Using Local Agroecological Knowledge in Climate Change Adaptation: A Study of Tree-Based Options in Northern Morocco

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Using Local Agroecological Knowledge in Climate Change Adaptation: A Study of Tree-Based Options in Northern Morocco

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Abstract: Communities in northern Morocco are vulnerable to increasing water scarcity and food insecurity. Context specific adaptation options thus need to be identified to sustain livelihoods and agroecosystems in this region, and increase the resilience of vulnerable smallholders, and their farming systems, to undesired effects of social-ecological change. This study took a knowledge-based systems approach to explore whether and how tree-based (i.e., agroforestry) options could contribute to meeting these adaptation needs. We analysed local agroecological knowledge of smallholders from the Mèknes–Tafilalet region, to (i) characterise existing farming systems at local landscape scale; (ii) identify possible niches for farm-trees within these systems; and (iii) explore locally perceived barriers to tree-based diversification. An iterative cycle of qualitative interviews, with a purposefully selected sample of 32 farmers, revealed that socio-economic constraints and agroecological conditions in the area differed markedly along a relatively short altitudinal gradient. Agroforestry practices were already integral to all farming systems. Yet, many were at risk of degradation, as water scarcity, low profitability of production systems and uncontrolled grazing constituted critical barriers to the maintenance and diversification of farm-trees. We demonstrate the discriminatory power of local knowledge, to characterise farming conditions at the local landscape scale; and unveil adoption barriers and options for tree-based diversification in northern Morocco.

Keywords: local agroecological knowledge; agroforestry; sustainable agriculture; climate change; adaptation; vulnerability; resilience; livelihoods; rural development; Morocco

1. Introduction

Climate change will likely exacerbate existing pressures on the Mediterranean drylands, and strain livelihood systems that depend on the provision of ecosystem services from these ecosystems. Throughout the world, dryland smallholders operate in fragile production environments, which are naturally water scarce, drought prone and afflicted by socio-economic barriers—including limited access to markets and technology, challenging institutional and policy environments, underdeveloped infrastructure, poverty and population growth [1–3]. In Morocco, people are particularly vulnerable to future food-insecurity, as the country's population continues to grow and food demand increases, but agricultural production fluctuates and is likely to diminish as a result of climate change [4].

Current model predictions suggest that Morocco will experience the greatest climate change induced precipitation decrease among the Middle East and North African countries; with increasing mean temperatures in all seasons, declining rainfall, and greater vegetation reference evapotranspiration—leading to decreased runoff, less groundwater recharge and enhanced water stress [5,6]. Wheat yields, one of the populations' staple crops, are closely linked to annual rainfall patterns, and severe crop shortfalls are common during drought periods [7]. Further, the country is at great risk of external shocks such as food price inflation, due to its strong import dependence and exposure to international markets [8].

Agriculture employs close to a quarter of the total economically active population of Morocco [9]. Employment opportunities outside the sector remain scarce and agriculture anchors people to rural areas, providing basic security and preventing progressive urbanisation—rendering the development of small and medium sized farms central to the social and economic well-being of Morocco's society [1]. But the sector is characterised by a dualism [1]: Intensive crop production on irrigated lowlands, which constitute only a small fraction of cultivated land area in Morocco [10], stands in stark contrast to more traditional, subsistence-oriented farming practices that dominate the countries rainfed farmlands. A total of 5.5 million rural Moroccans are landless or own micro farms [1].

In 2008, the Kingdom's leadership launched the Plan Maroc Vert (Green Morocco Plan) to modernise the country's agricultural sector, encourage rural development and institutional innovation and address the threat of increasing water scarcity in the context of global climate change. Activities under the framework of this initiative, *inter alia*, seek to advance the large-scale conversion of prevalent, water intensive cereal cropping systems to high value tree orchards, particularly olive. Such a shift to monoculture tree-based systems may have the potential to improve livelihoods and support farmers to adapt to climate change. But it could also re-create dependencies on narrow crop portfolios and inherently associated socio-economic risks. Agroforestry practices that combine annual crops and woody perennials, in contrast, already have a long tradition in Morocco's mountain regions and oases [11]. Their promotion towards more diverse, multifunctional production systems could thus be a more promising strategy to sustainably develop Morocco's agroecosystems, and shift smallholders' livelihoods onto resilient pathways [12].

Knowledge about locally applicable portfolios of tree-based adaptation options would be a crucial foundation to foster interest in such an agroforestry-based resilience strategy among relevant smallholders and policy actors. But previous assessments of farming systems in north Africa have been conducted on a broad scale [13]. They provided farming system characterisations that are too coarse to serve as a foundation for the identification and innovation of tree-based adaptation options for northern Moroccan smallholders, or for the successful local adaptation of agroforestry practices that have been developed elsewhere [14]. Further, agricultural innovation scholars, have argued that agroforestry research often remains ineffectual, because farmers do not embrace developed technologies, due to insufficient consideration of intrinsic and extrinsic drivers motivating adoption [15]. Agroforestry innovations of past decades often failed to be taken-up rapidly or at wide scale, because the contextual knowledge, perceptions and aspirations of targeted farmers were insufficiently considered during the design, implementation and evaluation phases of development processes [14–16].

This has motivated a call for a paradigm shift to "research 'in', rather than 'for' development", to account for "fine scale variation in social, economic and ecological context" that influences smallholders' adoption decisions [17] (p. 73). And for research approaches that allow for "co-learning amongst research, development and private sector actors" [17] (p. 73). Researchers, who adopt a system perspective and explicitly strive to integrate local agroecological knowledge and scientific understandings of socio-ecological systems and change processes, may—following this line of reasoning—avoid some of the pitfalls associated with earlier approaches to inquiry, and more successfully identify intervention options that are appropriate to specific livelihood and agroecosystem contexts [14,16,18].

The principal aim of this research was thus to critically evaluate the utility of local knowledge methods to characterise variation in farming systems and adaptation contexts at our study site. And to assess the opportunity space for a tree-based diversification of livelihoods and agroecosystems in the Meknès–Tafilalet region. Specifically, we asked: (i) what are the characteristics of current farming systems and agroforestry practices in the study area; (ii) which niches exist for farm-trees and agroforestry practices within these systems; and (iii) what barriers to the maintenance and planting of trees on farms can be identified, on the basis of smallholders' local agroecological knowledge?

The contribution of this study is twofold: First, we demonstrate the utility of local agroecological knowledge for assessments of fine scale variation in adaptation contexts, and thus for the adoption of agroforestry practices, at local landscape scale. We then argue, that such robust socio-ecological characterisations are essential pre-requisites for developing targeted agroforestry adaptation options, and identifying context specific barriers to a tree-based diversification of livelihoods and smallholder farming systems in northern Morocco.

