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# Evidence of collaborative opportunities to ensure long-term sustainability in African farming

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ABSTRACT

Farmers face the challenge of increasing production to feed a growing population and support livelihoods, whilst also improving the sustainability and resilience of cropping systems. Understanding the key factors that influence farming management practices is crucial for determining farmers' adaptive capacity and willingness to engage in cooperative strategies. To that end, we investigated management practices that farmers adopt and the factors underlying farmers' decision-making. We also aimed to identify the constraints that impede the adoption of strategies perceived to increase farming resilience and to explore how the acceleration of technology adoption through cooperation could ensure the long-term sustainability of farming. Surveys were distributed to farming stakeholders and professionals who worked across the contrasting environments of Morocco. We used descriptive statistics and analysis by log-linear modelling to predict the importance of factors influencing farmers' decision-making. The results show that influencing factors tended to cluster around environmental pressures, crop characteristics and water availability with social drivers playing a lesser role. Subsidies were also found to be an important factor in decision-making. Farming stakeholders generally believed that collaborative networks are likely to facilitate the adoption of sustainable agricultural practices. We conclude that farmers need both economic incentives and technical support to enhance their adaptive capacity as this can lessen the socioeconomic vulnerability inherent in arid and semi-arid regions.

## 1. Introduction

Across Africa, and in particular, in arid and semi-arid regions, farmers face the daunting challenge of increasing production to feed a growing population and support livelihoods, whilst improving the sustainability and resilience of cropping systems. Environmental, economic, and social factors (e.g., land tenure, or cultural practices) influence and constrain farming practices. These factors also drive or constrain the adoption of new practices. Therefore, to determine opportunities for the adoption of more sustainable practices it is important to understand the factors influencing farm management decisions.

Africa is particularly affected by climate change (Diffenbaugh and Giorgi, 2012) and the negative impacts are predicted to be substantial compared with other regions of the world. Climate warming has adverse implications for agricultural production. Land suitability for agricultural use, yield potential, growing season length and dates are expected to be compromised, particularly in semi-arid and arid regions (Ramos and Kahla, 2009). The continuous and significant warming temperatures mean that drought conditions are likely to be aggravated (Cook et al., 2016) leading to an increased risk of crop losses. Climate change is not only an environmental challenge but also a development issue as its adverse effects disproportionately poorer countries where economies mostly rely on agriculture. These problems are exacerbated by the fact that farmers from arid and semi-arid African developing countries have little capacity to adapt (Faiyetole and Adesina, 2017). However, how farmers are likely to adapt to the pressures associated with climate

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change has not been fully characterised.

Moreover, in response to current and expected water scarcity and to keep abreast of increasing food demands, there is a drive to expand the irrigated land where possible (Mashnik et al., 2017). Current agricultural intensification has resulted in unsustainable water withdrawal exceeding the regenerative capacity of the water table (Hamed et al., 2018), and intensive large-scale irrigation has led to increased soil salinity (van Weert et al., 2009). Water shortage and soil salinity are not the only environmental challenges faced by farmers in arid and semi-arid regions of Africa, they also face risks of erosion and soil fertility decline resulting in depleted carbon sequestration (Lal, 2012). These biophysical pressures are exacerbated by the deficient and inadequate application of nutrients impoverishing the already depleted African soils (Bationo, 2009).

In arid areas where there is water scarcity, and the extent of fertile land is limited, population pressure and the limited extent of fertile lands due to urbanization have contributed to the steady increase in agricultural intensification. Optimizing land use is necessary and requires efficient use of fertilizers. Although the agrochemical industries are designing products based on appropriate application rates for optimum crop growth, environmental and economic concerns are still related to agricultural inputs (Ryan et al., 2012). With rising global energy costs and associated increases in fertilizer costs, fertilizer use for smallholder farmers is becoming prohibitively expensive. These factors are also likely to impact farmer decision-making to varying extents.

Current agricultural methods rely on accelerated agricultural production to meet global food demand. Climate change is already affecting food security. Yet, many of the techniques that farmers adopt to increase productivity have a negative impact on sustainability. Unsustainable land management and poorly implemented intensification can have unintended consequences (Masson-Delmotte et al., 2019). It can cause biodiversity loss, and soil salinization, and threaten the viability of farmers' livelihoods. These challenges and other drivers exacerbate the vulnerability of arid and semi-arid ecosystems and heighten the socio-economic inequity between farmers. Considering that Africa faces increased risks and limited benefits associated with climate change, most opportunities lie in optimizing the continent's response to future climate shocks.

There are key areas of management that can be targeted to develop sustainable solutions and mitigate the negative impacts of climate change. For example, the introduction of agroforestry provides potential means to cope with the adverse effects of changing climate conditions through microclimate improvement. It plays a crucial role in enhancing the ecosystem's resilience through extended soil moisture retention and increased rainfall utilization (Mbow et al., 2014). Agroforestry contributes to buffering atmospheric accumulation of greenhouse gases and enhancing carbon sequestration, thus, strengthening smallholder farming systems' resilience (Verchot et al., 2007). Sustainable intensification provides the opportunity to achieve food security, act as a climate mitigation strategy, and present an alternative to the over-use of agrochemicals. A further example is no-till farming, an integrated agroecological approach to enhance ecosystem resilience and increase adaptation and mitigation (Corbeels et al., 2014). Compared with conventional tillage practices such as ploughing, no-till farming has the potential to reduce nutrient losses by wind and water erosion, increase soil carbon sequestration and in the longer term improve crop productivity. Finally, low-efficiency surface irrigation systems can be replaced by drip irrigation technology which meets crop water needs and improves water-use efficiency. These systems also hold the potential to incorporate nutrients thereby improving the efficiency of fertilizers. These agricultural management practices help deliver multiple ecosystem services mitigating climate change through soil organic carbon sequestration and reducing the intensity of water scarcity inherent in landscapes across African countries.

Understanding the key factors influencing farmers' decision-making is crucial for ongoing dialogues for climate mitigation and sustainability strategies (Wood et al., 2014). Wood et al. (2014) assessed and compared factors associated with reported changes in agricultural practices by smallholder farmers across multiple regions. They found economic factors, participation in local institutions and access to weather information were significantly associated with changing farming practices. Perez et al. (2015) examined the conditions in East and West Africa that underlie the vulnerability of farmers and their resilience to climate change. They identified population growth, commercialization of the economy, and natural resource use policies as key drivers of change with better yields and profit being the most commonly reported drivers. These studies do not explicitly explore opportunities to increase sustainability, nor do they attempt to directly link influencing factors to specific management choices.

In this study, we focused on Morocco given that its widely varying climates are representative of the diversified agroclimatic zones found across a wide range of arid and semi-arid African countries. In addition, climate change is expected to have a greater negative impact on Morocco relative to other African countries given the high reliance of the country's economy on rain-fed agriculture (Schilling et al., 2012). This makes Morocco an ideal model representative of the climatic pressures that African countries are experiencing or are expected to experience.

This study aims to identify and describe opportunities to enhance the sustainability of farming practices by investigating the key factors underlying farmers' decision-making and willingness to cooperate. We set out to explore crop management practices that farmers adopt in combination with the key factors underlying farmers' decision-making. We identify the constraints that impede the adoption of strategies perceived to be more sustainable to explore how the acceleration of technology adoption through cooperation could benefit farmers and the environment. Our analysis contributes to a better understanding of the opportunities and constraints affecting the sustainability of farming in arid and semi-semi regions.

