Crop Farmers' Adaptations to Adverse Environmental Conditions in the Nile River Delta

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ABSTRACT

Ongoing rapid climate change is threatening food security worldwide. Coastal countries, such as Egypt, are especially vulnerable due to their proximity to the sea. The at-risk agriculture in these areas is key to understanding how crop farmers tackle ongoing and worsening environmental factors, notably soil salinity, water shortage, and high temperatures. Impacts extend to crop farmers' livelihood and half of the Egyptian population depending directly or indirectly on the agricultural sector. This research delves into understanding how crop farmers perceive environmental change, and ultimately, how they decide to adapt to it. Similarly, it aims to highlight the dynamics between different actors (private companies, farmers' association, etc.) and crop farmers in the adaptation process. Through a literature review, semi-structured interviews and questionnaires completed with crop farmers and representatives of various fundamental actors of the adaptation process, it became clear that crop farmers require increased financial support. This is necessary for them to invest in long-term solutions to tackle crop losses. This should be coupled with strong collaboration between academic centres, private companies, and local associations to allow building trust with crop farmers and support them through their adaptation process. This research additionally highlights the importance of collaborative work between crop farmers, which notably relies on less risk-averse crop farmers, acting as pioneers by testing new solutions, which, if successful, may laterally spread to an entire community.

INTRODUCTION

The Nile River Delta (NRD), in northern Egypt, is an environment vulnerable to climate change and human-induced changes. It was listed as amongst the most vulnerable deltas to sea-level rise and one of the three "extreme" vulnerability hotspots worldwide (Abdrabo & Hassaan, 2014; Gouda, 2020). Low precipitation, sea-level rise, sea water intrusion, groundwater pollution, soil salinization, water shortage, land fragmentation, urbanization, etc. are a few reasons leading to soil degradation, ultimately affecting crop production. With two thirds of Egyptian crops produced along the Nile, crop losses due to climate change and other related factors would lead to disastrous impacts (Abd-Elmabod et al., 2019). Food security is deemed at risk, as impact studies conducted by the Ministry of State for Environmental Affairs expect the productivity of wheat, maize, and vegetables to decrease by 19.2%, 15.2% and 28% respectively by 2060 (El-Aidy, 2023). Egyptian agriculture is also a source of income for close to 50% of the population (Siam & Abdelhakim, 2019). With the Nile Delta being qualified as a low resilience delta, the livelihood of crop farmers and others dependent on agriculture are at risk. This research takes a bottom-up approach to the agricultural adaptations required to deal with rapid climate change. Interviewing crop farmers directly will allow for a better understanding of the challenges they face in terms of adverse environmental factors. Working alongside them additionally highlights the help they seek to adapt, as well as the factors limiting their capacity to adapt (e.g.: lack of financial support). This research's objectives are thus 1) establishing adverse environmental factors perceived by crop farmers as affecting their crop production (in terms of quality, quantity, or cost), 2) investigate main adaptations adopted by crop farmers to face adverse environmental factors, 3) understand the key actors helping crop farmers adapt (where crop farmers seek help), and 4) define the factors that prevent crop farmers' adaptation. This research thus focuses on crop farmers' perceptions, informing the way they adapt, and where they could seek help. This research is not intended to develop an exhaustive list of crop farmers' adaptations, or a cumulative list of environmental factors affecting crop farmers. It rather tries to bring in a new angle into existing research by working alongside crop farmers. In fact, understanding their perception is key to efficiently implementing adaptation projects required to ensure future food security in a rapidly changing climate.

Let us delve further into the various environmental and social challenges affecting crop production in the NRD, which were investigated through a literature review.

LITERATURE REVIEW

Socio-economic factors

Abdulmoneim et al. (2012), looked at the impact of land fragmentation on land degradation. Cropland area loss, mostly due to urbanization, is accompanied by a loss of fertile land. Abd-Elmabod et al. (2019) assessed the impact of the urbanization process on agriculture and water use. They established that since the 1970s, urbanization trends pushed agricultural activities to expand into the desert. Agricultural land thus shifted from fertile soils to marginal soils, requiring more irrigation and fertilizer. This need for over-irrigation and fertilization has led to increased soil salinity (Abd-Elmabod et al., 2019). Despite these observations, urbanization may be coupled with maintained fertile agricultural land, if urban expansion is directed towards the desert to protect existing fertile land found in the lowland Nile Delta areas.

