equivalent to Simpson's index, ni indicates the number of weed species, and N denotes the number of all weed species.

Margalef's/Species richness index

The index, which varies depending on the number of species, has no limit value and is utilized for comparing districts (Margalef 1958).

$$\text{Margalef Index} = (S-1)/\text{Ln}(N) \tag{7}$$

S is total number of species, N is total number of individuals of all the species.

Menhinick's index

This index is a biodiversity index that measures the richness of species in a given area, considering the size of the area. Menhinick's Index is commonly used in ecology to compare the biodiversity of different regions or habitats (Menhinick 1964).

$$D_{mn} = S/\sqrt{N} \tag{8}$$

S Total number of species

N Total number of individuals of all the species

Pielou's index

Pielou's Index provides a quantitative measure of the relative abundance of each species in a given area, and it is calculated by taking into account the number of species present and their respective abundances (Dar et al. 2017).

$$J = H/H_{max} \tag{9}$$

Margalef's and Menchinick's indices share many similarities. Nevertheless, Margalef's index has a weaker correlation with sample size than Menhinick's, as stated by Wilhm (1967). Pielou's index is widely used in ecology to assess the biodiversity and stability of ecosystems, as it can reveal whether a single species dominates a particular area or whether there is a more even distribution of species. In addition, Pielou's Index can help identify areas at risk of losing biodiversity due to human activities such as deforestation, pollution, and climate change. By using this index, ecologists can develop strategies to conserve and restore ecosystems, thus ensuring species' long-term survival and sustainability (Dar et al. 2016).

Grouping of weed species

To facilitate the understanding of the concept of gradual changes in the vegetation composition of saffron fields in three districts of Karukh, Injil, and Ghoryan, and to help better understand the relationship between species and environmental factors, grouping is done in terms of the composition of similar species. Determining ecological groups and species was done using Two Way Indicator Analysis (TWINSPAN) based on species density. TWINSPAN classification used PC-Ord for Win version 4/17 (McCune and Mefford 1999). The evaluation of the correctness of the classification of plant communities resulting from the process of ecological classification was determined using diagnostic analysis and based on the soil factors of the saffron farms of the three studied regions by SPSS version 26 software (George and Mallery 2019). The detection functions not only select the most critical independent environmental variables affecting the distribution pattern of plant communities but also show the probability of assigning each sample piece to each of the plant groups, and based on this, the correct classification percentage of the groups is determined. In this research, Wilks lambda and Kappa statistics were used to evaluate the level of significance and statistical evaluation of the prediction accuracy of diagnostic functions, respectively.

Data analysis

The diversity indices were calculated using Excel 2013 software. The obtained standardized values for indices were analyzed by ANOVA, whereby entry points and district means were separated by Least Significant Difference (L.S.D.). Excel 2013 was also used to draw the corresponding graph.

Results

Composition of weed species

The composition of weeds in 30 farms in three districts (Ghoryan, Injil, and Karukh) was similar, and most of the identified weed species were observed in all three districts. While some weed species were observed only in one district. *Alhagi maurorum*, *Astragalus bisulcatus*, *Centaurea stoebe*, *Sisymbrium officinale*, and *Xanthium strumarium* were observed only in the Ghoryan District (Table 3). *Anchusa italica*, *Anthriscus sylvestris*, *Falcaria vulgaris*, *Goldbachia laevigata*, *Hordeum spontaneum*, *Lappula squarrosa*, *Silybum marianum*, *Sorghum halepense*, *Tragopogon* spp., and *Veronica persica* were observed only in the Injil District (Table 4). *Artemisia annua*, *Bromus tectorum*, *Launaea arborescens*, *Rosa persica*, *Rumex acetosella*, *Sinapis arvensis*, and *Tribulus terrestris* were observed only in Karukh District (Table 5).

Furthermore, *Cynodon dactylon* and *Lolium temulentum* were not observed in the Ghoryan District (Table 3). *Cerastium inflatum*, *Hordeum murinum*, *Malva neglecta*, and *Trifolium repens* were not observed in the Injil District (Table 4). Also, *Euphorbia helioscopia*, *Fumaria officinalis*, *Galium aparine*, *Lactuca serriola*, *Taraxacum officinale*, *Vicia sativa* were not observed in the Karukh District (Table 5).