## 2. Materials and methods

### 2.1. Study context

The agricultural sector is a key national priority for Morocco given its contribution to the Gross Domestic Product (GDP): of 13% (MAPMDREF, 2018). Similar to other developing countries, farming is the prime employer and provides a living for 73.7% of the active rural population in Morocco. The Utilised Agricultural Land (UAA) is estimated to be 8.7 Mha, with croplands largely focused on the north of the country (Fig. 1b). Cereals account for 59% of the UAA although they only contribute to 18% of the overall value of agricultural production. In contrast, horticulture with only 3% of the UAA, contributes to 21% of the overall agricultural production. According to the De Martonne aridity index, (which has been used to assess the aridity trends in several semi-arid and arid regions across Africa (Kenawy et al., 2016; Muhire and Ahmed, 2016);), there are four distinct climatic zones in Morocco (Fig. 1a). These range from humid and subhumid to hyperarid (Mokhtari et al., 2013). Morocco receives approximately 29 billion $m^3$ of rainfall per year, out of which 69% is considered to have hydraulic potential that can be mobilised. The distribution of UAA is 81% rain-fed lands, 9% Large-scale hydraulics, 4% small and medium-scale hydraulics and 6% private irrigation scheme (MAPMDREF, 2018).

### 2.2. Survey design and dissemination

The majority of farmers in Morocco are either illiterate or do not have internet access. In addition, there are very few online farmer networks through which to disseminate a survey. Hence, we aimed our survey at farming stakeholders from across Morocco. This allowed data to be gathered over a wide area enabling us to assess the generalizability of our results across contrasting environments.

The survey consisted of semi-structured questions on farming

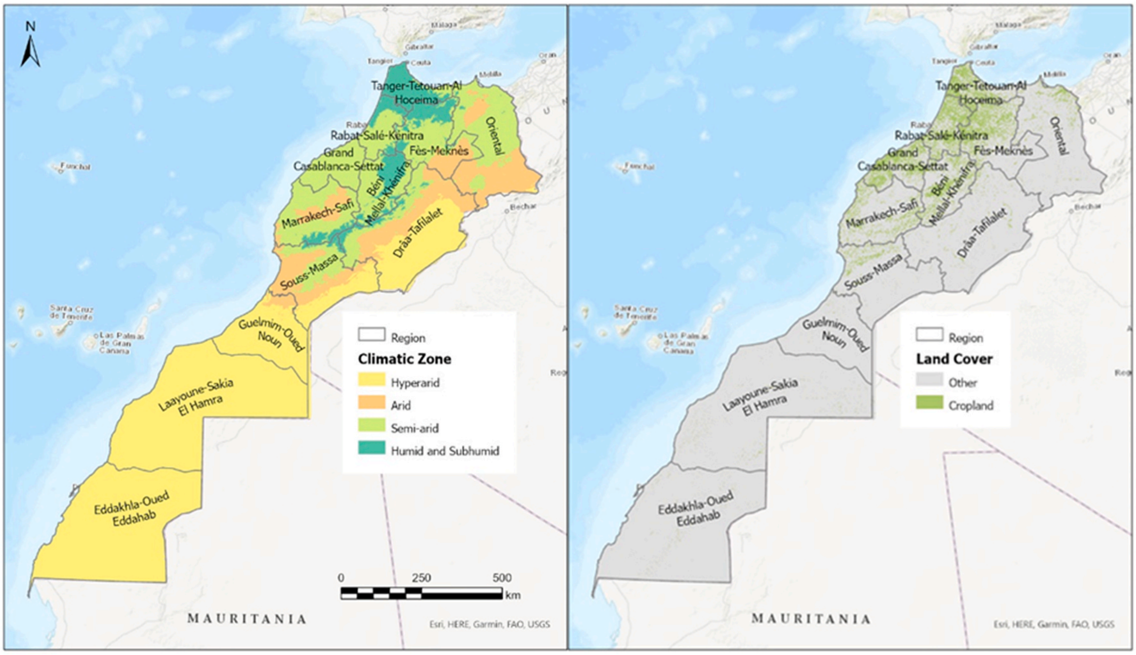


**Fig. 1.** A map of Morocco delineated according to administrative regions showing (a) climatic zones based on the De Martonne aridity index and (b) the distribution of cropland.

stakeholders' perceptions of different agricultural management practices in Morocco. We asked their perceptions about the factors that motivate the decisions of farmers in relation to crop management and posed questions about opportunities to improve the environmental sustainability of farming.

### 2.2.1. *Survey design and structure*

The survey structure was defined with reference to (Campbell et al., 2017).

The questions were organised into five sections (Tables 1 and S1). Section 1 was about the general background of the respondents who assigned themselves to one of four "professional" groups. These were (1) "agronomist" which included government scientists, engineers, and technicians; (2) "agronomist developer" which included agronomists in charge of promoting products and technologies related to agriculture; (3) "agronomist consultant" refers to self-employed or employees in private companies or institutions that convey and recommend progressive agronomic and cultural practices to their growers, and (4) "agronomist advisors" refers to state farm extension agents working closely with farmers assisting them to solve problems in crop production. This question acted as a screener question to ensure we collected data from the target stakeholder group. The following sections were: i) Crop choices; ii) Tillage; iii) Irrigation and iv) Fertilizer management.

We first investigated the current management practices that farmers undertake. For tillage and irrigation, we asked respondents to rank a set of agricultural practices from most to least common. For fertilizer practices, we posed a multiple-choice question and allowed respondents to select the most common practice. We note that the analogous questions about which crops farmers grow were not asked. Instead, we obtained this information from regional crop statistics (MAPMDREF, 2018).

We asked the respondents to identify the key factors that influence farmers' decisions. The respondents were requested to rank the options provided using a 3-scale point (Not important, moderately important, and very important). To mitigate the risk of failing to satisfy the assumptions of multi-way contingency table analyses (expected cell counts of less than 5) we opted for a 3-point scale.

Thereafter, we asked the respondents if they noticed any behavioural persistence or slow adoption of innovative practices. Finally, we asked their opinion on whether the acceleration of technology adoption would benefit through cooperation between farmers. A summary of the survey is given in Table 1. The survey was piloted with a group of 15 agronomists and changes were made accordingly.

### 2.2.2. *Survey dissemination*

The survey was created and hosted using Qualtrics (Qualtrics, Provo, UT), which is a web-based survey platform. An anonymous survey link was generated and disseminated through social media groups associated with agronomy using LinkedIn, Facebook, and Gmail, from June 2020 to January 2021. To ensure no duplicate entries, we asked respondents to fill in basic personal details, corresponding to Section 1 of the survey (Table S1). We allowed the respondents to stop in mid-survey and resume later where they left off. The responses in progress were retained for up to two weeks after the respondents started the survey. Respondents were able to review and change their responses up to the point they submitted them. Prior to data analysis, the data collected were anonymized and the respondent's IP address served as the unique ID in our database. Participation in the survey was voluntary, all questions were optional, and no incentive was offered for completing it. Prior to the data collection, the survey was submitted for ethical approval through Cranfield University's research ethics approval system.

## 2.3. *Methods of analysis*

Respondents were asked to record the administrative region of Morocco in which they worked but for statistical purposes, we aggregated responses across climatic zones based on the De Martonne aridity index (Fig. 1). The zones used in our classification were "subhumid to humid", "semi-arid and subhumid to humid", "semi-arid" and "arid to hyperarid" (Tables S1 and S2).