2. Materials and Methods

2.1. Study Site

Our study area was situated within the Meknes-Saiss action site for sustainable intensification, which belongs to a network of strategic research sites in North Africa and West Asia. These sites were established to operationalise and achieve proof of concept for a research paradigm that seeks to achieve food security and improved dryland livelihoods, via an integrated agro-ecosystem and livelihood-system approach [18]. The field campaign was conducted between March and June 2014, with farmers of three rural communes: Nzalet de Beni Amar, Kermet Ben Salem and Walili. These administrative units surround Moulay Idriss Zerhoun (34°3′15″ N and 5°31′38″ W), the historic city and current socio-economic centre of the Zerhoun massif. Records of local extension services [19] and the Research Program on Dryland Systems, of the Consortium of International Agricultural Research Centres [20], allowed for a basic characterisation of the study site: The Zerhoun massif is situated in one of Morocco's most favourable cropping regions, with a typical Mediterranean Climate. A total of 90% of rainfall occurs between November and April, with a mean annual precipitation of 580 mm. The mean annual minimum and maximum temperatures are 11 °C and 28 °C, respectively. Elevations across the massif range from below 300 m in the fertile plain west of Moulay Idriss Zerhoun, to the peak of Jbel Zerhoun, rising above 1000 m. Great proportions of farmland are located on slopes greater than 15%. Soil types are varied, but calcareous vertisols dominate.

Rain fed cereal production is the dominant land use. Legumes, olive (*Olea europaea*) and fruit trees are other crops cultivated at substantial scale. Nationally, the site is famous for its olive groves and oil. Local forest cover is extremely sparse. Limited market access and adoption of technological packages, land tenure constraints, illiteracy and land fragmentation hamper income generation from agriculture. A total of 25% of the rural population currently live below the poverty line. The area's rich cultural heritage, with the tomb of Idris I—an important place of pilgrimage for the country's Muslim population—and the world heritage listed Archaeological Site of Volubilis, support modestly developed tourism.

2.2. Data Collection and Analysis

Local knowledge about landscape scale variation of agricultural activity, existing agroforestry practices, ecosystem services of trees, and opportunities and constraints for tree-based diversification on farms was collected using knowledge-based system methods [21,22]. A scoping study was conducted, to gain an initial understanding of farming conditions and practices in the target area and provide a basis for the subsequent definition of interview strata. Scoping activities involved transect walks, conversations with local extension workers and focus group discussions with resident farmers (methods described in [23]).

Next, a purposive sample of willing and knowledgeable farmers (n = 32) were recruited for in-depth (1–2 h), qualitative interviews. Results from the scoping study suggested that stratification across an altitudinal gradient would be best suited to reveal variation in farming practices, socio-economic and agroecological conditions. Detailed local agroecological knowledge was elicited, using an iterative interview process. Interviews were conducted in Darija and then translated to English. Interview locations were outdoors on farms, whenever possible, allowing respondents contextual triggers, to explain their local knowledge.

Elicited knowledge was recorded using the AKT5 software system [24]. This involved tabulation of data to detect emerging themes and disaggregation of relevant knowledge into sets of unitary statements, represented using a formal grammar [22]. Formal terms were defined, illustrated with photographs and organised in object hierarchies (e.g., of farm trees and their irrigation requirements), where necessary and appropriate [24]. This knowledge was evaluated for coherence and consistency as it was collected, using a suite of automated reasoning tools [25] and a diagrammatic interface to explore connections among statements [26]. Information gaps that were identified during the development of unitary statements were addressed in subsequent interviews. Follow-up interviews (n = 13) of 1–2 h were conducted to gain deeper explanatory knowledge and resolve inconsistencies between different knowledge sources.

Three additional focus group discussions were held with shepherds, lower slope and mountain farmers towards the end of field activities, to validate and triangulate information that had been derived from depth interviews, and expand upon insights from the first interview round. Participant recruitment for these discussions was based on availability and willingness to partake. Knowledge about local policies, and the objectives and activities of extension services was derived from in-depths interviews with two experts of the Direction Provincial Agricole de Meknès and the Direction Régionale du Eaux et Forêts et de la Lutte Contre la Désertification du Moyen Atlas—Meknès. These expert interviews, together with a feedback session with researchers of the Centre Régional de la Recherche Agronomique de Meknès, and the International Center for Agricultural Research in the Dry Areas, facilitated a discussion and validation of preliminary findings.

3. Results

3.1. Characteristics of Farming Systems

Farming systems of respondent strata were set apart by differences in biophysical characteristics and dissimilar socio-economic traits at disparate landscape position. Five strata were identified. These included: (i) irrigation farmers, owning irrigated orchards located near Lkhammane River; (ii) lowland farmers, with properties situated in the fertile plain west of Moulay Idriss Zerhoun; (iii) lower slope farmers, cultivating farmland in the foothills of the mountain range; (iv) mountain farmers situated in the massif north and northeast of Moulay Idriss Zerhoun; and (v) livestock farmers (shepherds) primarily involved in livestock husbandry.

Respondents of all strata, except for shepherds, cultivated tree crops, cereals, legumes, forages and vegetables, but with dissimilar levels of commercial orientation, intensification and relevance of various agricultural practices (Appendix A). Figure 1 illustrates the stark contrast among dominant farming practices across strata.

Farm size varied both among and within strata and most respondents struggled to specify the exact size of their property, as fragmentation of cultivated land, lease of additional cropland and joint land ownership between family members were common. Two strata constituted exceptions to this trend: Most shepherds owned very small properties, just sufficient to house their families and livestock, but too small to support tree husbandry or crop production. Tenure rights of all lowland farmers had been formally recognised and documented in a process of land distribution, at the end of post-colonial French settlement.

Slope on farms progressively increased, from flat terrain on lowland farms, to steep slopes near ridges of the Zerhoun massif. Soil types on farms were diverse—with sediments in riparian areas along Lkhammane River, dark and fertile soils in the lowland plain, and white and red clay soils on mountain foothills and ridges.

All respondents, except irrigation farmers, depended on rain fed cropping practices, although access to motorised pumps allowed few lowland farmers to realise supplementary irrigation on small sections of their cropland, through traditional flooding, sprinklers or drip irrigation.