The highest Frequency, Uniformity, MFD, and AI in the Karukh District were related to *Lolium temulentum* (24.9, 92.50, 13.27, and 129.9, respectively). In this district, the lowest Frequency, Uniformity, MFD, and AI were for *Sonchus oleraceus* (0.1, 2.5, 2.0, and 4.6, respectively) (Table 3). But in the Injil District, the highest Frequency, Uniformity, MFD, and AI was for *Lepidium draba* (31.1, 84.5, 22.2, and 137.8, respectively), and the lowest were related to *Goldbachia laevigata* (0.05, 2.50, 2.00, and 4.55, respectively) (Table 4). In the Karukh District, the trend was different; In this district, the highest Frequency, Uniformity, MFD, and AI were related to *Hordeum murinum* (28.3, 89.3, 17.2, and 134.8, respectively) (Table 5). On the other hand, in the Karukh District, the lowest Frequency, Uniformity, MFD, and AI were observed for *Vicia sativa* (0.02, 2.50, 2.00, and 4.52, respectively) (Table 5).

Structure of weed species

The monitoring of the weed community structure showed that these saffron fields were almost infested with monocotyledons. In other words, dicotyledons comprised 85.42% of the weeds, while monocotyledons accounted for 14.58%. According to the life cycle of sampled weeds, annual weeds were the most prevalent at 41.67%, followed closely by perennial weeds at 37.50%. Biennial weeds constituted 10.42% of the total. The remaining categories were less common:

Table 3 Characteristics for weed flora in saffron fields of the Ghoryan District, Afghanistan, during 2020–2022 growing seasons

No	Scientific name	Family	Life cycle	Type	2020–2021				2021–2022			
					F (%)	U (%)	MFD (Plant/m^2)	AI	F (%)	U (%)	MFD (Plant/m^2)	AI
1	*Achillea lanulosa* L.	*Asteraceae*	PE	D	1.76	20.00	21.63	43.38	1.84	22.50	20.11	44.45
2	*Acroptilon repens* L.	*Asteraceae*	PE	D	2.44	85.00	7.06	94.50	2.70	107.50	6.16	116.3
3	*Alhagi maurorum* Medik.	*Fabaceae*	PE	D	0.03	2.50	3.00	5.53	0.09	7.50	3.00	10.59
4	*Allium vineale* L.	*Amaryllidaceae*	PE	D	3.80	165.0	5.67	174.4	3.96	172.50	5.64	182.0
5	*Astragalus bisulcatus* (Hook.) A. Gray	*Fabaceae*	PE	D	0.65	40.00	4.00	44.65	0.77	52.50	3.62	56.89
6	*Avena fatua* L.	*Poaceae*	AN	M	11.13	382.5	7.15	400.7	10.41	412.50	6.20	429.1
7	*Capsella bursa-pastoris* L.	*Brassicaceae*	AN	D	0.25	20.00	3.13	23.38	0.25	15.00	4.17	19.42
8	*Lepidium draba* L.	*Brassicaceae*	PE	D	3.62	172.5	5.16	181.2	3.76	177.50	5.21	186.4
9	*Centaurea stoebe* L.	*Asteraceae*	BI/PE	D	0.06	2.50	6.00	8.56	0.20	7.50	6.67	14.37
10	*Cerastium inflatum* Link ex Desf.	*Caryophyllaceae*	BI/PE	D	0.41	47.50	2.11	50.01	0.55	52.50	2.57	55.62
11	*Cichorium intybus* L.	*Asteraceae*	PE	D	0.23	25.00	2.30	27.53	0.38	30.00	3.08	33.46
12	*Cirsium arvense* L.	*Asteraceae*	PE	D	6.52	147.5	10.86	164.8	6.66	152.50	10.74	169.9
13	*Convolvulus arvensis* L.	*Convolvulaceae*	PE	D	1.78	45.00	9.72	56.50	1.78	55.00	7.95	64.73
14	*Euphorbia helioscopia* L.	*Euphorbiaceae*	AN	D	0.09	7.50	3.00	10.59	0.09	5.00	4.50	9.59
15	*Fumaria officinalis* L.	*Papaveraceae*	AN	D	2.69	135.0	4.89	142.5	2.69	127.50	5.18	135.3
16	*Galium aparine* L.	*Rubiaceae*	AN	D	28.36	405.0	17.21	450.5	26.10	310.00	20.69	356.8
17	*Hordeum murinum* L.	*Poaceae*	AN	M	0.14	2.50	14.00	16.64	0.28	7.50	9.33	17.12
18	*Lactuca serriola* L.	*Asteraceae*	AN/BI	D	24.73	277.5	21.90	324.1	24.87	210.00	29.11	263.9
19	*Malva neglecta* L.	*Malvaceae*	AN	D	0.07	12.50	1.40	13.97	0.07	10.00	1.75	11.82
20	*Medicago lupulina* L.	*Fabaceae*	AN	D	1.67	80.00	5.13	86.79	1.67	80.00	5.13	86.79
21	*Plantago lanceolata* L.	*Plantaginaceae*	PE	D	1.51	45.00	8.22	54.73	1.65	50.00	8.10	59.75
22	*Polygonum aviculare* L.	*Polygonaceae*	AN	D	5.17	52.50	24.19	81.86	5.17	50.00	25.40	80.57
23	*Scandix pectin-veneris* L.	*Apiaceae*	AN	D	1.96	42.50	11.35	55.82	1.96	35.00	13.79	50.75
24	*Sisymbrium officinale* (L.) Scop.	*Brassicaceae*	AN	D	0.09	5.00	4.50	9.59	0.09	2.50	9.00	11.59
25	*Sonchus oleraceus* L.	*Asteraceae*	BI	D	0.07	12.50	1.40	13.97	0.37	27.50	3.27	31.14
26	*Taraxacum officinale* F.H. Wigg.	*Asteraceae*	PE	D	0.22	25.00	2.20	27.42	0.37	30.00	3.00	33.37
27	*Trifolium repens* L.	*Fabaceae*	PE	D	0.39	15.00	6.33	21.72	0.53	27.50	4.73	32.76
28	*Vicia sativa* L.	*Fabaceae*	AN	D	0.02	2.50	2.00	4.52	0.00	0.00	0.00	0.00
29	*Xanthium strumarium* L.	*Asteraceae*	AN	D	0.12	2.50	12.00	14.62	0.00	0.00	0.00	0.00