To analyse the data, we first tested to see if management preferences varied significantly according to climatic zones using a Pearson $\chi^2$ test. Under the null hypothesis, the responses are independent of the climatic zone, and so the same distribution of responses is expected for each climatic zone. Where no significant difference in management preference was found, data were subsequently pooled across administrative

**Table 1**
A summary of sections 2 – 4 of the survey questions.

| Management practices | Section 2: Crop choices | Section 3: Tillage | Section 3: Irrigation | Section 4: Fertilizer management |
|---|---|---|---|---|
| Management preferences | Literature | Q 3.1: Rank the following tillage systems (conventional, reduced and no-tillage) according to how commonly they are adopted in your area. | Q 4.1: Rank the following irrigation systems (localized irrigation, surface irrigation, sprinkler irrigation, and rain-fed lands) according to how commonly they are adopted in your area. | Q 5.1: In your area, what type of fertilizer (organic fertilizers only, predominance of organic fertilizers and limited use of chemical fertilizers, equal use of both organic and chemical fertilizers, and predominance of chemical fertilizers and lower use of organic fertilizers) do farmers use the most? |
| Factors affecting farm management choices (see S1 in Appendix A for the list of factors). | Q 2.1: To what extent do the following factors influence the choice of crops? | Q 3.2: To what extent do the following factors influence the choice of (i) conventional tillage, (ii) reduced tillage and (iii) No-tillage? | Q 4.2: To what extent do the following factors lead farmers to adopt (i) surface irrigation in your area (ii) localized irrigation in your area and (iii) sprinkler irrigation in your area? | Question 5.2: To what extent do the following factors influence the use of (i) chemical fertilizers and (ii) organic fertilizers? |
| Behavioural persistence, change or adaptation | Q 2.2: Have you noticed any behavioural persistence or slow adoption of agroforestry? Yes or No.<br>If yes expand, if not, why do you think so? Text entry. | Q 3.3: Have you noticed any behavioural persistence or slow adoption of no-tillage practice? Yes or No.<br>If yes expand, if not, why do you think so? | Q 4.3: In your area, how do farmers adapt to water shortages and other weather conditions? | Question 5.3: How can you describe changes in the use of fertilizers? For the list of options given in the survey see supplementary data.<br>Question 5.4: To what extent do the following factors influence change in fertilizer use? For the list of factors given in the survey see supplementary data. |
| Cooperation patterns | Q 2.3: In your opinion, are there opportunities to improve agroforestry adoption through collaboration networks or co-creation plans? Yes or No.<br>If yes expand, if not, why do you think so? | Q3.4: Are there opportunities to improve tillage practices through collaboration networks or co-creation plans?<br>Yes or No. If yes expand, if not, why do you think so? | Q 4.4: In your opinion, are there opportunities to improve water management through collaboration networks or co-creation plans? Yes or No. If yes expand, if not, why do you think so? | Question 5.5: In your opinion, are there opportunities to improve fertilizer practices through collaboration networks or co-creation plans?<br>Yes or No. If yes expand, if not, why do you think so? |

zones of Morocco for further analysis, where differences were significant, we analysed data accounting for the climatic zones.

For questions about ranking management practice, we tabulated responses with ranks as the rows and practice types as the columns pooled across climatic zones. We tested to see if the ranking was significant compared with that expected from random allocation using the Friedman test (Friedman, 1937). The mean rank was also calculated.

To assess the differences between the fertilizer regimes, we conducted a Pearson $\chi^2$ test.

For the questions about what influences farmers' choices of management, we presented the results in contingency tables in which the rows are responses to the questions and the columns are the factors affecting the choice of management. The contingency table for Q 3.2 is given as an example (Table 2). The $\chi^2$ test (described above) is appropriate where the data can be expressed in a two-way table, but for more complex tables log-linear modelling offers a suitable extension allowing one to partition out the effects due to individual variables. (Chagumaira et al., 2021; Welham et al., 2014). In this case, the null hypothesis is that there is no interaction between management type and importance or influencing factor and importance. Therefore, we started with a baseline model that represents the null hypothesis. This model included the main effect of the response classifying factor (Importance) and the interaction involving the potential explanatory factors (Management type * Influencing factors). For example, in the case of Question 3.2 for tillage, the base model was given by:

Number of responses = Tillage type * Influencing factor + Importance

We then examined the interactions between the explanatory factors and responses by sequentially adding them to the model and testing to see whether including interactions between Importance and each Factor (Influencing factor and Management practice) significantly explained the variation in the data (Fig. 2). Having identified the most appropriate models, tables of predictions were produced and plotted. These predictions are estimated mean values, formed on the scale of the linear predictor presented on the log-linear scale.

To explore the influence of various factors on crop choice (Q2.1) we adopted a similar approach to the above, but in this case including the climatic zone within our log-linear model as the climatic zone was found to be significant in crop choice. In this case, we used the relative proportion of responses since the factors were aggregated in broad-scale factors except for water availability (Fig. 2).

For the irrigation systems, the factors "Capacity and readiness to invest" and "Subsidies and grants" are not relevant to surface irrigation. Therefore, we fitted one log-linear model excluding these factors across all three irrigation systems and a second including these factors for localized and sprinkler irrigation.

**Table 2**
The full contingency table showing how many individuals selected a response to Q3.2: "To what extent do the following factors influence the choice of (i) conventional tillage, (ii) reduced tillage and (iii) no-tillage?" The Influencing factors are A) soil and land characteristics; B) crop characteristics; C) water availability; D) Subsidies and grants; E) farm size; F) passed down through the generations; G) phytosanitary management.

| Influencing factors | Factors for choosing tillage systems | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conventional Tillage | | | | | | | Reduced Tillage | | | | | | | No-tillage | | | | | | |
| | A | B | C | D | E | F | G | A | B | C | D | E | F | G | A | B | C | D | E | F | G |
| Not important | 10 | 6 | 15 | 23 | 20 | 13 | 21 | 11 | 8 | 14 | 30 | 23 | 28 | 22 | 16 | 11 | 16 | 27 | 23 | 27 | 23 |
| Moderately important | 28 | 32 | 34 | 38 | 32 | 30 | 36 | 29 | 38 | 28 | 34 | 31 | 25 | 39 | 23 | 25 | 20 | 31 | 31 | 35 | 31 |
| Very important | 48 | 47 | 38 | 23 | 33 | 41 | 29 | 41 | 36 | 40 | 18 | 28 | 27 | 21 | 44 | 46 | 47 | 25 | 27 | 21 | 27 |

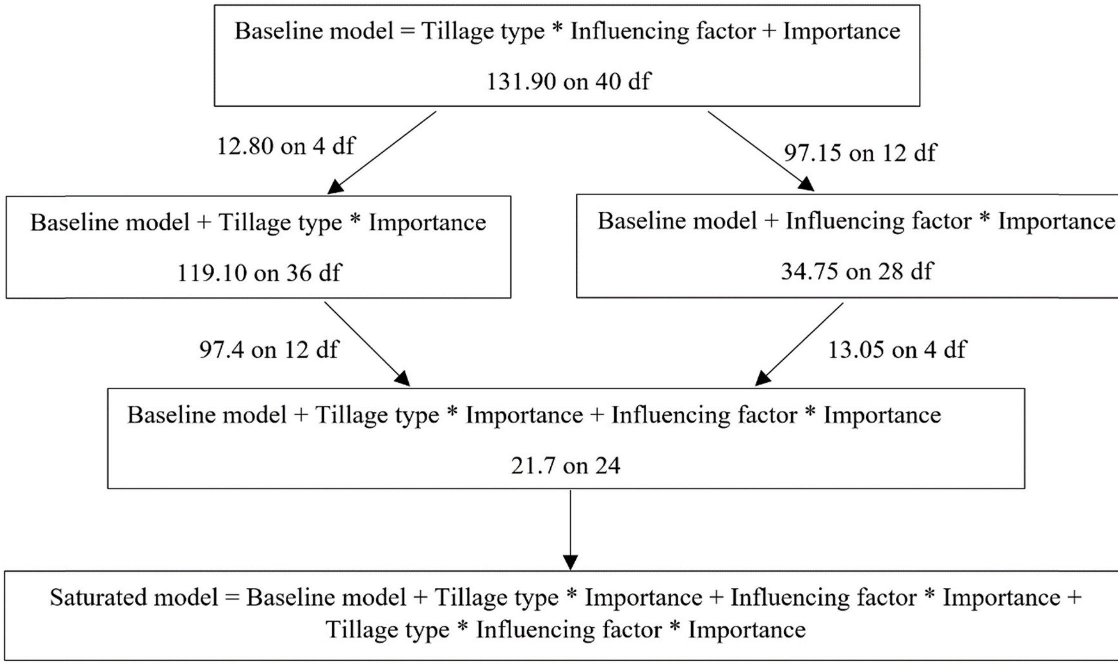


**Fig. 2.** A network diagram illustrating the log-linear model's sequential fitting for contingency tables analysis. The base model describes the null hypothesis that there are no interactions between the response classifying factor (importance) and the potential explanatory factors. Interactions are sequentially added, and models and tested to see if the deviance reduces significantly. The order of fitting the interaction terms influences the change in deviance because the model is not orthogonal.

