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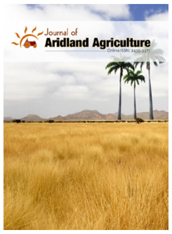

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Agricultural land measures for climate change adaptation in arid regions: Can the farmers do it alone?

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ABSTRACT

Climate change has become an unequivocal issue; changing precipitation patterns and climate variability will have disastrous impacts on the fragile agricultural land resources of arid regions. Farmers, equipped with indigenous knowledge and readily available resources, are the most direct stakeholders interacting with agricultural lands; examining farmers' capacity to successfully implement farm-level adaptive measures is a pressing matter. This paper provides an overview of various agricultural measures for climate change adaptation in arid regions and discusses some major relevant constrains and the extent of farmers' capabilities to implement such strategies. Various techniques such as shifting sowing dates, conservation agriculture, and rainwater harvesting have shown potential to serve as adaptive strategies. These can help reduce crop failure risks, improve soil moisture conservation, and increase water availability for crops, and could help adapt to precipitation variability in arid regions. However, there is strong evidence that many farmers in arid regions may not be able to implement such strategies successfully as adaptive measures and there is no clear evidence that climate variability is currently less of a risk with the existence of such measures. This can be attributed to the various constraints such as the need for reliable access to resources, climatic data, and research output by farmers for successful implementation. These constraints could be circumvented by institutional-level measures such as agricultural subsidies and relevant and dynamic policies and programs. Lessons learned from various projects suggest that this is only possible through the involvement of various stakeholders in the planning process such as researchers, farmers, and the private sector.

KEYWORDS: Climate change adaptation, Precipitation variability, Conservation agriculture, Agricultural policy

INTRODUCTION

Climate change has become an unequivocal issue that is addressed from different angles. Researchers in the science and engineering disciplines address aspects such as the effects of anthropogenic activities, the evidence from atmospheric physics and chemistry, the hydrological impacts, and the relevant technological advancements (Held, 1993; Houghton, 2005; Qiu *et al.*, 2023; Roy *et al.*, 2023; Wang *et al.*, 2023). Research works in the human sciences elaborate on the socioeconomic complications of climate change impacts (Hermansen & Heen, 2012; Lenton *et al.*, 2023; McGuirk & Nunn, 2024). Subsequently, there is global agreement that measures need to be taken to both mitigate and adapt to its impacts (Falkner, 2016; Rogelj *et al.*, 2016). One area which has been receiving increasing attention in the literature is the adaptation measures relevant to agricultural lands (Ali & Erenstein, 2017; Kaye & Quemada, 2017; Abid *et al.*, 2019; Gebre *et al.*, 2023). The is due to the increasing evidence that climate variability is causing an increased risk of crop failure and reduced yields (Challinor *et al.*, 2010), and the role of adaptive measures in enhancing the agricultural sector's resilience, ensuring food security and protection of many people's livelihood (Agesa *et al.*, 2019). These aspects relate to several sustainable development goals (SDGs) including SDG 1 (No Poverty) and SDG 2 (Zero Hunger). The significance of adapting agricultural lands to climate change impacts can also be attributed to the role of the agricultural lands on climate. Specific cropping and tillage strategies can promote carbon sequestration (Freibauer *et al.*, 2004) and agriculture strategies for soil moisture conservation could help reduce temperature extremes (Whan *et al.*, 2015). The Intergovernmental Panel on Climate Change (IPCC), a prominent key player in coordinating between decision-makers and researchers around the world, defines adaptation as "*the process of adjustment to actual or expected climate and its effects*" (IPCC, 2014). Climate change adaptation in agriculture is not a novel concept; many farmers have always adopted strategies to cope with climate change impacts and variability (e.g. changing sowing dates and crop types), and there is evidence that farmers are aware, to some degree, of climate change impacts and variability (IPCC, 2014; Agesa *et al.*, 2019; Gebre *et al.*, 2023). However, the implementation of such strategies by farmers was not always found to be suitable by investigators (IPCC, 2014; Kattumuri *et al.*, 2017). What strategies farmers choose to resort to is a function of many variables including climate, access to resources, and education level but there is still no thorough and holistic understanding of what influences farmers to choose a certain measure (Ng'ang'a *et al.*, 2016; Kattumuri *et al.*, 2017; Gebre *et al.*, 2023). What is well understood is that agricultural lands can be more vulnerable in certain climates; arid lands can be more vulnerable to some impacts due to the fragile nature of their land resources (El-Beltagy & Madkour, 2012). Arid regions such as North Africa and West Asia suffer from low rainfall relative to evapotranspiration (Figure 1) and would suffer from even more reduced precipitation in the future which, without adaptation measures, would wreak havoc on agricultural production (El-Beltagy & Madkour, 2012; Assane & Waounde, 2023). And even locations in arid regions which may experience increased precipitation would have unfavorable timing and distribution for agricultural production, i.e. it would be accompanied by increased intensity (Thornton *et al.*, 2010). There is no shortage of data on the anticipated negative impacts of climate change on crop production and native vegetation in arid regions without suitable adaptation measures (Howden *et al.*, 2007; Schlenker & Lobel, 2010; Abdullah *et al.*, 2024).