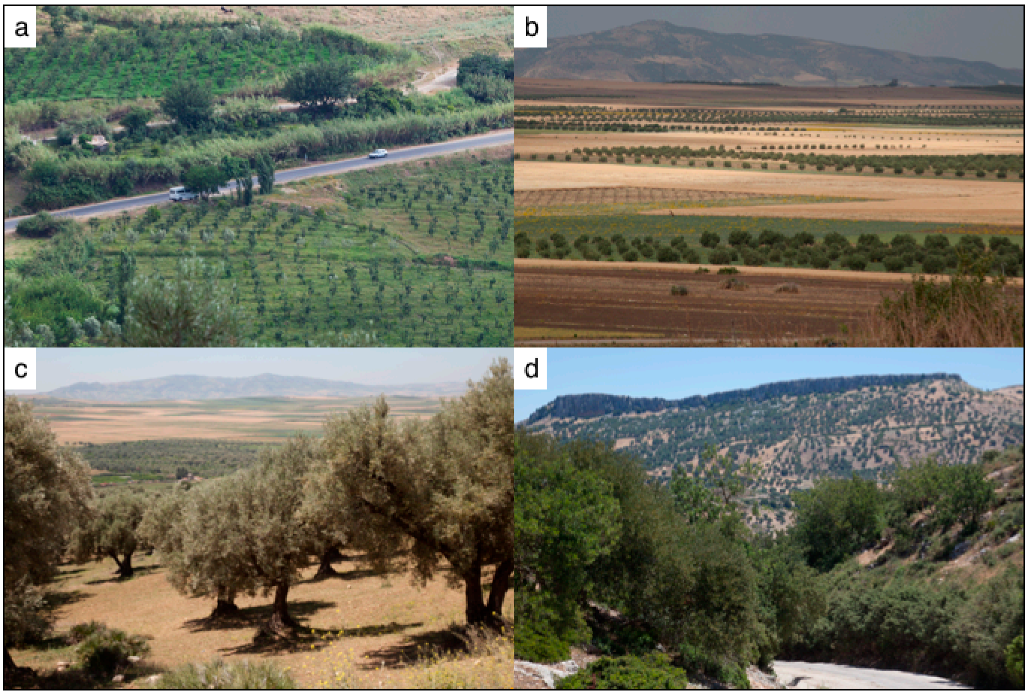

Figure 1. Typical farming systems across strata. The images contrast dominant farming practices of irrigation, lowland, lower slope and mountain farmers, depicting: (**a**) irrigated fruit orchards; (**b**) intensified cereal and legume cropping; (**c**) the transitional zone of annual cropland and mature olive stands; and (**d**) mixed olive and carob orchards, respectively.

Bi- or triennial rotation of cereals and legumes was practices on lowland, lower slope and mountain farms. Lowland farmers focused on commercial production, distributing their harvests via wholesalers or on regional markets. Production on lower slope and mountain farms, in contrast, was more subsistence oriented. Vegetables were primarily grown to meet household needs, except by irrigation farmers, who sold fruits from trees, vegetables and aromatic herbs locally and on regional markets. Tree crops, particularly olives, were a key source of cash income for lower slope and mountain farmers. Annual crop production and tree husbandry on lowland and irrigation farms were intensified, with frequent use of pesticides and synthetic fertilisers, respectively. Lower slope and mountain farmers managed their farms extensively, due to financial limitations and an affirmation of traditional agricultural practices and the region's socio-cultural heritage.

All strata, except shepherds perceived their farming practices as labour intensive, particularly during the harvest season for annual crops and olives. Labour shortages were aggravated by a lack of trust among family and community members, limiting collaboration. More affluent lowland and irrigation farmers hired seasonal workers to meet labour needs during the busiest times of the cropping season.

Most shepherds did not own land to grow trees, crops or forages for their herds, and thus relied on pastoralism—shifting rangelands across the landscape to follow a pattern of seasonal forage availability (Figure 2). With just enough land to provide night-time shelter for their herds, respondents heavily depended on access to forests, land under management of the Ministry for Endowments and Public Affairs, and olive groves and cropland in private ownership. Cows, goats and sheep, typically in flocks of 30–50 animals, were sold to realise cash incomes. However, not all shepherds owned the herds in their care; some respondents were hired workers, receiving their wages in form of profit shares, from the annual sale of livestock.

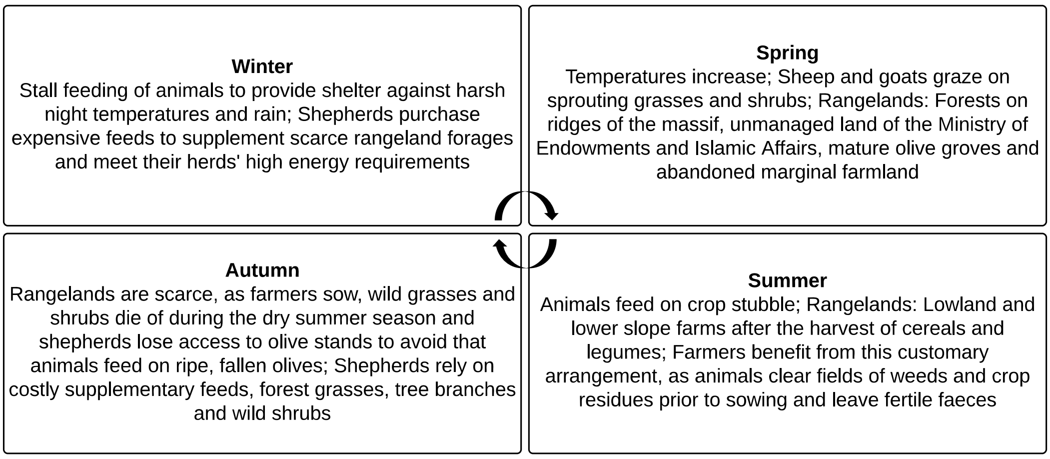

Figure 2. Pattern of seasonal forage availability and rangeland migration of shepherds.

3.2. Current Tree-Cover and Agroforestry Practices

A total of nineteen cultivated and seventeen wild or remnant tree species were observed or reported to grow on respondents' farms. Interviewees classified these species according to a basic typology that distinguished cultivated trees suited to rain fed farming, cultivated trees requiring regular irrigation, and wild or remnant trees on farms. Furthermore, species were either common or rarely cultivated (Table 1). Agroforestry practices were common to farming systems irrespective of strata. Yet the extend of tree cover on farms, and types of observed agroforestry, differed markedly among respondent groups. There was a trend of increasing tree cover on farms—following an altitudinal gradient from the plain west of Moulay Idriss Zerhoun, to properties situated within the mountain range to the northeast. Olive was, by far, the most prominent species on farms, except on irrigated land.