AN annual, *BI* biennial, *PE* perennial, *M* Monocotyledon, *D* Dicotyledon

F Frequency index, *U* Uniformity Index, *MFD* The Mean Frequency Index, *AI* Dominance index

Table 4 Characteristics for weed flora in saffron fields of the Injil district, Afghanistan, during 2020–2022 growing seasons

No	Scientific name	Family	Life cycle	Type	2020–2021				2021–2022			
					F (%)	U (%)	MFD (Plant/m^2)	AI	F (%)	U (%)	MFD (Plant/m^2)	AI
1	*Achillea lanulosa* L.	*Asteraceae*	PE	D	1.24	10.00	13.50	24.74	1.31	12.50	11.40	25.21
2	*Acroptilon repens* L.	*Asteraceae*	PE	D	0.69	17.50	4.29	22.47	0.99	12.50	8.60	22.09
3	*Allium vineale* L.	*Amaryllidaceae*	PE	D	2.60	92.50	3.05	98.15	2.78	97.50	3.10	103.3
4	*Anchusa italica* L.	*Boraginaceae*	PE	D	0.07	2.50	3.00	5.57	0.14	7.50	2.00	9.64
5	*Anthriscus sylvestris* (L.) Hoffm.	*Apiaceae*	BI	D	0.90	27.50	3.55	31.94	0.78	22.50	3.78	27.06
6	*Avena fatua* L.	*Poaceae*	AN	M	7.76	132.50	6.38	146.6	7.76	142.50	5.93	156.1
7	*Capsella bursa-pastoris* L.	*Brassicaceae*	AN	D	2.11	22.50	10.22	34.84	2.11	25.00	9.20	36.31
8	*Cichorium intybus* L.	*Asteraceae*	PE	D	0.57	25.00	2.50	28.07	0.55	30.00	2.00	32.55
9	*Cirsium arvense* L.	*Asteraceae*	PE	D	0.41	20.00	2.25	22.66	0.51	22.50	2.44	25.45
10	*Convolvulus arvensis* L.	*Convolvulaceae*	PE	D	0.09	5.00	2.00	7.09	0.11	7.50	1.67	9.28
11	*Cynodon dactylon* L.	*Poaceae*	PE	M	1.10	20.00	6.00	27.10	1.17	27.50	4.64	33.31
12	*Euphorbia helioscopia* L.	*Euphorbiaceae*	AN	D	1.36	45.00	3.28	49.63	1.26	35.00	3.93	40.19
13	*Falcaria vulgaris* Bernh.	*Apiaceae*	BI	D	1.38	32.50	4.62	38.49	1.24	35.00	3.86	40.10
14	*Fumaria officinalis* L.	*Papaveraceae*	AN	D	0.07	2.50	3.00	5.57	0.00	0.00	0.00	0.00
15	*Galium aparine* L.	*Rubiaceae*	AN	D	0.76	20.00	4.13	24.88	0.57	12.50	5.00	18.07
16	*Goldbachia laevigata* (M. Bieb.) DC.	*Brassicaceae*	AN	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	*Hordeum spontaneum* L.	*Poaceae*	AN	M	12.24	122.50	10.88	145.6	10.40	102.50	11.05	123.9
18	*Lappula squarrosa* (Retz.) Dumort.	*Boraginaceae*	AN/BI	D	0.07	5.00	1.50	6.57	0.00	0.00	0.00	0.00
19	*Lactuca serriola* L.	*Asteraceae*	AN/BI	D	0.51	17.50	3.14	21.15	0.48	20.00	2.63	23.11
20	*Lepidium draba* L.	*Brassicaceae*	PE	D	31.12	152.50	22.21	205.8	32.18	157.50	22.24	211.9
21	*Lolium temulentum* L.	*Poaceae*	AN	M	6.55	85.00	8.38	99.93	5.83	60.00	10.58	76.42
22	*Medicago lupulina* L.	*Fabaceae*	AN/PE	D	0.23	5.00	5.00	10.23	0.16	2.50	7.00	9.66
23	*Plantago lanceolata* L.	*Plantaginaceae*	PE	D	10.08	75.00	14.63	99.72	10.68	87.50	13.29	111.4
24	*Polygonum aviculare* L.	*Polygonaceae*	AN	D	0.07	5.00	1.50	6.57	0.05	2.50	2.00	4.55
25	*Scandix pecten-veneris* L.	*Apiaceae*	AN	D	4.94	25.00	21.50	51.44	5.08	35.00	15.79	55.86
26	*Silybum marianum* (L.) Gaertn.	*Asteraceae*	BI	D	0.30	12.50	2.60	15.40	0.41	20.00	2.25	22.66
27	*Sonchus oleraceus* L.	*Asteraceae*	BI	D	0.32	12.50	2.80	15.62	0.48	15.00	3.50	18.98
28	*Sorghum halepense* (L.) Pers.	*Poaceae*	PE	M	0.41	5.00	9.00	14.41	0.51	10.00	5.50	16.01
29	*Taraxacum officinale* F.H. Wigg.	*Asteraceae*	PE	D	0.05	5.00	1.00	6.05	0.30	17.50	1.86	19.66
30	*Tragopogon* spp.	*Asteraceae*	BI	D	0.37	12.50	3.20	16.07	0.51	22.50	2.44	25.45
31	*Veronica persica* Poir.	*Plantaginaceae*	AN	D	11.58	75.00	16.80	103.3	9.92	52.50	20.57	82.99
32	*Vicia sativa* L.	*Fabaceae*	AN	D	0.11	7.50	1.67	9.28	0.05	2.50	2.00	4.55

