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Determinants of Smallholder Maintenance of Crop Diversity in Morocco's High Atlas Mountains

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Abstract
Smallholder farmers are important managers of global crop diversity. However, agricultural modernization is changing farming practices and raising questions about the socio-ecological factors that support crop diversity. In the context of the semi-arid High Atlas Mountains in Morocco, we explored determinants of crop diversity through a cross-sectional survey and farmer interviews in villages adopting new crops such as apples. Through a multiple linear regression analysis and farmer interviews, we found that market participation, land holdings, and water access influenced crop diversity. We highlight the importance of water access for crop diversity, especially in semi-arid regions with uneven hydrological resources.

Key Words: Agrobiodiversity, crop diversity, arid climate, water access, apple cultivation, market integration, High Atlas Mountains, Morocco

Introduction

Global environmental and social changes present new challenges for maintenance of local agrobiodiversity (Zimmerer 2010a). Agrobiodiversity encompasses all components of biological diversity of relevance to food and agriculture, including the biological diversity that constitute agricultural ecosystems (e.g. animals, fungi, plants, and micro-organisms) at the genetic, species, and ecosystem levels (Thrupp 2002). Agrobiodiversity supports agroecological functions such as pollination and nutrient cycling that are important for overall plant productivity and resilience to environmental disturbance (Frison *et al. 2011*). Most studies assess agrobiodiversity using a proxy measure such as the number of crop and livestock species or varieties of a single crop in a particular system or household farm (i.e., Skarbø 2014). More rarely, studies use plot-based assessments of all species present in the system, including non-cultivated ones (Brookfield 2002). We look at food crop diversity, measured by the number of food crops, which is one component of agrobiodiversity that provides important human and environmental benefits.

Crop diversity is important because it supports the stability and quality of food supply along with providing environmental and production benefits. At the national scale, increasing crop diversity is associated with year-to-year stability of the food supply (Renard and Tilman 2019). Moreover, as agricultural systems and diets around the world are becoming more homogenous and less diverse (Khoury *et al.* 2014), on-farm species richness can improve household dietary diversity and nutrition (Jones 2017; Powell *et al.* 2015). This is especially important when global markets and climates

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become unstable (Frison *et al.* 2011; Johns *et al*. 2013; Thrupp 2002).

Crop diversity may also be positively associated with a wide range of environmental benefits. Farm management that incorporates agroecological practices, such as rotating and mixing different crops, can reduce dependence on agrochemical inputs and increase insect biodiversity (Altieri *et al.* 2017; Davis 2012; IPES-Food 2016).

Global market integration is a key factor that is changing smallholder maintenance of crop diversity (Thrupp 2002; Zimmerer and de Haan 2017). Globalization and market integration expose local agricultural systems and livelihoods to global economic, political, social, and cultural pressures (Padoch *et al.* 1985; Rueda and Lambin 2013). Market integration drives agricultural intensification and land use change, increasing access to and pressure to use agricultural inputs, and changes in livelihoods, migration, and on-farm labor availability (Zimmerer *et al.* 2015). Zimmerer *et al.* (2019) describe how poorer and wealthier farmers tend to conserve diversity, while those in between do not. At the community level, market integration might lead to changes in local seed markets that are important for maintaining crop diversity (Patel *et al.* 2015; Pautasso *et al.* 2013).

These factors shape the maintenance of crop diversity in complex, often place-specific ways. While agricultural intensification through establishment of monocultures has a negative impact on agrobiodiversity, Zimmerer (2013) found that peach intensification in Bolivia did not negatively impact agrobiodiversity of maize cultivars. Proximity to markets is often associated with lower crop diversity (Abebe 2013; Gauchan *et al.* 2005), while other case studies have shown that market participation does not decrease species richness or agrobiodiversity (Garcia-Yi 2014; Major *et al.* 2005; Trinh *et al*. 2003; Williams *et al.* 2018).

Household socioeconomic factors are also important to the maintenance of agrobiodiversity. Work led by Coomes and colleagues has shown that wealthier households have access to more plant material and knowledge, which helps them to maintain higher crop diversity (Coomes and Burt 1997; Coomes and Ban 2004; Perrault-Archambault and Coomes 2008). In Nepal, Gauchan *et al.* (2005) found rice diversity to be associated with distance to market, subsistence ratio, sale of a modern rice variety, land types, and adult labor. Changes in labor and migration are also increasingly noted as key factors shaping agrobiodiversity (Bellon and Brush 1994; Bhattarai *et al.* 2015; Zimmerer 2013, 2014). There are also important and complex relationships between gender, women’s labor, migration, and crop diversity, especially in the context of agricultural intensification (Bhattarai *et al.* 2015; Zimmerer *et al*. 2015). For example, in some contexts women play a central role in seed systems and protection of diversity in home gardens (which are often sites of exceptionally high crop diversity) (Greenberg 2003; Trinh *et al.* 2003).

