VEGETATION CLASSIFICATION AND SURVEY

International Association for Vegetation Science (IAVS)

Vegetation Classification and Survey 4: 31–45
doi: 10.3897/VCS.86024

RESEARCH PAPER

AFRICAN VEGETATION STUDIES

Plant diversity in traditional agroecosystems of North Morocco

Soufian Chakkour[1], Erwin Bergmeier[2], Stefan Meyer[2], Jalal Kassout[1,3], Mohamed Kadiri[1], Mohammed Ater[1]

1 *Bio-Agrodiversity Team, Laboratory of Applied Botany, Faculty of Sciences, University of Abdelmalek Essaadi, Tétouan, Morocco*
2 *Department of Vegetation and Phytodiversity Analysis, University of Göttingen, Göttingen, Germany*
3 *National Institute of agronomic Research, INRA, CRRA, Marrakech, Morocco*

Corresponding author: Erwin Bergmeier (Erwin.Bergmeier@bio.uni-goettingen.de)

Academic editor: Manfred Finckh ♦ **Received** 14 May 2022 ♦ **Accepted** 15 December 2022 ♦ **Published** 28 February 2023

Abstract

Questions: While globalisation favours intensive yield-maximizing agriculture with cropping practices that entail agrobiodiversity loss, extensive production systems still exist in areas of marginal lands such as in mountainous regions or islands. It is overdue to study such systems, their sustainability and ecology as potential models for decentralized environmentally balanced land-use. For that purpose, we investigated the composition of the wild arable (segetal) flora in traditional thermo- to mesomediterranean cereal-growing agroecosystems of northwestern Morocco. **Study area:** The Tingitane (Tangier) Peninsula in the Northwest of Morocco. **Methods:** A sample of 94 relevés was collected in six areas in the foreland of the Rif Mountains. **Results:** We found 209 species in 150 genera and 41 families, a mean of 22 species per relevé and a Shannon index of 3.04±0.06. A TWINSPAN classification revealed a high level of similarity between the areas, with the plant communities corresponding to the order *Brometalia rubenti-tectorum*, but also differences in species composition as a result of climatic, soil and land-use effects. Therophytes dominated, but biennial and perennial herbs indicating shallow tillage and fields under fallow were also common. Almost half of the species found were agrestal species (confined to arable fields), and almost a third were apophytes (native species occurring in fields but also in natural habitats). Twenty-nine species (14%) of the segetal flora were regional endemics and six are considered nationally rare. Although there is evidence of recent structural and floristic diversity decline, traditional agroecosystems tend to favour native species including some of particular conservation interest. **Conclusions:** The traditional agroecosystems of the Rif Mountains fulfil criteria of High Nature Value agriculture but, in view of recent socio-economic change, require support by policy for their maintenance.

Taxonomic reference: Euro+Med PlantBase (http://www.europlusmed.org) [accessed 26 Nov 2022].

Syntaxonomic reference: EuroVegChecklist (Mucina et al. 2016).

Abbreviations: TWINSPAN = Two Way Indicator Species Analysis.

Keywords

agriculture, arable fields, *Brometalia rubenti-tectorum*, life form, northwestern Africa, segetal flora, species richness, taxonomic diversity, vegetation classification, weed

Introduction

The segetal flora comprises wild plants growing in fields of cereal cropping without being sown for cultivation (Godinho 1984). They are often dismissed as undesirable weeds competing with crops for nutrients and water and causing yield losses. Segetal plants are adapted to cultivated fields by traits such as mimicking crop attributes and resisting frequent disturbance regimes (Holzner and Numata 1982; Barrett 1983; McElroy 2014). Obligate weeds (Zohary 1950), or 'messicole' in French (Jauzein 1997), can be described as agro-dependent segetal plants (Holzner 1978; Aavik and Liira 2009), whereas facultative weeds are found both in non-cultivated habitats and in cultivated fields. Such species can be native (apophytes) or alien (introduced and established) (Jauzein 2001a, 2001b; Lisek 2012).

Nowadays, chemical weed control is important in production-oriented intensive agricultural practices. In consequence, the segetal flora, and especially the obligate segetal plants, in many European countries is among the most vulnerable and threatened groups of plants (Storkey et al. 2012). Agricultural intensification has been identified as the main cause of agrobiodiversity loss (Storkey and Westbury 2007; Potts et al. 2010; Meyer et al. 2013). Several studies have shown that intensive arable farming negatively affects arable plant communities in terms of their biodiversity as well as the ecosystem services they provide (Marshall et al. 2003; Meyer et al. 2015; Chamorro et al. 2016; Štefanić et al. 2019; Görzen et al. 2021). The recognition of the importance of the segetal flora for agroecosystems supporting a diverse fauna and beneficial microorganisms has focused attention on the need to maintain traditionally cultivated habitats (Storkey and Neve 2018; Mupepele et al. 2019; Böhning-Gaese et al. 2020; Bourgeois et al. 2020; Gaba et al. 2020). This led to the development of new concepts such as High Nature Value Farming (EEA 2004), the setup of a nation-wide network of conservation fields in Central Europe (Meyer 2021) and the promotion of certain soil practices such as conservation agriculture (Reicosky 2015).

While yield-maximizing intensive agriculture with cropping practices resulting in agrobiodiversity loss prevail in Europe and the Mediterranean, there are agricultural landscapes with less intensive production systems, such as northern Morocco (Deil 1997; Ater and Hmimsa 2008; Hmimsa and Ater 2008). These agroecosystems are characterized by traditional agricultural practices such as polyculture, agroforestry, shallow tillage, crop rotations including fallow, and refraining from the use of chemical herbicides. These practices promote the structure and biodiversity of fields in the landscape context (Deil 1997; Altieri 1999). In the Maghreb, weed control is generally coupled with the use of crop and weed biomass as fodder (Jouve 1993). The practice of fallowing is part of the feeding calendar of herds where weeds are an important fodder resource. Furthermore, some segetal species are gathered as part of the traditional human diet, e.g. *Bekoule*, a Moroccan dish containing wild food plants of species such as *Lavatera trimestris* , *Malva* spp., *Rumex* spp., *Scolymus* spp., *Beta* spp. (Nassif and Tanji 2013; Powell et al. 2014; Bogaard et al. 2018; Aboukhalaf et al. 2022).

Several floristic and agronomic studies have been conducted on the weed flora in Morocco (Tanji and Boulet 1986; Lastic 1989; Taleb and Maillet 1994; Taleb et al. 1998; Zidane et al. 2010), particularly in regions with predominantly intensive agriculture. However, relatively little is known about the segetal flora of cereal crops in traditionally managed Moroccan agroecosystems. The mountainous western Rif region and its foreland is characterised by the persistence of traditional agrosilvopastoral production systems (CGDA 2011), where cereals occupy almost half of the territory's utilised agricultural area (CGDA 2008).

The present work is the first contribution to the knowledge of field-scale plant diversity of traditional agroecosystems in the wider Rif mountains. These agroecosystems are part of a differentiated rural landscape composed of a mosaic of semi-natural and human-made habitats. The objectives of this research are: i) evaluating the segetal flora under various aspects (taxonomic and life form spectrum, chorology, plant community), ii) their interpretation in relation to the land-use and abiotic particularities of these agroecosystems and iii) assessing the interest of this flora for conservation.

Study area

The study area is known as the Tingitane (Tangier) Peninsula located in the northwest of Morocco. It corresponds to the western part of the Rif Mountains (Figure 1) which has been listed as one of the Mediterranean biodiversity hotspots (Médail and Quézel 1999; Myers et al. 2000). It is a biogeographical crossroad with Mediterranean, West Eurasian and subtropical floristic influences (Arènes 1951; Quézel 2000). Most extensive in the region is the thermomediterranean vegetation zone, replaced at higher altitudes by the mesomediterranean and supramediterranean vegetation zones (Benabid 1982). The Rif corresponds to a mosaic of contrasting landscapes: narrow alluvial plains on the Mediterranean side, hills on the pre-Rif rim, and the rest of the territory is mountainous as in the Talassemtane National Park. The region is classified as a favourable agro-climatic zone with arable fields rising to an elevation of 1.200 m (Saidi et al. 2007). It ranges from humid on the wettest high summits to semi-arid on the Mediterranean coast east of Oued Laou (Benabid 1982; Mokhtari et al. 2013).

Despite the relief, the area favourable for agriculture is relatively large and represents more than one quarter (28%) of the Tingitane Peninsula (CGDA 2008). The prevalent cropping system is rainfed cereal farming (mainly soft wheat, durum wheat, and barley) (CGDA 2008) with a cereal-fallow or cereal-legume rotation. The traditional agro-sylvo-pastoral production system is based on smallholder subsistence agriculture and livestock-rearing. Generally, small and medium-sized fields are tilled in late autumn with swing ploughs drawn by animals (mules,