The primary production objective of most lower slope farmers was commercial cereal cropping. Olive boundary plantings were very common in this stratum, allowing farmers to meet domestic needs for oil and table olives, while limiting competition for water, soil and nutrients; and interference with mechanised crop production. Widely spaced olive orchards had been established recently, following governmental incentives under the Plan Maroc Vert or as part of on-farm trials of extension services. Mature olive stands dominated the steeply sloped farmland of lower slope and mountain farms, where carob (*Ceratonia siliqua*), fig (*Ficus carica*) and almond trees (*Prunus dulcis*) were also commonly cultivated. Following the example of other farmers in the greater region, a few lower slope farmers had begun to establish mixed stands of olive, fig, almond and pomegranate trees (*Punica granatum*), on former annual cropland in the foothills of the Zerhoun massif.

Irrigated fruit trees dominated the commercially orientated farming systems of all irrigation farmers. But such trees were few in number on lowland, lower slope and mountain farms, where they were typically cultivated in home gardens or in small clumps on cropland, solely to meet domestic needs. Agrosilviculture was practiced on all irrigated farms, were respondents intercropped vegetables, forages and aromatic herbs in fruit orchards. Forage cultivation and silvopasturalism in olive stands on lower slope and mountain farms was of great seasonal importance for livestock owners, to support their herds. Shepherds recognised tree branches and wild shrubs as important feed sources in times of forage scarcity, yet preferred to feed their animals grasses, cereals and legumes due to the greater nutritional value of these plants.

Living fences of *Acacia* sp., cacti and hedgerows of retained wild trees were common to extensively managed properties of lower slope and mountain farmers, were the number and diversity of wild trees were greatest.

Table 1. Tree cover and agroforestry practices by farming systems, according to farmers' local agroecological knowledge and observations.

Typology According to Farmers' Local Agroecological Knowledge	Tree Cover and Agroforestry Practices by Farming Systems			
	Irrigated Systems	**Lowland Systems**	**Lower Slope Systems**	**Mountain Systems**
Very common cultivated species; well suited to rain fed farming (*Olea europea*, *Ceratonia siliqua*, *Ficus carica*, *Prunus dulcis*)	Rare; single dispersed trees in fruit orchards	*O. europea* in widely spaced, immature orchards (10 × 10 m) on cropland; *O. europea* in boundary plantings along field boundaries; few or single *C. siliqua*, *F. carica* or *P. dulcis* on cropland and near houses	*O. europea* in mature orchards; few or single *C. siliqua* dispersed in *O. europea* stands; few or single *F. carica* dispersed on cropland; *O. europea*, *F. carica* and *P. dulcis* in recently established mixed orchards on former cropland in the foothills	*O. europea* in mature orchards; some recently established *O. europea* orchards and stands rejuvenated through pollarding; smaller *C. siliqua* and *F. carica* stands of various ages and single trees in home gardens; small orchards of *P. dulcis* and single trees in home gardens
Other cultivated species; well suited to rain fed farming (*Acacia* cf. *horrida*, *Agave* sp., *Opuntica ficus-indica*)	n/a	Dispersed or in small clumps near houses	Living fences in settlements and along field boundaries	Living fences in settlements and along field boundaries
Common cultivated fruit tree species; to some extend suited to rain fed farming (*Prunus armeniaca*, *Punica granatum*)	Single trees in fruit tree orchards	Single trees in mixed clumps of fruit trees or in home gardens near houses	Single trees in mixed clumps of fruit trees or in home gardens near houses; immature *P. granatum* in recently established mixed orchards on former cropland in the foothills	Single trees in mixed clumps of fruit trees or in home gardens near houses
Common cultivated fruit tree species; unsuited to rain fed farming (*Citrus* spp., *Cydonia oblonga*, *Morus alba*, *Prunus persica*, *Prunus* spp., *Pyrus* spp., *Vitis* spp.)	Dominant; mostly in recently established commercial fruit tree orchards; single dispersed mature trees, established by previous farmer generations	Individual or clumps of up to ten trees on cropland or in home gardens near houses	Individual or clumps of up to ten trees on cropland or in home gardens near houses; *Vitis* spp. on extensively managed or semi-abandoned farmland near ridges	Individual or clumps of up to ten trees on cropland or in home gardens near houses; remnant and declining *Vitis* spp. established by previous farmer generations in orchards or on cropland
Rare cultivated fruit tree species; unsuited to rain fed farming (*Eriobotrya japonica*, *Malus domestica*, *Ziziphus jujuba*)	Single *E. japonica* and *Z. jujuba*; few *M. domestica* in decline	Single trees on cropland	n/a	n/a
Wild or remnant species on farms (*Arbutus unedo*, *Celtis australis*, *Fraxinus* cf. *angustifolia*, *Tamarix* cf. *aphylla*, *Chamaerops humilis*, *Crateagus* sp., *Cupressus sempervirens*, *Eucalyptus* spp., *Nerium oleander*, *Olea europea var. Oleaster*, *Pinus* spp., *Pistacia atlantica, Pistacia lentiscus*, *Populus* sp., *Quercus* cf. *rotundifolia*, *Ricinus communis*, *Ziziphus lotus*)	Rare; alongside stream banks	Very rare; dispersed alongside roads or field boundaries; few remnant trees near houses, established during post-colonial French settlement	Commonly retained in hedgerows along field boundaries; few remnant trees near houses, established during post-colonial French settlement; wild shrubs and trees on extensively managed or semi-abandoned farmland near ridges	Commonly retained in hedgerows along field boundaries; alongside roads and stream banks on cropland

3.3. Niches for Farm-Trees and Perceptions about Tree-Based Diversification

Respondents from all strata valued farm trees for their provisioning services, supplying households with commercial tree-crops, fruit for subsistence consumption and, in case of livestock owners, supplementary forage and shade for their animals. There was, however, limited understanding of the regulating capacity of farm-trees and farmers expressed little appreciation of potential negative consequences for livelihoods, should regulating services decline. Only two irrigation farmers had actively established trees on stream banks on their properties, to control erosion alongside streams and Lkhammane River.

All farmers were eager to raise their households' income, and most had therefore great interest in increasing or diversifying tree cover on their farms. And they wished to improve their tree management practices, to capitalise on commercial opportunities. However, disparate production objectives and existing tree-cover on farms caused notable differences in respondents' perception about desirable species and potential niches for new farm trees. Strata agreed that there were fundamental differences between lowland, lower slope and mountain farms. The former was best suited for annual crop production, while commercial tree orchards belonged to the latter farm types—with their steep terrain and clay soils. On lower slope and mountain farms trees had been central to livelihoods for generations.

