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An Approach to Sustainable Management of Two Mountainous Areas

In this study, analysis of land use and suitability maps for 2 contrasting mountainous ecosystems was used to identify areas where a change from existing to potential land use was required. A socioeconomic survey was carried out to select locations for implementing 2 land management packages with the full participation of farmers. The first package included cultivation of wheat landraces in a high-rainfall site (Ajloun), while the second included community-based rangeland rehabilitation and management, including fodder shrub plantations in water harvesting structures in the low-rainfall rangeland areas (Jiza). Results showed that the average grain and straw yield of wheat landraces was significantly higher than that of the improved cultivars, which could lead to high and diverse farm income. In the low-rainfall site, fodder shrubs increased the overall land productivity and aided in improving the cover of native vegetation. After 2 years of protection, dry matter production (620 kg/ha) in the community-protected location was significantly higher than that at an experimental station (465 kg/ha). Findings from both packages indicated the possibility of improving the suitability of both mountainous areas for rainfed cultivation while conserving agrobiodiversity. Development of the arid areas as open ranges could be enhanced by the introduction of suitable cultivation practices (contour furrows in this study), with a view to improving productivity and rehabilitating the native vegetation.

Keywords: *Land use; rangeland; remote sensing; GIS; Mediterranean; arid; Jordan.*

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Introduction

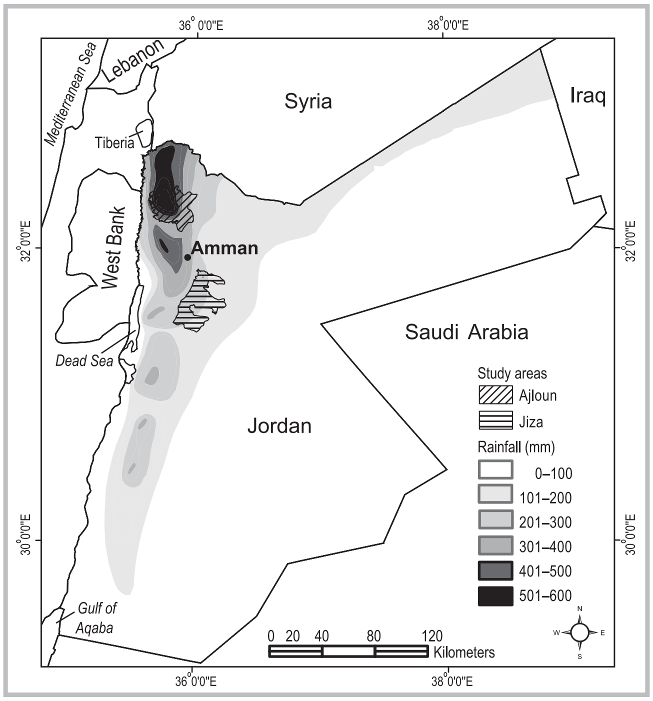
In many developing countries, a mismatch between existing and potential land use is often observed because of lack of land use planning and proper investigation of the suitability of land parcels for particular uses. Therefore, spatial information is needed to identify areas to implement alternative land use practices. This requires the integration of geographic information systems (GIS) and remote sensing tools with ground data to map and analyze land uses. It has been argued that these tools provide more accurate information than that obtained from topographic maps (Harahsheh et al 1998; Gautam and Watanabe 2004) or from time-consuming ground surveys.

In Jordan, land use is highly variable depending on the ecological zone, available resources, and the traditional knowledge of local farmers (Millington et al 1999; Al-Bakri et al 2001). Located in the eastern Mediterranean between 29°11′–33°22′ N and 34°19′–39°18′ E, Jordan has 3 distinct ecological zones: 1) the Jordan Valley, which forms a narrow strip located below the mean sea level, with warm winters and hot summers, and agriculture mainly based on irrigation; 2) the western highlands, with relatively high rainfall and a typically Mediterranean climate; and 3) the arid and semi-arid inland to the east, known as the *Badia*, where annual rainfall is below 200 mm. *Badia* is an Arabic word referring to the open rangeland where Bedouins (nomads) live and practice seasonal grazing and browsing.