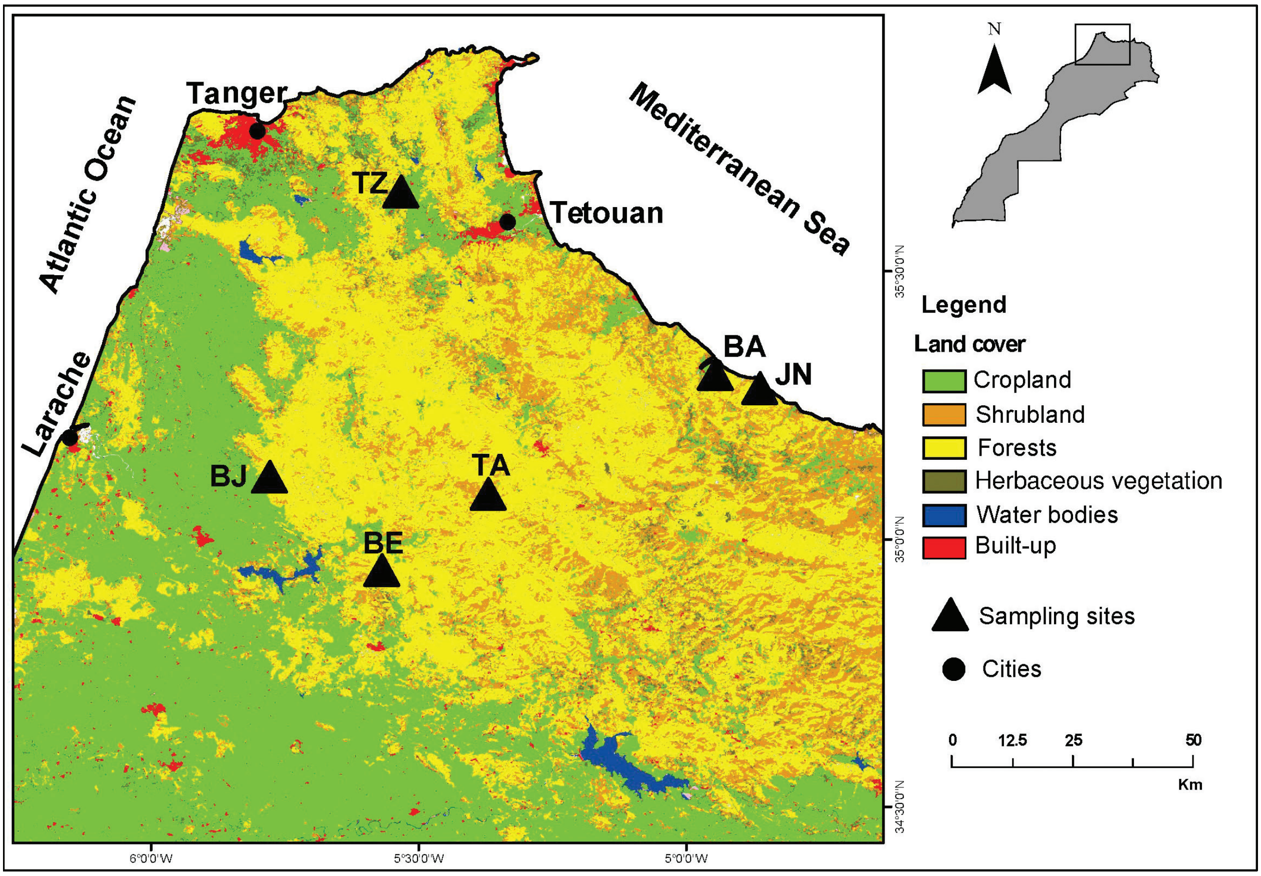

Figure 1. Location of study areas in the Tingitane Peninsula of the Rif Mountains (Morocco). BA: Bou Ahmed; BE: Bellota; BJ: Boujediane; JN: Jnan Annich; TA: Tanakoub; TZ: Tafza. Map basis: land cover from Copernicus Global Land Service (Buchhorn et al. 2020).

donkeys, or oxen), or manually by picks or hoes in inclined fields, while larger and flatter fields are tilled with tractors. Farmers often broadcast seeds harvested from their own previous crops, and fertilize the fields close to the farms and for market gardening with manure. Synthetic fertilizers are used when available. In general, however, cereal and legume fields are not weeded, or occasionally hand-weeded. The weeds are still used as fodder or food, but the practice is decreasing (Bogaard et al. 2018).

Methods

Data collection

Ninety-four relevés were collected in two field campaigns between April and June 2017, in six areas of traditional agriculture (Tafza, Bellota, Tanakoub, Boujediane, Bou Ahmed, and Jnan Annich) (Figure 2; Table 1; Suppl. material 1). The fields with a mean size of 0.24 ± 0.04 ha were sampled by traversing in different directions until the number of plant species found no longer increases ("Tour de Champs" method; Le Bourgeois 1993). For each species, the abundance was estimated using the scale suggested by Braun-Blanquet (1952). Absolute frequency corresponds to the number of relevés in which the species was recorded, and the relative frequency corresponds to the proportion of relevés in which the species was recorded.

The plant species were identified using the relevant catalogues and Floras covering the study region (Sauvage and Vindt 1952, 1954; Fennane et al. 1999, 2007, 2014; Valdes et al. 2002a, 2002b; Fennane and Ibn Tattou 2005, 2008). Endemism and rarity assessment follow the catalogue by Fennane and Ibn Tattou (1998) which recognizes five categories for endemism (Morocco (E), Morocco and Algeria (A), Morocco and the Canary Islands (C), Morocco and the Iberian Peninsula (I), Morocco and Mauritania (M)) and three for rarity (very rare (RR), rare (R) and suspected rare (R?)). In the absence of an official red list based on the IUCN methodology and criteria, this coarse classification is widely used in Morocco.

Life form, chorology and floristic status

Life forms based on the position of the perennating buds in relation to the soil surface during the unfavourable season (Raunkiær et al. 1934) were determined as phanerophytes (Phan), chamaephytes (Ch), hemicryptophytes (Hem), geophytes (G), and therophytes (Th) on the basis of our field observations and the descriptions in the consulted Floras. Taxa with two life forms were considered in both.

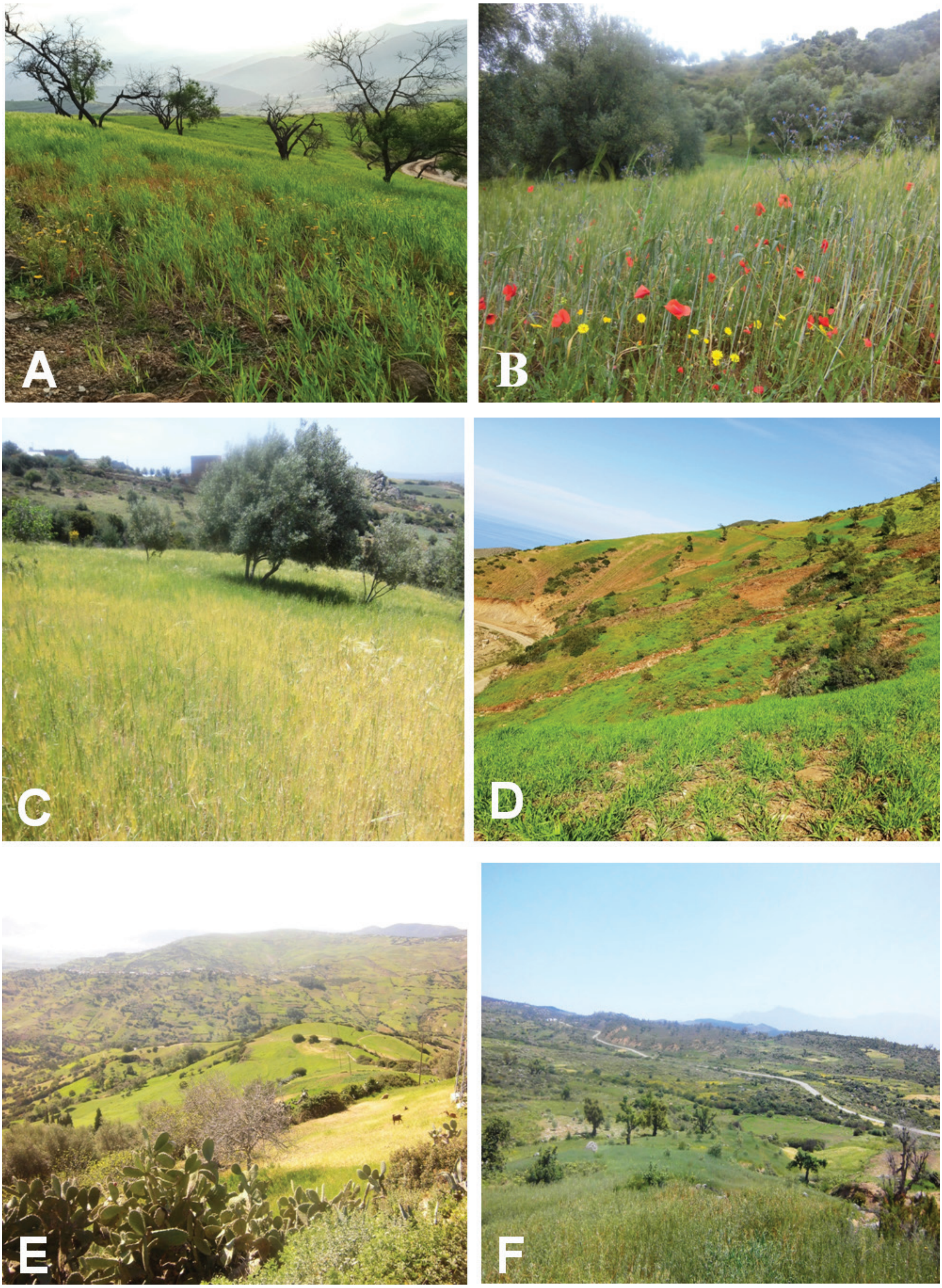

Figure 2. Traditional agroecosystem landscapes of the Rif Mountains (Morocco): (A) traditional cereal crops with almond trees inside the fields at Bou Ahmed; (B) cereal crops mixed with traditional olive orchads at Bellota; (C) a mixture of soft wheat and traditional olive groves in hillside fields at Boujediane; (D) mosaic of cereal crops and natural ecosystems (Cork oak) on erosion-prone slopes at Jnan Annich; (E) traditional agroecosystems corresponding to a bocage landscape at Tafza; (F) traditional cereal fields in agroforestry systems of mountains at Tanakoub.

Table 1. The main characteristics of the surveyed study areas.

Study area	Bou Ahmed	Bellota	Boujediane	Jnan Annich	Tafza	Tanakoub
GPS coordinates	35.310851°N, 4.946986°W	35.940417°N, 5.568200°W	35.116183°N, 5.778017°W	35.269527°N, 4.868646°W	35.67121°N, 5.543115°W	35.089853°N, 5.368622°W
Range of elevation (m)	40–350	420–460	225–350	90–770	180–310	650–740
Range of slope (%)	5–25	10–25	2–15	10–25	0–15	0–18
Mean field size (ha)	0.36 ± 0.08	0.21 ± 0.13	0.32 ± 0.06	0.20 ± 0.05	0.28 ± 0.09	0.13 ± 0.04
Relief	Low mountains	Hills	Hills	Low mountains	Hills	Mountains
Rural landscape	Mosaic of natural ecosystems (forests and matorrals), crops and wastelands	Traditional olive groves and crops	Traditional olive groves and crops	Mosaic of natural ecosystems (forests and matorrals), crops and wastelands	Bocage landscape	Mosaic of natural ecosystems (forests and matorrals), crops and wastelands
Bioclimate	Semi-arid	Subhumid	Subhumid	Semi-arid	Subhumid	Subhumid
Soil texture	Sandy loam	Clay loam	Clay loam	Clay	Clay loam	Clay loam

The chorology of the species relies on regional Floras and catalogues (Valdes et al. 2002a, 2002b; Fennane and Ibn Tattou 2005, 2008; Blanca et al. 2011). Thus, we recognized 36 different chorotypes (Suppl. material 2), which we grouped into five distributional categories: Regional (R) containing Maghrebian and Ibero-Maghrebian species; Extended (E), including the western Mediterranean and North Africa; Mediterranean broad-ranging (M), comprising the entire Mediterranean; Palearctic (P); and Cosmopolitan (C).