The qualitative data, particularly questions related to the behavioural persistence, change or adaptation toward the adoption of new farming technologies, in addition to cooperation among farmers, were coded and categorised following the identification of similar themes. Subsequently, we assessed whether the willingness or unwillingness to adopt sustainable farming techniques varied depending on the climatic zones by performing a $\chi^2$ permutation test for the "crop choices" and "tillage" sections.

## 3. Results

### 3.1. Responses recorded per region

Table 3 shows the number of useable responses per climatic zone for each section of the survey.

### 3.2. Contextual questions

#### 3.2.1. Crop choices

The distribution of the surface areas of crop types varies significantly between climatic zones ($\chi^2 = 1415.22$, $p < 0.001$), indicating a significant effect of the climatic zone on crop choices. All zones are dominated by cereals, with olive trees making up the next largest proportion of crop areas except for the arid-hyperarid zone where citrus, almond and date palm trees showed a slight dominance over olive trees (Tables S3 and S4).

**Table 3**
Useable responses recorded per climatic zone.

| Climatic zones | Tillage | Crop choices | Fertilizer | Irrigation |
|---|---|---|---|---|
| Subhumid to humid | 4 | 5 | 5 | 4 |
| Semi-arid and subhumid to humid | 32 | 27 | 16 | 24 |
| Semi-arid | 20 | 23 | 14 | 17 |
| Arid to hyperarid | 12 | 15 | 10 | 12 |
| Respondents that did not identify with a region | 25 | 6 | 2 | 4 |
| Total | 93 | 76 | 47 | 61 |

#### 3.2.2. Tillage

The results from the $\chi^2$ test gave no evidence to suggest that the ranking of tillage practice varied according to climatic zone (conventional tillage: $p = 0.563$, reduced tillage: $p = 0.405$ and no-tillage $p = 0.531$, (Tables S5, S6 and S7). Conventional tillage was ranked most common by the majority of respondents (Table S8). The mean ranks obtained for conventional, reduced and no-tillage are 1.169, 2.253 and 2.554, respectively, where the smaller the value the more common the tillage type.

#### 3.2.3. Irrigation

The results from the $\chi^2$ test gave no evidence to suggest that the rankings of the irrigation systems varied according to climatic zone (localized irrigation $p = 0.735$, surface irrigation $p = 0.246$, sprinkler irrigation $p = 0.237$ and rainfed lands $p = 0.792$, (Tables S9, S10, S11 and S12).

Localized irrigation was ranked most common by just over half of the respondents ($p < 0.001$, (Table S13). The mean ranks obtained for localized irrigation, rainfed lands, surface and sprinkler irrigation were: 2, 2.359, 2.533 and 3.109, respectively.

#### 3.2.4. Fertilizer management

There were no significant differences in dominant fertilizer type according to climatic zone ($p = 0.932$, (Table S14). There is a preponderance of "Predominance of chemical and lower use of organic fertilizers" (29 responses) and fewer counts of "Organic fertilizers only" (2 responses) ($p < 0.001$, Expected values = 11.25).

### 3.3. Factors affecting farm management choices

#### 3.3.1. Crop choices

As our results showed significant differences in the distribution of crops according to climatic zones, we examined the effect of the climatic zone on the factors affecting crop choices. We first considered the broad scale which are "crop characteristics", "farm size and facilities", "water availability" as well as "environmental", "economic", and "social" factors (Fig. 3, Table S15). Second, we examined the sub-factors of each set (Fig. S1, Tables S16, S17, S18, S19 and S20).

The accumulated analysis of deviance (Table 4) shows that there were no significant interactions between the climatic zones and the levels of importance on crop choice. On the other hand, the interaction between factors and importance was significant ($p < 0.001$) implying that some factors are more important than others in influencing the choice of crops.

The prediction model (Fig. 3) shows that "water availability" was considered the most important factor influencing farmers' decision-making about crop choice. The respondents believe that farmers are almost equally sensitive to the "environmental factors" and "crop characteristics" and that the "economic factors", "farm size and facilities" along with "social factors" are less important (Table S2).

Regarding the "Economic factors", the benefit from "subsidies and grants", the "labour availability", in addition to the "profitability", are expected to influence crop selection (Pearson $\chi^2$, $p < 0.001$, (Fig. S1, Table S17). Amongst the "environmental factors", the "climate" and "water availability" are the most important factors in this category (Pearson $\chi^2$, $p < 0.001$) (Fig. S1, Table S16),). For the social factor, the farming stakeholders deemed "the prior experience with the crop" as very important (Pearson $\chi^2$, $p < 0.001$ (Fig. S1, Table S18),). Regarding "crop characteristics", "high yield" is considered the key determinant of crop selection (Pearson $\chi^2$, $p < 0.001$ (Fig. S1, Table S19),). The Pearson $\chi^2$ shows no significant differences between the factors within the "farm size and facilities" ($p = 0.131$ (Fig. S1, Table S20),).

### 3.3.2. Tillage

Significant interactions existed between the tillage systems, the levels of importance, and the factors and importance (Table S21). The effect of factors is twice the effect of tillage systems. This means that there is a significant interaction between importance and tillage systems and that some factors are significantly more important in influencing the adoption of a particular tillage system than others.

The prediction model shows that "water availability", "soil and land characteristics" and "crop characteristics" are shown to be important drivers of choice for all tillage systems (Fig. 4 and S2, Tables S22, S23 and S24).

### 3.3.3. Irrigation

We found significant interactions between the irrigation system and the importance and factors and importance, with differences in response across irrigation types more substantial than differences across factors (Tables S25 and S26). The predictions (Fig. 5) highlight that across all systems "crop characteristics" and "water availability" are the most important factors for irrigation. This is particularly true for surface irrigation (Fig. S3, Table S27). Notably, "labour availability" is less important for surface and sprinkler irrigation. "Climate" and "soil and land characteristics" are least commonly reported as very important for sprinkler irrigation (Fig. S3, Table S29). "Profitability", "capacity and readiness to invest" and "subsidies and grants" were deemed very important for localized irrigation by a large proportion of respondents (Fig. S3, Table S28).

For both localized and sprinkler irrigation, the benefit from "grand and subsidies" along with "capacity and readiness to invest" are recurrently ranked very important (Fig. 5).

**Table 4**
Accumulated analysis of deviance for crop choice including the independent variables climatic zone and factors, factors, and importance and associated two-way interactions.

| Change | d. f. | deviance | mean deviance | deviance ratio | approx chi pr |
|---|---|---|---|---|---|
| Climatic zones | 3 | 168.77 | 56.26 | 56.26 | <.001 |
| Factors | 5 | 0.00 | 0.00 | 0.00 | * |
| Climatic zones. Factors | 15 | 0.11 | 0.01 | 0.01 | 1 |
| Importance | 2 | 145.99 | 73.00 | 73.00 | <.001 |
| Climatic zones. Importance | 6 | 4.25 | 0.71 | 0.71 | 0.643 |
| **Factors. Importance** | **10** | **76.24** | **7.62** | **7.62** | **<.001** |
| Residual | 30 | 28.35 | 0.95 | | |
| Total | 71 | 423.72 | 5.97 | | |

### 3.3.4. Fertilizer management

The accumulated analysis of deviance showed no significant interaction between fertilizer types and importance ranking and so we pooled across fertilizer types for our predictions (Table S30). These show that achieving a "high yield" and "profitability" are key factors driving the use of fertilizers (Fig. 6 and S4, Tables S31 and S32).