Avoiding the impacts of climate variability on agricultural arid lands heavily relies on farmers' capacity to successfully implement adaptive measures in such regions, as they are the most direct stakeholders interacting with agricultural lands. However, research efforts are heavily focused on agricultural systems and strategies for climate change adaptation and may sometimes neglect farmers' ability to successfully implement such measures. Many researchers examining different agricultural systems show impressive results with promising outcomes for adapting to climate impacts (Farina *et al.*, 2018; Olajire *et al.*, 2019). However, observational studies reporting on the general status of adaptive capacity of agricultural lands, and the farmers adopting said measures report otherwise (Agesa *et al.*, 2019; Chinseu *et al.*, 2019; Emoit & Gaynor, 2023). So, it is a pressing matter to discuss major constraints relevant to farmers' ability to successfully implement adaptive measures.

This paper examines various agricultural land measures for climate change adaptation in arid regions and discusses some constraints that may restrict farmers from successful implementation and how these can be circumvented. While some aspects of this topic had been addressed by previous researchers (Lal, 2012; Javadinejad *et al.*, 2020), this paper provides a more holistic, full length, discussion, and incorporates findings from more recent literature.

METHODOLOGY

For this paper, search tools such as the Scimago Journal Finder and Google Scholar were used, but no specific set of journals were exclusively considered. Disciplines and key words used included: agronomy, agricultural systems, agricultural policy, climate change adaptation, sustainable development, and land use. The exploration of articles expanded from February 2020 to January 2022 and mainly focused on literature published throughout the last decade (2010-2021), while some more recent articles were included during the review process. Findings incorporated in this review were from research works that fill in any of the following scopes:

1. Investigations in arid and semi-arid regions that used field experiments and incorporated modeling and simulation software to evaluate adaptive strategies under projected climate conditions or used data analysis or showed results from long term field studies. Special attention was given to works that studied on-farm strategies for adapting to projected precipitation variability in arid climates. Investigations that showed short-term results or focused only on short-term coping techniques were excluded unless sufficient justification was provided to relate their findings to climate change adaptation.

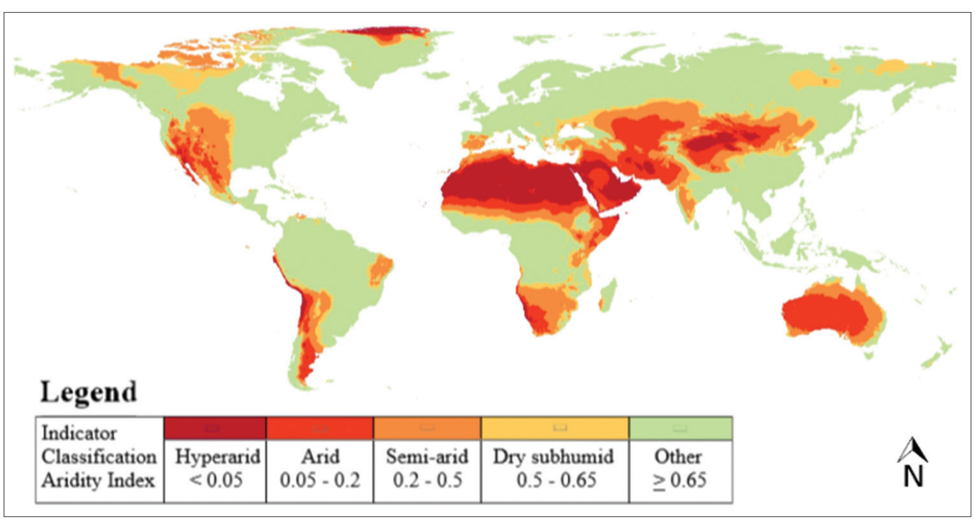

Figure 1: Global distribution of arid regions and their specific aridity classifications. *Aridity Index: Annual Precipitation divided by Potential Evapotranspiration. (Original map "Global Map of Aridity" was downloaded from http://www.fao.org/geonetwork)

2. Research works that studied and evaluated farmers' choices, constrains, and strategies for adopting adaptive measures in arid regions, or evaluated their general success in implementation and some relevant factors to that matter (observation or experimental).
3. Research works that discussed the role of institutional involvement via programs and policy, or the role of different stakeholders on farmers' adaptive capacity or their ability to implement farm-level adaptive measures.

RESULTS AND DISCUSSION

The majority of articles (>90%) found during initial exploration were short to med term field experiments (1-3 seasons), and very limited works were found to compile long term data to reflect association with climate change. While some of these works may extrapolate from their findings to claim association with climate change adaptation, such association would comprise high uncertainty. Along with few long-term studies, simulation studies and interviews with farmers were also considered in this review, the majority of the studies found to incorporate long term results were observational studies, and less than 30% were either simulation or long-term field studies. In this section findings from experimental research are compared with findings from observational research that focused on farmers' practices and claims, along with an overview of relevant policy and strategies at the institutional level.

Farm-level Adaptation Measures

Many of the agricultural systems and adaptation measures investigated and evaluated by research groups for suitability in arid and semiarid regions were noted to primarily focus on improving crop water use efficiency, improving soil moisture conservation and water augmentation. This can be attributed to land resources in arid regions being particularly vulnerable to climate change impacts that disturb crop's water supply and demand.