For the floristic status we adopted the reference by Fennane et al. (1999, 2007, 2014) to regard four groups of habitat preferences of species: i) Agricultural (AgH): cultivated or recently abandoned fields and fallow land; ii) Ruderal (R): otherwise disturbed or trampled habitats and roadsides; iii) Natural open (NHO): natural or semi-natural habitats with sparse vegetation such as rocks, scree, gravels, coastal sands, clay slopes, sandy places and cliffs, and iv) Natural closed (NHC): habitats with dense vegetation cover such as forests, scrubland, wetlands, forest clearings and grasslands.

Depending on the type of habitat, we recognized three floristic status categories: 1) agrestal species (Ag) occurring mainly in AgH, 2) apophyte species (Ap) typical for NHO and NHC and including species of former forest ecosystems, and 3) ruderal species (Rd) occurring chiefly in R and also in AgH.

Diversity indices

Three indices were used to evaluate the diversity of segetal communities. Species richness (S), is the average number of species found in a study region. Shannon Index (1948) ($H' = -\sum^{S}_{i=1} p_i \log_e p_i$, where S is the total number of species, and p_i is the proportional abundance of species i), expresses the diversity by considering the number of species and the abundance of individuals. The evenness index (J') of Pielou (1966) ($J' = H'/\log_e(S)$, where H' is the value of the Shannon Index, and S is the total number of species) measures the distribution of individuals within the sample, independently from species richness (Scherrer 1984). It is particularly important for comparing surveys with different species richness. The index values range from 0 to 1, and they are highest when the species have the same abundance, and lower when one or a few dominate the sample. The higher J', the more balanced is the distribution of species within the sample. The calculations were done with R software (R Core Team 2020) using the vegan package (Oksanen et al. 2020). The Jaccard index (J), calculated using PAST software (Hammer et al. 2001), quantified the variation in species composition between the areas (β-diversity). This index varies between 0 and 1, considering only positive associations. If the index increases, a large number of species occurred in both areas, suggesting that species turnover is low. If the index decreases, only a small number of species are present in both areas indicating a high turnover of species (De Bello et al. 2007). The correlation between geographical distances and the Jaccard index (J) was verified by the Mantel test (1967).

Classification

The floristic abundance data matrix consisting of 94 relevés and 209 species was classified by modified TWINSPAN (Roleček et al. 2009) using JUICE software, version 7.1.24 (Tichý 2002). Dissimilarity was calculated using the default settings (five pseudospecies cut levels, 0%, 2%, 5%, 10%, 20%; minimum group size = 5) and total inertia. Constant species were identified using a relative frequency threshold of 30%. For the names and ranks of syntaxa, we followed the EuroVegChecklist (Mucina et al. 2016).

Results

Species richness, taxonomic and life form diversity

In the sample of 94 vegetation relevés (Table 1, Figure 1), we found 209 vascular plant species belonging to 43 families and 150 genera (Suppl. material 3). Five families were represented by more than ten species and together account for 55% of the diversity: *Asteraceae* (21.1%),

Table 2. Diversity indices of segetal flora species in the study areas. CI: Confidence interval; CV: Coefficient of Variation; X̄: The overall mean.

Study area	Number of relevés	Mean field size (ha)	Total number of species	Species richness (S)			Shannon diversity (H')			Pielou evenness (J')		
		Mean ± CI		Mean ± CI	Min–Max	CV%	Mean ± CI	Min–Max	CV%	Mean ± CI	Min–Max	CV%
Bou Ahmed	20	0.36 ± 0.08	109	30.5 ± 2.52	22–43	19.12	3.39 ± 0.08	3.09–3.77	5.58	0.09 ± 0.01	0.06–0.12	18.1
Bellota	9	0.21 ± 0.13	58	18.11 ± 3.21	12–26	27.11	2.86 ± 0.18	2.49–3.26	9.45	0.15 ± 0.02	0.10–0.21	25.02
Boujediane	16	0.32 ± 0.06	67	19.25 ± 3.21	14–27	13.27	2.95 ± 0.09	2.64–3.30	4.77	0.14 ± 0.01	0.10–0.18	14.04
Jnan Annich	24	0.20 ± 0.05	107	19.54 ± 2.81	11–40	35.99	2.96 ± 0.14	2.40–3.69	11.61	0.15 ± 0.02	0.07–0.22	30.62
Tafza	10	0.28 ± 0.09	76	20.7 ± 1.65	17–25	12.89	3.02 ± 0.08	2.83–3.22	4.3	0.12 ± 0.01	0.10–0.15	12.42
Tanakoub	15	0.13 ± 0.04	72	20.7 ± 4.7	13–26	22.66	3.01 ± 0.16	2.56–3.26	8.66	0.13 ± 0.02	0.10–0.19	27.75
X̄		0.25±0.075	81 ± 17.1	21.90 ± 1.36	11–43	30.69	3.04 ± 0.06	2.40–3.69	9.96	0.13 ± 0.01	0.06–0.22	29.14

Poaceae (12.9%), *Fabaceae* (9.1%), *Caryophyllaceae* (7.2%) and *Brassicaceae* (4.8%). The remaining 15 families account for 45% of the diversity with two to nine species each (Suppl. material 4). The most diverse genus is *Rumex* with six species.

Species richness (S) showed high variability within and between the areas (Table 2). The mean number of species per relevé was 22 species with a coefficient of variation of 30.7%. The number of species per survey varied between a minimum of eleven and a maximum of 43 species. With a mean of 30 species, the Bou Ahmed area had a much higher species richness than the other five areas. In contrast, Bellota had the lowest richness, with only 18 species. The Shannon diversity index (H') values varied similarly (Table 2; Suppl. material 5). Bou Ahmed had the highest value of H' (3.39). For the other areas, the values of H' ranged from 3 to 2.8. This index had a lower variability than the specific richness with a coefficient of variation ranging from 4.3% to 11.6%. Values greater than or equal to three and less than four indicate a good level of diversity (Molvær et al. 1997), as is the case for the areas of Bou Ahmed, Tanakoub and Tafza. Values below three and equal or higher than two indicate a moderate level of diversity, as is the case for Jnan Annich, Boujediane and Bellota. The values of Pielou's evenness index (J') were relatively low and varied between 0.09 and 0.15, showing strong differences in species abundance within the relevés with a preponderance of rare species and some dominant species (Table 2). This trend is relatively more pronounced in Bou Ahmed with E = 0.09, while the coefficients of variation vary from 12.4% for Tafza to 30.6% for Jnan Annich.

Jaccard's similarity index (J) shows a relative heterogeneity in the floristic composition of the regions (Figure 3). The similarity values vary from a minimum of 0.509 between Bou Ahmed and Jnan Annich to a maximum of 0.935 for the Bellota - Bou Ahmed pair. Overall, we found that the similarity is rather high on mean, except for the region of Jnan Annich which is showing the lowest similarity values with other regions. No positive correlation was found between similarity index and geographical distance ($r = 0.3099$, p-value = 0.1462).

Therophytes are the dominant life form with 157 species representing three-fourth (75.1%) of the encountered species (Figure 4).

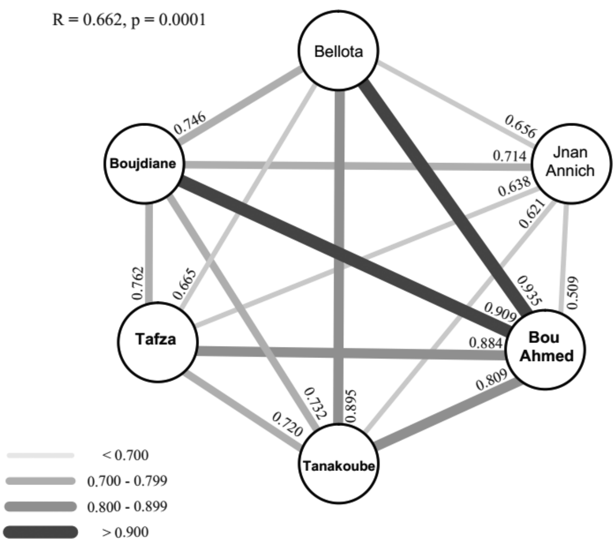

Figure 3. Diagram of Jaccard similarity index values between the studied areas in traditional agroecosystems in the Rif Mountains (Morocco).

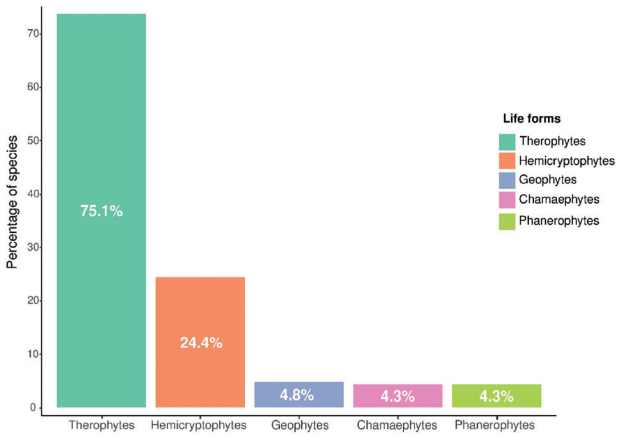

Figure 4. Life form spectrum according to Fennane et al. (1999, 2007, 2014) of the inventoried segetal plants of traditional agroecosystems in the Rif Mountains (Morocco).