Sea Water Intrusion

Climate change is contributing to sea-level rise, directly impacting the NRD. The IPCC's fifth assessment report (2014) predicted a sea-level rise ranging from 52 cm to 98 cm by 2100, reinforcing the existing concern of sea-level rise impacts on deltas. Broadus et al. (1986) highlighted how up to 15% of arable land was threatened by sea-level rise under the optimistic scenario (one metre sea level rise). The main impact expected was thus on subsistence agriculture, threatened by the contamination of groundwater due to sea water intrusion. Beyond groundwater contamination, land is also directly threatened. Abutaleb et al. (2018) warned about the loss of low-lying agricultural and urban land due to the inundation of coastal areas. The problem of sea water intrusion is exacerbated by the vulnerability of the delta's lowland areas to erosion. Fawaz and Soliman (2016) found that, if the sea level rose by near half a meter, 12% to 15% of high-quality agricultural land would be lost in the NRD. Overall, sea water intrusion and groundwater salinity have consistently been associated with land degradation and, consequently, a reduction in agricultural land (Abdulmoneim et al., 2011; Radwan et al., 2019). Kheir et al. (2019) quantified the loss of agricultural land as approximately 60% of the total agricultural land of the northern region of the NRD. This was established under the risky scenario of sea-level rise, meaning a rise of two metres. Abdrabo and Hassaan (2014) found that summer crops (cotton, rice, etc.) would be most affected and thus suffer most economic losses. So, even if various measures at the global and local levels are adopted to mitigate the sea-level rise (primarily by reducing greenhouse gas emissions), there is a sea-level rise commitment due to the low diffusion of heat towards the deep ocean layer (Kuenzer & Renaud, 2012). It was found that, if countries followed the Paris Agreement emission pledges until 2030, the sea level would rise by one metre by 2100 (Nauels et al., 2019). It is thus key to find ways to adapt to consequences of sea water intrusion under different scenarios.

Soil Salinization

Despite its renowned highly fertile soils, 15% of the Nile Delta's best arable land is affected by soil salinization (FAO, 2016). Soil salinization, further exacerbated by low precipitation, high evaporation, and seawater intrusion raising the groundwater table level, is thus a serious threat to the entire agricultural sector and measures to tackle this issue have been adopted since the eighties (Abdulmoneim et al., 2011; Ragab, 2020). Soil salinization is also exacerbated by specific irrigation methods. Usage of drainage water (rich in salts, chemicals, and various pollutants) is a common irrigation method for farmers downstream who may experience water shortage in the summer months, which contributes to soil salinization and negatively impact crops, notably by reducing soil fertility and leading to significant agricultural losses in terms of productivity (Khater et al., 2014; Ragab, 2020). Indicating an existing inequality between farmers upstream, who do not rely on drainage water and have enough access to high quality irrigation water, compared to farmers downstream. Molle et al. (2018), supported this result by looking at the drainage water salinity. They found that, in the northern regions of the delta, water released into the sea through pumping stations had almost three times the salt mass of the freshwater entering the delta through the Nile River. The northern delta is thus more impacted by soil salinization than the southern delta.