## 3.4. Behavioural persistence, change or adaptation toward the adoption of new farming technologies

### 3.4.1. Crop choice: agroforestry

There was no significant effect of the climatic zone on the perceived willingness of farmers to adopt agroforestry (Q 2.3, p = 0.114

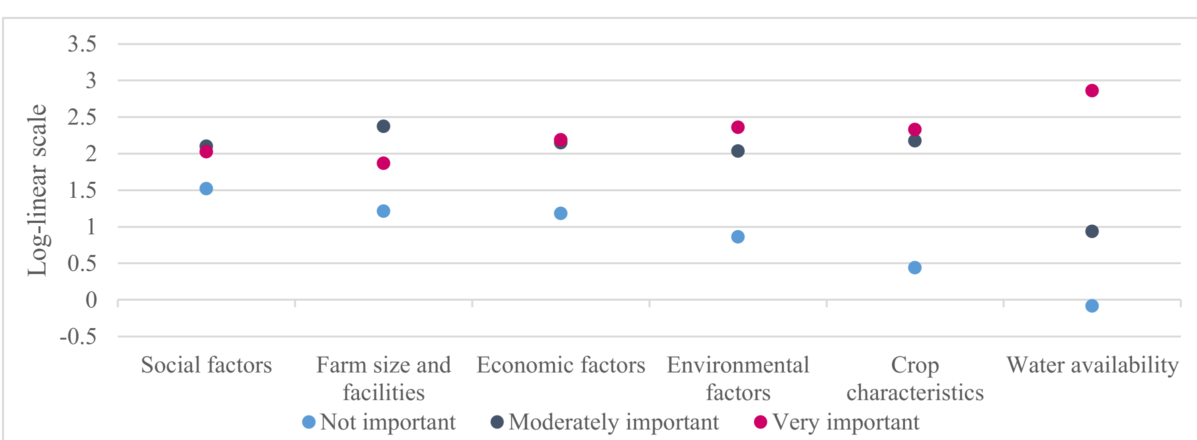


**Fig. 3.** Predictions from the log-linear model of the importance of influencing factors on crop preferences. Where the points are tight or coincide, there was no strong opinion among those surveyed.

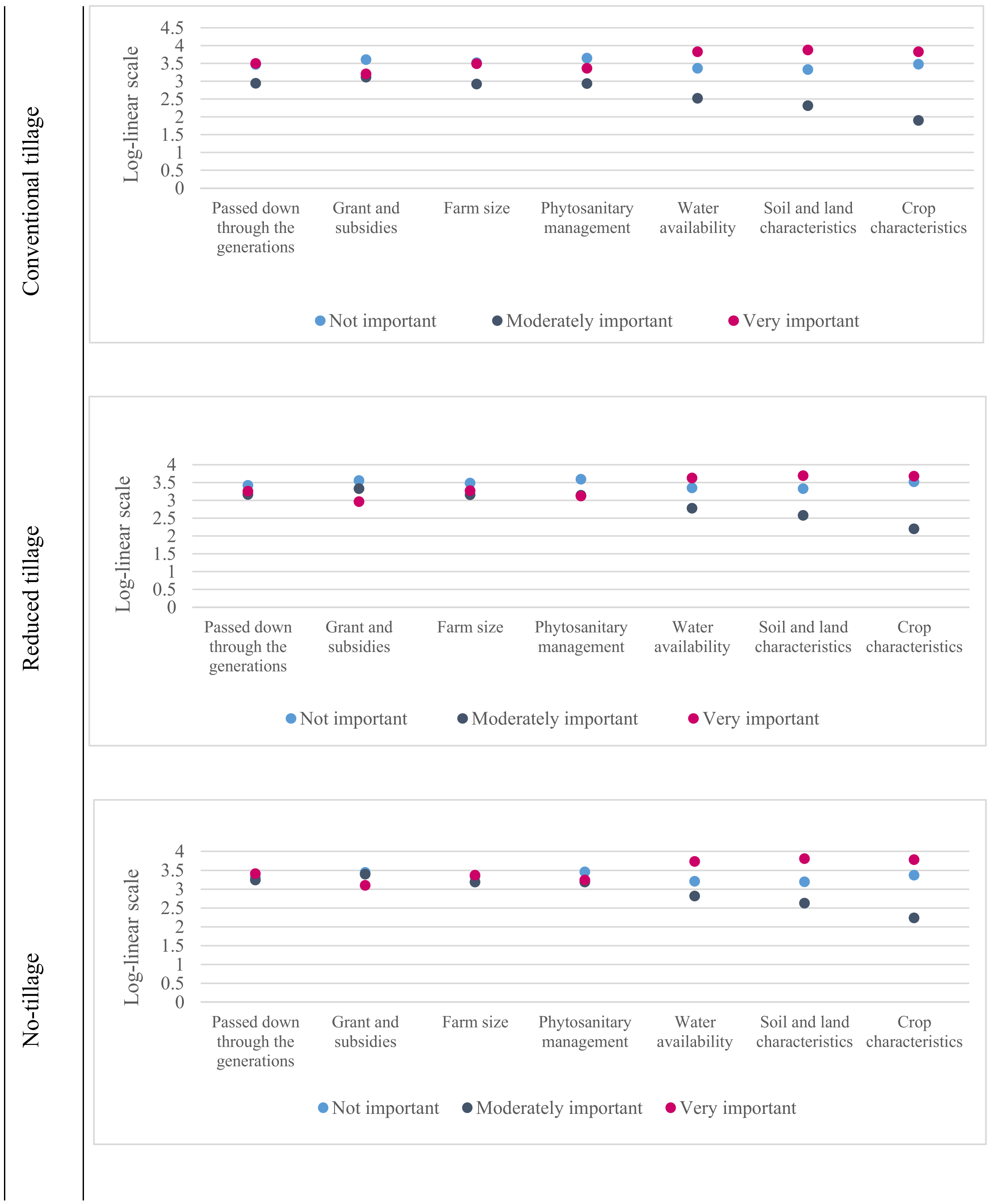


**Fig. 4.** Predictions from the log-linear model of the importance of influencing factors on the adoption of conventional tillage, reduced tillage, and no-tillage. Where the points are tight or coincide, there was no strong opinion among those surveyed.

(Table S33),). When pooled across the climatic zone, just over 33% of respondents noted a reluctance of farmers to adopt agroforestry. This unwillingness was attributed to the low profitability and the delayed profit compared to intensive agriculture (11 out of 17 qualitative responses). The results also suggest that farmers prefer income-generating crops, are unwilling to adapt, and have a strong propensity to intensify production systems (6 out of 17 qualitative responses).

### 3.4.2. *Tillage*

Just over 45% of respondents noted a reluctance of farmers to adopt no-tillage. There was a significant effect of the climatic zone on the perceived willingness of farmers to adopt no-tillage systems (Q 3.3, $p = 0.05$), with a pronounced reluctance in the "Humid and Subhumid" and "Semi-arid/Humid and Subhumid" climatic zones compared to the other ones.

According to the results, lack of information on benefits (11 out of 38 qualitative responses) and the reluctance of farmers to adopt new practices (9 out of 38 qualitative responses) are the factors impeding no-tillage adoption. Farmers believe that no-tillage will hinder the growth and development of the crop and cause a decrease in crop productivity. In addition, no-tillage requires adequate equipment that may not be available (6 out of 38 qualitative responses).