We present a case study from communities in Morocco’s High Atlas Mountains. Morocco is home to high levels of agrobiodiversity (Hmimsa and Ater 2008) and is a center of diversity for several crops including barley, durum wheat, fava bean, and figs (Khoury *et al.* 2016). Nonetheless, agricultural practices have changed in the last century. Starting with the French Protectorate (1914-1956), new crops, notably apples and citrus, were introduced to the High Atlas and other parts of Morocco. These crops have gradually been adopted by more producers and have spread to new regions, becoming major cash crops. We seek to understand how market participation through cash crops affects crop diversity in relation to other determinants of crop diversity (including land tenure, wealth, water access, etc.).

Methods

Study Area

Morocco is situated in the Maghreb region, located in northwest Africa and surrounded by the Atlantic Ocean to the west, the Mediterranean Sea to the north, and Algeria and Mauritania to the east and south. Morocco contains many mountain regions that create climatic gradients between the coastline and the desert.

The High Atlas Mountain Range extends from the Atlantic Ocean to the Algerian border between the smaller Anti-Atlas and Middle Atlas Mountain Ranges that run more parallel to the Atlantic Ocean (Fig. 1). We conducted field work in Toubkal commune, south of Jbel Toubkal, the highest peak in the High Atlas (4167 m). Toubkal commune is situated on the southern and eastern slopes of the High Atlas. The area is part of the watershed for the Souss-Massa river, which empties into the Atlantic at Agadir (Choukr-Allah *et al*. 2017). The elevation ranges from 1200m – 2100 m and climate and agriculture are shaped significantly by elevation (through water access, growing season, and frost vulnerability). The temperature in the study site varies from –10° to +42°C. Most of the rainfall occurs between October and April, and ranges from 215-300 mm annually (Personal Communication with Monssef Ettalbi March 2019; Auclair *et al.* 2011). Research applying climate models in the region predict that the area is likely to continue to become drier and hotter during this century (Baba *et al.* 2018; Marchane *et al.* 2017; Rochdane *et al.* 2012; Simonneaux *et al.* 2015).

The area lies within the Mediterranean hotspot for global biodiversity: the High Atlas Mountains are especially important as a hotspot of endemic plant diversity in the region, containing important populations of oak, Atlas cedar, and juniper species (Medail and Quezel 1997; Myers *et al.* 2000). There are 44 villages with 8489 inhabitants in Toubkal commune (Haut-Commissariat au Plan du Maroc 2014). Most people practice agropastoralism that incorporates animal husbandry and cultivation of grain, vegetables, fodder, medicinal and aromatic plants, and tree crops on irrigated terraces (Barrow and Hicham 2000; Montanari 2013). Local livelihood strategies and farming techniques vary with water access and elevation.

Study Design and Data Collection

We used a cross-sectional study design to assess household farm management practices in 12 villages. Villages were selected to achieve stratification across two factors: elevation and apple production (proportion of households producing apples and quantity of apples produced by the whole village), as a proxy for more general cash crop production. While our goal was to have an equal number of villages evenly distributed across these two selection criteria, the actual sample of villages was not evenly distributed across stratification categories because apple production was more common at lower elevations and there were few villages with high levels of apple production at the highest elevations (Table 1).