Chorology, patrimonial values and floristic status

Species with a Mediterranean broad-ranging distribution account for 44.1% of the total, more than half of which (54.8%) being strictly Mediterranean (Figure 5; Suppl. material 2). Cosmopolitan species ranked second in terms of occurrence, accounting for 20.2% of the total. Species of

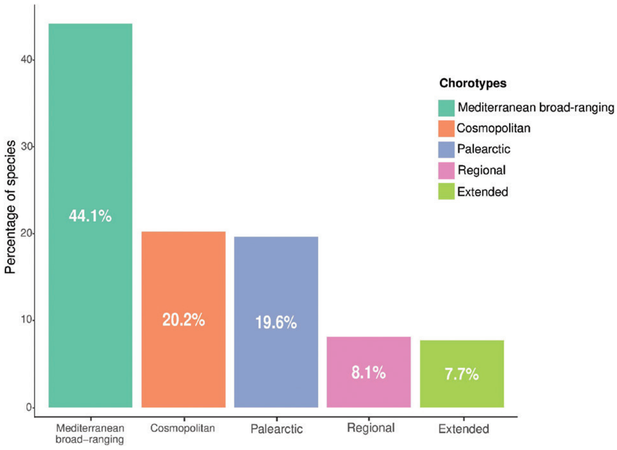

Figure 5. Species chorotype distribution according to Blanca et al. (2011), Fennane and Ibn Tattou (2005, 2009) and Valdes et al. (2002) of traditional agroecosystems in the Rif Mountains (Morocco).

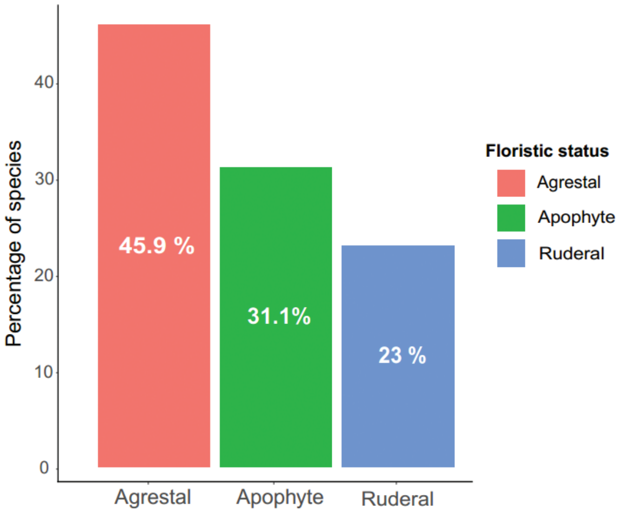

Figure 6. Number and percentage of species counted per segetal flora type of traditional agroecosystems in the Rif Mountains (Morocco).

regional distribution (17) accounted for 8.1% of the total. The remaining species have either a Palearctic (19.6%) or an extended (7.7%) distribution in the Mediterranean.

Several endemic and/or rare species were found in our relevés. Overall, we recorded 33 regional to extended endemics representing 15.8% of the encountered flora (Figure 5; Suppl. material 2). For the Moroccan native flora, we noted two species considered very rare according to Fennane and Ibn Tatou (1998) (*Brassica barrelieri* and *Echinops spinosissimus*), two rare species (*Filago ramosissima* and *Herniaria hirsuta*) and two species suspected rare (*Alyssum simplex* and *Calendula stellata*).

Agrestal species comprised 46% of the encountered flora, followed by 31% apophytes, and 23% ruderal species (Figure 6). Habitat specialists occurring chiefly in a specific group of habitats accounted for 40.6%, of which 8.6% are in AgH, 8.1% R, 3.8% NHC and 20.1% occurring in NHO. On the other hand, 59.4% of the species normally inhabited two or three different habitat type groups. For example, 45.5% of the arable plants (facultative species) may colonise other habitat types beside of agricultural habitats (Suppl. material 6).

Classification

The TWINSPAN classification of the 94 relevés separated four clusters indicating area-dependent variation in species composition (Figure 7). Clusters 1–3 included relevés of the Jnan Annich, Bou Ahmed, and Tanakoub areas, respectively. Cluster 4 comprised the remaining areas of Tafza, Bellota and Boujediane. The areas differ in landscape, climate, soil and land-use characteristics (Table 1), and turned out to differ accordingly in species composition of the segetal vegetation (Table 3, full table in Suppl. material 7).

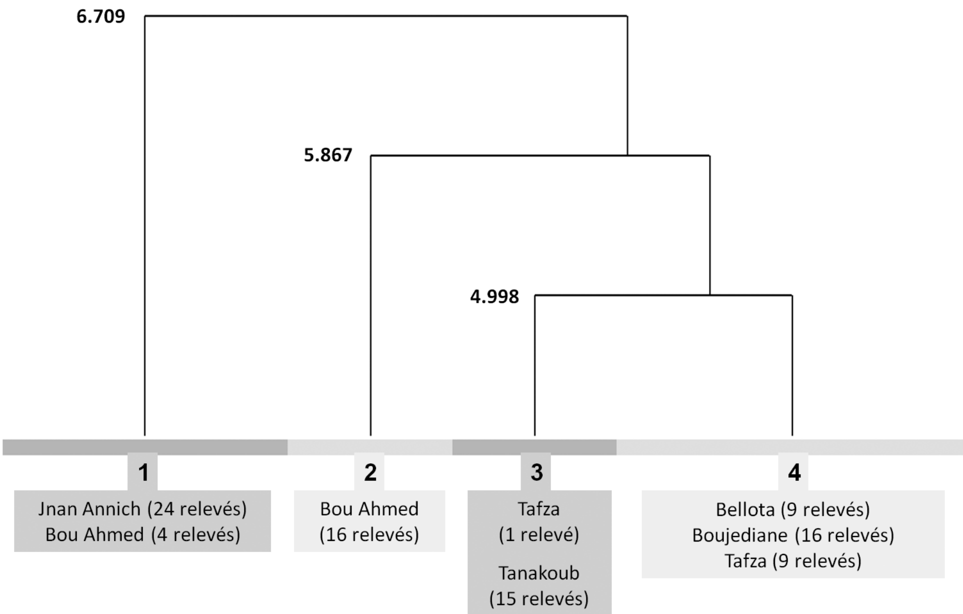

Figure 7. Dendrogram of the modified TWINSPAN classification. The numerical value on each division level represents the total inertia as a measure of cluster heterogeneity.

High constancy and dominance of wild grasses were found throughout all areas, with *Anisantha madritensis* and *Lolium rigidum* in clusters 1 and 2, and *Avena sterilis* in clusters 2, 3 and 4. The local dominance of *Lolium temulentum* in cluster 4, together with several other rare arable plants, indicated traditional practices in the hillside fields of the three areas represented here, such as using farm-owned seeds, cereal-legume cropping, and absence of weeding. The proportion of biennial and perennial herbs was considerable, especially in clusters 1 and 4, indicating crop-fallow rotations and manual shallow tilling by picks and hoes rather than deep ploughing. Species of slightly acidic soils were most common in clusters 2 and 3 (e.g., *Brassica barrelieri*, *Raphanus raphanistrum*, *Rumex bucephalophorus*, *Silene gallica*), indicating a component of sand to the generally heavy clayey soil texture. In contrast, in the fields of cluster 1 species of (more) neutral soils prevailed. It should be emphasized that non-native plants are rare in most of the examined fields, except in cluster 3 which contains a neophyte (*Verbesina encelioides*). It occurred chiefly in cannabis cropland developed by clearance of semi-natural woodland.

Table 3. Summarized synoptic table of the plant communities with percentage frequency values derived from 94 relevés in cereal fields of the Rif Mountains (Morocco). The table includes only species with constancy greater than 30% in a group. Light gray indicates species moderately constant in a group (30–80%), while dark gray indicates species with constancy higher than 80%. The letters after species names indicate phytosociological affinities to the classes *Chenopodietea* (C), *Papaveretea rhoeadis* (P) and to the alliance of the latter class occurring on acidic soil, *Rumicion bucephalophori* (P_a), respectively. Species without a letter are assignable to other classes. The affiliation is based on Lastic (1989), Nezadal (1989), Deil (1997) and Rivas-Martínez et al. (2002). (Full synoptic table in Suppl. material 8).

Cluster number		1	2	3	4
Number of relevés		28	16	16	34
Total number of species		123	104	79	118
Number of diagnostic species		21	45	30	21
Lactuca serriola		57	6	.	.
Carduus pycnocephalus		57	19	.	3
Senecio vulgaris		50	.	.	.
Fedia cornucopiae	C	36	.	6	12
Ochlopoa annua		36	.	19	18
Mauranthemum decipiens		32	19	.	.
Stellaria media		32	.	.	6
Cichorium intybus		32	.	13	3
Fumaria parviflora	P	32	6	.	3
Polygonum aviculare		32	.	19	18
Anacyclus radiatus	C	7	100	.	3
Plantago afra		11	56	13	3
Pallenis spinosa		4	50	.	12
Lamarckia aurea		11	44	.	.
Ammi majus		.	44	.	12
Polycarpon tetraphyllum		21	44	.	.
Launaea nudicaulis	C	14	38	.	18
Erodium moschatum	C	14	38	13	.
Scandix pecten-veneris	P	14	38	.	3
Malva parviflora	C	.	38	.	.
Alyssum simplex		.	38	6	.
Lobularia maritima		21	38	.	.
Euphorbia exigua	P	21	31	.	.
Fumaria agraria	P	4	31	.	.
Misopates orontium	P	4	31	.	.
Sisymbrium officinale		7	31	.	.
Filago pyramidata		.	31	.	.
Chenopodium murale	C	25	31	.	3
Dysphania ambrosioides		21	31	.	.
Rumex thyrsoides		.	.	50	.
Andryala integrifolia		.	19	44	26
Filago ramosissima		.	.	44	6
Scorzoneroides muelleri		.	.	44	3
Vicia benghalensis	P_a	.	.	31	.
Chamaemelum fuscatum	P_a	.	.	31	.
Lolium multiflorum	P_a	.	.	31	3
Centaurea calcitrapa		.	6	31	18
Silybum marianum		.	.	31	18
Lolium temulentum	P	.	.	.	47
Scorpiurus muricatus		.	13	6	38
Capsella bursa-pastoris		11	19	.	38
Cynodon dactylon		11	25	6	35
Echium horridum		50	75	.	.
Sherardia arvensis	P	46	44	6	26
Lolium rigidum	C	39	75	6	.
Hordeum murinum	C	32	81	6	3
Phalaris minor		32	31	13	3
Glebionis segetum	P_a	14	88	56	3
Vicia sativa subsp. *nigra*		.	81	.	32
Sonchus oleraceus	C	11	63	.	38
Rumex bucephalophorus	P_a	18	63	44	12
Phalaris brachystachys	C	14	50	13	41
Anchusa azurea	P	18	44	6	35
Galium verrucosum	P	4	44	50	9
Papaver rhoeas	P	29	44	56	26
Raphanus raphanistrum	P_a	14	38	56	24
Muscari comosum		.	38	25	35
Biscutella auriculata	P	.	38	44	24
Medicago polymorpha		4	31	6	62
Emex spinosa	C	7	25	75	65
Glebionis coronaria	C	18	19	63	56
Sinapis arvensis	P	.	13	56	32
Convolvulus arvensis		25	6	50	47
Allium nigrum		21	19	31	35
Galactites tomentosus	C	18	25	31	41
Dittrichia viscosa		50	75	31	15
Senecio leucanthemifolius		43	44	94	.
Silene vulgaris		32	69	38	18
Silene gallica	P_a	32	100	75	29
Convolvulus althaeoides	C	7	69	75	53
Avena sterilis	C	11	63	56	59
Hirschfeldia incana	C	29	38	31	32
Anisantha madritensis	C	61	81	38	41
Anagallis arvensis		54	88	81	62