AN annual, *BI* biennial, *PE* perennial, *M* Monocotyledon, *D* Dicotyledon

F Frequency index, *U* Uniformity Index, *MFD* The Mean Frequency Index, *AI* Dominance index

Table 5 Characteristics for weed flora in saffron fields of the Karukh District, Afghanistan, during 2020–2022 growing seasons

No	Scientific name	Family	Life cycle	Type	2020–2021				2021–2022			
					F (%)	U (%)	MFD (Plant/m^2)	AI	F (%)	U (%)	MFD (Plant/m^2)	AI
1	*Achillea lanulosa* L.	*Asteraceae*	PE	D	7.29	52.50	7.05	66.84	6.50	47.50	6.95	60.95
2	*Acroptilon repens* L.	*Asteraceae*	PE	D	0.30	7.50	2.00	9.80	0.34	12.50	1.40	14.24
3	*Allium vineale* L.	*Amaryllidaceae*	PE	D	3.15	37.50	4.27	44.92	3.00	35.00	4.36	42.36
4	*Artemisia annua* L.	*Asteraceae*	AN	D	0.20	5.00	2.00	7.20	0.20	5.00	2.00	7.20
5	*Avena fatua* L.	*Poaceae*	AN	M	3.99	42.50	4.76	51.25	4.83	57.50	4.26	66.59
6	*Bromus tectorum* L.	*Poaceae*	AN	M	0.59	10.00	3.00	13.59	0.34	7.50	2.33	10.18
7	*Capsella bursa-pastoris* L.	*Brassicaceae*	AN	D	1.33	12.50	5.40	19.23	1.58	12.50	6.40	20.48
8	*Cerastium inflatum* Link ex Desf.	*Caryophyllaceae*	BI/PE	D	0.15	2.50	3.00	5.65	0.20	10.00	1.00	11.20
9	*Cichorium intybus* L.	*Asteraceae*	PE	D	0.39	5.00	4.00	9.39	0.25	7.50	1.67	9.41
10	*Cirsium arvense* L.	*Asteraceae*	PE	D	0.49	12.50	2.00	14.99	0.49	17.50	1.43	19.42
11	*Convolvulus arvensis* L.	*Convolvulaceae*	PE	D	3.84	32.50	6.00	42.34	3.55	27.50	6.55	37.59
12	*Cynodon dactylon* L.	*Poaceae*	PE	M	14.43	62.50	11.72	88.65	14.98	77.50	9.81	102.2
13	*Hordeum murinum* L.	*Poaceae*	AN	M	14.33	67.50	10.78	92.61	15.86	105.0	7.67	128.5
14	*Launaea arborescens* (Batt.) Murb.	*Asteraceae*	PE	D	0.00	0.00	0.00	0.00	0.15	20.00	0.38	20.52
15	*Lepidium draba* L.	*Brassicaceae*	PE	D	8.08	72.50	5.66	86.23	8.08	52.50	7.81	68.39
16	*Lolium temulentum* L.	*Poaceae*	AN	M	24.19	92.50	13.27	129.9	22.32	82.50	13.73	118.5
17	*Malva neglecta* L.	*Malvaceae*	AN	D	1.48	20.00	3.75	25.23	1.72	27.50	3.18	32.41
18	*Medicago lupulina* L.	*Fabaceae*	AN/PE	D	2.17	20.00	5.50	27.67	2.61	22.50	5.89	31.00
19	*Plantago lanceolata* L.	*Plantaginaceae*	PE	D	7.00	22.50	15.78	45.27	8.62	27.50	15.91	52.03
20	*Polygonum aviculare* L.	*Polygonaceae*	AN	D	4.73	35.00	6.86	46.59	4.73	35.00	6.86	46.59