Water Shortage and Existing Irrigation Methods

Egypt's climate is dry and hot, with very low annual precipitation. To counter scarcity of freshwater, drainage water represents 12.6% of the annual Egyptian freshwater supply (Khater et al., 2014). More than a tenth of Egypt's freshwater supply comes from water that is reused (e.g., agriculture drainage), supported by an extensive drainage system and very dense network of irrigation canals to allow perennial irrigation (Abdulmoneim et al., 2011). This causes Egypt to have a negative water balance as more water is used than what is supplied by the natural environment. Khater et al. (2014) looked at difficulties experienced by farmers due to water scarcity, highlighting that 71% of farmers judge that water available in their irrigation canals is not enough to meet the water demand in summer months. The water shortage, enhanced at the end of irrigation networks, therefore poses a threat to the livelihoods of crop farmers. However, the authors highlighted the huge waste of water occurring on agricultural land. They found that crops grown utilize less than 50% of what is annually supplied by the irrigation water. The remaining is lost through drainage systems and is thus of lower quality if reused in the future. Moreover, the authors looked at the types of crops planted and their water demand. Findings show that in the summer months, rice and cotton are the main crops cultivated, occupying 93% of the agricultural land. However, cotton, and rice, are considered highly water-intensive. Their water consumption is twice as large as maize's water consumption (Khater et al. 2014). The authors therefore highlight the need to look into water management strategies to limit waste of water, as well as shifting towards the cultivation of crops with lower irrigation requirements. In a more recent experiment, Abdelradi and Yassi (2020) looked at the impact of water scarcity on agricultural production and land degradation. In their experiments, they looked at the impact of increased temperatures on the ten most grown crops in Egypt (incl. rice, tomatoes, cotton, wheat, etc.) and the variation in their water consumption. They found that all crops saw an increase in water consumption in high heat conditions compared to normal conditions, except for barley. This therefore shows that water scarcity linked to warmer temperatures brought by climate change will be worsened by the increased water requirements of most summer crops. Water scarcity is thus another important pressure put onto the agricultural sector, and crop farmers must learn to adapt to it.

Aswan to Ethiopian Grand Renaissance Dam

It must be highlighted that the building of the Ethiopian Grand Renaissance Dam (GERD) is a further challenge for downstream crop farmers who face the risk of future water shortage (Aziz et al., 2019). Large dam projects bring considerable changes to the ecological system. The Aswan Dam built in 1902 received various critics and praises during and after its construction. Broadus et al. (1986) were particularly worried about the impact of the dam on sediment transportation. They argued that since its construction, a decreasing number of nourishing sediments were reaching downstream areas. Abd-El Monsef et al. (2015) and Xu et al. (2017) brought a more nuanced view. They acknowledge that the Aswan Dam has led to saltier less fertile soils, and that the decrease in sediment deposits has worsened coastal erosion, due to the dam trapping sediments and runoffs. In addition to highlighting that continuous irrigation allowed by the dam has raised the groundwater table, contributing to soil salinization. However, their argument outlined construction as the source allowing multicropping, as farmers are now able to have three crops a year, thanks to available freshwater for irrigation during the dry season. They continue to argue that even though the quality of downstream soils has decreased since the dam's construction, farmers have been able to adapt to saltier, less rich in nutrients, soils. They thus conclude that the Aswan Dam has had an overall positive impact on the Egyptian agricultural production. They also mention that the dam grants protection against important changes in the river flow. By stabilizing the flow at a fixed level, the dam prevents important flooding or droughts, which could negatively affect both the agricultural and urban lands (Abd-El Monsef et al., 2015; Xu et al., 2017).

The Ethiopian Grand Renaissance Dam (GERD) is a project announced by the Ethiopian government in 2011 to build a hydroelectric dam on the Nile River. Egypt has raised concern about their water security in light of this project, and negotiations are currently in place with the Ethiopian government (Carnegie, 2023; Bearak & Raghavan, 2022; Naddaf, 2023). Concerning the GERD, recent papers warn about its potential impacts on the fertility of agricultural land, as well as on the problematic of water shortage, which is already an issue due to low precipitation in the Nile Delta. For example, Aziz et al. (2019) assess the potential impact of the GERD on the NRD. They highlight how the surface water level (SWL) and groundwater level (GWL) are tied to one another: a reduction in the SWL would cause a reduction in the GWL. They established that the GERD could lead to a 50% reduction in SWL, thus a two to five metres reduction in GWL. This would cause pressure on crop yield, soil salinity and water resources. The GERD is therefore another factor that must be accounted for by farmers and officials when establishing to which degree they will need to adapt to water scarcity and soil salinization.