Lowland farmers perceived tree husbandry as more labour intensive than crop cultivation, which constituted an adoption barrier. There was also little commercial interest in expanding olive tree stands, as farmers currently lacked opportunities to sell their harvests from this species. Tree based diversification with irrigated fruit trees, in contrast, was perceived as particularly favourable, as farmers expected great financial returns from cultivating those species. There was, however, also interest in expanding the range of species adapted to rainfed farming conditions, and tree-crops that could be stored, sold and consumed locally—such as figs. Most respondents would welcome authorities to provide seedlings for a range of drought tolerant species, e.g., fig, almond and pomegranate, rather than focusing solely on the promotion of various olive varieties. Farmers did not perceive income opportunities, and were therefore not interested in planting woody species locally classified as "wild trees". Farmers further believed that the sale of wild trees—if cultivated outside of forests, on private farms—would require costly permits from the forest authority.

3.4. Perceived Barriers to Tree-Based Diversification

Farmers identified three interlinked barriers to tree cover increase and tree-based diversification in the study area: water scarcity, the low profitability of their agricultural production systems and uncontrolled livestock grazing. At the time of the field campaign, these barriers formed a set of chronic pressures, which in combination reduced the resilience of smallholder livelihoods and agroecosystems in Zerhoun.

3.4.1. Water Scarcity

Water scarcity was the most important factor limiting tree vitality, productivity, grafting success and intercropping on farms across all strata. Respondents experienced the local biophysical environment as drought prone, and negatively affected by limited regional ground water availability. In recent years, shifts in precipitation patterns had been witnessed locally. Commercial fruit tree species could not be maintained in the absence of irrigation during the dry season, and even species tolerant to drought required supplementary irrigation for the first five years after establishment. Dieback of grape vines, fruit and fig trees—attributed to increasing water scarcity in past decades—concerned lower slope farmers.

Although all respondents agreed on the effects of this barrier, there were dissimilar perceptions of underlying factors among strata (Figure 3). Dependence on rain-fed cultivation practices severely restricted production opportunities of lowland, lower slope and mountain farmers, who had no or very little access to irrigation infrastructure. Several lowland farmers owned wells, but legislative restrictions on admissible water extraction levels and lack of investment capital resulted in minimal uptake of drip-irrigation technology or instalment of sprinkler systems. Some respondents knew about state subsidies for drip-irrigation technologies, covering up to 80% of accrued installation costs. However, concerns about overlong reimbursement periods, bureaucratic approval procedures that involve multiple authorities, and existing outstanding depths with the agricultural bank hindered lowland farmers from seizing this opportunity.

Unfavourable topography and the lack of surface water bodies prevented the construction of wells and irrigation with pumps, on most lower slope and mountain farms. Great depths to the groundwater table and bedrock material made the excavation of well-shafts labour and cost intensive—unattainable without heavy machinery, and in the absence of subsidies. Restrictive tenure rules prevented the expansion of irrigation infrastructure on leased cropland in the foot slopes of lowland farms. Irrigation farmers were least affected by water scarcity, irrigation their property, following scheduled, inherited water extraction rights, associated with each landholding. Yet, these respondents were concerned about the vulnerability of their farming systems in the event of declining (irrigation-)water availability. This was fueled by experiences of tree dieback and the regression of irrigated land, as surface water bodies and natural springs dried up during drought events; and an impending re-allocation of local water resources to a tourism enterprise, likewise perceived as threatening, by the lower slope respondents.

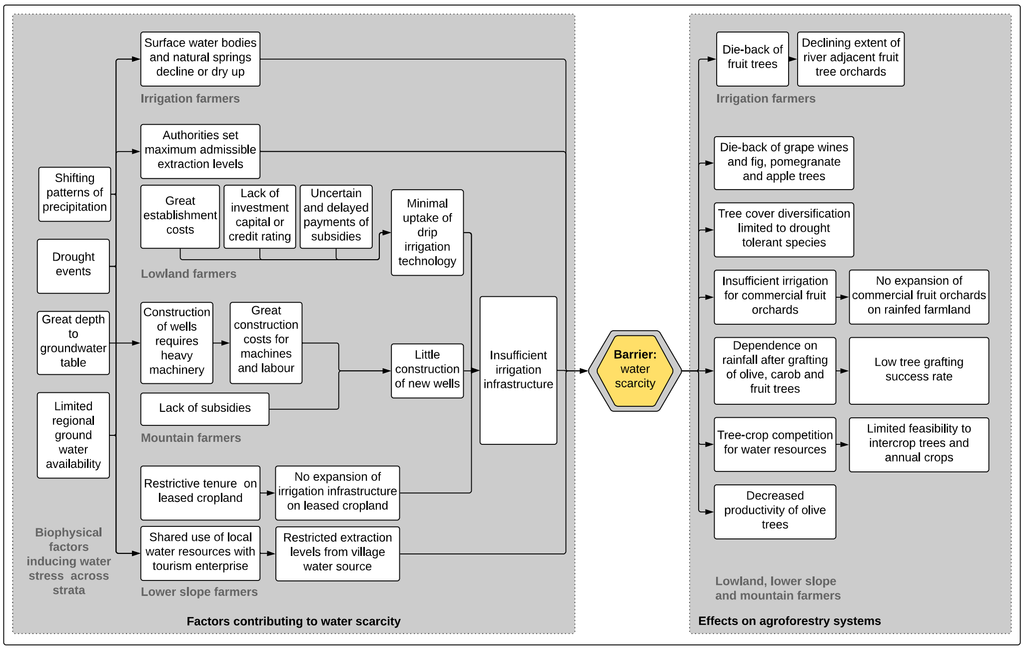

Figure 3. Water scarcity. Causal diagram of water scarcity as a barrier to tree planting and tree-based diversification and its effects on agroforestry systems.

3.4.2. Low Profitability

Low profitability of smallholder production systems was the second identified barrier to tree-cover increase and tree-based diversification, reducing farmers' motivation to engage in farming activities and causing a need for (rural) off-farm employment (Figure 4). Respondents adapted through a diversification of livelihood activities. There was a growing number of shepherds and absent landowners, and a trend of youth migration to urban areas and Europe. Remaining farmers were often reluctant or unable to direct labour or financial resources towards tree husbandry and consequently abandoned marginal orchards or traditional management practices e.g., the excavation of pits to catch run-off near the base of trees, despite authorities' efforts to encourage tree planting and improved tree-husbandry in the study area.