Unfortunately, most of the western highlands in Jordan have been altered by distinct land use changes accelerated by socioeconomic factors due to high population growth (2.5% for Jordan in 2004), urbanization, and agricultural intensification. The agricultural intensification and land use shifts observed in many Mediterranean mountains (Al-Bakri 2005; Lasanta et al 2006) have resulted in the replacement of landraces and local varieties by some unsuitable cultivars of grain crops and fruit trees that are not adapted to the local environment. Such replacement might therefore be considered a major threat to the local landraces (Khresat et al 1998), although many improved cultivars were specifically bred for the area (http://www.icarda.org/Crops_Varieties.htm).

The arid and semi-arid zones, on the other hand, have been heavily utilized and degraded by extensive barley cultivation to support herds whose stocking densities are too high, and uprooting of woody plants to serve as an energy source for heating and cooking (Abu-Zanat et al 2004). These practices have led to a reduction in the number of native plants, a decline in agrobiodiversity, and the spread of poisonous and noxious plants (MoE 2006). Therefore, a national collaborative program, "Conservation and Sustainable Use of Dryland Agro-biodiversity in Jordan," involving several governmental and non-governmental agencies, has been implemented to promote sustainable land use and conserve the genetic diversity of native plants and landraces in areas where rainfed agriculture is practiced. The program also promotes modified and alternative land use practices through a community-based on-farm habitat and species management system. The research reported in this study is part of this program and explains how land use mapping and socioeconomic analysis are being used to encourage farmers to implement technical packages for sustainable land management in 2 mountainous regions in Jordan.

FIGURE 1 Location of the 2 sites within the different rainfall zones in Jordan. (Map by Jawad Taleb Al-Bakri)



Study sites

The study was implemented in 2 mountainous sites (Figure 1): Ajloun, which has a dry sub-humid Mediterranean climate, and Jiza, which has an arid climate. Ajloun covers a total area of 747 km^2 and is located in the north of the country at a maximum altitude of 1250 m (Figure 2). The mean annual rainfall ranges from 400 to 600 mm. Indigenous forests of *Pinus*, *Quercus,* and *Ceratonia* are abundant at this site (GCEP 2000). Wild relatives and local cultivars of fruit trees, olives, and wheat are also grown in this area.

Jiza is located southeast of Amman and has a total area of 815 km^2. The site is undulating and hilly in the north and in the east, where it reaches a maximum altitude of 950 m, but is relatively flat and gently sloping in the south at altitudes of 760 to 800 m (Figure 2). The mean annual rainfall ranges from 150 to 250 mm but shows considerable interannual variability. Overgrazing of native vegetation by sheep and continuous ploughing to cultivate barley have resulted in severe erosion of the soils, which are silty and shallow (10–60 cm deep). The dominant vegetation is *Poa bulbosa*, *Bromus* spp., and *Hordeum spontaneum*, though other species such as

FIGURE 2 Digital elevation models of Ajloun (left) and Jiza (right). (Maps by Jawad Taleb Al-Bakri)