The coping and adaptation strategies reportedly used by farmers and evaluated by investigators involved manipulation of crop water demand to cope with reduced precipitation by various cropping practices and improving soil structure by soil preparation and management in a way that allowed for improved soil moisture conservation and better tolerance to drought conditions, while other measures extended beyond that to increasing water supply by water augmentation measures. This section elaborates on such agricultural systems and measures and what aspects need to be considered for successful implementation.

Crop rotations & mixed cropping

Agricultural lands in arid regions face the risk of crop failure due to water stresses, crop rotations and mixed farming can help reduce this risk. In crop rotations, farmers grow different crops consecutively (ex: soybean + corn) which would induce benefits such as improved soil structure and reduce risk of pest infestation, and thus reducing farming costs (Hennessy, 2006). In Mediterranean climates, a modeling and simulation experiment by Farina *et al.* (2018) showed that planting durum wheat in succession with Chickpea under climate change predicted conditions can produce improved yield when compared to mono-cropping farming, and a crop rotation consisting of planting durum wheat and bare fallow land under projected climate change conditions can reduce the risk of yield reduction due to precipitation and temperature variability. This suggests good potential for widespread practice in areas such as the Middle East. Additionally, He *et al.* (2022) demonstrated how a wheat-wheat-canola crop rotation improved abatement of greenhouse gas emissions and yields under different climate projections in arid regions in southeastern Australia through a long-term simulation. Deep insights on the dynamic relations between crop rotation systems and climate change impacts can be found in Teixeira *et al.* (2018).

In mixed cropping, additional crops such as drought-tolerant varieties of sorghum and maize are grown in the same duration as the main crop, these would have a better chance of surviving moisture stress and even pest stresses, thus reducing the risk of complete crop failure. This practice may often reduce economic returns, and thus, there is a risk-returns tradeoff to be considered (Kattumuri *et al.*, 2017). Mixed cropping was reportedly adopted by many farmers in arid and semiarid regions with different degrees of success (Azumah *et al.*, 2017; Kattumuri *et al.*, 2017; Agesa *et al.*, 2019). There seems to be a lack of research works investigating long term effect of this practice as an adaptation measure to climate change in arid regions.

Whither farmers would resort to such prescribed agricultural systems or change their cropping practices, and the success of their implementation, is dependent on their understanding of climate variability, access to information, access to resources, and availability of suitable seeds among other factors, which are not widely available to all farmers in arid and drought prone regions (Kuntashula *et al.*, 2014; Banerjee, 2015; Fisher *et al.*, 2015; Ojo & Baiyegunhi, 2020; Emoit & Gaynor, 2023). These are highly relevant considerations since the exact technique of incorporating crop rotations or crop mixing significantly impacts water conservation potential in water scarce conditions (Dinar *et al.*, 1992; Araya *et al.*, 2017). Lack of access to research output on climate variability would lead farmers to operate under high uncertainty; in such situations farmers in some arid regions would resort to risk aversion in their choice of crop rotation systems. This can result in compromising a major proportion of the potential crop yield, this was verified by Hochman *et al.* (2020) who incorporated the impacts of 35 years of climate variability in investigating yield gaps associated with cropping systems.

Shifting sowing dates

As arid and semiarid regions would experience changing patterns of precipitation such as delayed rainfall events, delaying sowing and transplantation of crops can serve as an adaptive measure to such conditions, and was recorded to be practiced by many farmers and possibly impacts crop yields substantially

(Kattumuri *et al.*, 2017; Nouri *et al.*, 2017; Acharjee *et al.*, 2019). This practice was recommended by the Ministry of Agriculture in Jordan for farmers in the Jordan valley when a delayed rainfall season was anticipated. Using a long run simulation, yield reductions caused by climate change-induced precipitation variability in the Rift Valley dry lands in Africa were reportedly avoidable by shifting sowing dates from April/May to June (Muluneh *et al.*, 2017). Furthermore, based on analysis of data collected from numerous African farmers, the use of weather reports to schedule planting dates, by either delaying them or having them earlier than common dates, was found to offset the impact of precipitation variability on yield (Ndhleve *et al.*, 2017). Further evidence on the role of changing sowing dates as a climate change adaptive measure can be found in Waha *et al.* (2013). While this practice seems reasonable and easily implemented, it does require that stakeholders have reliable access to weather data and sound use of weather analysis techniques, and even then, there would still be a level of uncertainty which poses some risk (Rodriguez *et al.*, 2017). Yet, some farmers only count on indigenous knowledge for implementation of this technique (Aniah *et al.*, 2019), which is problematic since such knowledge is passed down from previous generations and does not account for future climatic projections. Due to meteorological data scarcity, researchers resort to alternative sources such as open-access satellite data (Al-Kilani *et al.*, 2021), but this requires a level of technical expertise.