21	*Rosa persica* Michx. ex Juss.	*Rosaceae*	PE	D	0.20	5.00	2.00	7.20	0.30	7.50	2.00	9.80
22	*Rumex acetosella* L.	*Polygonaceae*	PE	D	0.20	5.00	2.00	7.20	0.25	10.00	1.25	11.50
23	*Scandix pecten-veneris* L.	*Apiaceae*	AN	D	0.15	2.50	3.00	5.65	0.25	2.50	5.00	7.75
24	*Sinapis arvensis* L.	*Brassicaceae*	AN	D	0.15	2.50	3.00	5.65	0.25	2.50	5.00	7.75
25	*Sonchus oleraceus* L.	*Asteraceae*	BI	D	0.00	0.00	0.00	0.00	0.15	2.50	3.00	5.65
26	*Tribulus terrestris* L.	*Zygophyllaceae*	AN	D	0.84	7.50	5.67	14.00	0.94	10.00	4.75	15.69
27	*Trifolium repens* L.	*Fabaceae*	PE	D	0.39	10.00	2.00	12.39	0.44	12.50	1.80	14.74

AN annual, *BI* biennial, *PE* perennial, *M* Monocotyledon, *D* Dicotyledon

F Frequency index, *U* Uniformity Index, *MFD* The Mean Frequency Index, *AI* Dominance index

annual/biennial weeds and biennial/perennial weeds each comprised 4.17%, while annual/perennial weeds accounted for 2.08% of the total.

The number of weed species varied across the districts, with Injil having the highest (30.5 ± 4.1) and Ghoryan the lowest (28.1 ± 3.3). The Simpson diversity index ranged from 0.61 ± 0.14 in Karukh to 0.74 ± 0.21 in Injil, indicating moderately high diversity. The Shannon-Wiener index followed a similar trend, ranging from 1.06 ± 0.14 in Karukh to 1.23 ± 0.2 in Injil. The Margalef and Menhinck indices, which account for species richness, were also highest in Injil (0.98 ± 0.14 and 0.67 ± 0.11, respectively) and lowest in Ghoryan (1.15 ± 0.09 and 0.73 ± 0.13, respectively). The Pielou index, which measures evenness, ranged from 0.61 ± 0.14 in Ghoryan to 0.74 ± 0.19 in Injil (Table 6).

Classification

Using TWINSPAN analysis and based on canopy percentage values, 46 weed species related to 30 saffron farms were classified, identified, and separated into three ecological groups at the second level (Table 7). Combining the results of TWINSPAN analysis and indicator species analysis was as follows. In the first group, there were 15 plant species and two species, *Lappula squarrosa* and *Hordeum spontaneum* showed the highest values with index values of 99.6

Table 6 The diversity indexes for weeds of saffron fields in Karukh, Injil, and Ghoryan districts of Afghanistan (averaged cropping years of 2020–2021 and 2021–2022)