Factors causing low profitability were numerous: Population growths and the traditional order of succession had led to a severe fragmentation of landholdings on lower slope and mountain farms, which were furthermore difficult to access, due to their often steeply sloped terrain and an underdeveloped road infrastructure. This increased the already great labour intensity of commercial tree cultivation, particularly problematic in absence of collaboration amongst farmers and family members in all strata. Most lowland, lower slope and mountain farmers were adversely affected by production shortfalls, losing labour and financial investments due to increasing pest and disease pressure, unpredictable rainfall patterns or drought. Browsing damage from small ruminants in the mountains and lack of crop shortfall insurance for lowland farmers aggravated the situation.

The range of cash crops that could be grown on rain-fed farms was limited, leaving farmers, who expected greater support from governmental authorities, frustrated about missed commercial opportunities. Lowland and lower slope farmers lacked market access for their tree products, particularly olive oil and suffered from great price volatility. Markets where oversaturated after normal yields, and thus demands primarily arose during unproductive years, when olive oil was in scarce supply. Respondents aspired to access European markets, but were convinced that larger scale farms gained preferential market access and that higher-level corruption and blending with sub-standard quality oil along the trade chain, had caused the termination of previous trade agreements with the continent. Consequently, many farmers stored olive oil from several production years in their homes, hoping for opportunities to sell, in coming years.

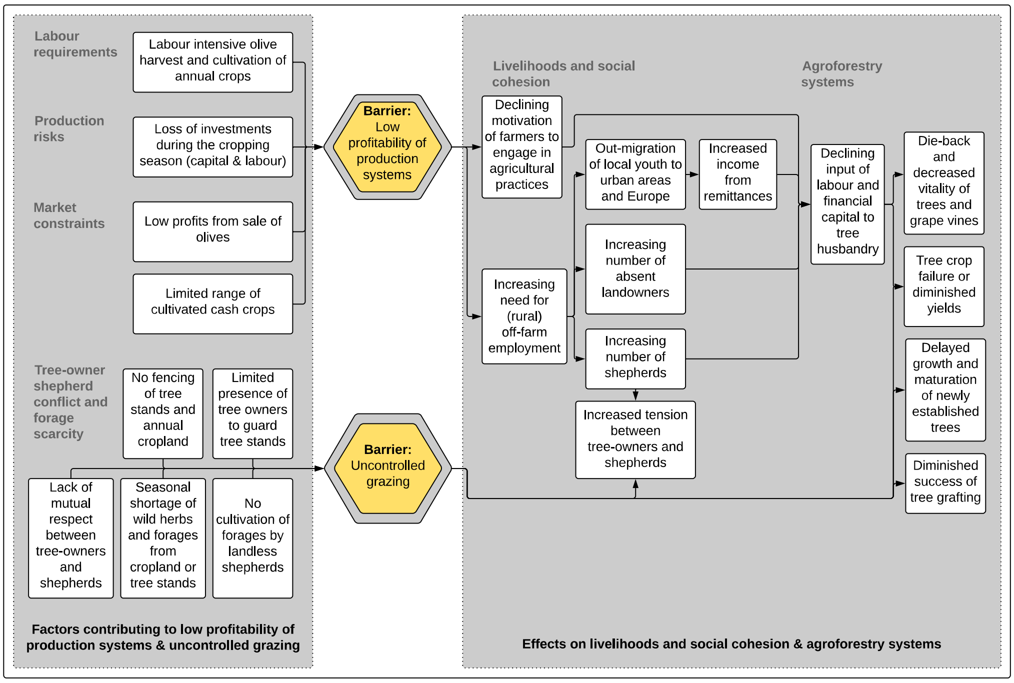

Figure 4. Low profitability and uncontrolled grazing. Causal diagram of low profitability and uncontrolled grazing as barriers to tree planting and tree-based diversification and their effects on livelihoods, social cohesion and agroforestry systems.

3.4.3. Uncontrolled Grazing

Grazing pressure was a third substantial barrier to tree planting and tree-based diversification in Zerhoun. Farmers with orchards on lower slopes and mountains, which were accessed by shepherds to graze their herds, suffered ill-effects of uncontrolled grazing—including the death of immature trees and substantially declined or delayed yields of tree crops. These farmers further reported that shepherds regularly cut-off tree branches, to feed their herds (Figure 4). The threat of destruction and potential loss of financial investments required to establish trees, prevented afforestation of otherwise suitable cropland and gave rise to tension within communities.

Tree owners and shepherds attributed the conflict to different sets of contributing factors. Tree owners identified shepherds' limited access to rangelands, a lack of stables and knowledge about zero-grazing practices, and increasing landscape scale tree-cover as causes. Respondents were unable to prevent browsing, as fragmentation and engagement in off-farm wage labour made it impossible for farmers to guard their tree stands against trespassing, and respondents lacked funds to invest in fencing. Shepherds, in contrast, felt that blame for damage to trees was illegitimate. Browsing in tree stands was perceived to be justified, as tree owners themselves abandoned their orchards, due to their low profitability and farmers' lack of motivation. Shepherds were unable to support their herds by other means, as they rarely had access to cropland or investment capital to cultivate forages, received no support from extension services, and experienced a steep rise of prices for purchasable feeds. Some shepherds perceived tree planting across strata as a severe threat, which could aggravate the scarcity of accessible rangelands. Others believed that sufficient cropland would remain to support their herds. Lowland farmers did not fear trespassing in their tree stands, convinced that they were able to ensure prosecution for violation of their property rights.

3.5. Entry-Points for Tree-Based Adaptation, and Identified Extension and Innovation Priorities

Respondents identified several entry-points for the development of tree-based adaptation options, and could imagine adopting landscape approaches to overcome current barriers to tree-based diversification, including: (i) the improved management of local water and soil resources; (ii) the delivery of targeted extension services, focusing on management practices for trees; and (iii) conflict-mitigation and improved livestock husbandry by shepherds.

Small landslides, gully formation on rainfed farms, and bank erosion on irrigated farms—caused by extensive winter rain, soil compacting and seasonally scarce groundcover—rendered farmland unproductive, obstructed machine operation on cropland, and posed a hazard to livestock. Several lowland farmers thus identified erosion channels as a potential niche for tree establishment in their otherwise intensified cropping systems. Irrigation farmers were likewise interested in combating erosion, and two respondents had begun to establish trees to stabilise soil on stream banks. Other suggestions for improved water management included water harvesting to irrigate trees on lowland farms, and subsidies to maintain and repair existing irrigation channels and basins of irrigation farmers.