Shifting to drought-tolerant crops

Shifting to planting crops that have relatively higher tolerance to drought conditions is a popular coping strategy that can be an important adaptive measure in arid regions that would experience reduced precipitation (Lunduka *et al.*, 2019; Paul, 2019). Numerous varieties of grains and cereals such as maize and wheat can be used for this purpose (Pegoraro *et al.*, 2019). It is also possible to shift to drought-tolerant varieties of the same planted crop; shifting from regular maize cultivars to climate-resilient maize cultivars was found to increase yield by 20-100% under water-stressed conditions in various African regions (Setimela *et al.*, 2018). Switching to orange-fleshed sweet potato, a drought-resistant cultivar, from commonly used cultivars increased yearly average yields by 0.3 tons/ha in Mozambique (Andrade *et al.*, 2017). Yield losses were also found to be reduced by 1-6% when using drought tolerant varieties through long-term simulations in Nigeria (Tofa *et al.*, 2021). While this measure may seem like an obvious option, there are many aspects to be considered such as annual precipitation and economic returns; this measure would often generate lower economic returns (Paul, 2019), and thus cost-benefit analysis and risk analysis would need to be performed. However, it is yet another strategy in which some farmers resort to indigenous knowledge in its implementation (Aniah *et al.*, 2019). Several major barriers that would restrict many farmers from shifting to drought tolerant cultivars were identified by Fisher *et al.* (2015), these included: high prices or unavailability of improved seeds, lack of resources, and inadequate information. What further complicates this strategy is that there is evidence that improved breeding mechanisms are needed for drought-tolerant varieties to account for temperature stress, otherwise it would not be very helpful as an adaptation strategy (Tofa *et al.*, 2021).

Conservation tillage

Conservation tillage can be any of a variety of practices used to incorporate crop residue in the soil surface with the objective of improving the conservation of soil moisture and water infiltration and reducing soil erosion (Reicosky, 2015). Due to the nature of its effect on soil moisture conservation, it can be a suitable agricultural adaptive measure to climate change-induced water stresses. There were limited works found to address the long-term effect of this strategy as a climate change adaptation measure, but one study was done via a long-term simulation based on data from the sub-catchment of the Great Ruaha river basin in Africa by Mkoga *et al.* (2010). The research group compared conventional and conservation tillage practices and found that conservation tillage can help avoid crop failure during dry spells and alleviates crop yield reduction during dry periods. Mkoga *et al.* (2010) reported conservation tillage to be a good adaptive measure for areas vulnerable to dry spells and found it particularly suitable for areas with limited annual precipitation. While for short term effect of conservation tillage, a study by Idowu *et al.* (2019) showed that for many parameters and indicators, there were no significant changes noted for conservation tillage but reported that adopting conservation tillage would not account for economic losses during initial transition to this practice. However, Mkoga *et al.* (2010) reported that under high precipitation periods conservation tillage may lead to a slight reduction in yield for maize. An important consideration in this instance is wither farmers would proceed with a certain adaptive strategy if they do not see relatively quick results, particularly where lack of information and lack of genuine regard for projected climate variability are dominant. Conservation tillage was also reported by He *et al.* (2022) to improve carbon sequestration in the soil through long-term simulation under different climate projections.

Conservation agriculture

Conservation agriculture can be defined as a set of agricultural practices or an agricultural system that involves minimum disturbance of soil, allowing a permanent residue cover over soil and a diversified crop rotation (FAO, 2008). This strategy is highly promising for agricultural land resources for regions such as North African and East Asian regions. Kuntashula *et al.* (2014) investigated two elements of conservation agriculture which were minimum tillage and crop rotations as climate change adaptation strategies for maize production at several sites in Tanzania. The study found minimum tillage to increase on-farm productivity by 26-38% and crop rotations to increase productivity by 21-24%. Thierfelder and Wall (2010) compared conservation agriculture with conventional agriculture based on water relations and crop yield data produced over four years. The study reported that water infiltration was 3-5 folds higher on fields that adopted conservation agriculture practices, allowing for higher soil moisture which would allow crops to overcome drought effects and seasonal dry spells and reduce crop failure risk. According to Kassam *et al.* (2012), conservation agriculture shows good potential for implementation in North African and East Asian regions, but the review of recent literature didn't show any evidence that this practice receives widespread adoption in those regions. Some insight is available, for example, farmers in Malawi lacking technical knowledge were noted to abandon conservation agriculture when they don't perceive short term economic returns (Chinseu *et al.*, 2019).

Rainwater harvesting

Rainwater harvesting can help improve water availability for crops, its main function for agricultural lands is to diverge effective precipitation from a catchment area to a cultivable area (Yousef *et al.*, 2018), but it also serves as a means to improve soil structure by increasing soil organic matter content, reduction of surface runoff and soil erosion, reducing drought impact and improving the soil's capacity to store water (Shawaheen *et al.*, 2011).

Water harvesting techniques can be applied at different scales; there are systems available for on-farm, micro-catchment and macro-catchment levels (Velasco-Muñoz *et al.*, 2019). An investigation was carried out by Yousef *et al.* (2018) in Jordan, a notoriously water-scarce country, to evaluate water harvesting effectiveness at multiple sites; the study examined intermittent trenches and continuous contour for capturing precipitation runoff. The study found that rainwater harvesting can increase water storage by up to three times in a cropping area, but many parameters need to be considered such as slope and spacing of contour ridges. Mutune and Nunow (2018) reported that Zai-Pets, which are systems for harvesting rainfall runoff, were used by thousands of farmers in arid regions of Kenya and reported the practice to increase crop yield by promoting efficient utilization of limited soil organic matter.