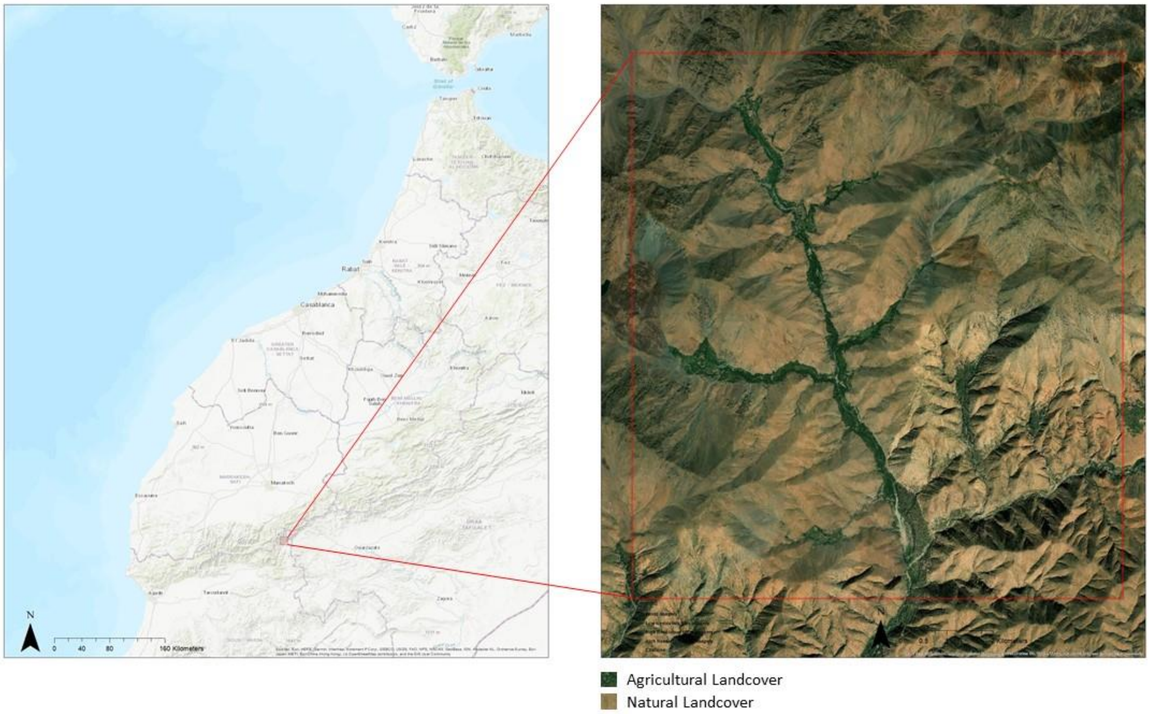

Figure 1: Approximate of Location (Left) and Satellite Picture (Right) of Study Area

Table 1: Distribution of 12 Selected Villages across the Two Primary Selection Criteria: Apple Production and Elevation

	1600-1800m	1800-1950m	1950-2100m	2100-2300 m
High market-oriented apple production (more than 5 producers)	3	1	0	2
Low market-oriented apple production (5 or less producers)	0	2	3	1

Within each of the 12 villages, 10 households were randomly selected from a list of names provided by the village leaders (the *Jmaat*). Numbers were randomly assigned to all the names on the list and the first ten were selected and approached to participate in the survey. Households were excluded because of an extended absence from the village, sickness, or, in a few cases, requests not to be surveyed; in these cases, the next household on the list was approached to replace them. We collected survey data primarily in homes but also in cafes, shops, and public spaces. Surveys and interviews were conducted in Tashelhit, the local dialect of the Amazigh language, with the translation by our research assistant Mr. Hassan Akorsal, and in the presence of the first author. Working with a local research assistant, who was very familiar with many of the villages and participants, likely discouraged reporting bias and helped ensure that cases of misreporting were identified. Informed consent was obtained from all research participants and the study had IRB approval from the Pennsylvania State University (STUDY00009839).

Household Survey

The household survey was conducted in n=120 households with the head of each household during the summer of 2018. The survey included questions about household demographics, agricultural practices, crop diversity, land and water access, market orientation, and pesticides (Table 2). The survey was based on a previous research tool used in Morocco (see Johns *et al.* 2013) and adjusted after a pilot period.

We assessed agricultural practices and crop diversity over a 12-month period, based on participants self-reporting. Direct field-based assessment of crop diversity was not feasible given time and resource constraints. We collected data on market orientation, fertilizer use, pesticide application, irrigation, and seed practices for each crop.[4] We used local units of weight and landholdings which we later converted to metric units (i.e., kilograms and hectares). For example, many farmers reported landholdings according to the number of days required for cultivation using animal traction (1 day = 0.33 ha).

Quantitative Data Analysis

We analyzed quantitative data through linear regression using Stata/SE 12.0 for Mac to assess the factors associated with crop diversity. Independent variables in the model included:

- Elevation
- A binary variable of agricultural market participation (did the household sell any crops in the past year)
- Percent of crops sold to market in the past year
- Logarithmic transformed land holdings
- An asset-based wealth rank
- Water access at the village level, a categorical variable based on qualitative data

The dependent variable, crop diversity, was a count of the number of food crops cultivated and was normally distributed. We established elevation using google map coordinates near the village center and using the GPS coordinates tool for Google Maps on the website: maps.ie. Landholdings were based on self-reported amount of privately held land and shared land divided by the total number of shareholders (assuming even division). We then entered landholdings into a logarithmic function to achieve normality (most of the households had less than a quarter hectare but some had up to two hectares).

We constructed the assets-based wealth rank using a Guttman scale. This method required data on the presence and absence of a shared set of assets. The construction of a Guttman scale involved counting the number of assets and then tallying errors based on expected possessions (Guest 2000). Both Guttman's Coefficient of Reproducibility and Coefficient of Scalability, two measures of error, were well within expected ranges. The assets included in the ranking included: plumbing, electricity, cellphone, donkey or mule, motorcycle, and automobile.

Water access or use is a difficult variable to quantify in Morocco, where it is determined by water flow rates and a complex and varying set of ownership and governance institutions. Crawford (2008)

[4] Each crop (and variety) has specific biophysical and management considerations that are important but were not recorded in this study.

was able to quantify water access in a village near our study site through an extensive ethnography, but this was not feasible within the time and resource constraints of our study. We constructed a water access scoring system for each village to include water access in our quantitative analysis. We used data from semi-structured interviews and observation to create ordinal ranking of water access by village (Limited Water Access, Low Water Access, Medium Water Access, and High Water Access; see results below). This ranking was confirmed by community members. Pesticide use was highly correlated with market participation and thus had to be excluded from the model. Finally, we omitted education, age, household size, and other variables from the model because they were not statically significantly related to crop diversity.