### 3.4.3. *Irrigation*

In the "humid and subhumid" zone, farmers are not affected by water shortages and no contingency strategy is anticipated to face severe

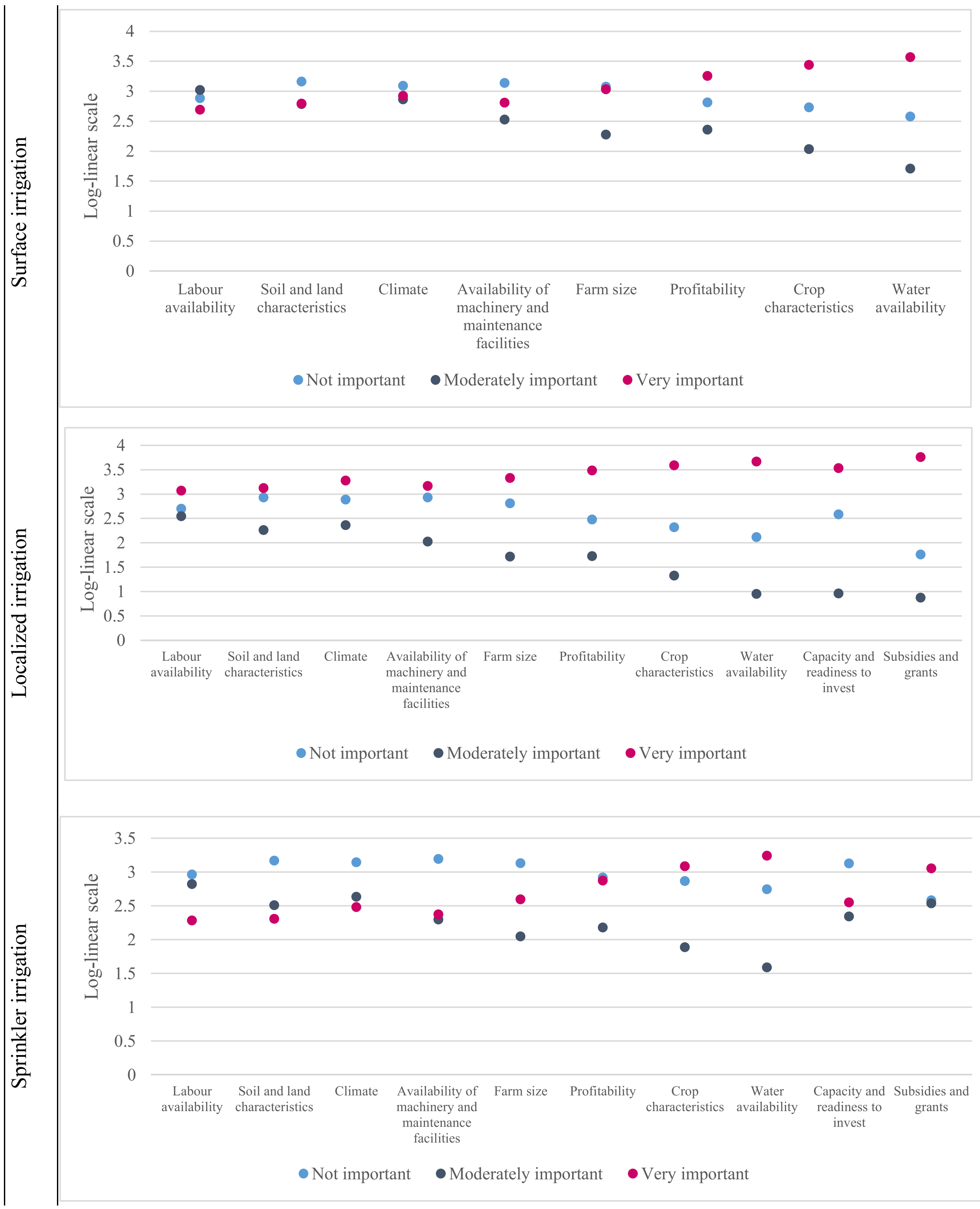


**Fig. 5.** Predictions from the log-linear model of the importance of influencing factors on the adoption of surface, localized and sprinkler irrigation. Where the points are tight or coincide, there was no strong opinion among those surveyed.

drought. For other regions, the adaptation strategies adopted were grouped into three categories: sustainable adaptation, unsustainable adaptation and forced adaptation.

Sustainable adaptation included the use of drought-resistant plants and varieties (9 out of 21 qualitative responses), adoption of drip-irrigation (6 out of 21 qualitative responses), adoption of new cultivation methods (3 out of 21 qualitative responses) such as no-tillage, construction of water accumulation basins (2 out of 21 qualitative responses) and transhumance (3 out of 21 qualitative responses) where intensive agriculture is not practised. Unsustainable practices such as the overexploitation of groundwater (3 out of 11 qualitative responses) coupled with deepening wells and drilling boreholes (8 out of 11 qualitative responses) are adopted by farmers to cover the deficit in crop water needs. According to the survey, forced adaptation translates mainly into the reduction in the area farmed (6 out of 12 qualitative responses), conversion to rain-fed crops (3 out of 12 qualitative responses) and reduction of irrigation frequency (3 out of 12 qualitative responses). Another coping strategy reported was seawater desalination (2 out of 12 qualitative responses).

### *3.4.4. Fertilizer management*

Differences in the importance of factors driving the uptake of chemical fertilizer were significant ($p < 0.001$, Fig. 7), with "Profitability", "high yield" and "improved nutrient content" perceived to be

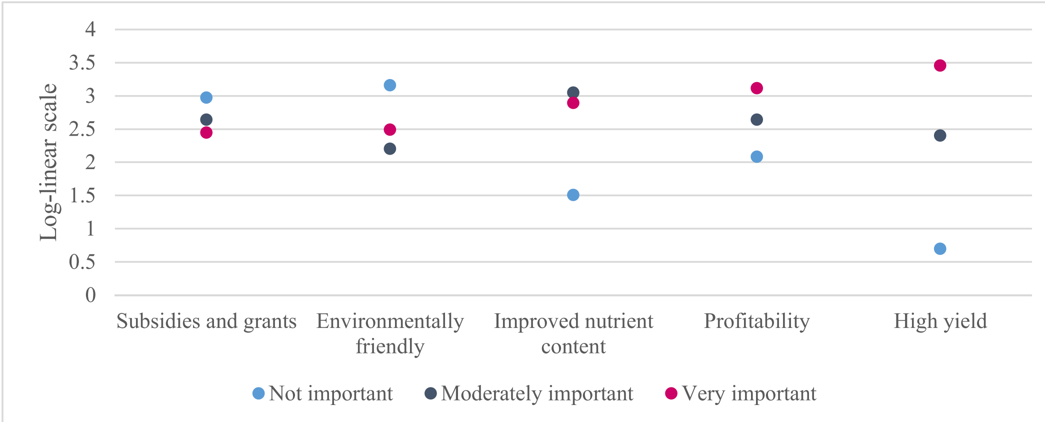


**Fig. 6.** Predictions from the log-linear model of the importance of influencing factors on the adoption of chemical and organic fertilizers.

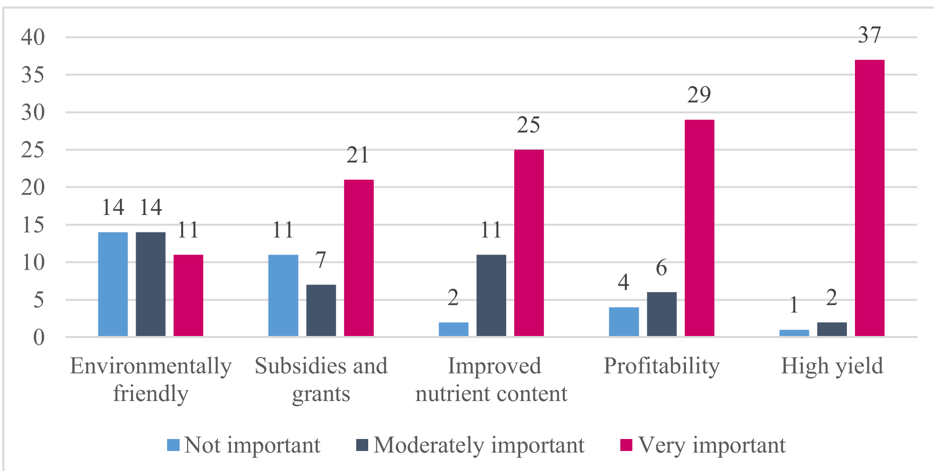


**Fig. 7.** Factors affecting the change in the use of fertilizers.

the main factors driving the change toward greater use of chemical fertilizer coupled with organic amendments (Fig. 7, Table S34). According to the survey study, farmers recognize the role of mineral fertilizers as a supplement to the soil's nutrient stocks, which can be rapidly absorbed by crops.

### 3.5. Farmer's willingness to adopt sustainable farming practices

#### 3.5.1. Crop choices

The survey revealed that 60% of respondents believe that agroforestry take-up could be improved through collaboration networks. Our respondents suggested that agroforestry adoption and management should be based on a participatory approach, supported by policy-makers, associations, and governmental organizations (7 out of 25 qualitative responses). They also suggested the creation of cooperatives and associations to promote agroforestry and carry out field demonstration platforms and farmer field schools as a capacity-building strategy (7 out of 25 qualitative responses) to demonstrate the profitability and associated benefits of agroforestry (9 out of 25 qualitative responses).