Agricultural Sector's Vulnerability

Gouda (2020) highlighted that farmers see a decrease in their resilience to changing environmental conditions and are thus more vulnerable to those changes. She highlighted that, to be able to adapt to changing conditions, farmers and local communities in general must first be aware of the changes occurring, and then access reliable information to make decision allowing them to adapt. It is thus key to efficiently share information about existing heat-tolerant crops, efficient water management practices, and other efficient adaptations to allow farmers of the NRD to effectively adapt to their changing environment. Gouda (2020) notably emphasized the role of the public agricultural extension sector as the bridge between research and farmers. Highlighting that farmers, potentially risk-averse and facing budget constraints, may turn towards inexpensive adaptations, which may not be as sustainable and efficient as more expensive adaptations, potentially harming nearby farmers. It is therefore key to allow for a concerted effort between farmers, and to support farmers financially through their adaptation process. Kassem et al. (2019), however, argue that extension services dedicated to raise farmers' awareness, such as pamphlets, visits, posters, or radio programs, have been found to have a low impact on farmers knowledge. They conducted interviews with farmers to collect quantitative and qualitative data on their knowledge on the causes of environmental changes, and adaptations they came up with. They found that 50% of farmers had no knowledge of climate change, and that the best way to increase farmers' awareness was through education in skills development programs. This had a higher impact on farmers' capacity to respond effectively to changing environmental conditions. They also found that farmers' capacity to adapt was especially influenced by their education level, the diversity of crops they produced and if they took part in the Water User Association. Determining that less than a tenth of farmers did not adopt any adaptation measures, well the rest adopted various adaptations, such as;

a) Plantation of rice crops

More than a third of crop farmers cultivate salinity resistant varieties (Kassem et al., 2019). Rice cultivation is indeed an efficient way to prevent sea water intrusion, reduce soil salinity and maintain soil quality (Kotb et al., 2000). Abdulmoneim et al. (2011) established that annually, 294,000 ha of rice cultivation was required in the northern governorates of the NRD to limit soil salinization. In a 2018 study, Molle et al. looked at the role of rice cultivation in salt management. Molle et al. reported that farmers had to grow rice crops once every two years to maintain the soil quality by reducing soil salinity. In this study, it was notably warned that improvement in irrigation efficiency from 50% to 66% would lead to a drainage water salinity multiplied by one and a half. Therefore, increased irrigation efficiency might further raise the need for multiple rice crops planting.

b) Increased cropping efficiency and cultivars resistance

Kassem et al. (2019) found that farmers aware of climate change mostly adapted through changing crop patterns and crop rotation, also finding that more than half planted drought resistant varieties. This relies on research and development, and its creation of more heat and salinity resistant crops. There is notably a project of *smart crops* development by the UNDP to ensure future sustainable agricultural practices. These crops are chosen based on the resistance to heat, wind, and salinity (Wahab, 2022). The testing of different cultivars to establish the most resistant to changing environmental conditions is therefore key. Kheir et al. (2019) found that a particular wheat cultivar (Misr3) was more resistant to higher temperatures while also benefitting from higher CO_2 concentrations. Plantation of this specific wheat cultivar could thus allow increased crop yield parallel to warmer temperatures and higher CO_2 concentrations. Khater et al. (2014) also highlighted how planting crops sensitive to salinity upstream and more resistant crops downstream could enhance crop productivity.

c) Drainage

Currently, there are official government pumping stations and unofficial farmers' pump. These both allow reusing drainage water from the drainage canals by directing it back to irrigation canals and thus be used again as irrigation water. This process was found to increase the Egyptian available water resource by more than 10%, allowing to meet the current agricultural demand, especially in northern governorates facing water shortage in the summer months (Khater et al., 2014). However, considering previously mentioned information that drainage water can accumulate salt and other pollutants, it is key to carefully monitor drainage water to prevent using it as irrigation water for crops not resistant to salinity. Abdrabo and Hassaan (2014) notably recommend upgrading the existing drainage canals to improve the usage of drainage water in irrigation. They estimate that this upgrade would cost around 190.8 million LE which is less than 5% of the estimated agricultural losses by 2100 due to accumulation of potential damage.

d) Other adaptations

Farmers have come up with various other adaptations. In the Kafr El Sheikh governorate, farmers increased crop yield by planting early, managing fertilizer carefully, using manure to increase the soil's content in organic matter and avoid irrigation deficit (Kheir et al., 2019). Authors also highlighted the need for protective measures against sea level rise. McCarl et al. (2013) notably highlighted that infrastructure protecting the land from sea-level rise would lead to almost no land losses (even lowlands). This was emphasized by Frihy (2003) who suggested strengthening the shoreline defence against beach erosion to mitigate sea-level rise impacts.