Discussion

Dominance of native arable plant species in traditional agroecosystems

The total number of species found in our study area (209 vascular plant species in 94 fields) is similar or higher when compared to other studies conducted in the Mediterranean region on a comparable number of cereal fields and under approximately similar conditions: northeastern Spain, 175 species in 138 fields (Cirujeda et al. 2011); southern Spain, 80 species in 64 fields (Hidalgo et al. 1990); Greece, 103 species in 86 fields (Damanakis 1983); Turkey, 71 in 83 fields (Arslan 2018), indicating that the traditional agro-ecosystems of the Rif Mountains host a high level of phytodiversity. In contrast, surveys in traditional cereal fields of Crete, Portugal, Algeria and northwestern Morocco established higher total richness than the aforementioned papers: Bergmeier (2006) recorded 344 species in 74 plots in the South Aegean island of Crete; Ramôa et al. (2015) revealed 264 species in 105 crop fields of Portugal; Kazi Tani et al. (2010) reported 274 species in 100 Algerian cereal fields; Lastic (1989) found 375 species in 407 plots in the Rharb plain, and Deil (1997) 226 species in 46 wheat fields in the wider region of Tanger-Tétouan. The high local-scale (field) diversity in traditional agriculture is due to the moderate land-use intensity, the absence of herbicides and the crop rotation practice that involves fallowing (Deil 1997).

The floristic spectrum of the traditional agroecosystems (Suppl. material 4) shows the dominance of five families (*Asteraceae*, *Poaceae*, *Fabaceae*, *Caryophyllaceae* and *Brassicaceae*), typically reflecting the overall Moroccan flora (Fennane and Ibn Tattou 2012) and the segetal flora in western and northern Morocco (Zidane et al. 2010). These families also had higher expression in studies conducted in the northern Mediterranean region (Guillerm and Maillet 1982; Saavedra et al. 1989; Hidalgo et al. 1990; Dessaint et al. 2001; Ramôa et al. 2015; Fanfarillo et al. 2020; Munoz et al. 2020). The dominance of the Mediterranean chorotype in the Rif Mountains is in line with the figures for the entire Moroccan flora, two thirds of which are Mediterranean species, as well as with those found by Guillerm and Maillet (1982) for cereal fields in the western Mediterranean, and by Fanfarillo et al. (2019a) for traditional agroecosystems in Italy. This coincidence may be interpreted as an indication of the conservative character of the flora of traditional agroecosystems in which neophytes are rather rare (Fanfarillo et al. 2019b).

The significant percentage of apophytes in the arable fields can be linked to shallow tillage in traditional agro-ecosystems, as well as to the fallow period. In fact, woody apophytes such as *Quercus coccifera*, *Chamaerops humilis*, *Pistacia lentiscus* and *Cistus salviifolius*, possibly relicts of former woodlands and shrublands, continued to occur in the fields unless cleared by intensified tillage. The heterogeneous floristic status observed in the traditional agro-ecosystems of the Rif Mountains reflects the small size of the fields as well as the diversely structured agricultural landscapes which comprise different open natural habitats.

The largely autochthonous flora can be explained by the interlocking, transitions and permeability of the fields and the surrounding semi-natural habitats, as well as by the use of farm-owned seeds from previous harvests.

Life form spectrum

The life-form spectrum is dominated by therophytes, which account for three-quarters (75.1%) of the segetal species (Figure 4). Most annual segetal species depend on regular replenishment of the seed bank (Benarab 2008). However, the therophytes rate is lower than in the segetal flora of western Morocco which may be explained by the low-intensity agriculture in combination with regular fallow periods in our study areas, as opposed to the high-intensity management in western Morocco (Taleb and Maillet 1994; Taleb et al. 1998; Zidane et al. 2010). Hemicryptophytes are well represented in our study, where they comprise 24.4% of the arable flora. They amount to 15% more than found by Taleb et al. (1998) in autumn cereals for the entire country, approximately three times higher than that found by Hidalgo et al. (1990) in dryland wheat crops of the Cordoba region (Spain) and twice as many as found by Kazi Tani et al. (2010) on the arable land of Northwest Algeria.

Perennial plants and especially hemicryptophytes become more important in arable fields as a result of shallow tillage combined with regular fallow periods (Deil 1997; Zanin et al. 1997; Légère and Samson 1999; Streit et al. 2002; Young and Thorne 2004; Murphy et al. 2006; Trichard et al. 2013; Bergmeier and Strid 2014). Chamaephytes and phanerophytes are also remarkably well represented (6.6%). This percentage is higher than that reported from cereal crops in other parts of the Maghreb (Guillerm and Maillet 1982; Taleb and Maillet 1994; Taleb et al. 1998; Kazi Tani et al. 2010; Zidane et al. 2010). This life-form spectrum can be explained by the specificity of the traditional agroecosystems of the western Rif Mountains, which form a mosaic in which cultivated (crops, young and old fallows, abandoned fields), natural (forests, matorral), and semi-natural habitats (hedges, paths, drains and ditches) coexist (Ater and Hmimsa 2008).

Classification and vegetation composition

The vegetation of the arable fields in the study area consists mainly of plant species characteristic of two classes – *Chenopodietea* and *Papaveretea rhoeadis*, the former with strong ruderal ties, the latter of segetal character (Table 3). Our results confirm that cereal fields in the South Mediterranean accommodate a higher proportion of species of the *Chenopodietea* and a lower of the *Papaveretea rhoeadis* than further north (Nezadal 1989; Bergmeier 2005, 2006). The classification chiefly along territorial affiliation indicates that local-scale conditions, both abiotic and land-use related, are decisive factors in our study area when it comes to vegetation differentiation. The plant communities found by us should not be understood, therefore, as syntaxa of wider than area-related validity. Species indicating the inclusion of fallows in the rotational system of cereal or cereal-legume cropping (such as *Helminthotheca echioides*, *Dittrichia viscosa*) are prominent in many of the examined fields, quite like in other fields in North and Northwest Morocco (El Antri 1985; Lastic 1989; Deil 1997). Certain structural characteristics observed by Deil (1997) about three decades ago, which contributed much to the local-scale species richness, such as patches of the palm *Chamaerops humilis* spared from tilling in the fields, have been removed in most places nowadays.

The first classified cluster, sampled in fields chiefly of Jnan Annich, is somewhat heterogenous, probably due to the wide altitudinal range of almost 700 m. The nutrient-rich clayey soil and the more or less pronounced thermomediterranean conditions, together with the non-intensive tillage and rotation including fallow years supports species of the order *Brometalia rubenti-tectorum* and, though rather indistinctly, of its alliance *Cerintho majoris-Fedion cornucopiae* (represented by *Fedia cornucopiae*). The latter is an alliance known chiefly from the Cádiz province in southern Andalusia opposite the Strait of Gibraltar (Nezadal 1989).

The second and third clusters, of Bou Ahmed and Tanakoub, respectively, differ from the first one in several species indicating less nutrient-rich and moderately acidic sandy soil. Typical are *Anacyclus radiatus*, *Chamaemelum fuscatum*, *Rumex bucephalophorus* and *Vicia benghalensis*. Noteworthy is also the fairly high constancy of rather late-ripening species such as *Ammi majus*, *Anacyclus radiatus* and *Malva parviflora* (in Cluster 2), *Andryala integrifolia* and *Chamaemelum fuscatum* (in Cluster 3), and *Emex spinosa* and *Glebionis segetum* (in both), together with early-flowering plants of fields with sandy soil such as *Rumex bucephalophorus* and *Galium verrucosum*. Altogether, with its strong winter-annual grass component (*Avena sterilis*, *Anisantha madritensis*, *Hordeum murinum*) the vegetation of the Clusters 2 and 3 may well be assignable to the *Brometalia rubenti-tectorum*, but the species mentioned above, which vary in abundance between fields, make it reminiscent of *Rumicion bucephalophori*, *Diplotaxion erucoidis* and *Chenopodion muralis* as well, vegetation alliances with, in that order, decreasing segetal and increasing ruderal affinity (see Nezadal 1989; Rivas-Martinez et al. 2002).

In the fourth cluster, from fields of three areas under subhumid climate and on nutrient-rich clay-loam soil, species of the *Papaveretea rhoeadis*, which largely indicate mesomediterranean climatic conditions, are not very pronounced and the frequencies of species such as *Convolvulus althaeoides*, *Emex spinosa*, *Glebionis coronaria* and the annual wild oats and brome-grasses suggest thermomediterranean segetal *Brometalia rubenti-tectorum* vegetation, but as with the other clusters, alliance affiliation remains unclear and needs further comparative studies.

Conservation interests

Traditional farming in the rural landscapes in the Rif Mountains – characterised by a combination of low-intensity land-use, the presence of semi-natural vegetation at the field- and landscape-scale, and variation in land cover and land-use – favours the preservation of agrobiodiversity. Cropping practices within traditional agroecosystems correspond to the concept of High Nature Value agriculture (HNV), as described in European low-intensity farming systems (Beaufoy 2008; Oppermann et al. 2012; Reicosky 2015) with low inputs beneficial for biodiversity enhancement (Bignal and McCracken 2000; Pienkowski 2011; Egan and Mortensen 2012). The conservation of HNV was included in the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) initiated at the Kiev Conference in 2003 (UNECE 2003). The traditional agroecosystems of the Rif Mountains are similar to HNV in the low-intensity soil tillage, low agro-chemical inputs (particularly the absence of herbicide application), low machinery, and landscape-scale land cover diversity with the coexistence of crops, fallow land, semi-natural and natural vegetation. Therefore, in a next step, it is suggested to develop HNV arable species lists and HNV evaluation systems on Moroccan arable land.