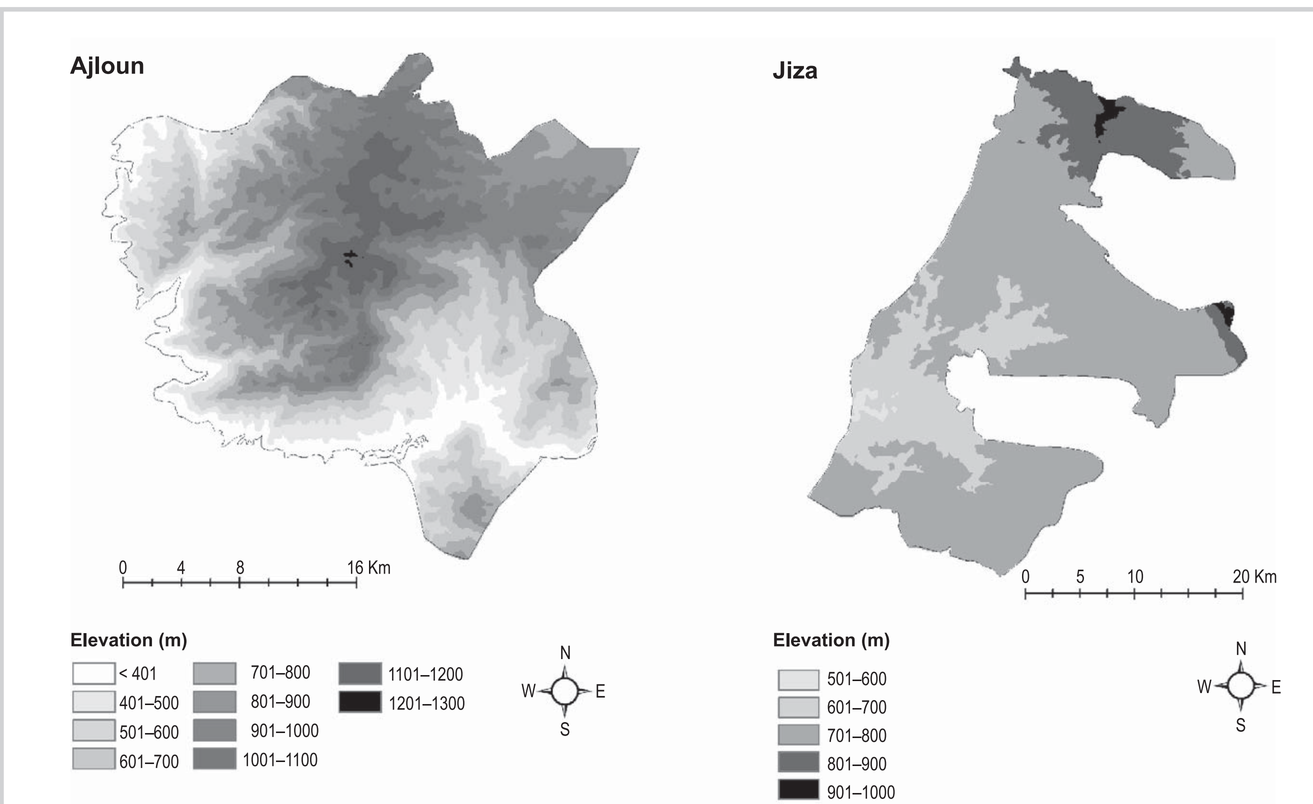


TABLE 1 Suitability ratings for potential use of rainfed arable land and open rangeland. S1 = Highly suitable, S2 = Moderately suitable, S3 = Marginally suitable. If the rating is lower than S3, land is classified as not suitable.

Land use type	Rainfed arable land			Open rangeland (grazing)		
Factors affecting suitability	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Climate: Rainfall (mean annual, in mm)	>350	300–350	250–300	>250	200–250	100–200
Winter growth potential (days over 8ºC)	>250	–	–	>400	250–400	<250
Soil: Available water-holding capacity (mm water/1 m soil)	>150	75–150	<75	>110	75–110	40–75
Carbonate (% secondary concretions)	<12	–	–	<12	–	–
Erosion: Hazard (rill or gully)	1	2	3	1	2	3
Hazard (sheet and/or wind)	2	3	4	2	3	4
Topography: Slope (%)	<4	4–8	8–16	<25	25–40	40–100
Rockiness: Outcrop (%)	<5	5–10	10–20	<20	20–50	50–100
Surface stone cover (%)	<20	20–40	40–60	<30	30–60	60–100
Stone of surface horizon (%)	<10	10–20	20–30	<20	20–50	50–100

Aegilops spp., *Vicia monantha*, *Trigonella* spp., *Medicago orbicularis,* and *Astragalus* spp. are found at some locations at lower elevations.