Table 2: Survey Descriptive Data (n=120)

Variable	%	Mean	Min	Max	Standard Deviation
Mean age of household head (years)		52.7	24	88	16.2
Mean household size		7.8	2	22	4.16
Male Headed Households	98.3				
Household head never attended school	50.8				
Household head only received religious education	25.8				
Household head attended primary school	22.5				
Mean Landholdings in hectares		0.212	0	2	0.328
Households producing Corn and Barley (%)	66.7				
Households producing either Corn or Barley (%)	89.2				
Household owning Walnut Trees (%)	93.3				
Households owning Apple Trees (%)	68.3				
Consumption Crop Diversity		8.1	1	22	3.75
Market Crop Diversity		2.20	1	7	1.12
Percentage of Households Producing for Market	65.0				

Qualitative Data Collection and Analysis

We collected qualitative data in 2018 and 2019 through participant observation, 52 semi-structured and open-ended interviews, and six focus groups. Semi-structured interviews were conducted with farmers, community members, and government leaders, and covered crop selection and preferences, water, agricultural knowledge, and pesticide practices. We identified qualitative participants during surveys and over the course of field work. Audio recordings were rarely possible, so the first author kept detailed notes from all interviews and focus groups. Quotations were rephrased from the research assistant's translation.

We analyzed the qualitative data analysis using Atlas.Ti. Data were first transcribed from notes and audio recordings and then uploaded into the software program. The first author reviewed and coded transcripts to identify determinants of crop diversity (e.g., water, pesticide use, livelihoods, market participation and policies). Coding was guided by knowledge of the literature on the determinants of crop diversity. All material for a given code was then complied and summarized, and quotes selected when available (Saldaña 2015).

Results

Agriculture and Crop Diversity in the Commune of Toubkal

The 120 households in the survey were primarily led by men (98.3%) and had an average 7.8 members. Average land holdings were low (0.212 hectares) but consistent with smallholder producers elsewhere in Morocco. The mean number of crops produced was 8.1. The most common crops included walnuts (93.3% of households), barley (80.8%), corn (75%), onions (73.3%), apples (68.3%), and zucchini (65.8%) (Table 3). The varieties of apples grown in the study communities include Gala, Hana and Golden Delicious; walnut varieties include Hartley and Marbot. Other common crop trees included cherry (varieties Bigaro and Bing), plum (varieties Centa rosa, Oumlil, and Bou'aman), as well as almonds (largueta and marcona). Most crops were reportedly irrigated, although almonds and walnuts less commonly. The differences in the crops grown in higher and lower elevation villages are primarily due to growing season and climatic factors. For example, winter squash, peas, and tomatoes were more frequently planted in low elevations, while potatoes were more common in high elevations, and almond and pomegranate were more prevalent in lower villages, while quince and plum were more common in higher ones.

The agricultural year in the study site starts in November and December when communities till the land and plant annual crops (barley and wheat). In higher elevations communities plant earlier to ensure seed is in the ground before snow falls; seeds sprout after the snow melts in February. Once the annual crops are planted the period for pruning fruit trees (apples and plums) runs from December to February. Barley and wheat harvest occurs from April through June. Corn is planted on the same land shortly after the barley and wheat harvest, and is harvested in July. Apple trees bloom in March and April (later in higher elevations) and can be negatively affected by late frost or snow. Apples are treated with chemicals from April through the beginning of June and harvest starts in July (Gala and Hana varieties), with the harvest of the most common variety, Golden Delicious, in August and September. Similarly, the cherry harvest occurs from June through August depending on elevation, variety, and weather. The walnut harvest starts at the end of September. The busiest time of year starts with the grain harvest in May and continues through the ripening and harvesting of fruits. By July the work decreases, and a period of post-harvest celebration begins (this is the season for weddings).

Only 65.0% of households sold crops to markets, which included sales within village or commune but also sales to middlemen and distribution to major markets in cities. The farmers from Toubkal commune sell their crops in a diverse range of markets including: the closest (local) market of Larbaa, markets in other communities (Sebt Assarague in Commune of Assarague 10km away, Had Aoulouz in the Commune of Aoulouz 73km away, at the Festival Safran in Talouine Commune 107km away) and to markets in large cities (Souk Jemla in Marrakech 180km away and markets in Casablanca 424km away and Inezgane Market 230km away).