Supplemental irrigation

Supplemental irrigation can be a critical measure for land resources suffering from moisture deficiency and susceptible to unfavorable precipitation patterns (Kattumuri *et al.*, 2017). Many farmers in arid regions use supplemental irrigation to cope with limited or shifting precipitation, and some farmers go as far as describing this practice as one of the most important strategies to cope with soil moisture stresses (Kattumuri *et al.*, 2017; Ndhleve *et al.*, 2017). To evaluate supplemental irrigation as an adaptation measure to climate change, a simulation was done by Muluneh *et al.* (2017); the research group reported that supplemental irrigation can help circumvent total crop failure during drought years, and simulation results showed that maximum crop yields were achieved when supplemental irrigation was applied if planting density was optimized. However, the study reported that no significant enhancement was noted when applying supplemental irrigation during years with good rainfall levels. Avoiding unnecessary water application to conserve water resources is essential in regions with severe water scarcity. This can be done through irrigation scheduling methods such as meteorological data (e.g. FAO 56 model) or soil moisture sensors and can reduce irrigation water use by over 40% (Abioye *et al.*, 2020; Datta & Taghvaeian, 2023). These methods are mainly restricted by cost, calibration requirements, and technical complexities (García *et al.*, 2020; Abdelal & Al-Kilani, 2024). Supplemental irrigation can be applied from freshwater or from adequately treated wastewater. Thus, treatment and reuse of wastewater can play a significant role in reducing pressure on freshwater resources in water scarce regions (Faour-Klingbeil & Todd, 2018; Tabatabaei *et al.*, 2020). However, there are numerous complexities, considerations, and risks associated with the choice of technology and treated water reuse; effective treatment, planning, and policies promoting social acceptance can be critical for its success (Farhadkhani *et al.*, 2018; Ofori *et al.*, 2020; Tabatabaei *et al.*, 2020; Bani-Melhem *et al.*, 2023; Bani-Melhem & Al-Kilani, 2023). There have been various works demonstrating the potential benefits of wastewater reuse in irrigation, such as improved yields, reduced risks from precipitation variability and increasing plant nutrients in the soil (Urbano *et al.*, 2017; Ungureanu *et al.*, 2018; Samarah *et al.*, 2020; Abu-Awwad, 2021). However, it can be difficult to reliably assess its long-term effect under projected climatic scenarios. This is mainly because the most crop simulation models such as DSSAT, AquaCrop, and APSIM do not account for biochemical changes in soil resulting from prolonged application of treated wastewater.

Resorting to water augmentation techniques such as water harvesting and supplemental irrigation in some arid prone areas has been shown to highly rely on several factors including drought severity, access to credit, land area, and availability of agricultural subsidies (Al-Amin *et al.*, 2019).

The discussed measured can be critical in arid regions experiencing reduced and changing patterns of precipitation, wither through reducing water demand (e.g. drought tolerant species) or through water augmentation (e.g. rainwater harvesting). In many situations, comprehensive approaches to managing both water supply and demand need to be taken (Yousef *et al.*, 2018). A summary of farm-level adaptive strategies, their impacts, and some major considerations discussed in this study are presented in Table 1. Further research material on adaptive farm-level practices can also be found in previous resources (Dinesh, 2016; Aryal *et al.*, 2019).

Some investigators report that despite farmers adopting various adaptation strategies in dry lands, there is still a reduction in crop yields reported in such areas (Agesa *et al.*, 2019). And there is no well-established evidence or wide-spread literature suggesting that arid regions are reaching substantial adaptive capacity or that climate variability is less of a risk with the current technology and knowledge on adaptive measures. This indicates that the limitations and constraints of agricultural adaptive measures are still dominant or not considered thoroughly. This goes to show that leaving farmers to fend for themselves relying only on their readily available resources and indigenous knowledge would do nothing to help reduce climate risks, especially that farmers' indigenous knowledge would not account for changes not yet experienced. Research output must be incorporated, and adaptive capacity of farmers needs to be increased, which requires intervention at institutional capacity.

Table 1: Impacts and constraints of different agricultural adaptive land measures for arid regions