However, northwestern Morocco is experiencing profound changes in its landscapes and land cover (Taiqui 1997; Benabid 2002; Chebli et al. 2018, 2021). Such changes in the mountain production systems have caused negative effects (forest and matorral clearing, excessive pumping of groundwater, erosion, the increasing use of synthetic fertilizers, etc.) detrimental to the ecological and socio-economic sustainability (Kradi 2012). Due to the small size of the fields and the poor and eroded soils, traditional cereal growing, arboriculture and animal husbandry are insufficient to ensure the subsistence of the smallholders, leading to exodus, land abandonment or the extension of cannabis cultivation (Lara et al. 2015). Thus, traditional agroecosystems based on polyculture and biodiversity-friendly agricultural practices are facing socio-economic challenges that threaten their sustainability. Hence, conservation measures to protect traditional agriculture and agroecosystems must at the same time promote the local farmers' socio-economic and cultural status.

Conclusions

The traditional agroecosystems studied favour a high level of plant species and community diversity at the field- and landscape-scale. This agrophytodiversity is linked to environmental heterogeneity (soil, climate, topography) as well as to land-use and agricultural practices.

The specific thermomediterranean wild arable plant communities related to the vegetation order *Brometalia rubenti-tectorum* are characterized by the presence of generalist apophytes as well as by a remarkable representation of perennial species and the near-absence of neophytes. Among the segetal species representing Morroco's cultural and natural heritage, being narrow-range or rare species of the regional flora, several appear to be in decline. Thus, the preparation of a red list of plant species would be a priority action. In the current context, these agroecosystems and their diversified landscapes and rare segetal species are particularly threatened by recent socio-economic transformations leading to profound changes in land-use and the abandonment of traditional agriculture. Thus, the maintenance of the traditional agroecosystems and agricultural practices requires effective policy measures.

Data availability

The datasets of the current study are available from the corresponding author on reasonable request.

Author contributions

S.C. and M.A. planned the research and conducted the field sampling; S.C. and M.K. identified the botanical taxa; S.C. and M.A. performed statistical analyses and prepared figures and tables; E.B. and S.M. provided numerous comments, additions and developed the text; all authors reviewed and contributed to the final version.

Acknowledgements

We acknowledge support by the Open Access Publication Funds of the Göttingen University. Thanks are due to all the members of the BioAgrodiversity Team for their valuable comments and discussions. We are also thankful to the Applied Botany Laboratory and the Faculty of Sciences Abdelmalek Essaadi University for providing healthy working conditions to conduct this study. We thank the farmers for allowing admittance to the fields, the reviewers for their useful suggestions and comments, and Pierre-Yves Lastic for making available his thesis.

References

Aavik T, Liira J (2009) Agrotolerant and high nature-value species—Plant biodiversity indicator groups in agroecosystems. Ecological Indicators 9: 892–901. https://doi.org/10.1016/j.ecolind.2008.10.006

Aboukhalaf A, Tbatou M, Adil K, Naciri K, Moujabbir S, Sahel K, Rocha JMF, Belahsen R (2022) Traditional knowledge and use of wild edible plants in Sidi Bennour region (Central Morocco). Ethnobotany Research and Applications 23: 1–18. https://doi.org/10.32859/era.23.11.1-18

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment 74: 19–31. https://doi.org/10.1016/S0167-8809(99)00028-6

Arènes J (1951) À propos des connexions ibérico-marocaines et siculo-tunisiennes. Compte-rendu sommaire des séances de la Société de Biogéographie 241: 67–72.

Arslan ZF (2018) Decrease in biodiversity in wheat felds due to changing agricultural practices in fve decades. Biodiversity and Conservation 27: 3267–3286. https://doi.org/10.1007/s10531-018-1608-9

Ater M, Hmimsa Y (2008) Agriculture traditionnelle et agrodiversité dans le bassin versant de l'Oued Laou. Travaux de l'Institut Scientifique, Rabat, série générale 5: 107–115.

Barrett SH (1983) Crop mimicry in weeds. Economic Botany 37: 255–282. https://doi.org/10.1007/BF02858881

Beaufoy G (2008) HNV farming - explaining the concept and interpreting EU and national policy commitments. European forum on nature conservation and pastoralism, Stratford-upon-Avon, UK. http://www.efncp.org/download/EFNCP-HNV-farming-concept.pdf

Benabid A (1982) Étude phytoécologique, biogéographique et dynamique des associations et séries sylvatiques du Rif occidental (Maroc). Ph. D. thesis, Aix-Marseille III, Marseille, FR.

Benabid A (2002) Le Rif et le Moyen-Atlas (Maroc): biodiversité, menaces, préservation. African mountains high summit conference for Africa. UNEP, Nairobi, KE.

Benarab H (2008) Contribution à l'étude des mauvaises herbes des vergers de la région nord de Sétif. Master thesis. Ferhat Abbas University, Setif, DZ.

Bergmeier E (2005) Eine pflanzensoziologische Studie zu traditionell bewirtschafteten Getreideäckern auf Kreta. Hoppea 66: 351–375.

Bergmeier E (2006) The diversity of segetal weeds in Crete (Greece) at species and community level. Annali di Botanica n.s. 6: 53–64.

Bergmeier E, Strid A (2014) Regional diversity, population trends and threat assessment of the weeds of traditional agriculture in Greece. Botanical Journal of the Linnean Society 175: 607–623. https://doi.org/10.1111/boj.12181

Bignal EM, McCracken DI (2000) The nature conservation value of European traditional farming systems. Environmental Reviews 8: 149–171. https://doi.org/10.1139/a00-009

Blanca G, Cabezudo B, Cueto M, Morales Torres C, Salazar C [Eds] (2011) Flora vascular de Andalucía oriental. Universidades de Almería, Granada, Jaén y Málaga, Granada, ES, 802 pp.

Bogaard A, Ater M, Hodgson JG (2018) Arable weeds as a case study in plant-human relationships beyond domestication. In: Stépanoff C, Vigne JD (Eds) Hybrid communities: Biosocial approaches to domestication and other trans-species relationships. Routledge, London, GB, 97–112. https://doi.org/10.4324/9781315179988-6

Böhning-Gaese K, Klein AM, Wägele WJ (2020) Biodiversity and management of agricultural landscapes. German National Academy of Sciences Leopoldina, Halle (Saale), DE, 76 pp.

Boulet C, Tanji A, Taleb A (1989) Index synonymique des taxons présents dans les milieux cultivés ou artificialisés du Maroc occidental et central. Actes Institut Agronomique et Vétérinaire (Maroc) 9: 65–98.

Bourgeois B, Gaba S, Plumejeaud C, Bretagnolle V (2020) Weed diversity is driven by complex interplay between multi-scale dispersal and local filtering. Proceedings of the Royal Society B 287: 20201118. https://doi.org/10.1098/rspb.2020.1118

Braun-Blanquet J (1952) Les groupements végétaux de France méditerranéenne. Centre National de la Recherche Scientifique, Paris, FR, 297 pp.

Buchhorn M, Smets B, Bertels L, De Roo B, Lesiv M, Tsendbazar NE, Herold M, Fritz S (2020) Copernicus global land dervice: land cover 100m: collection 3: epoch 2019: Globe (V3.0.1). https://zenodo.org/record/3939050#.Y4NNTr3MKM8/ [accessed 5 Oct 2020]

CGDA (2008) Atlas de l'agriculture marocaine. Edition 2008. Royaume du Maroc, Ministère de l'Agriculture et de la Pêche Maritime, Rabat, MA, 143 pp.

CGDA (2011) Situation de l'agriculture marocaine, No 9. Ministère de l'Agriculture, du Développement Rural et des Pêches Maritimes, Rabat, MA, 202 pp.

Chamorro L, Masalles RM, Sans FX (2016) Arable weed decline in Northeast Spain: Does organic farming recover functional biodiversity? Agriculture, Ecosystems & Environment 223: 1–9. https://doi.org/10.1016/j.agee.2015.11.027

Chebli Y, Chentouf M, Ozer P, Hornick JL, Cabaraux JF (2018) Forest and silvopastoral cover changes and its drivers in northern Morocco. Applied Geography 101: 23–35. https://doi.org/10.1016/j.apgeog.2018.10.006

Chebli Y, El Otmani S, Elame F, Moula N, Chentouf M, Hornick JL, Cabaraux JF (2021) Silvopastoral system in Morocco: Focus on their importance, strategic functions, and recent changes in the Mediterranean side. Sustainability 13: 10744. https://doi.org/10.1016/j.apgeog.2018.10.006

Cirujeda A, Aibar J, Zaragoza C (2011) Remarkable changes of weed species in Spanish cereal fields from 1976 to 2007. Agronomy for Sustainable Development 31: 675–688. https://doi.org/10.1007/s13593-011-0030-4

Damanakis M (1983) Weed species in wheat fields of Greece—1982, 1983 survey. Zizaniology 1: 85–90.

De Bello F, Lepš J, Sebastia MT (2007) Grazing effects on the species-area relationship: variation along a climatic gradient in NE Spain. Journal of Vegetation Science 18: 25–34. https://doi.org/10.1111/j.1654-1103.2007.tb02512.x

Deil U (1997) Zur geobotanischen Kennzeichnung von Kulturlandschaften. Vergleichende Untersuchungen in Südspanien und Nordmarokko [Erdwissenschaftliche Forschung 36]. Franz Steiner, Stuttgart, DE, 189 pp.

Dessaint F, Chadoeuf R, Barralis G (2001) Diversité des communautés de mauvaises herbes des cultures annuelles de Côte-d'Or (France). Biotechnologie, Agronomie, Société et Environnement 5: 91–98. https://popups.uliege.be/1780-4507/index.php?id=14903

UNECE (2003) United Nations Economic Commission for Europe - Kyiv resolution on biodiversity. Fifth ministerial conference environment for Europe [Report no. ECE/CEP/108]. Kyiv, UA, 7 pp.