#### 3.5.2. Tillage

Approximately, 75% of respondents believe that the adoption of no-tillage could be increased through collaboration networks. It was stated that without consolidating the efforts of the various farming stakeholders via a collaborative approach, the adoption of no-tillage will remain meagre and have little impact, hence the prominent role of a participatory approach for no-tillage implementation (5 out of 45 qualitative responses). Respondents mentioned that farmers will adopt no-till practices if they see positive results in field conditions that are similar to their own. They also suggested organizing farmer field schools and workshops for farmers to demonstrate the long-term benefits associated with no-tillage (18 out of 45 qualitative responses). It was suggested that farmers could be organized into cooperatives (14 out of 45 qualitative responses) and credits could be facilitated for the purchasing of shared equipment (8 out of 45 qualitative responses).

#### 3.5.3. Irrigation

Approximately, 80% of respondents believed that water management can be improved through collaboration. According to the results, several approaches could be adopted such as capacity-building training (9 out of 31 qualitative responses), land fragmentation correction (2 out of 31 qualitative responses), participatory management of water resources (2 out of 31 qualitative responses) and crop coordination (1 out of 31 qualitative responses). Respondents mentioned technical solutions such as the improvement of irrigation systems by fostering the implementation of localized irrigation (9 out of 31 qualitative responses), water treatment such as desalination and sewage treatment (4 out of 31 qualitative responses) as well as the construction of dams (1 out of 31 qualitative responses) in addition to grants and subsidies (3 out of 31 qualitative responses).

#### 3.5.4. Fertilizer management

Of those surveyed, 78% believed that fertilizer management could be improved through collaboration. Respondents suggested the implementation of capacity-building training and the participatory management of fertilizer use (9 out of 14 qualitative responses). Technical solutions (fertilizers based on soil analysis, 2 out of 14 qualitative responses) are perceived as an important component of sustainable fertilizer use (2 out of 14 qualitative responses).

## 4. Discussion

Our study set out to evaluate the potential for African farmers to adopt sustainable farming practices and contributes to the emerging literature on ways to operationalize cooperation-mitigation strategies (Döring, 2020; Perez et al., 2015). Our approach was to identify and describe the current practices adopted by farmers, the key factors that influence these and determine obstacles to the adoption of practices that are considered more sustainable. In our analysis, the key influencing factors tended to cluster around environmental pressures, crop characteristics and water availability.

### 4.1. Crop choice: influences and constraints on the adoption of sustainable practice

Our analysis shows that to assess the suitability of crops for specific agro-climatic zones in Africa, it is important to account for water availability, environmental factors, and crop characteristics. Local ecosystems have implications for crop adaptability and adoption by growers. Smallholder farmers' productivity often depends on rainfed farming (Mitchell et al., 2006). Increasing yield potential, drought, and heat tolerance of commonly grown crops, such as Groundnut (*Arachis hypogaea* L.), can benefit farmer livelihoods (Singh et al., 2014). Moreover, short growth cycles of cereals such as Millet (*Panicum miliaceum* L.) and Sorghum (*Sorghum bicolor* (L.) Moench) have also shown potential adaptation to climatic variations (Kouressy et al., 2008; Sultan et al., 2014).

Small-scale mixed cropping and livestock systems are reported to be the best strategy to become more environmentally sustainable and resilient to future climate shocks (Nhemachena et al., 2010). Drawing from (Toujgani et al., 2021), agroforestry, beyond its ecological role as a sustainable intensification solution can help to generate additional income in marginalized land testifying to its socio-economic importance. However, our findings highlight that 33% of farmers are reluctant to adopt agroforestry due to their propensity to intensify production systems, perceived low profitability or delayed profit of agroforestry. The adoption of a farmer-centric approach can overcome those constraints through technical assistance provided by extension services.

Subsidizing investment costs could also hasten farmers' agroforestry adoption as this would alleviate issues related to the delay in profitability. Since smallholder farmers are labour-constrained, agroforestry offers the opportunity to spread the demand for labour across the growing season. That is if farmers diversified their production, harvest periods will occur at more spaced-out times.

In addition, the type of tenure inherited from the protectorate period and post-independence in north African countries between the forester (representative or owner of the tree where it is) and the farmers who consider that they must have full control of their exploitation, pose a serious threat to the adoption of agroforestry. Raising awareness of land appropriation reform can influence farmer-decision making to opt for agroforestry as a mitigation solution to climate change. The respondents of our study provide useful insights into the role of a participatory approach in the development and management of agroforestry. It constitutes a sustainable farming model for smallholder farmers who can expand their market opportunities and convert marginalized lands into more productive ones.

### 4.2. Tillage choice: influences and constraints on the adoption of sustainable practice

The adoption of specific tillage systems was reported to be most impacted by soil and land characteristics, crop characteristics and water availability. These results are consistent with the findings of (Bonzanigo et al., 2016) who indicated that the environmental constraints (i.e., soil and climate), in addition to rotations, crop characteristics, and residues availability are the key factors in determining tillage choice.

The results also suggest that farmers are not inclined to transition from conventional tillage to no-tillage; up to 45% of respondents noted a reluctance of farmers to adopt no-tillage. Several limitations hinder this transition, the most frequently cited are the lack of information on benefits, the reluctance of farmers to adopt new practices, the lack of appropriate equipment and the perception of yield loss.

To improve the no-tillage adoption rate, policymakers need to consider the limiting conditions to its adoption and tailor policies according to different farmers' typologies since smallholder farmers are generally more vulnerable to climate change. No-tillage cropping systems have been shown to offer many benefits to soils and grain production (Grandy et al., 2006). it has the potential to reduce soil, organic carbon, and nutrient loss erosion. Moreover, its effectiveness with respect to erosion control is high in arid and semi-arid regions given the expected increase in rainfall intensity events responsible for accentuating the erosion rate in those areas (Martínez-Mena et al., 2020). Furthermore, enhanced cover crops and incorporation of plant residues into the soil nutrient and organic carbon recycling lead to improve soil conditions and increase water retention capacity.

The results highlight that the reluctance to adopt no-tillage is more pronounced in the "Humid and Subhumid" and "Semi-arid/Humid and Subhumid" climatic zones compared to the other ones. The drought is especially acute in arid zones and no-tillage has the potential to reduce the soil evaporation rate. This explains the willingness of farmers to adopt no-tillage in drought areas compared to less impacted regions.

To improve the no-tillage adoption rate, farming stakeholders need to make a concerted effort to lift the veil of yield loss perception associated with no-tillage through collective action and communicate long-term gains associated with it.

Designing customised policies that respect farmers' typologies is essential given the socio-economic constraints of smallholder farmers struggling to meet their immediate needs (Baudron et al., 2015; Branca et al., 2021). Therefore, allowing farmers to gradually adopt no-tillage components and progressively improve them along with the technical support of extension services, can demonstrate the full potential of this practice as part of a socio-technical network (Yigezu et al., 2021).

### 4.3. Irrigation choice influences and constraints on the adoption of sustainable practice

Although it is complex to predict the behaviour of individual farmers, it is possible to identify factors that tend to influence their decision-making in predictable ways. Overall localised irrigation was ranked the most common form of irrigation by the respondents closely followed by rainfed. This somewhat contradicts national statistics which suggest that by area rainfed agriculture is dominant (MAPMDREF, 2018). Additionally, a large proportion of the irrigated area (63%) is still under surface irrigation (MEF, 2019). This contradiction could stem from the fact that a greater proportion of production is from irrigated areas or because there is a trend toward the uptake of localised irrigation. The adoption of localised irrigation was substantially more influenced by subsidies and grants and the capacity to invest than other forms of irrigation. This demonstrated the link between the adoption of localized irrigation and subsidies.