Table 3 - The 20 most common crops and their characteristics

	Households	Households (%)	Market (%)	Irrigates Regularly (%)	Uses Chemical Fertilizer (%)	Percent of HH cultivating crop	
						Below 1950 m	Above 1950 m
Walnut	112	93.3%	50%	84.8%	9.8%	91.7%	95.0%
Barley	97	80.8%	0	95.9%	58.8%	76.7%	85.%
Corn	90	75.0%	0	100.0%	37.8%	80%	70%
Onion	88	73.3%	0	100.0%	19.3%	68.3%	78.3%
Apple	82	68.3%	49.2%	100.0%	37.8%	65.0%	71.7%
Zucchini	79	65.8%	0	98.7%	27.8%	68.3%	63.3%
Radish (traditional)	67	55.8%	0.8%	98.5%	13.4%	55.0%	56.7%
Potato	63	52.5%	1%	98.4%	27.0%	45.0%	60.0%
Almond	56	46.7%	14.2%	64.3%	28.6%	75.0%	18.3%
Cherry	33	27.5%	16.7%	97.0%	30.3%	4.0%	15%
Fava	31	25.8%	0	96.8%	19.4%	38.3%	13.3%
Radish (non-traditional)	22	18.3%	0	100.0%	9.1%	23.3%	13.3%
Plum	21	17.5%	2.2%	100.0%	38.1%	11.7%	23.3%
Tomato	20	16.7%	0.8%	95.0%	15.0%	26.7%	6.7%
Carrot	19	15.8%	0	100.0%	15.8%	21.7%	10.0%
Peach	16	13.3%	1.7%	93.8%	50.0%	13.3%	13.3%
Peas	15	12.5%	0.8%	100.0%	6.7%	23.3%	1.7%
Quince	14	11.7%	1.7%	100.0%	42.9%	3.3%	20.0%
Winter Squash	11	9.2%	1.7%	90.9%	0.0%	18.3%	0%
Pomegranate	7	5.8%	0.8%	100.0%	14.3%	11.7%	0%

Water Access Ranking

We constructed village level water access ranking with four categories. Limited water access (Score 1) describes villages that struggle to procure drinking water and maintain drought tolerant crops (i.e., almonds) due to lack of water. Low and medium water access refers to villages with water resources managed through reservoirs. Low water access villages (Score 2) severely constrain farmers' options, while farmers in medium access villages (Score 3) indicated that they would like to grow other crops if they had water. Finally, high water access (Score 4) describes villages that are not limited by water availability and do not need reservoirs due to their position in the watershed.

Table 4: Example Quotes on Water from Four Villages and Associated Scores for Analysis

Score 1: Limited Water Access	"I would grow traditional vegetables when there is water." (Interview 7) "If I have water, I would grow what others grow: apples and almonds." (Interview 13) "When there was water, I grew potato and onion." (Interview 14) "People grow apples and vegetables according to water. If I have lots of water, I would grow for food and market." (Interview 16)
Score 2: Low Water Access	"People grow just a little bit. [There is] not enough water and land… [I] just farm places on [my] land that the water reaches." (Interview 35) "[I] need water and would like to farm everything...My ancestors told me there was snow until June and July. [My] ancestors farmed enough barley and maize but now [I have] go to the market." (Interview 36) "If you want to farm, you need water. If you want to be a shepherd, you need sheep...[I] just grow a little bit of vegetables because of [inadequate supply of] water." (Interview 37)
Score 3: Medium Water Access	"I would get better product with more water. In the past, we just farmed half of all land. Now we farm all the land and don't have enough water to irrigate all the crops. Sometimes there is conflict [...] Some people steal water from each other." (Interview 31)
Score 4: High Water Access	"There is no reservoir [here], but I have water here irrigate apples every 10 days...There is no strategy for water. Its available freely." (Focus Group 1)

Factors that Shape Crop Diversity

In the regression model, market participation, land holdings, and water access were found to be determinants of crop diversity (Table 5). The regression explained 39% of the total variance in crop diversity. There was a non-linear relationship between market integration and crop diversity.[5] Compared to households that sold no crops, those that sold one or more crops had significantly higher crop diversity, but as the percentage of crops sold increased, crop diversity decreased. Households with more land and better water access also had significantly higher crop diversity (Fig. 2). Neither wealth asset index nor elevation were statistically significant in the model.

Table 5: Regression Table for Household Species Richness

Variable	Coefficient (Standard Error)
Household Market Participation (Binary)	4.5002 (.8382) **
Percent of crops marketed	-10.5061 (1.9734)**
Household Landholdings (Logarithmic Scale)	1.811 (.5454)**
Household Wealth Index based on Guttman Scale	-0.1519 (.3837)
Village Water Access (See Table V)	1.0493 (.3606)**
Village Elevation	-0.9914 (.0018)
Constant	10.35
n=	118
Adjusted R^2	0.3866

*Less or Equal to .05 (95% Confidence); **Less or Equal to .01 (99% Confidence)

Market Integration and Participation

Discussions with farmers aligned with the quantitative results showing that greater production of cash crops was related to lower crop diversity. Participants noted trade-offs between crop diversity and income, and many farmers prioritize income over the benefits of crop diversity. Few farmers talked about the benefits of crop diversity, and those that did alluded to tradition and cultural values and autonomy from markets.