Adaptive measure	Impact of adaptive measure	Constraints/considerations for farmers	References
Crop rotations & mixed cropping	Improved soil structure. Reduced farming costs. Reduced risk of crop failure.	Availability of suitable seeds. Access to resources and information. Requires some level of understanding of climate variability.	Hennessy, 2006; Azumah *et al.*, 2017; Kattumuri *et al.*, 2017; Farina *et al.*, 2018; Teixeira *et al.*, 2018; Agesa *et al.*, 2019
Shifting sowing dates	Offsets impacts of precipitation variability. Reduced risk of crop failure/ reduced yields.	High degree of uncertainty. Need for reliable access to weather data and analysis techniques. Farmers rely on indigenous knowledge for this strategy.	Muluneh *et al.*, 2017; Ndhleve *et al.*, 2017; Nouri *et al.*, 2017; Acharjee *et al.*, 2019; Aniah *et al.*, 2019
Shifting to drought-tolerant crops	Improves or maintains yield under current or projected water stress.	Requires cost-benefit and risk analysis (risk of reduced returns). Farmers need access to resources and adequate information. Availability and prices of improved seeds are critical.	Fisher *et al.*, 2015; Andrade *et al.*, 2017; Setimela *et al.*, 2018; Aniah *et al.*, 2019; Paul, 2019; Lunduka *et al.*, 2019; Paul, 2019
Conservation tillage Conservation agriculture	Improvement of soil moisture conservation and infiltration. Reduction of soil erosion. Offsets precipitation variability impacts. Improves economic returns.	Lack of economic returns except on the long term. Genuine regard for climate variability is important. Reduced short term economic returns in some situations. Access to credit, resources and information can be crucial.	FAO, 2008; Mkoga *et al.*, 2010; Thierfelder & Wall, 2010; Kassam *et al.*, 2012; Kuntashula *et al.*, 2014; Reicosky, 2015; Chinseu *et al.*, 2019; Idowu *et al.*, 2019
	Improves crop yield Reduces labor costs.	Requires a certain level of technical knowledge.	
Rainwater harvesting	Increased crop water availability. Improved soil structure and soil moisture conditions. Increased soil organic matter reduction of runoff and soil erosion.	Requires a certain level of technical knowledge. Many parameters need to be considered and accounted for properly, ex: soil workability, slope, spacing of contour ridges, etc. Location-specific considerations such as climate and land area.	Shawaheen *et al.*, 2011; Mutune & Nunow, 2018; Yousef *et al.*, 2018; Velasco-Muñoz *et al.*, 2019
Supplemental irrigation & Wastewater reuse in agriculture	Offsets impacts of precipitation variability. Improved crop water availability. Avoid risk of crop failure. Improved crop yield.	Water availability and access to resources are essential. Economic evaluation is needed Suitable application requires a certain level of technical knowledge. Optimized cropping practices are needed. Many variables should be considered in planning (climate, water quality, soil, land area, etc.).	Muluneh *et al.*, 2017; Ndhleve *et al.*, 2017; Urbano *et al.*, 2017; Faour-Klingbeil & Todd, 2018; Farhadkhani *et al.*, 2018; Ofori *et al.*, 2020; Tabatabaei *et al.*, 2020; Abu-Awwad, 2021
	Increased soil nutrients/ reduced fertilizer costs.	Wastewater reuse is associated with contamination and safety concerns and public acceptance is a major factor.	

Institutional-level Adaptive Measures

While the previous section discusses adaptation measures that can be implemented at farm-level, there is another type of climate change adaptation measure which is intervention through policy and institutional and societal efforts. This type of intervention could be referred to as "Planned Adaptation" (McCarthy *et al.*, 2001). Adaptation measures at the institutional level can play a critical role for climate change adaptation in the agricultural sector. These could provide resources, programs and planning that increases adaptive capacity of farmers (Hansen *et al.*, 2019). Many adaptive measures require that farmers have reliable and practical access to resources, research output and relevant data such as climatic data, and the adaptive capacity of farmers in a given region highly relies on the institutional capacity in that region (UNCCD, 2009; Ng'ang'a *et al.*, 2016; Hansen *et al.*, 2019).

Government programs and policy

A good example of how government intervention could play a role in increasing the adaptive capacity of agricultural lands in arid regions is government incentive programs for water reuse in the Middle East and North Africa. Many agricultural lands in Jordan and Tunisia have improved their adaptive capacity to climate change-induced precipitation variability due to government incentives for wastewater treatment and reuse in agricultural systems (Abu-Madi, 2004). Also, government programs in Gundlapalli which improved farmers' access to irrigation were reported to increase farmer's adaptive capacity to climate variability (Kattumuri *et al.*, 2017). Access to credit has been cited in the literature as a factor that significantly influenced farmers' choice to take farm-level adaptive measures such as shifting to drought tolerant cultivars, supplementary irrigation, and water harvesting (Al-Amin *et al.*, 2019; Ojo *et al.*, 2021). However, incentive programs and agricultural subsidies could be more reliable approaches, as farmers may misuse agricultural credit and allocate it to non-agricultural activities; this is known as "Credit Fungibility" and is a well-recognized problem in regions such as Pakistan (Hussain & Thapa, 2016; Elahi *et al.*, 2018).

Agricultural subsidies have also been cited as a factor that strongly influenced farmers to take on-farm adaptive measures to climate change (Al-Amin *et al.*, 2019). These are investments the government makes to influence costs and returns and the supply of agricultural commodities and can play a critical role in allowing access of farmers to adaptive measures such as irrigation, suitable seeds, and various technologies (Meyer, 2011). Subsidies do not leave much space for farmers to reallocate such resources for non-agricultural activities, or to short-term coping measures. One of the main factors that led to India's substantial increase in agricultural production and improved adaptive capacity to climate variability was the initiated subsidy schemes; these allowed access to agricultural technologies and farming inputs for farmers who were not financially able to acquire them (Kaur & Sharma, 2012). Another way to avoid wasted financial investments by the government in pursue of increasing the adaptive capacity of agricultural lands could be in rewarding early adopters, this strategy can show a realistic assessment of proposed adaptation measures and has shown good results in some developed countries (Howden *et al.*, 2007).

The success of the previously mentioned strategies requires the development of relevant and dynamic policies. Due to the high uncertainty in the magnitude and timing of climate change impacts, relevant policies would accordingly need to be dynamic and integrated with other policies on sustainable development and other areas (Howden *et al.*, 2007; Kanter *et al.*, 2018). Specific attention should be given to policies that promote education, training and awareness of farmers, as these can be critical for the success of strategies that provide them with access to technology and resources to adopt on-farm adaptive strategies (Elahi *et al.*, 2018). In other words, what good is the technology if farmers don't have the knowledge to utilize it. An example on this is how farmers without sufficient technical knowledge reportedly avoided conservation agriculture, despite being informed of its many advantages such as reducing time and labor costs (Chinseu *et al.*, 2019). Policies that aim to improve farmers' access to resources as well as training and building their knowledge on adaptation strategies and climate risks can play a significant role in minimizing impacts of risks from climate variability (Hansen *et al.*, 2019; Aryal *et al.*, 2020).