Methodology

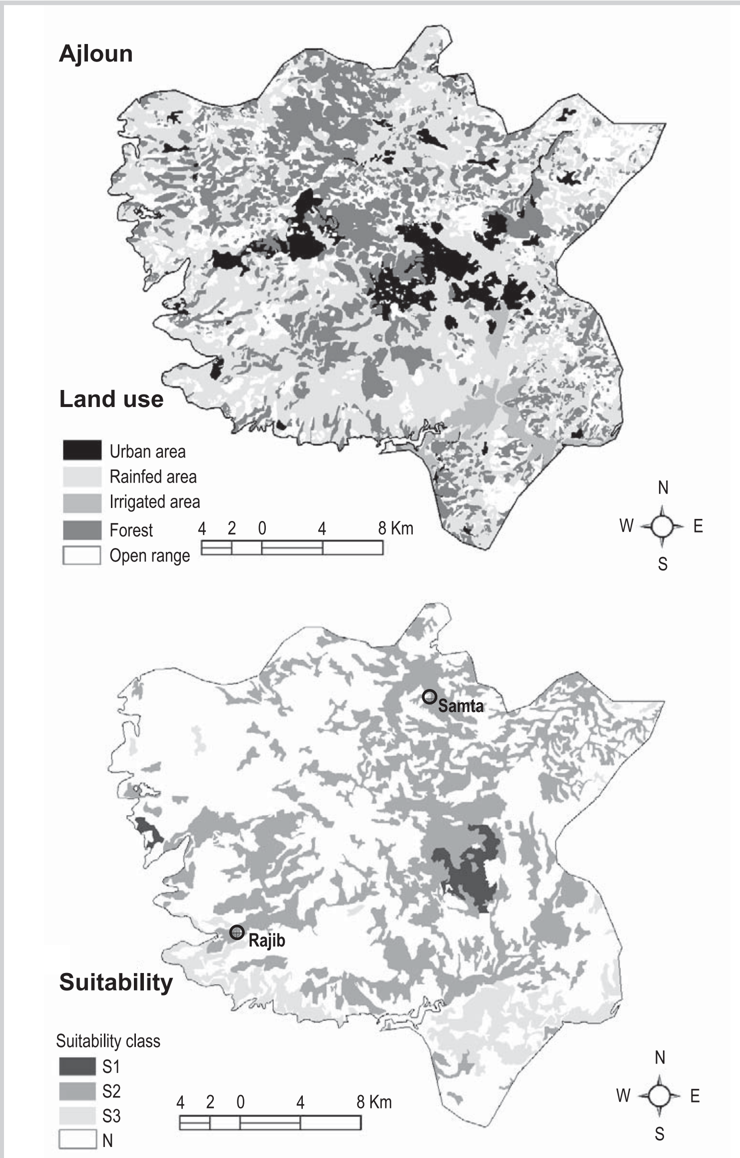
The general methodology was based on analysis of existing land uses from satellite images and comparison of the output maps with potential land use maps to identify areas of intervention where packages of alternative land use practices could be demonstrated and implemented. To determine social acceptability, a socioeconomic survey was conducted to propose sustainable land use packages in the 2 target areas, where land use is different. The most practical and socially accepted package (according to the farmers' opinions reflected in the socioeconomic survey) was developed and implemented in selected sites within Ajloun and Jiza.

Land use mapping

Visual interpretation of Landsat Enhanced Thematic Mapper (ETM+) imagery (30-m resolution) acquired in 2002 was carried out to derive land use maps using an on-screen digitizing procedure. These maps were verified by field visits, and their accuracy assessed by comparing the agreement between a set of random points (16 for each class) of interpreted land use polygons with ground data.

Potential land use maps at a scale of 1:50,000 (semi-detailed level) were prepared using soil maps and field observations. This was accomplished using the FAO methodology of land suitability analysis (FAO 1976; FAO 1983) and land suitability criteria adopted from 2 previous projects (MoA 1995; JAZPP 1997). For each proposed land utilization type (LUT), a rating of suitability classes according to land characteristics was identified (Table 1). Field data, with a density of 3.5 observations/km^2, were aggregated for each soil mapping unit. The average value of continuous variables (rainfall, available water-holding capacity, winter growth potential, surface cover percentage, limiting soil depth, slope, and surface stoniness) and the modal values for ordinal variables (erosion type, erosion class, and surface cover type) were calculated from all the observations within each soil mapping unit and were compared with land use requirements (Table 1) for rainfed cultivation at Ajloun and for the use of Jiza as an open range. Subsequently, a new column of suitability was added to the attribute table of the soil map and was used to derive the potential land use map for each LUT. Existing land use maps for Ajloun and Jiza were cross-tabulated with the potential land use maps to quantify agreement and disagreements between potential and actual land uses, and to identify areas where conservation of landraces of wheat in Ajloun and barley and fodder shrubs in Jiza are needed.