The latter provoked an adjustment in farmers' behaviour shifting from surface irrigation to localized irrigation. Designed incentives targeting farmers at different scales enhanced the uptake of localized irrigation in Morocco. This policy enabled technology transfer, but we do not know if farmers' behaviour will readjust when the incentives no longer prevail.

The change in the irrigation methods, incentivised by subsidies, has induced a change in plantation choice. The influence of the politico-economic factors on crop selection is illustrated in (Theriault and Smale, 2021), where the Malian government launched a fertilizer subsidy program to enhance fertilizer use by targeting strategic crops. This incentive played a crucial role in shifting the agricultural landscape and orienting crop diversity, reinforcing farmers' predisposition to align with the national strategies of governments.

We can infer from the results some indicators associated with resilience when it comes to water conservation practices. Thus, farmers may adopt sustainable, unsustainable, and/or forced adaptation strategies to reduce drought impact. These differences across adaptation patterns can lead to a positive and resilient outcome such as the use of drought-resistant plants and varieties or can lead to an unviable agricultural practice for example the overexploitation of groundwater. This demonstrates that adaptation strategies vary across farmers and are context specific. Consequently, policies should be designed to meet the adaptation capacities of farmers and drive them towards sustainable solutions and away from ones that are not viable in the long term.

### *4.4. Fertilizer choice influences and constraints on the adoption of sustainable practice*

Innovative approaches need to consider profitability. As revealed by our findings, chemical fertilizers are the predominant form used by farmers and this is driven by the desire to achieve a high-income yield. Our study shows a perceived shift towards greater use of inorganic fertilizers coupled with organic amendments and is driven by achieving a high yield and profitability. Higher incomes mean that farmers will be able to achieve higher potential returns on fertilizer investment. In Sub-Saharan Africa, the average fertilizer consumption is estimated at 22.5 kg of nutrients per hectare of arable land, much lower than the world's average fertilizer consumption (estimated at 135 kg/ha) making African agriculture one of the least productive worldwide.

Additionally, African countries display a heterogeneous trend in fertilizer adoption, due to the limited accessibility, investment costs, and unawareness of the benefits associated with fertilizers (Sheahan and Barrett, 2014). For example, Malawi and Nigeria record the highest number of chemical fertilizer applications and Uganda records the fewest. In Malawi and Nigeria, the use of fertilizers is endorsed by a governmental subsidy programme (Holden, 2018), testifying to the role of policies in shaping farmer decision-making. However, such programmes must be deployed carefully. The over-use of fertilizers and pesticides in agricultural production can cause disturbance in the ecosystem and lead to increased risk of environmental pollution, namely, surface and groundwater quality (Sutton M et al., 2019), soil pollution (Huang and Jin, 2008), air quality (Walling and Vaneeckhaute, 2020), and ecosystem health (Khan et al., 2017). Thus, the efficiency of agrochemicals depends on conflicting socio-ecological objectives, leading to a complex multi-objective decision-making process (Pastori et al., 2017). Nonetheless, African farmers can significantly improve their livelihoods while preserving the environment. This objective can be achieved by maximizing the efficiency of applied fertilizers which can contribute to sustainable agricultural intensification, and indirect reduction in carbon sequestration when considering enhanced yield without expanding arable land at the expense of forested areas and woodland.

Dissemination of improved fertilizer use needs to be accompanied by appropriate guidance on sustainable use so that agricultural growth does not occur at the expense of the environment. Cooperation can foster participatory learning and encourage knowledge transfer between farmers and through training sessions provided by extension services.

### *4.5. Approaches to support the adoption of more sustainable management*

The findings of this study demonstrate that the policy design, supported by subsidies, influenced the update of localized irrigation, and induced a change in crop choice. Many African countries have established ambitious policy frameworks to promote the economic growth of the agricultural sector. For instance, the exacerbation of existing drought periods influenced policy reform and led to substituting cash crop cultivation (e.g., cotton) with food crops in irrigated perimeters. This agricultural drought-driven policy, contributed to ensuring food security in Sudan, but failed to maintain the economic viability of the agricultural sector and led to unsustainable use of water resources (Ahmed, 2020). The dependency on subsidies can have unintended consequences by disrupting adaptation strategies aiming to reduce food insecurity. In particular, when a subsidy targets the promotion of high-value crops at the expense of others considered non-strategic, it can be a driver of biodiversity loss and limit income diversification and hence resilience to market shocks. Therefore, subsidy design must be undertaken with care, and impacts reviewed at regular intervals.

Another example is the economic impact of policy interventions in changing irrigation practices through water policy restrictions. In South Africa, farmers reduced the cultivated area to meet water crop requirements. However, the gross margin for certain crops such as planted maize increased due to higher yield income recorded for full irrigation in a reduced area (Jordaan and Bahta, 2020).

In African countries, there is a rich variety of national agricultural policies leading to different behavioural responses towards the uptake of sustainable agricultural practices. Yet, to identify targets for improvement and provide mitigation solutions, it is not sufficient to consider only the biophysical and politico-economic drivers of farmers' decision-making, but it is also necessary to account for the collective rules governing farmers' organization (Mekki et al., 2018).

In our study, we highlighted four key management areas where more sustainable approaches could be adopted. For irrigation, fertilizer management, and tillage our respondents largely agreed that collaboration networks would improve the adoption of sustainable practices (80%, 78%, and 75% respectively) and a majority (60%) felt this to be true for the adoption of agroforestry.

These results accord with (Dayamba et al., 2018) who demonstrated the efficiency of the participatory decision-making approach adopted in both Senegal and Mali to support farmers identify options to increase farming resilience adapted to their local socio and climatic conditions. Participatory approaches are important but not sufficient. Farmers may reject sustainable farming methods when they do not align with their objectives or are unsuitable for them. This can be seen by the propensity of the new generation of farmers to modernize their farms and engage in sustainable farming practices whereas the older ones are less inclined to learn new farming techniques but focus on securing their livelihood (Kuper et al., 2009; Petit et al., 2018).

The introduction of new farming practices via a collaborative approach should consider the previous or existing agricultural co-operatives and the co-existence of different farming systems within the same area. Some African governments launched state-led policies relying on a top-down approach with a limited engagement of farmers (Bamoi and Yilmaz, 2021). In west Africa, it was faced with the reluctance of growers to embrace this structural adjustment and the disinvestment in the agricultural sector.

Drawing on the example of North African countries, the agrarian reform cooperatives established in Morocco, to modernize agriculture post-independence faced severe resistance from farmers. They opted out of collective organizations resisting the coercive approach established by the state-driven vision to adhere to these cooperatives (Le Coz, 1968). There is also a need to address farmers' apprehensions about the state-farmer subsidiarity and that the concerted collective approach will not hinder farmers' emancipation.

Combining technology transfer and capacity transfer can help lessen the socioeconomic vulnerability inherent in north African countries. This is consistent with the findings of (Senyolo et al., 2018) who emphasized the role of skills provision in influencing the adoption of climate-smart practices. This result largely confirms the results of (Wood et al., 2014) as well, showing evidence that access to information and participation in social institutions influenced farmer behaviour and decision-making.

## 5. Conclusion

This study explores the factors that influence farmers' decision-making in relation to crop choice, tillage, irrigation and fertilizer, to identify constraints and opportunities related to adopting more sustainable practices. We found that current agricultural management practices are impacted by various drivers that compel farmers to change and adapt. Overall, influencing factors tended to cluster around environmental pressures, crop characteristics and water availability with social drivers evidently playing a lesser role. While influencing factors are recurrently generalizable, adaptation strategies are context specific. Such information can help target policies and innovative techniques adapted to the socio-economic and biophysical environment within which farmers operate. If farmers' behaviour was found to be impacted by constraints rather than opportunities, subsidies were found to strongly adjust farmers' behaviour. Moreover, the importance of cooperation in shaping agricultural management practices was highlighted. Farmers need both economic incentives and technical support to enhance their adaptive capacity toward climate change and more sustainable management.

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## CRediT authorship contribution statement

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data used is attached

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## Appendix A. Supplementary data

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