ECE/CEP/108 (2003) Kyiv resolution on biodiversity. Fifth ministerial conference environment for Europe. Kyiv, UA, 7 pp.

EEA (2004) High nature value farmland - characteristics, trends and policy challenges. EEA, European Environment Agency, Copenhagen, DK, 32 pp.

Egan JF, Mortensen DA (2012) A comparison of land sharing and land-sparing strategies for plant richness conservation in agricultural landscapes. Ecological Applications 22: 459–471. https://doi.org/10.1890/11-0206.1

El Antri M (1985) Approche synsytématique des groupements commensaux des cultures du Maroc. Colloques Phytosociologiques 12: 283–311.

Fanfarillo E, Latini M, Iberite M, Bonari G, Nicolella G, Rosati L, Salerno G, Abbate G (2020) The segetal flora of winter cereals and allied crops in Italy: species inventory with chorological, structural and ecological features. Plant Biosyst 154: 935–946. https://doi.org/10.1080/11263504.2020.1739164

Fanfarillo E, Scoppola A, Lososová Z, Abbate G (2019a) Segetal plant communities of traditional agroecosystems: a phytosociological survey in central Italy. Phytocoenologia 49: 165–183. https://doi.org/10.1127/phyto/2019/0282

Fanfarillo E, Kasperski A, Giuliani A, Abbate G (2019b) Shifts of arable plant communities after agricultural intensification: A floristic and ecological diachronic analysis in maize fields of Latium (central Italy). Botany Letters 166: 356–365. https://doi.org/10.1080/23818107.2019.1638829

Fennane M, Ibn Tattou M (1998) Catalogue des plantes rares, menacées ou endémiques du Maroc. Bocconea 8, Palermo, IT, 243 pp.

Fennane M, Ibn Tattou M, Mathez J, Ouyahya A, El Oualidi J (1999) Flore Pratique du Maroc, Vol. 1. Travaux de l'Institut Scientifique, Série Botanique, n° 36, Rabat, MA, 560 pp.

Fennane M, Ibn Tattou M (2005) Flore vasculaire du Maroc: inventaire et chorologie, Vol. 1. Travaux de l'Institut Scientifique, Série Botanique, n° 37, Rabat, MA, 483 pp.

Fennane M, Ibn Tattou M, Ouyahya A, El Oualidi J (2007) Flore Pratique du Maroc, Vol. 2. Travaux de l'Institut Scientifique, Série Botanique, n° 38, Rabat, MA, 636 pp.

Fennane M, Ibn Tattou M (2008) Flore vasculaire du Maroc : inventaire et chorologie, Vol. 2. Travaux de l'Institut Scientifique, Série Botanique, n° 38, Rabat, MA, 398 pp.

Fennane M, Ibn Tattou M (2012) Statistiques et commentaires sur l'inventaire actuel de la flore vasculaire du Maroc. Bulletin de l'Institut Scientifique, section Sciences de la Vie, Rabat 34: 1–9.

Fennane M, Ibn Tattou M, El Oualidi J (2014) Flore Pratique du Maroc, Vol. 3. Travaux de l'Institut Scientifique, Série Botanique, n° 40, Rabat, MA, 793 pp.

Gaba S, Cheviron N, Perrot T, Piutti S, Gautier JL, Bretagnolle V (2020) Weeds enhance multifunctionality in arable lands in South-West of France. Frontiers in Sustainable Food Systems 4: 4. https://doi.org/10.3389/fsufs.2020.00071

Godinho I (1984) Les définitions d' "adventice" et de "mauvaise herbe". Weed Research 24: 121–125. https://doi.org/10.1111/j.1365-3180.1984.tb00579.x

Görzen E, Diekötter T, Meyerink M, Kretzschmar H, Donath TW (2021) The potential to save agrestal plant species in an intensively managed agricultural landscape through organic farming - a case study from northern Germany. Land 10: 219. https://doi.org/10.3390/land10020219

Guillerm JL, Maillet J (1982) Western Mediterranean countries of Europe. In: Holzner W, Numata M (Eds) Biology and ecology of weeds. Springer, Dordrecht, NL, 227–243. https://doi.org/10.1007/978-94-017-0916-3_20

Hammer Ø, Harper DA, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4: 9. https://palaeo-electronica.org/2001_1/past/issue1_01.htm

Hidalgo B, Saavedra M, Gracia-Torres L (1990) Weed flora of dryland crops in the Cordoba region (Spain). Weed Reseach 20: 209–318. https://doi.org/10.1111/j.1365-3180.1990.tb01718.x

Hmimsa Y, Ater M (2008) Agrodiversity in the traditional agroecosystems of the Rif mountains (north of Morocco). Biodiversity 9: 78–81. https://doi.org/10.1080/14888386.2008.9712890

Holzner W (1978) Weed species and weed communities. Vegetatio 38: 13–20. https://doi.org/10.1007/BF00141295

Holzner W, Numata M (1982) Biology and ecology of weeds. Springer, The Hague, NL, 461 pp. https://doi.org/10.1007/978-94-017-0916-3

Jauzein P (1997) La notion de messicole: tentative de définition et de classification. Le monde des plantes 458: 19–23.

Jauzein P (2001a) Biodiversité des champs cultivés: l'enrichissement floristique. Dossier de l'environnement de l'INRA 21: 43–64.

Jauzein P (2001b) L'appauvrissement floristique des champs cultivés. Les dossiers de l'environnement de l'INRA 65–78.

Jouve P (1993) Adaptation des systèmes de production à l'aridité au Maroc et au Sahel. Ph.D. thesis, Paul Valéry University Montpellier 3, Montpellier, FR.

Kazi Tani Ch, Le Bourgeois T, Munoz F (2010) Aspects floristiques des adventices du domaine phytogéographique oranais (Nord-Ouest algérien) et persistance d'espèces rares et endémiques. Flora Mediterranea 20: 29–46.

Kradi C (2012) L'agriculture solidaire dans les éco-systèmes fragile au Maroc. INRA, Rabat, MA, 185 pp.

Lara EL, Daïde H, Chaouki M (2015) Cannabis cultivation and depleted forest areas in the province of taounate Rif southern, morocco: landscape and economic repercussions. Boletín de la Asociación de Geógrafos Españoles 68: 473–476. https://bage.age-geografia.es/ojs/index.php/bage/article/view/1874

Lastic P-Y (1989) Die Unkrautgesellschaften der Rharb-Ebene (Marokko). Ph.D. thesis, University of Bayreuth, Bayreuth, DE.

Le Bourgeois T (1993) Les mauvaises herbes dans la rotation cotonnière au Nord-Cameroun (Afrique). Ph.D. thesis, University of Montpellier II, Montpellier, FR.

Légère A, Samson N (1999) Relative influence of crop rotation, tillage, and weed management on weed associations in spring barley cropping systems. Weed Science 47: 112–122. https://doi.org/10.1017/S0043174500090731

Lisek J (2012) Synanthropic orchard flora in west Mazovia - central Poland. Journal of Fruit and Ornamental Plant Research 20: 71–83. https://doi.org/10.2478/v10290-012-0017-5

Mantel N (1967) The detection of disease clustering and a generalized regression approach. Cancer Research 27: 209–220.

Marshall EJP, Brown VK, Boatman ND, Lutman PJW, Squire GR, Ward LK (2003) The role of weeds in supporting biological diversity within crop fields. Weed Research 43: 77–89. https://doi.org/10.1046/j.1365-3180.2003.00326.x

McElroy JS (2014) Vavilovian Mimicry: Nikolai Vavilov and his little-known impact on weed science. Weed Science 62: 207–216. https://doi.org/10.1614/WS-D-13-00122.1

Médail F, Quézel P (1999) Biodiversity hotspots in the Mediterranean basin: setting global conservation priorities. Conservation Biology 13: 1510–1513. https://doi.org/10.1046/j.1523-1739.1999.98467.x

Meyer S, Wesche K, Krause B, Leuschner C (2013) Dramatic losses of specialist arable plants in Central Germany since the 1950s/60s – a cross-regional analysis. Diversity and Distributions 19: 1175–1187. https://doi.org/10.1111/ddi.12102

Meyer S, Bergmeier E, Becker T, Wesche K, Krause B, Leuschner C (2015) Detecting long-term losses at the plant community level – arable fields in Germany revisited. Applied Vegetation Science 18: 432–442. https://doi.org/10.1111/avsc.12168

Meyer S (2020) The status of arable plant habitats in Central Europe. In: Hurford C, Wilson P, Storkey J (Eds) The changing status of arable habitats in Europe. Springer, Zug, CH, 55–72. https://doi.org/10.1007/978-3-030-59875-4_5

Mokhtari N, Mrabet R, Lebailly P, Bock L (2013) Spatialisation des bioclimats, de l'aridité et des étages de végétation du Maroc. Revue Marocaine des Sciences Agronomiques et Vétérinaires 2: 50–66. https://hdl.handle.net/2268/186890

Molvær J, Knutzen J, Magnusson J, Rygg B, Skei J, Sørensen J (1997) Classification of environmental quality in fjords and coastal areas. Norwegian Pollution Control Authority [Report no. TA-1467/ 1997], Oslo, NO, 36 pp.

Mucina L, Bültmann H, Dierßen K, Theurillat J-P, Raus T, Čarni A, Šumberová K, Willner W, Dengler J, … Tichý L (2016) Vegetation of Europe: Hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Applied Vegetation Science 19(suppl. 1): 3–264. https://doi.org/10.1111/avsc.12257

Munoz F, Fried G, Armengot L, Bourgeois B, Bretagnolle V, Chadoeuf J, Mahaut L, Plumejeaud C, Storkey J, … Gaba S (2020) Ecological specialization and rarity of arable Weeds: Insights from a comprehensive survey in France. Plants 9: 824. https://doi.org/10.3390/plants9070824

Mupepele AC, Böhning-Gaese K, Lakner S, Plieninger T, Schoof N, Klein AM (2019) Insect conservation in agricultural landscapes:an outlook for policy-relevant research. GAIA 28: 342–347. https://doi.org/10.14512/gaia.28.4.5

Murphy SD, Clements DR, Belaoussoff S, Kevan PG, Swanton CJ (2006) Promotion of weed species diversity and reproduction of weed seedbanks with conservation tillage and crop rotation. Weed Science 54: 69–77. https://doi.org/10.1614/WS-04-125R1.1

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GA, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853–858. https://doi.org/10.1038/35002501

Nassif F, Tanji A (2013) Gathered food plants in Morocco: the long forgotten species in ethnobotanical research. Life Sciences Leaflets 37: 17–54. https://doi.org/10.1186/s13002-022-00500-4

Nègre R (1978) Données phytosociologiques sur les associations thérophytiques du Maroc aride. Colloques Phytosociologique 6: 23–32.