FIGURE 3 Maps of existing land use (top) and suitability for rainfed cultivation (bottom) in Ajloun. Suitability classes: S1 = Highly suitable, S2 = Moderately suitable, S3 = Marginally suitable, N = Not suitable. (Maps by Jawad Taleb Al-Bakri)



Land management packages

The socioeconomic survey was conducted through a questionnaire developed and completed during field visits and interviews with 67 farmers in the 2 areas in 2002. The questionnaire included several questions about farmers' attitudes regarding changes in land use, the land tenure system, the best crop management practices to promote agrobiodiversity conservation, the willingness of farmers to implement a proposed land management package, current land use practices in Ajloun, and the most acceptable types of grazing resource management in Jiza. Results of the survey showed that low-yielding primitive varieties (landraces) dominated the cropping system at Ajloun and the open range in Jiza. Therefore, the following 2 packages were developed with the participation of local communities and implemented at 2 sites in each target area.

Package I: improvement of wheat landraces at Ajloun

This package promoted the utilization of wheat landraces by improving productivity and grain quality. These landraces (primitive varieties)—the most common durum wheat maintained by farmers for at least 10 years—were collected from farmers' fields and were planted in 20-m · 30-m plots on different farms in both villages at a rate of 100 kg/ha in December 2002. The package was tested through a participatory approach with farmers at Rajib and Samta villages in Ajloun, with standard practices implemented in all experiments. The landraces and the improved varieties were evaluated visually by farmers and agricultural experts at harvesting time, on 2 July 2003. For each entry, 5 random samples (1 m^2 each) were harvested to determine grain and straw yield. Grain and straw productivities of the wheat landraces were compared with those of 2 improved varieties (ACSAD 68 and Sham 1).

Package II: community-based improvement and management of grazing resources at Jiza

This package aimed to rehabilitate and increase the capacity of rangeland in Jiza while simultaneously conserving on-site native species. The package was implemented at the Jordan University Station for Dryland Research (JUSDR) at Muwaqar and on farmed land in Mhareb village. The former was totally protected from grazing, while the latter was provided by local communities to implement the proposed package. Harsh climatic and edaphic conditions limited the option of direct seeding of forage plants. Therefore, the suggested package at both Muwaqar and Mhareb included transplanting of shrub species (*Atriplex halimus*, *Atriplex nummularia*, *Salsola vermiculata*, *Achillea fragrantissima*, and *Artemisia herba-alba*) in contour furrows, and direct seeding of a local variety of barley (*Hordeum spontaneum*) between furrows at a rate of 80 kg/ha.

Planting was carried out in late December 2002 for Mhareb and early January 2003 for Muwaqar; 25 ha were planted at each location. Seeding of the barley in the second season was carried out in December 2003; 68 contour furrows (50-cm width and 30-cm depth), with length ranging from 20 to 230 m, were planted at each site. The layout of furrows was planned to be in a cluster on slopes facing watercourses. This layout of furrows was modified after discussions with farmers to allow the use of machinery and to facilitate the movement of grazing livestock in the spaces between furrows. An auger mounted on a tractor was used to open the pits (40 × 40 × 40 cm) for planting inside the contour furrows. Micro-dams (ties) were built across the

TABLE 2 Percentage land use in Ajloun and Jiza, and percentage agreement with potential land use for rainfed agriculture in Ajloun and open rangeland in Jiza. S1 = Highly suitable; S2 = Moderately suitable; S3 = Marginally suitable.

Land use type	Ajloun	Jiza	Mapping accuracy (%)	Agreement (%)		
				S1	S2	S3
Urban area	6.7	2.8	100	–	–	–
Rainfed area	42.6	39.4	88	2.2	39.1	9.0
Forest	27.5	0.0	94	–	–	–
Open rangeland	20.3	47.4	94	0.0	46.6	53.4
Irrigated area	2.9	10.4	88	–	–	–

furrows between the pits for proper distribution of harvested rainfall. Barley was planted in 50% of the area between furrows to induce surface water runoff into the planted shrub seedlings and to utilize the uncultivated area.