Some major considerations are highlighted in this regard; government outreach could be limited, or government staff may not be fully suited to provide advisory or training to farmers, as indicated to be the case in Malawi (Chinseu *et al.*, 2019). Such services could also be more available to farmers from other sources such as nongovernmental agencies (NGOs), and in some cases, farmers would prefer to resort to NGOs as an adaptive measure as appose to changing cropping practices (Elahi *et al.*, 2018). These considerations, along with many others, signify another element in the discussion, which is the role of the various stakeholders besides the farmers and the government.

Role of stakeholder involvement

Despite the clear evidence that institutional intervention can be critical for increasing the adaptive capacity of agricultural lands in arid regions, many farmers still have limited or no access to government programs, incentives or similar resources in regions such as Kenya, Tanzania, Uganda, and Ethiopia (Po & Hickey, 2018; Bryan *et al.*, 2009; Reynolds *et al.*, 2020). Even where such institutional interventions are acted upon, there is evidence that they are not implemented properly in some regions and poses many negative impacts such as increased agricultural input use, natural resources degradation, productivity decrease, and increased costs (Abadi, 2018). Another aspect which poses limitations is the malpractices done by some private companies responsible for agricultural input, which comes in the way of government programs achieving their goals in increasing the adaptive capacity of agricultural lands (Johl, 2012). This indicates that government adaptive planning for agriculture must include all stakeholders, including the private sector. The private sector can be a key player in increasing farmers' adaptive capacity. Insuring the availability of seeds of drought tolerant varieties and allowing farmers the option to purchase micro-packs of seeds, which are more affordable, are some of the ways the private sector can help small scale farmers to take adaptive measures (Fisher *et al.*, 2015).

Another group of stakeholders that need to be considered in planning is the research community. Some government policies and incentive programs for agricultural adaptation that are economically driven may discourage farmers from changing cropping systems (Smith & Lenhart, 1996); this would result in limiting the adaptive capacity of farmers in some situations because changing cropping systems in certain scenarios is well established as an important climate change adaptation measure by researchers (Lunduka *et al.*, 2019; Paul, 2019). Involvement of researchers in adaptive planning is particularly important as some farmers may choose not to resort to research output directly in their choice of adaptive measures. This is either due to lack of convincement (Chinseu *et al.*, 2019), or unavailability of extension officers that link farmers with research output (Banerjee, 2015). This point to another consideration; that researchers should also be prompted to include other stakeholders in the research process (Kanter *et al.*, 2018).

Furthermore, in some arid regions government and non-governmental institutions may lack a thorough understanding of the means to promote climate change adaptation among small-scale farmers, who are the most vulnerable to climate change impacts (Twomlow *et al.*, 2008; Chinseu *et al.*, 2019). This can be overcome by including international organizations with expertise in this domain.

An evaluation of adaptive governance strategies in the Middle East and North Africa based on climate change models was done by Sowers *et al.* (2011). The research group reported that adaptive governance in those regions was not set as a priority by decision-makers and reported that decision-makers and experts in water resources often do not include societal actors in risk evaluation. The study also reported that resources in those regions were primarily allocated to large scale supply augmentation projects and not to water demand optimization. This could suggest limited involvement of the researchers from various fields. Another work by Lejars *et al.* (2017) mentioned that the lack of including suppliers and production chains of groundwater and irrigation systems in public policies in some North African countries stands in the way of adaptation to decreasing water tables. Lejars *et al.* (2017) also stated that relevant actors in the private sector are largely marginalized in the planning processes by policymakers. A summary of the significance of different stakeholders as discussed in this section is presented in Table 2.

The problems mentioned earlier are generally noted in developing countries, but not so much in developed countries. A research work by Bizikova *et al.* (2014) aimed to provide experiences and lessons learned from developed countries where institutional-level interventions via government policy,

Table 2: Different stakeholder roles and their significance in avoiding constrains related to on-farm adaptive measures