Respondents also perceived a need for targeted extension services, to overcome critical knowledge gaps about tree husbandry, which would allow them to realise greater profits from their tree-crops. Lowland and lower slope farmers required extension services to identify tree and crop species best suited to soil and water resources available on their farms. All strata, except shepherds, expressed an urgent need for knowledge development about best practice phytosanitation, and subsidies to purchase agro-industrial inputs. Irrigation, lower slope and mountain farmers had knowledge about advantages of tree grafting to increase the yield of carob trees, and utilise drought tolerant local rootstock. However, technical knowledge gaps limited respondents' grafting success, and interviewees expressed interest in attending grafting workshops. Mountain farmers thus hoped to unlock new income opportunities, as they strove to graft hedgerows of hawthorn and mastic trees with commercial fruit tree species. Farmers also expressed a need for support to overcome mistrust and conflicts among community members, to facilitate collaboration—such as joint commercialisation of products, shared use of farm machines and joint maintenance of fragmented tree stand.

Ideas to mitigate the tree owner–shepherd conflict, and avoid future browsing damage to trees, included knowledge development of shepherds, to facilitate zero grazing practices; the establishment of living fences, with species of commercial utility such as prickly pear, agave or fig trees; and the mitigation of forage scarcity, through preferential and subsidised lease of community land to local shepherds.

4. Discussion

The objectives of this study were to characterise local farming systems, identify niches for farm-trees within these systems and explore farmers' perceptions of barriers to a tree-based diversification of their farms and livelihoods. The derived insights are prerequisites for the identification of tree-based adaptation options, suited to increase the resilience of northern Moroccan farming systems, to the dual threat of water scarcity and food insecurity.

4.1. Farming System Characterisation with Local Agroecological Knowledge

Based on a classification of Middle Eastern and North African countries, Northern Moroccan farming systems have previously been characterised as rain fed mixed systems [13]. Although useful to obtain an overview of regional development priorities and agricultural practices, this characterisation inadequately captures the local landscape-scale variation of farming systems in Zerhoun. We found that fine scale variation of farming systems and current agroforestry practices was characteristic of the study site. Strata-specific differences in social, economic and environmental adaptation context, which the respondents identified, were manifest in a pattern of intensified farming and low tree-cover on rain-fed lowland farms. In contrast with extensive farming, and high tree-cover, further within the mountain range of Zerhoun. Lower slope farms, at an intermediate landscape position, lay within this spectrum. Shepherds—who seasonally shifted rangelands, and irrigation farmers—who cultivated irrigated fruit orchards, were distinct exceptions to this pattern.

Attributes of lowland farms that were observed in the present study match those of the rain fed mixed systems category of international classifications [13]. However, lower slope, mountain farms and shepherds had characteristics corresponding to both rain-fed mixed systems, and highland mixed systems [13], whereas irrigated farms matched the description of large-scale irrigation subsystems [13].

This partial mismatch of standard classification schemes, and observations and results of local agroecological knowledge research, likely arises from unequal scales of analysis. It is problematic, as Dixon, Gulliver and Gibbon [13] outline strategic development priorities for farming system categories, which would be an adequate foundation to design development interventions—if target systems and classification categories were matched correctly. Our results, however, demonstrate that local knowledge methods capture the local landscape scale variation of farm characteristics, farming systems and adaptation contexts at much greater detail, and are thus locally more accurate. Our research refines the resolution of existing classifications, and bridges knowledge systems, thereby enabling researchers and extension agents to translate established classifications and development priorities into interventions that target specific farmer groups, rather than offering one-size-fits-all solutions.

In absence of respective records [19,27], local knowledge research provided a means to rapidly assess existing agroecological conditions and agroforestry practices at our study site, at the local landscape scale. Such assessments are vital for the identification of tree-based adaptation options, and the closure of knowledge gaps about tree husbandry, pest and disease management, commercial opportunities for tree crops, or species suited to diversify existing tree-cover on farms, which were evident among respondents in Zerhoun. Farmers of different strata, engaged in agriculture in different farming contexts. Therefore, they exhibited unequal knowledge gaps and perceived disparate extension and innovation priorities. Identifying respondents' needs and aspirations at strata level, the present work adds depths and facilitates the conception of adaptation options, and the operationalisation of adult education interventions, to meet extension needs that have been recognised by sectoral experts and relevant authorities, at higher administrative scales [1,27,28].

4.2. Overcoming Adoption Barriers through Co-Learning and Cooperation

Our analysis shows that farmers faced a complex, interlinked set of barriers to tree-cover increase and diversification—the most prominent being water scarcity, low profitability of smallholder production systems, and shepherd–tree owner conflict.

Biophysical factors, such as the natural water scarcity of the production environment, pest and disease pressure and the unfavourable topography of lowland and mountain farms certainly contributed to these barriers. Yet, in line with Kadi and Benoit [1] our analysis indicates that socio-economic and cultural factors were of at least coequal importance as factors shaping local adaptation contexts, and respondents' (non-)adoption decision-making. Zerhoun's farmers worked primarily individually. Collaboration among households was limited—even on lowland farms, where respondents were formally organised in an association. This lack of joint resource management was attributed to a mutual distrust in the working morale of extended family and community members. Low or declining social capital of Moroccan smallholders has been ascribed to the destabilisation of rural communities, as a result of labour migration to urban centres [29]. And there is evidence of below country average trust amongst rural neighbours in northern Morocco, and of very low cooperation levels in agricultural associations [30].

This situation is unfortunate, as expert interviews confirmed that farmers' formal organisation in associations is a pre-requisite to gain access to almost all extension services under the Plan Maroc Vert; and to receive support from other government agencies. Farmers' frustration and distrust in extension agents confirmed the emphasis from Coe, Sinclair and Barrios [17] on the importance of a supportive institutional environment and adequate delivery mechanisms, to foster adoption of agroforestry options. Our research indicates that increased profitability of Zerhoun's farming systems will unlikely be achieved without substantial institutional support and public investment, to compensate for farmers' lack of capital to make investments or even maintain traditional infrastructure; and strengthen their position in regional and global markets. Institutions implementing the Plan Maroc Vert should facilitate tree-based diversification as envisaged by farmers, rather than an expansion of monoculture olive plantations. Such interventions could help to overcome at least some of the currently substantial barriers to tree-based adaptation in the area, and thus shift farming systems towards more resilient development pathways. With diversified income from portfolios of tree species, which provide a wide range of tree-crops. The severity of vulnerabilities arising from global change pressures, on contemporary farming systems in northern Morocco may, however, ultimately result in—or require—active development interventions that foster more "radical transformational change to a completely different system" [31] (p. 9) to sustainably meet future livelihood needs.