Although it is a major investment to grow apples, some farmers would like to expand or adopt apple production since it is more profitable. One farmer noted that he wants to plant more apples and cherries because: "It doesn't make any sense to grow 20 *aabras* of barley for 1000 *dirhams*" (Interview 30). He felt that he had to grow a

[5] Although the result was significant when percent of crops marketed squared was the sole market-related independent variable, we chose household market participation and percent of crops marketed as the final variables for the regression because that model had a higher adjusted R^2.

lot of barley, requiring a lot of land, for relatively little money.

Another farmer explained that: “Apples get you money and are more effective than growing barley and maize. Growing barley and maize are a habit” (Interview 21). Yet another farmer reported that his family grows half of their grain and buys the other half because buying all they need “can be expensive.” This strategy effectively hedges against market fluctuation when they depend on grain for the practice of animal husbandry. Another reason that barley and corn remain popular crops is that fruit trees require expensive inputs, including plant material, pesticides, and labor for building canals and pruning trees. Some farmers continue to cultivate grains (i.e., barley and maize), fodder plants (i.e., alfalfa), vegetables (i.e., radishes, carrots, and squash), and iris (sold as a medicinal plant) in the understory when the trees are young or between the mature trees if there is enough space.

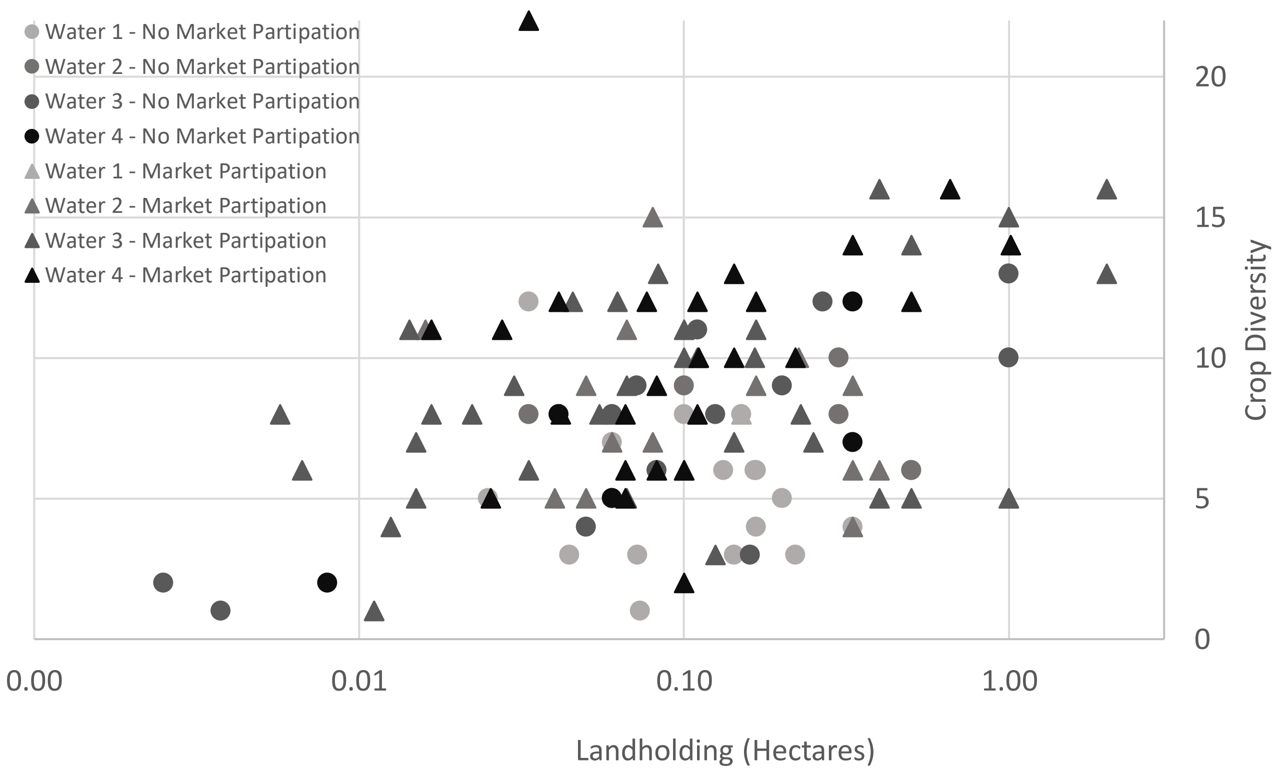

Figure 2. Crop Diversity in Relation to Land Holdings, Market Participation, and Water Access (households marked with circles sell one or more crops, while those marked with triangles sell no crops; households marked with light fill have low water access, while those marked with darker fill have better water access).

Water Access and Irrigation Regimes

Water access is an issue of key importance to Moroccan farmers and a major factor shaping the number of crops that are grown. In the village with the least water access, farmers stated that they would grow a more diverse selection of crops if they had water. For example, one said that: “If I ha[d] water, I would grow what others grow: apples and almonds” (Interview 13). Another farmer in the same village said that: “I would grow traditional vegetables when there is water” (Interview 7). Others looked to past times with more water access: “When there was water, I grew potato and onion” (Interview

14). Water is such a constraint in this village that some people have moved to adjacent valleys, giving up proximity to social institutions, such as the school and mosque, along with amenities like piped drinking water.