Stakeholder group	Role and significance	Some key challenges	References
Farmers	The most direct stakeholder interacting with agricultural lands.	May lack awareness, technical knowledge, and resources to take adaptive measures.	Bryan *et al.*, 2009; Kuntashula *et al.*, 2014; Banerjee, 2015; Fisher *et al.*, 2015; Po & Hickey, 2018; Chinseu *et al.*, 2019; Ojo & Baiyegunhi, 2020; Reynolds *et al.*, 2020
Government body	Can provide planning, policy and programs aimed at providing farmers with resources, training, and knowledge and increase their adaptive capacity (ex: incentive programs, agricultural subsidies, agricultural credit, dynamic and relevant policies).	May lack sufficient outreach and knowledge to promote adaptive measures. Farmers may prefer to resort to non-governmental organizations. Poorly planned intervention can lead to negative impacts (ex: increased agricultural input use, natural resources degradation, increased costs).	Abu-Madi, 2004; Twomlow *et al.*, 2008; Sowers *et al.*, 2011; Kattumuri *et al.*, 2017; Abadi, 2018; Al-Amin *et al.*, 2019; Chinseu *et al.*, 2019
Non-governmental organizations	Has better outreach and flexibility than government institutions and can be more available to farmers.	Can be restricted by some factors (ex: funding, decision maker's priorities, national policy).	Twomlow *et al.*, 2008; Ariti *et al.*, 2018; Elahi *et al.*, 2018; Chinseu *et al.*, 2019
Private sector	Involvement in planning is critical for the success of planned adaptation. Can influence availability of certain agricultural inputs to farmers.	Limited inclusion and involvement in planning Primarily incentivized by economic gain.	Johl, 2012; Fisher *et al.*, 2015
Researchers	Key player in advancement of knowledge and strategies for climate change adaptation. Monitoring farmers adaptive capacity and relevant factors affecting farmers choices and ability to take adaptive measures.	Farmers are not easily "convinced". Rely on extension staff as a connection with farmers. Government policies that are economically driven may exclude research output.	Smith & Lenhart, 1996; Banerjee, 2015; Kanter *et al.*, 2018; Chinseu *et al.*, 2019; Lunduka *et al.*, 2019; Paul, 2019

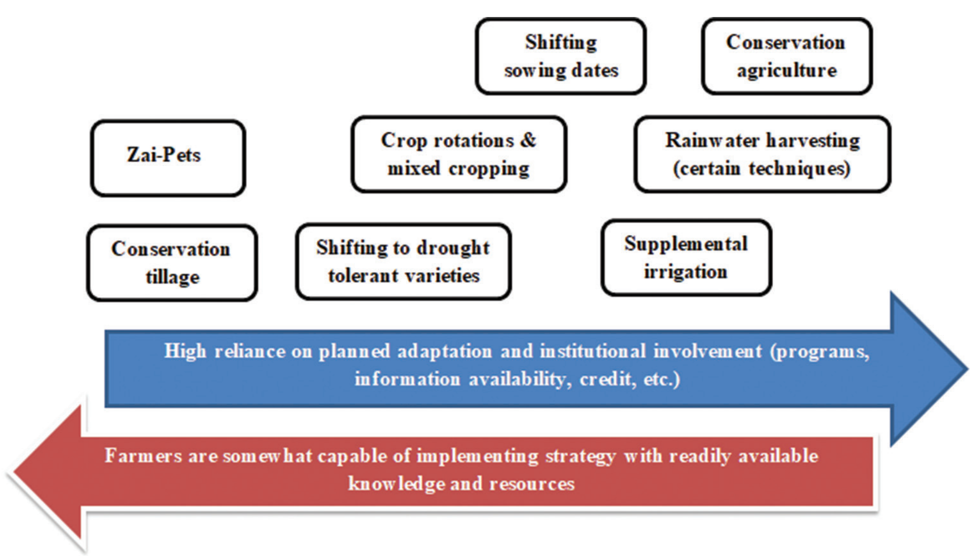

Figure 2: Estimated classification of some agricultural strategies based on possibility of successful implementation by farmers in arid regions

development programs and non-governmental organizations' involvement for improving adaptation of agricultural lands were evidently successful.

Bizikova *et al.* (2014) reported that the success of adaptation planning in agriculture relies on developing skills and sharing knowledge between all relevant stakeholders, incorporation of research output and dynamic relations between policymakers and all stakeholders, the study also reported the interactive and dynamic development of the capabilities of involved institutions as an important element in this process.

By taking a general outlook on adaptive agricultural land measures, and the extent to which they rely on institutional involvement, and by considering the findings from some research works that examined factors influencing adaptive capacity of farmers in arid regions, we present an estimated classification of some adaptive agricultural land measures reviewed in this paper (Figure 2).

CONCLUSIONS AND RECOMMENDATIONS

Land resources in arid regions are particularly vulnerable to climate change impacts, especially changes in precipitation patterns. Farm-level adaptation measures such as crop rotations, shifting to drought-tolerant crops, supplemental irrigation, and rainwater harvesting show good potential to help avoid and alleviate various risks related to precipitation variability and soil moisture stresses in arid regions. This is because these measures can help improve soil moisture conservation, crop water use efficiency, and increase crop water supply. These advantages are well demonstrated by experimental studies, but observational research reports that these advantages are not yet reflected on farmers' conditions. Farm-level adaptation measures have various constraints and there are many aspects that need to be considered to succeed in the implementation of these adaptive measures. Some farmers seem to rely on indigenous knowledge alone to choose adaptive measures, and many farmers don't have sufficient access to resources or data to take adaptive measures and make sound decisions. This requires involvement at the institutional level to increase the adaptive capacity of farmers. Adaptive measures at the institutional level include policy provision and programs such as agricultural subsidies and incentive programs. These interventions show potential to increase the adaptive capacity of agricultural land resources in arid regions. These measures require all stakeholders to be involved and implementation of sound communication and incorporation of research output. Otherwise, such adaptive measures would fail to serve their purpose or can even lead to negative impacts on farmers and the agricultural sector.

Based on the reviewed material, it is strongly suggested that research works directed at adaptive measures should incorporate the socioeconomic and policy dimensions along with technical or experimental investigations. Such works should at least provide the limitations which farmers may run against for a given examined strategy.

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