Yet, successful research and adaptation initiatives in different dryland countries, demonstrate that barriers such as water scarcity, low profitability and uncontrolled grazing can, in some contexts, be overcome if social capital among farmers can be increased and co-learning processes of farmers, researchers and extension agents are being successfully initiated. Enhanced collaboration among farmers could facilitate improved access and management of scarce water resources in the study area. Positive experiences with the formation and training of water user associations have already been made elsewhere in Morocco [32]. They could thus inform attempts to replicate successes across national scaling domains. Such water user associations could also provide a platform for the development and implementation of community level rainwater harvesting [33]. Cooperation may further allow farmers to benefit from economies of scale, to improve their bargaining power, or receive agro-chemical inputs and training from extension agencies [34] to increase the profitability of their farming activities. Extension agents could provide training in low-cost phytosanitary measures, such as pruning [35], or the application of bio-pesticides that can be made from locally available spices, essential oils, soap or alcohol [28]. Conservation agriculture techniques, relying on soil cover increase and reduced tillage [36] are options to mitigate erosion and increase the water holding capacity of soils to facilitate tree establishment. However, such techniques can only achieve substantial results if they are implemented by a majority of farmers. Livestock owners in our study area may benefit from lessons learned, from a community centred approach that was implemented in Oudja, Morocco, and combined local knowledge and scientific expertise to overcome rangeland degradation, and secure the livelihoods of rural shepherds [37].

Further synergies for the development of agroforestry adaptation options in the study area could likely be realised through a combination of results from local knowledge research as presented in this study, with findings from more quantitative approaches to inquiry, e.g., socio-economic assessment of farmers' income and livelihood assets or assessments of local soil conditions and watershed resources. Or expert knowledge about regional, national and international structural constraints to the sustainable development of smallholder farming systems in dryland areas.

5. Conclusions

We investigated tree-based (i.e., agroforestry) options to adapt northern Moroccan farming systems to climate change impacts, and shift smallholder livelihood systems in this area onto more resilient trajectories. Our analysis of farming systems, niches for farm-trees, and barriers to tree-based diversification in northern Morocco illustrates, that the explicit incorporation of local agroecological knowledge strengthens agroforestry and climate adaptation research: The discriminatory power of local agroecological knowledge facilitated the assessment of local-scale variation in socio-economic and agroecological adaptation contexts, and pin-pointed disparate perceptions about adoption barriers among different strata of farmers in our study area. Further, local knowledge methods unveiled factors that respondents perceived as most decisive to decision-making about their livelihoods, farming systems and adaptation options. And they highlighted locally perceived extension and innovation priorities.

Results from local knowledge research, however, are typically qualitative and inherently place-specific—the focus of inquiry rests on individual farmers' agroecological knowledge and perceptions of local landscape scale processes and farming contexts. Obtained insights can thus not readily be generalised to settings elsewhere in the same country, or internationally. The approach, therefore, lends itself to application in combination with modelling and geo-spatial analysis, or detailed quantitative socio-economic and biophysical assessments. Within such mixed-methods research portfolios, local knowledge methods could thus serve as a tool for exploratory inquiry, to establish robust knowledge foundations and system understandings, upon which stakeholders could base decisions making about priorities for further quantitative, disciplinary inquiry. Local knowledge research could further add in local innovation processes for adaptation options that can be readily scaled-out—if relevant contextual factors, determining adoption decisions, are well understood through local knowledge inquiry. And if relevant scaling domains can be identified with complementary tools. Hence, this method may be particularly useful for academics, research or extension agencies, and other stakeholders with an interested in understanding socio-ecological system characteristics and processes at local landscape scale. And for those who work to foster sustainable livelihoods and farming systems, through site specific climate adaptation or rural development interventions.

Based on these insights, we judge local knowledge research and its findings to provide a robust and solid foundation for policy formulation, and the co-development of successful climate adaptation strategies in Morocco, and across the Mediterranean drylands.

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Appendix A

Table A1. Characterisation of farming systems in Zerhoun.

Characteristics	Farming Systems				
	Irrigated Systems	**Lowland Systems**	**Lower Slope Systems**	**Mountain Systems**	**Pastoral Systems**
Farm size	Up to 20 ha	≤9 ha	Variable	Variable	Very small land holdings
Bio-physical conditions	Variable terrain (flat to steep) Erosion of river/stream banks High soil fertility Traditional flood irrigation (seguas, motorised pumps)	Flat terrain Low erosion High soil fertility (black soils) Rain fed with supplementary irrigation on minor areas	Moderate slopes Moderate to high erosion Moderate to low fertility (clay soils) Rain fed	Moderate to steep slopes Moderate to high erosion Moderate to low fertility (clay soils) Rain fed	Rangelands span lowland, lower slope and mountain systems, state forests and land administered by the Ministry of Endowments and Islamic Affairs
Agricultural systems	Predominantly commercial Cash crops: Fruit from irrigated orchards Vegetables and aromatic herbs Irrigated forages (e.g., maize) Domestic consumption: Fruit and vegetables	Predominantly commercial Cash crops: Wheat, white onions, fava beans, chickpeas, lentils Domestic consumption: Olives (table and oil) and fruit Legumes, cereals, vegetables Green forages for livestock	Commercial and subsistence Cash crops: Olives (oil) Surplus production of wheat, fava bean, chickpeas Domestic consumption: Olives and fruit Legumes, cereals, vegetables Oat and barley for livestock	Commercial and subsistence Cash crops: Olives (oil), carob seed pots, figs, some almonds Domestic consumption: Olives and fruit Legumes, cereals, vegetables Oat and barley for livestock	Commercial Income source: Rearing of small ruminants and cattle for meat production
Level of intensification	Intensive cultivation of fruit trees Great reliance on manual labour	Intensified cereal production; seeds and agro-chemical inputs Tractors and harvesters for cropland preparation, sowing and harvest of cereals	Annual cropping systems (foothills) resemble those of lowland farmers, partly machine accessible Extensive management of mature olive stands	Extensive cultivation of tree stands and annual crops Great reliance on manual labour	Low; open rangeland grazing
Key threats	New tree pests and diseases Stream bank erosion Potential loss and conflict over water resources Declining water resources and deterioration of irrigation infrastructure	Drought events and changing precipitation patterns Increasing pest and disease pressure Increasing costs for agro-chemical inputs Adverse market trends (cereals) Debt with agricultural bank	Drought events and changing precipitation patterns Olive pests and diseases Adverse market trends (olives) Damage to trees and crops from browsing livestock Loss of access to village water resources	Drought events and changing precipitation patterns Damage to trees and crops from browsing livestock Increasing need for off-farm employment Tree pests and diseases	Livestock diseases Increasing costs for supplementary forages (winter) Conflict with tree-owners and state forest staff over access to rangelands

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