Farmers in villages with significantly better access to agricultural water also experience limitations due to water access. For example, a farmer in a village with more water resources (Score 3) said that: "If I only had a little land and water, I would plant apples, but if I had a lot of land and water, I would plant almost everything, including grapes, tomato, and potato" (Interview 22). In another village, a farmer stated: "People farm according to the amount of water [...] I have enough water for apples but not enough to harvest the corn, so the [corn] will be used for animals as fodder" (Interview 52). This farmer made the decision to stop irrigating and harvest corn stalks and leaves as fodder to concentrate his water allotment on apples and potatoes. Farmers in villages like this are considering new crops, specifically saffron, which requires less water and has been successful in nearby regions and with experimental farmers in the study area.

Environmental change was on many people's mind when discussing livelihood decisions. One farmer discussed changes in precipitation during the winter season: "In the past, I just looked at the clouds and knew it was going to rain but now I don't know. [In past] Novembers and Decembers, it would snow [2-3 m] and, we could not cross [the mountains]. Now there is less snow [and it is] just on the tops of mountains. There is less water because there is less snow" (Interview 28). This sentiment was echoed in many of the interviews.

Farmers mentioned how increasing focus on fruit as a cash crop had changed irrigation regimes. In the past, water was diverted into specific canals based on the season, which would dictate schedule for the crop plan. However, this does not work for fruit trees, like apples, that require constant irrigation inputs. One farmer stated: "There are some bad years, and you don't get fruits from apples and cherries. If you don't get fruit, they won't pay you, but we are forced to irrigate these apples in order to get fruit the next year" (Focus Group 2). He was explaining the need to irrigate fruit trees especially during dry years and the pressure to maintain irrigation canals. Another farmer noted: "In the past, I just farmed half the land every year but now people farm all the land [even the land] without [irrigation] water. When apples give fruits, they need a lot of water. There is a canal above that dries up and only works for one part of the land, so I don't always farm the other part" (Interview 28). In the past, water was allocated via the canal system on a designated rotation and now water is prioritized to the terraces with fruit trees and the other terraces are only cultivated when there is enough water. A local government official explained that: "Water in [the village] doesn't follow the ancestral system" and said that he believes that if people were to follow the system, they would always have enough water (Interview 23). He noted other villages that have less fruit production and maintain traditional water systems have fewer conflicts.

Another important shift in irrigation is the adoption and popularity of concrete canals. Concrete canals are preferred by most farmers particularly because they deliver water more effectively to target fields and require less routine maintenance. One farmer in a village that does not have concrete canals expressed his frustration, saying that: "They need to repair canals with cement and materials because traditional canals don't deliver enough water […] there are no concrete canals here" (Interview 30). However, others in his village felt that concrete canals would not fare well in the summer due to high temperatures and potential damage from landslides.

Discussion

Our study stresses the importance of both well-known determinants of crop diversity – market access and socioeconomic status – and the lesser theorized role of water access in semi-arid environments. Our findings have implications for the role of irrigation management and impacts of future climate uncertainty.

Climate and Elevation

Climate and elevation are important agroecological factors in a mountain environment that experiences significant daily temperature fluctuations, especially during critical periods of fruit tree bloom and post-bloom periods. Although we found that elevation was not related to crop diversity, past studies have shown that elevation can influence varietal diversity of corn and barley (Abay *et al.* 2009). In the High Atlas Mountains, farmers must make difficult decisions about which trees to plant based on the likelihood of possible frost damage in the spring. This particularly favors planting apples, which are less affected by frost as they bloom later in spring. At the same time, crops that might be otherwise more adapted to the environment, such as walnut and almond, are particularly affected by the cold nights in the spring.

Socioeconomic Status and Crop Diversity

While we did not find many measures of wealth, including assets and education, to be significant determinants in the regression model, we did find that landholdings were a significant predictor of crop diversity, as had been observed in previous studies (Asfaw *et al.* 2019; Benin *et al.* 2004; Tesfaye and Tirivayi 2020). That education was not significantly associated with crop diversity may have been related to the fact that only 22% of household heads had ever attended primary school and the rest had only Koranic School or no education. The lack of association with the wealth asset rank could have been due to the limited number of assets we used in this study and the poor performance of the asset-based wealth index. Wealth is difficult to capture in Morocco because of Islamic morals that discourage displays of wealth (Powell 2004 citing Gellner and Micaud 1972). Having additional land affords two opportunities: space to plant more species and area to devote to nurseries or propagation (Coomes and Ban 2004). Those who own more land also tend to be wealthier and better connected to social networks.