The Mhareb site was managed by the local community and protected from grazing during the 2002/2003 and 2003/2004 growing seasons. Plant cover percentage and yield (fresh weight of leaves and small twigs) of the planted shrubs were estimated for 5 transects in April 2004 using the reference unit technique (Abu-Zanat et al 2004), while productivity of barley was measured by direct clipping of 5 random 1-m^2 plots and weighing the above ground biomass. The percentage of area covered by barley was visually estimated while that of shrubs was measured for 3 50-m-long line transects.

Statistical analysis

Root mean square error (RMSE) (equation 1), index of agreement (D) (equation 2) and modified Nash-Sutcliffe efficiency (E) (equation 3) were computed according to Willmott (1984) and Krause et al (2005) to evaluate the differences between the productivity of landraces and the improved varieties in Ajloun and between the plant productivity at Mhareb and Muwaqar.

$$RMSE = \left[N^{-1} \sum_{i=1}^{N} \left(L_i - I_i \right)^2 \right]^{0.5} \tag{1}$$

$$D = 1 - \left[\frac{\sum_{i=1}^{N} \left(L_i - I_i \right)^2}{\sum_{i=1}^{N} \left(\left| L'_i \right| + \left| I'_i \right| \right)^2} \right], \ 0 \leq D \leq 1 \tag{2}$$

$$E = 1 - \frac{\sum_{i=1}^{N} \left(L_i - I_i \right)^2}{\sum_{i=1}^{N} \left(I_i - \bar{I} \right)^2}, \ -\infty < E \leq 1 \tag{3}$$

where N is the number of observations, L is the local variety (landrace) and I is the improved variety, $L'_i = L_i - \bar{I}$ and $I'_i = I_i - \bar{I}$, and $\bar{I}$ is the mean of the observed values of landraces. RMSE ranges from 0 to infinity, the lower the RMSE the better the agreement. D ranges from 0 to 1, where 1 means a perfect agreement and 0 means a poor one; while a negative value of E indicates that the mean value of the observed landraces would have better productivity than the improved ones. The same procedure was used to compare shrub productivity at Mhareb (L variable) with that at Muwaqar (I variable).

Results and discussion

Analysis of the land use map for Ajloun (Figure 3) showed that rainfed agriculture was practiced in 43% of the area (Table 2). Results from the socioeconomic questionnaire showed that most landholdings were managed by landowners or by one of the family members. Analysis of the potential land use map and its agreement with existing land use showed that 39% of the rainfed land was moderately suitable for rainfed agriculture and had a climatic limitation due to a low winter growth potential. About 50% of the rainfed area had topographic limitations. Therefore, the adoption of appropriate land management packages that enhance the use of landraces was justified in this area as they could be better adapted to climatic conditions.

Results from the implementation of the first land management package confirmed the above hypothesis and emphasized the importance of conserving landraces of wheat in Ajloun. All of the landraces that were tested at Samta outyielded the improved varieties in grain yield, and 2 landraces produced more straw than the improved varieties (Table 3). In Rajib, 1 landrace produced a better grain yield than the improved variety, and 2 landraces outyielded the improved varieties in straw production. Statistical analysis showed low agreement between grain yield of landraces and that of the improved varieties. The mean productivity of

TABLE 3 Grain and straw yield of different wheat landraces and improved varieties grown at Ajloun during the 2002/2003 growing season.

Site	Landrace	Mean straw yield (kg/ha)	Mean grain yield (kg/ha)
Samta	*Zara'ha bida*	1990	1410
	Zghibeya bida	2910	1440
	Mijari	2340	1220
	Improved variety (ACSAD 68)	1840	1090
	Improved variety (Sham 1)	2020	1050
Rajib	*Zara'ha bida*	9870	2640
	Zghibeya bida	4300	1207
	Mijari	6780	1160
	Improved variety (ACSAD 68)	5640	2120
	Statistical measurements		
	Mean (all varieties)	4188	1482
	Mean (improved varieties)	3167	1420
	Mean (landraces)	4698	1513
	Standard deviation	2766	541
	RMSE	3492	710
	D	0.40	0.18
	E	–2.98	–1.31

landraces (4698 kg straw/ha, 1513 kg grain/ha) was significantly higher than that of the improved varieties (3167 kg straw/ha, 1420 kg grain/ha). The negative values of E and the low values of D indicate the presence of high variations among the genotypes tested (landraces and improved varieties) in both sites. These findings were in agreement with the farmers' opinion about landraces and therefore would be considered as the foundation for new programs aiming at promoting the conservation and sustainable use of landraces by farmers and breeders to improve land productivity.