Districts	Number of species	Simpson diversity	Shannon Wiener	Margalef	Menhinck	Pielou
Karukh	26.2 ± 2.6 ns	0.61 ± 0.14 ns	1.06 ± 0.14 ns	1.21 ± 0.16 ns	0.70 ± 0.09 ns	0.62 ± 0.13 ns
Injil	30.5 ± 4.1 ns	0.74 ± 0.21 ns	1.23 ± 0.2 ns	0.98 ± 0.14 ns	0.67 ± 0.11 ns	0.74 ± 0.19 ns
Ghoryan	28.1 ± 3.3 ns	0.65 ± 0.17 ns	1.15 ± 0.08 ns	1.15 ± 0.09 ns	0.73 ± 0.13 ns	0.61 ± 0.14 ns

The parameters show significant differences according to the LSD test when different letters are used, with a p-value of 0.05. “ns” denotes no significant differences

Table 7 The maximum values of the index value of plant species in each ecological group

Species	Index value	Group	Species	Index value	Group
Scandix pecten-veneris L.	15.2 ns	First	*Convolvulus arvensis* L.	56.9 *	Second
Hordeum murinum L.	23.1 ns	First	*Anthriscus sylvestris* (L.) Hoffm.	62.9 **	Second
Sonchus oleraceus L.	28.1 *	First	*Falcaria vulgaris* Bernh.	67.2 **	Second
Sorghum halepense (L.) Pers.	29.3 *	First	*Anchusa italica* L.	77.8 **	Second
Silybum marianum (L.) Gaertn.	31.3 *	First	*Vicia sativa* L.	87.9 **	Second
Rumex acetosella L.	34.7 *	First	*Euphorbia helioscopia* L.	89.3 **	Second
Rosa persica Michx. ex Juss.	37.0 *	First	*Launaea arborescens* (Batt.) Murb.	93.3 **	Second
Fumaria officinalis L.	39.1 *	First	*Lactuca serriola* L.	97.8 **	Second
Sinapis arvensis L.	44.5 *	First	*Veronica persica* Poir.	8.3 ns	Third
Galium aparine L.	48.9 *	First	*Lepidium draba* L.	22.3 ns	Third
Goldbachia laevigata (M. Bieb.) DC.	49.1 *	First	*Capsella bursa-pastoris* L.	28.4 *	Third
Taraxacum officinale F.H. Wigg.	56.2 **	First	*Bromus tectorum* L.	44.4 **	Third
Sisymbrium officinale (L.) Scop.	78.2 **	First	*Avena fatua* L.	44.7 **	Third
Lappula squarrosa (Retz.) Dumort.	99.4 **	First	*Cerastium inflatum* Link ex Desf.	53.4 **	Third
Hordeum spontaneum L.	99.6 **	First	*Centaurea stoebe* L.	60.2 **	Third
Malva neglecta L.	6.8 ns	Second	*Artemisia annua* L.	62.7 **	Third
Polygonum aviculare L.	9.7 ns	Second	*Cirsium arvense* L.	67.2 **	Third
Plantago lanceolata L.	10.0 ns	Second	*Astragalus bisulcatus* (Hook.) A. Gray	68.1 **	Third
Tribulus terrestris L.	11.2 ns	Second	*Xanthium strumarium* L.	77.2 **	Third
Lolium temulentum L.	13.1 ns	Second	*Allium vineale* L.	79.5 **	Third
Medicago lupulina L.	20.9 ns	Second	*Alhagi maurorum* Medik.	79.7 **	Third
Cynodon dactylon L.	34.2 *	Second	*Acroptilon repens* L.	83.9 **	Third
Tragopogon spp.	48.2 *	Second	*Achillea lanulosa* L.	84.9 **	Third

In this table, ns, **, and * indicate no significant difference, significant disagreement at the probability level of 1 and 5%, respectively

Table 8 Statistical indicators of variables entered in diagnosis functions

	Soil variables	Wilks Lambda	*P* Value
Depth 0–25 cm	K	0.125	0.000
	Moisture	0.241	0.000
	C/N	0.081	0.000
	E.C.	0.402	0.000
Depth 25–50 cm	pH	0.247	0.000
	Moisture	0.068	0.000
	Organic C	0.098	0.000

Table 10 The matrix of standardized focal coefficients of soil variables and detection functions

Soil variables		Detection functions	
		Function 1	Function 2
Depth 0–25 cm	K	0.951	–0.166
	Moisture	0.922	0.593
	C/N	0.421	0.491
	E.C.	0.573	–0.740
Depth 25–50 cm	pH	0.309	–0.555
	Moisture	0.997	0.448
	C	0.695	0.354

and 99.4, respectively, and were determined as the index species of this group. The second group included 16 weed species, and *Lactuca serriola* species was defined as the indicator species in this group. The third group included 15 weed species, among which two species, *Achillea lanulosa* and *Acroptilon repens*, showed the highest values and were designated indicator species.