Nezadal W (1989) Unkrautgesellschaften der Getreide- und Frühjahrshackfruchtkulturen (*Stellarietea mediae*) im mediterranen Iberien. Dissertationes Botanicae 143: 1–205.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, … Wagner H (2020) vegan: community ecology package. R package version 2.5-7. https://cran.r-project.org/package=vegan/ [accessed 28 November 2020]

Oppermann R, Beaufoy G, Jones G (2012) High nature value farming in Europe: 35 European countries - experiences and perspectives. Verlag Regionalkultur, Ubstadt-Weiher, DE, 544 pp.

Pielou EC (1966) The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13: 131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Pienkowski M (2011) The nature conservation value of low-intensity farming systems. European Forum on Nature Conservation and Pastoralism. EFNCP Occasional Publication 17: 11.

Potts GR, Ewald JA, Aebischer NJ (2010) Long-term changes in the flora of the cereal ecosystem on the Sussex Downs, England, focusing on the years 1968–2005. Journal of Applied Ecology 47: 215–226. https://doi.org/10.1111/j.1365-2664.2009.01742.x

Powell B, Ouarghidi A, Johns T, Ibn Tattou M, Eyzaguirre P (2014) Wild leafy vegetable use and knowledge across multiple sites in Morocco: a case study for transmission of local knowledge? Journal of Ethnobiology and Ethnomedicine 10: 1–11. https://doi.org/10.1186/1746-4269-10-34

Quézel P (2000) Réflexions sur l'évolution de la flore et de la végétation au Maghreb méditerranéen, Ibis Press, Paris, FR, 117 pp.

R Core Team (2020) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, AT. https://www.R-project.org [accessed 22 June 2020].

Ramôa S, Oliveira e Silva P, Vasconcelos T, Fortes P, Portugal J (2015) Study of autumn-winter weeds in portugal and its ecological preferences. Planta Daninha 33: 387–394. https://doi.org/10.1590/S0100-83582015000300001

Reicosky DC (2015) Conservation tillage is not conservation agriculture. Journal of Soil Water Conservation 70: 103A–108A. https://doi.org/10.2489/jswc.70.5.103A

Rivas-Martínez S, Díaz TE, Fernández-González F, Izco J, Loidi J, Lousã M, Penas A (2002) Vascular plant communities of Spain and Portugal. Itinera Geobotanica 15: 433–922.

Roleček J, Tichý L, Zelený D, Chytry M (2009) Modified TWINSPAN classification in which the hierarchy respects cluster heterogeneity. Journal of Vegetation Science 20: 596–602. https://doi.org/10.1111/j.1654-1103.2009.01062.x

Saidi S, Sebbata O, Bencherqi A, Mrabet R, Oukabli A, Es Safi NE, Hamoutou M, Ouabbou H, Ibnou Ali Al Alaoui M (2007) Deuxième rapport sur l'état des ressources phytogénétiques pour l'alimentation et l'agriculture (RPGAA). Institut National de la Recherche Agronomique, Rabat, MA, 48 pp.

Sauvage C, Vindt J (1952) Flore du Maroc, analytique, descriptive et illustrée, Vol. 1. Tavaux de l'Institut Scientifique Chérifien, Série Botanique 3. Rabat, MA, 177 pp. https://doi.org/10.2307/1217694

Sauvage C, Vindt J (1954) Flore du Maroc, analytique, descriptive et illustrée, Vol. 2. Tavaux de l'Institut Scientifique Chérifien, Série Botanique 3. Rabat, MA, 283 pp. https://doi.org/10.2307/1217694

Saavedra M, Garcia-Torres L, Hernandez-Bermejo E, Hidalgo B (1989) Weed flora in the Middle Valley of the Guadalquivir, Spain. Weed Research 29: 167–179. https://doi.org/10.1111/j.1365-3180.1989.tb00857.x

Scherrer B (1984) Biostatistiques. Gaëtan Morin Editeur, Montréal, CA, 850 pp.

Shannon CE (1948) A mathematical theory of communication. Bell System Technical Journal 27: 379–423. https://doi.org/10.1145/584091.584093

Štefanić E, Kovačević V, Antunović S, Japundzić-Palenkić B, Zima D, Turalija A, Nestorović N (2019) Floristic Biodiversity of Weed Communities in Arable Lands of Istria Peninsula (from 2005 to 2017). Ekologia 38: 166–177. https://doi.org/10.2478/eko-2019-0013

Storkey J, Westbury DB (2007) Managing arable weeds for biodiversity. Pest Management Science 63: 517–523. https://doi.org/10.1002/ps.1375

Storkey J, Meyer S, Still KS, Leuschner C (2012) The impact of agricultural intensification and land-use change on the European arable flora. Proceedings of the Royal Society B: Biological Sciences 276: 1421–1429. https://doi.org/10.1098/rspb.2011.1686

Storkey J, Neve P (2018) What good is weed diversity? Weed Research 58: 239–243. https://doi.org/10.1111/wre.12310

Streit B, Rieger SB, Stamp P, Richner W (2002) The effect of tillage intensity and time of herbicide application on weed communities and populations in maize in central Europe. Agriculture, Ecosystems & Environment 92: 211–224. https://doi.org/10.1016/S0167-8809(01)00307-3

Taiqui L (1997) La dégradation écologique au Rif marocain: nécessités d'une nouvelle approche. Mediterránea, Serie de Estudios Biológicos 16: 5–17. https://doi.org/10.14198/MDTRRA1997.16.01

Taleb A, Maillet J (1994) Mauvaises herbes des céréales de la Chaouia (Maroc) II. Aspect écologique. Weed Research 34: 353–360. https://doi.org/10.1111/j.1365-3180.1994.tb02004.x

Taleb A, Bouhache M, Rzozi SB (1998) Flore adventice des céréales d'automne au Maroc. Actes de l'Institut Agronomique et Vétérinaire Hassan II 18: 121–130.

Tanji A, Boulet C (1986) Diversité floristique et biologique des adventices de la région du Tadla (Maroc). Weed Research 26: 159–166. https://doi.org/10.1111/j.1365-3180.1986.tb00691.x

Tichý L (2002) JUICE, software for vegetation classification. Journal of Vegetation Science 13: 451–453. https://doi.org/10.1111/j.1654-1103.2002.tb02069.x

Trichard A, Alignier A, Biju-Duval L, Petit S (2013) The relative effects of local management and landscape context on weed seed predation and carabid functional groups. Basic and Applied Ecology 14: 235–245. https://doi.org/10.1016/j.baae.2013.02.002

Valdes B, Rejdali M, Achhal El Kadmiri A, Jury JL, Montserrat JM [Eds] (2002a) Catalogue des plantes vasculaires du Nord du Maroc incluant des clés d'identification, Vol. 1. Consejo Superior de Investigaciones Científicas, Madrid, ES, 493 pp.

Valdes B, Rejdali M, Achhal El Kadmiri A, Jury JL, Montserrat JM [Eds] (2002b) Catalogue des plantes vasculaires du Nord du Maroc incluant des clés d'identification, Vol. 2. Consejo Superior de Investigaciones Científicas, Madrid, ES, 514 pp.

Young FL, Thorne ME (2004) Weed species dynamics and management in no-till and reduced-till fallow cropping systems for the semi-arid agricultural region of the Pacific Northwest, USA. Crop Protection 23: 1097–1110. https://doi.org/10.1016/j.cropro.2004.03.018

Zanin G, Otto S, Riello L, Borin M (1997) Ecological interpretation of weed flora dynamics under different tillage systems. Agriculture, Ecosystems & Environment 66: 177–188. https://doi.org/10.1016/S0167-8809(97)00081-9

Zidane L, Salhi S, Fadli M, El Antri M (2010) Étude des groupements d'adventices dans le Maroc Occidental. Biotechnology, Agronomy and Society and Environment 14: 153–166.

Zohary M (1950) The segetal plant communities of Palestine. Vegetatio 2: 387–411. https://doi.org/10.1007/BF00179724

E-mail and ORCID

Soufian Chakkour (chakkoursoufian@gmail.com), ORCID: https://orcid.org/0000-0002-3052-4265
Erwin Bergmeier (Corresponding author, Erwin.Bergmeier@bio.uni-goettingen.de), ORCID: https://orcid.org/0000-0002-6118-4611
Stefan Meyer (smeyer1@gwdg.de), ORCID: https://orcid.org/0000-0002-1395-5004
Jalal Kassout (jalalkassout@gmail.com), ORCID: https://orcid.org/0000-0002-3702-2751
Mohamed Kadiri (mohkadiri@gmail.com)
Mohammed Ater (mohammed.ater@gmail.com), ORCID: https://orcid.org/0000-0003-2637-8215

Supplementary material

Supplementary material 1
Geographical coordinates of the conducted relevés.
Link: https://doi.org/10.3897/VCS.86024.suppl1

Supplementary material 2
Biogeographic origin and chorology of the listed species of traditional agroecosystems in the Rif Mountains (Morocco).
Link: https://doi.org/10.3897/VCS.86024.suppl2

Supplementary material 3
List of segetal species in the traditional agroecosystems of the Rif Mountains (Morocco).
Link: https://doi.org/10.3897/VCS.86024.suppl3

Supplementary material 4
The distribution of segetal species per family of traditional agroecosystems in the Rif mountains (Morocco) listed by dominance.
Link: https://doi.org/10.3897/VCS.86024.suppl4

Supplementary material 5
Diversity indices values for each relevé of traditional agroecosystems in the Rif Mountains (Morocco).
Link: https://doi.org/10.3897/VCS.86024.suppl5

Supplementary material 6
The distribution of segetal flora species per habitat and typology of traditional agroecosystems in the Rif Mountains (Morocco).
Link: https://doi.org/10.3897/VCS.86024.suppl6

Supplementary material 7
Full species-relevés table.
Link: https://doi.org/10.3897/VCS.86024.suppl7

Supplementary material 8
Synoptic table of the four communities showing percentage constancy values of species.
Link: https://doi.org/10.3897/VCS.86024.suppl8