Better social networks provide better access to diverse seed and cutting materials as well as to knowledge of new and different varieties (Powell *et al.* 2017). Wealthier people are also more willing to take risks to try new crops and crop varieties and to afford the additional time and labor costs associated with experimentation (Powell *et al.* 2017). Certain crops might be associated with higher status, motivating wealthy families to cultivate them (Zimmerer 1996). However, poorer households might use crop diversification as a risk mitigation strategy, as they are just as capable of saving seeds and, in some cases, value the practice over wealthier households (Abbott 2005; Progressio 2009). Zimmerer *et al.* (2019) propose a non-linear relationship between household resources and agrobiodiversity based on this reasoning.

Market Participation and Crop Diversity

Our quantitative analysis showed a non-linear relationship between market participation and crop diversity. Households that are either not integrated with markets (sell none of their crops) or highly integrated with markets (sell a large proportion of their crops) had lower crop diversity, while households that have limited market integration have higher crop diversity. Other studies have found that market integration does not necessarily mean lower crop diversity (e.g., Vadez *et al.* (2004) found that market integrated households are more likely to cultivate more crops and intercrop; and Zimmerer (2013) found that peach intensification was compatible with maintenance of maize system diversity). Complex relationships that are related to the degree of market integration and the types of markets that farmers are oriented to have also been noted previously. For example, Garcia-Yi (2014) found that the type of markets that chili producers sold to influenced whether they conserved native varieties, and Chaves *et al.* (2018) report that manioc growers with greater market orientation favor varieties that are suited for production of flour, which is the main commodity.

In Morocco, market participation has been influenced by government policies that promote market participation through the development of commodity chains. The Green Morocco Plan (GMP) was adopted in 2008 as a strategy to increase gross domestic product through agriculture development (Akesbi 2012; Faysse 2015). In rural areas, the GMP has subsidized infrastructure for fruit production, specifically, in our study region, apples. This has led to unintended consequences, such as dependence on pesticides, to ensure quality standards for production and outsourcing of labor, especially for harvesting.

Water Access and Crop Diversity

Water access was central to many discussions with farmers and was a statistically significant determinant of crop diversity in our study. While the above factors (elevation, agroecology, socioeconomic status, land holdings, and market integration) are all widely discussed in the literature on crop diversity, water and water access are much less frequently addressed. Few studies on crop diversity even mention water access or resources. For example, in their Bulgarian study, Di Falco *et al.* (2010) discuss irrigation access but do not use it as a variable. In the Peruvian Amazon, Garcia-Yi (2014) used access to irrigation as a proxy measure for market participation for chili producers (see also Abay *et al.* 2009; Bonham *et al.* 2012; Gauchan *et al.* 2005; McCord *et al.* 2015; Rana e*t al.* 2007; Trinh *et al.* 2003; Williams *et al.* 2018). Bonham *et al.* (2012) most closely reflects our findings, identifying a relationship between quantitatively assessed irrigation and the conservation of millet varieties in Rajasthan. Water access is a key factor to which future studies of crop diversity should pay greater attention, especially in places with uneven hydrologic resources such as an arid climates and mountainous regions (Giuliani 2007; Tapia 2000; Zimmerer 2010b, 2011).

Limitations of our Study

Our research does have some important limitations. Our measurement of crop diversity ignores several important dimensions of agrobiodiversity, including intraspecies or varietal diversity and relative abundance or evenness of crops (which are difficult to assess without direct field observation over the course of a year). Our study was also limited in that we did not consider gender and had limited interaction and data collection with women since the first author is male and had no female assistants. Development of policy that promotes diversification should prioritize perspectives of women (Sardaro *et al.* 2016). Finally, as discussed above, wealth was difficult to measure as recording incomes was not possible due to cultural concerns.

Conclusion

Our research confirms previous findings that household socioeconomic and agroecological factors, namely market participation, landholdings, and water access, are important determinants of crop diversity. Both our qualitative and quantitative results highlight market integration and access to water as key determinants of crop diversity in the study site. Water access has been a focus of relatively few studies on crop diversity in the past; however, in semi-arid regions, such as the High Atlas Mountains, water access is a critical determinant of household crop diversity. Water access is likely to become even more important in this study site as water resources become less reliable due to climate change.

While we found that some market integration was associated with higher crop diversity, it is also important to examine new technologies that come with market integration. Both fertilizers and pesticides have become important components of farming that radically alter ecosystems by simplifying management (Frison *et al.* 2011; Meehan *et al.* 2011). Fertilizer impacts soil, plant, and water microbiomes, favoring or inhibiting different organisms in nitrate dominant conditions (i.e., Luo *et al.* 2018; Zhu *et al.* 2018). Pesticides also present challenges to life in all forms, including humans, bees, amphibians, and bacteria, reducing other components of agrobiodiversity not directly observed in our study (e.g., Sánchez-Bayo and Wyckhuys 2019).

Agricultural extension services based on agroecology to support communities in maintaining a rich selection of crops, including landraces, traditional vegetables, fruit production, along with animal husbandry practices, will help conserve the rich crop diversity of the High Atlas Mountains. Support should focus on a wide selection of crops that are culturally appropriate and not reliant on high water input.

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Conflict of Interest The authors declare that they have no conflict of interest.

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