Multivariate analysis of soil factor detection in ecological groups

Diagnostic analysis was used to determine the significance of soil variables among environmental groups and to check the correctness of the classification of groups. This analysis showed that six variables, including E.C., absorbable potassium, carbon/nitrogen ratio, acidity, moisture, and organic carbon percentage, were evaluated in order of importance during seven steps in dual functions, each at the 1% error level was significant (Table 8). This analysis showed that by using the mentioned variables, two detection functions are formed. The importance of dual functions based on their variance explanation share from the first function (90.5%) to the second function (9.5%) decreases drastically (Tables 9 and 10). Finally, the diagnostic analysis consensus table shows that the classification accuracy of the ecological groups of the region based on 24 measured environmental variables is 91.97% (Table 11). The similar membership of the sample in two series according to the groups, i.e., TWINSPAN and the groups resulting from the diagnosis analysis classification, is equal to 91.97%. In this regard, the Kappa coefficient evaluated the matching of ecological groups with the groups obtained from the diagnostic analysis as 0.901 (Table 12). In other words, based on the Kappa criterion, the classification accuracy of the groups in the diagnostic analysis was estimated at 90.1%.

Discussion

In this study, annual and perennial weeds showed more occupancy in saffron fields. Some were the dominant species, requiring attention to these species and searching for ways to eliminate them. Also, weed community structures were similar, and most identified weed species were observed in all three districts. The flora of a particular area is represented by the total sum of all plant species, whether wild or cultivated. Additionally, the floral diversity of an area provides insights into the density and interaction of plants with their environment (Ullah et al. 2023). This effect may be due to the chemical properties of each plant family. It is well known that members of the same plant family have common chemical properties, and the roots of plants release chemicals into the soil, which, in turn, substances affect weeds, either negatively or positively, according to allelopathy theory (Alsherif 2020). The current study highlighted the cereal weeds in the studied area and compared them with weeds of other crops. Another thing that was noticed was the difference between the abundance and density of a

Table 9 Summary for the statistics of focal detection functions

Functions	Special value	The percentage of variance explanation	Coefficient of focal correlation	Wilks Lambda	Degree of freedom	Chi-square	*P* Value
1	323	90.5	0.938	0.068	14	0.481	0.000
2	765	9.5	0.658	0.567	6	0.722	0.000

Table 11 Membership of fields and correct classification of ecological groups

Ecological groups	Groups predicted by diagnostic analysis based on environmental variables			Number of fields	Percentage of compliance*
	First	Second	Third		
First	18	0	0	18	100
Second	2	11	0	13	84.6
Third	0	0	15	15	100

* Average compliance percentage = 91.97%

particular species of weed, which seems to be the reason for the difference in the field management system, followed by the difference in agricultural operations in the fields of the three investigated districts because based on the study conducted by Šikuljak Pavlović et al. (2023), differences in crop management systems could be one of the main factors in increasing or decreasing the frequency and density of weed populations.

The diversity indices suggest that Injil district had the highest weed diversity in saffron fields, while Karukh had the lowest. The higher diversity in Injil could be attributed to various factors such as soil conditions, management practices, or environmental factors that favor the growth of diverse weed species. The moderate to high diversity observed across all districts indicates a complex weed community in saffron fields, which may necessitate effective weed management strategies to minimize competition with the crop. The non-significant differences for some indices across districts suggest that the weed diversity may not vary substantially in certain aspects. However, the significant differences observed for other indices highlight the importance of considering multiple diversity measures to accurately capture the complexity of weed communities. Overall, this study provides valuable insights into the diversity of weeds in saffron fields across different regions of Afghanistan, which can inform weed management strategies and contribute to the sustainable production of this high-value crop.

In the current study, relationships were observed between the soil characteristics and weed communities of saffron fields; in other words, six variables, including E.C., absorbable potassium, carbon/nitrogen ratio, pH, moisture, and organic carbon percentage, had the highest effect on weed diversity. It was reported that ecological characteristics could affect dominant weeds in saffron fields (Khorramdel et al. 2017; Javadzadeh 2019). Previous studies examining the relationship between the physicochemical and biological characteristics of soil and vegetation showed that soil characteristics (Imeni et al. 2020), especially its physical characteristics (Mhlanga et al. 2022), play an influential role in the separation of ecological groups and the expansion of plant communities. While soil properties were essential drivers of weed communities, management practices like chemical spraying, mowing, and grazing had an even more substantial effect on shaping the weed flora (Vahamidis et al. 2024). Alhammad et al. (2023) reported that the zero-tillage without residue treatment had the highest weed density and biomass, likely due to weed seeds remaining undisturbed near the soil surface, facilitating their germination.