These results showed that limitations for rainfed cultivation of wheat could be alleviated by adopting participatory breeding to select and cultivate landraces that produce high yield with good adaptation to the local conditions in the mountainous area of Ajloun. For ecologists, the on-farm conservation of landraces would play the patrimonial function in agrobiodiversity of mountains by promoting the conservation of these landraces by local communities (Tapia 2000). For farmers, the increase in crop production and income would encourage the adoption of this package.

Analysis of the land use map of Jiza (Figure 4) showed that 47% of the area was used as open range. Cultivation of barley was practiced in 39% of the total area, while 10% of the site was irrigated. The suitability map for the site showed that it was either moderately suitable (47%) or marginally suitable (53%) for use as an open range. The main limitations were low rainfall and high carbonate content in some soil mapping units. In general, grazing of native vegetation was the predominant land use in Jiza, especially in spring when the natural rangelands were heavily utilized and grazing extended onto rainfed barley fields. In the transhumant system which is dominant in Jordan (Al-Sharafat 1996; Millington et al 1999; Al-Bakri et al 2001), barley is usually cultivated for straw rather than for grain, to support the grazing herds of sheep, especially when drought is detrimental to grain yield.

The package suggested by the project as an alternative to conventional cultivation of barley included the planting of fodder shrubs and local cultivars of barley along contour furrows to provide reasonable feed resources and simultaneously conserve soil and water resources. This package was tested in a participatory way with the local community and showed that community-based management systems would improve vegetation cover and increase dry matter production per unit area. This was very clear from the cover percentages of native vegetation found in the 2 demonstration sites managed for 2 years: 38.8% for Mhareb and 46.3% for Muwaqar (Table 4). Biomass production of native vegetation (on a dry matter basis) at the 2 demonstration sites was 620 kg/ha (Mhareb) and 465 kg/ha (Muwaqar). These results show that the average dry matter production of native plants is comparable to the dry matter production of cultivated barley at both sites.

The community-based protection and management of the native vegetation increased its production to levels that were higher than the average straw yield of barley, as indicated by many farmers. The improvement of plant productivity with protection and limited access to rangeland agree with findings of previous research in similar ecosystems (eg Rahim and Maselli 2004). Therefore, the low biomass production of barley and the costs associated with its cultivation do not justify continuing the common practice of cultivating it for grazing on arid rangelands in Jordan. In addition, the animals can use the fodder shrubs for grazing after 2 years. The average survival percentage of the planted seedlings at the 2 sites was 89%, which was considered high compared to other studies dealing with protected sites (UOJ 2003; Abu-Zanat et al 2004).

FIGURE 4 Maps of existing land use (left) and suitability for open rangeland (right) in Jiza. (Maps by Jawad Taleb Al-Bakri)