Table 12 Report of kappa coefficient in determining the accuracy of predicted groups by diagnostic analysis

Value of Kappa coefficient	Criterion error	Significance
0.901	0.031	0.000

It was reported that in olive groves of Southern Greece, soil properties like pH, calcium carbonate content, and soil organic matter influenced the availability of micronutrients like Mn, Mg, and zinc, which in turn affected weed communities (Vahamidis et al. 2024). However, weed community could be affected by soil tillage (Chaniago et al. 2023), soil nutrition management (Esposito et al. 2023), precipitation and soil temperature (Mohammadkhani et al. 2023), and sustainable management practices (Radicetti et al. 2024).

It is perspicuous that weeds' growth preference (selective development and growth behavior) is a result of their response to the combined effect of the three environmental variables under study: crop diversification, crop seasonality, and soil type (Mahgoub 2021). The change of the combined effects of the eco factors from one region to the other has a significant adverse impact on the ecological range of some species (Mzabri et al. 2022) and their spatial distribution, which depends mainly on the higher ecological amplitude of species and broader ecological niche (Jalili et al. 2019). In a study, Mahgoub (2019a) reported a noticeable decrease in the total species richness γ-diversity, Whittaker, and it was concluded that the soil type has a pronounced impact on species distribution and weed community structure followed by crop type, crop sustainability, the prevailing climate, and urbanization, respectively. However, it should be kept in mind that the impact importance of these environmental factors is realistic for the sample area under study. Still, it is not a strict rule, as an ecological factor may dominate in determining the vegetation structure in a particular region and a co-factor in another depending on the availability of natural resources and the extent of human intervention (Mahgoub 2019b). Mahgoub (2019a) also reported that the prevailing climate was the principal factor in species distribution and weed community structure, followed by urbanization, crop, soil type, and crop sustainability.

It should be remembered that crop rotation in previous years can influence the abundance and diversity of species of weeds in a region. Moreover, in the long term, farmers can achieve greater control over weed abundance and tillage, weed management method, and crop type by, for example, changing planting dates throughout the crop sequence. One of the main factors determining the composition of communities is weeds (Adeux et al. 2022). Identifying communities and species on the edge of fields can also be one of the best strategies for preparing a map of weed distribution in fields, especially saffron fields (Rezvani Moghaddam et al. 2016). Another factor affecting the distribution of different weed populations is long-term fertilization management (Cordeau et al. 2021) because diversity in crop cultivation systems does not increase the diversity of weed species (Adeux et al. 2022).

According to the smoothness and unique characteristics of the studied saffron fields, it can be said that the change in the weed vegetation could be directly related to soil characteristics. Because in this classification, each plant group represents unique environmental conditions in terms of the physical and chemical characteristics of the soil. Also, to determine the relationship between the ecological species group and the change in soil characteristics, this study showed that using multivariate analysis provides a better understanding of the relationship between environmental factors and weed vegetation in the saffron fields affected by the differentiated populations.

Conclusion

Investigating the relationships between soil properties and floristic composition of weed communities could provide helpful and practical information for sustainable weed management. In other words, the study of ecological needs, environmental, agronomic, and management factors that affect the distribution of weed populations is necessary to influence and diminish the weed presence in saffron fields. According to the results of this study, E.C., absorbable potassium, carbon/nitrogen ratio, pH, moisture, and organic carbon percentage had the highest effect on weed diversity. In the authors' opinion, changing these factors might be a sustainable method for weed control in saffron fields. So, changing the composition of weed populations in saffron fields from dominant and resistant species in favor of species that crops tolerate could be possible by conducting selective pressures such as providing unsuitable conditions for weeds with differing E.C., absorbable potassium, carbon/nitrogen ratio, pH, moisture, and organic carbon percentage.

Acknowledgements The authors thank farmers who made a valuable cooperation to conduct the study.

Author contributions All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Obaidullah Ghafory. The first draft of the manuscript was written by Obaidullah Ghafory, and all authors commented on previous versions. All authors read and approved the final manuscript.

Conceptualization: Obaidullah Ghafory; Methodology: Obaidullah Ghafory; Formal analysis and investigation: Obaidullah Ghafory; Writing - original draft preparation: Obaidullah Ghafory; Writing - review and editing: Ghorban Ali Asadi, Mehdi Rastgoo, Mohammad Hassan Rashed Mohassel, Abdollah Mollafilabi; Funding acquisition: NA; Resources: NA; Supervisions: Ghorban Ali Asadi, Mehdi Rastgoo.

Declarations

Conflict of interest The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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