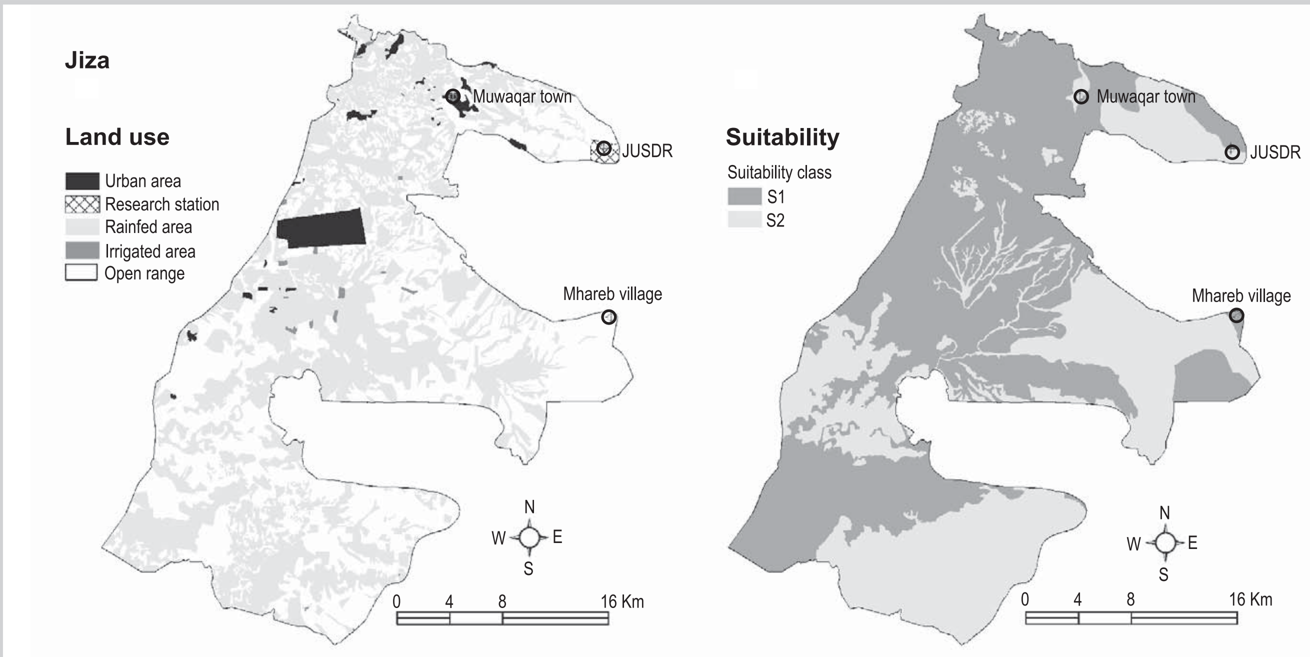


TABLE 4 Plant cover, fresh weight, and dry matter production of native plant species at the 2 demonstration sites in Jiza.

Transect	Plant cover (%)		Fresh weight (kg/ha)		Dry matter (kg/ha)	
	Mhareb	Muwaqar	Mhareb	Muwaqar	Mhareb	Muwaqar
1	39.5	56.5	946	784	476	416
2	37.5	55.5	954	1536	614	820
3	38.0	40.5	1408	852	788	300
4	36.0	38.5	933	996	465	408
5	43.0	40.5	1304	1312	756	380
Statistical measurements						
Mean	38.8	46.3	1109	1096	620	465
Standard deviation	1.4	9.6	232	341	151	229
RMSE	11.2		368.3		292.8	
D	0.58		0.39		0.33	
E	–1.30		–0.7		–1.6	

The overall browsing production of Mhareb was relatively higher than that of Muwaqar. This could be attributed to site characteristics at the former site, especially its larger catchment area, which enabled more water to be harvested than at Muwaqar. Combining the productivity of fodder shrubs with barley for both locations resulted in an average productivity of 3540 kg/ha (fresh weight) and 1522 kg/ha (dry matter). These levels were clearly acceptable to many farmers, who had indicated that the average productivity of barley would not exceed 1900 kg/ha of straw and 980 kg/ha of grain.

Conclusions

Results from our study indicated that decline of land resources and agrobiodiversity under intensive land uses need not be inevitable. Results from implementing land management packages have demonstrated the possibility of improving crop productivity and conserving agrobiodiversity in such environments. The relatively high productivity levels obtained after 2 years of community-based protection and management of arid rangelands showed that agrobiodiversity in arid mountains can be restored by effective land management and successful participation of local communities.

In the context of Jordan, this system of protection was previously known as *hema* and was implemented in many parts of the *Badia*. This system should be enhanced and improved by the implementation of new cultivation techniques (eg transplanting shrubs in contour furrows, and restoring well-adapted native plants and landraces) and the application of different water harvesting techniques and interventions. The success of such packages and interventions would depend on the interest of local communities and their participation, as indicated by previous research in other mountainous ecosystems (Rerkasem et al 2002; Rahim and Maselli 2004; Gerritsen and Wiersum 2005; Llambí et al 2005) and by results of this study.

This was clearly indicated by results of the second package, as the proposed layout of furrows was modified after discussions with farmers who preferred to open the furrows continuously along the contour lines to allow the use of machinery and to facilitate grazing in the spaces between furrows. Adopting this layout was advantageous as it obliged farmers to plow their lands perpendicular to the slope and therefore reduced possible soil erosion.

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