This literature review has shed light on the causes and impacts of soil salinity and water scarcity on the NRD's agricultural production. Rising sea level and sea water intrusion, increasing atmospheric CO2, warming temperatures, land degradation and soil salinization have been found to negatively impact farmers' livelihoods by decreasing crop production. Although, various adaptations already exist, and farmers have notably managed to reduce those negative impacts by adopting more resistant crops, cultivating rice, using drainage water as irrigation water, etc. The existing literature addressing these issues is mainly focused on a top-down approach: previous authors looked at the impact of changing environmental conditions on the agricultural production. Very few research takes a bottom-up approach by working hand-in-hand with farmers. This author found only one, the research by Kassem et al. (2019). It would therefore be interesting to further this line of research. While Kassem et al. (2019) have comprehensively assessed the type of farmers who decided to adapt (notably based on their level of education) and the way they adapted (changing crop patterns, use of manure, etc.), they did not look at how farmers adapted. As mentioned by Gouda (2020), the public agricultural sector is the bridge between research and farmers. In fact, farmers do rely on current research on crops to effectively adapt in the future. Further research on the relationship between crop farmers and research and development institutions in governorates particularly affected by soil salinization and water scarcity, such as the Kafr el-Sheikh Governorate, is fundamental to understand the processes behind farmers' adaptations. Such research could also highlight if farmers working closely with research institutions develop different adaptations compared to other farmers in their region.

METHODS AND MATERIALS

This study was conducted in the NRD, located in Northern Egypt, a dry and hot climate. The average annual temperature in the delta is 23°C, with a peak average temperature reached in August at 29°C. Annual precipitation is between 100 to 200 mm. Data was gathered within the boundaries or in the close periphery of various cities of the Delta: Sidi Salem, Alexandria, Tanta, Baltim, and Mansoura. Due to low sampling in Sidi Salem, Alexandria, and Tanta, the result sections will combine data collected in those cities under the category "Western Delta." A subset of this study was conducted in the periphery of El Minya, in the Minya Governorate in Upper Egypt. This is a desert climate with an average temperature of 23°C and an annual precipitation of 1 mm (condensed in January). Peak temperatures are reached in July with an average of 31°C. Despite the initial focus on the NRD, further sampling in El-Minya was conducted for a better understanding of the impacts of coupled water shortage with high temperatures, without the impacts of high soil salinity. The expansion of this research into Upper Egypt allows for a better highlight of the particularity of NRD's crop farmers in terms of their perceptions of adverse environmental factors, as well as their adaptation process.

Research Area Map – The study focused on the NRD, around five locations, displayed in a white font. A subset of the study was conducted in El-Minya, displayed in black. Map modified from Google Earth, 2023.

This research was two-folded. First, the study focused on haphazardly interviewing crop farmers located in the NRD (and El-Minya) who were each affected by soil salinization or water scarcity and were the main crop farmers working the land. They were interviewed on different aspects of their farms (i.e., size, types of crops…), how the environment was affecting them (what factor(s), consequences…), the solutions they were adopting to counter potential adverse environmental factors, where they were getting their information on how to adapt, and finally, if there were factors (economic, knowledge…) inhibiting them to efficiently adapt. Interviews were either conducted as semi-structured interviews in person, or through the completion of a questionnaire (see Fig. A1). Both questionnaires and in-person interviews had to be translated from English to Arabic and from Arabic to English. Second, representatives of the El Nahda Society for Rural Development (farmers' association), the Al-Safwa company (private sector), the Kafr El-Sheikh University (academic institution) and the Desert Research Center (governmental organization) were interviewed through semi-structured interviews. Discussions focused on their work with crop farmers and their perceptions on how climate change may affect agriculture in Egypt and potential solutions. Information gathered in interviews was combined with field observations made to complete crop farmers' narratives.

Consent for interviews was obtained verbally (see Form A2 for oral consent script). All data gathered from crop farmers was anonymized and uploaded on the OneDrive online platform, protected by a password.

LIMITATIONS

This study has encountered various limitations that could be overcome in future studies provided with more funding, time, and knowledge.

First, crop farmers interviewed were met by the intermediary of either university representatives (students or professors), agricultural engineers, farmers' association, or private companies. This is a fundamental aspect of the study that could be interpreted as a limitation, as crop farmers that do not engage with various knowledge sharing organizations may have significantly different answers. It is thus key to understand that this study does not provide an exhaustive approach of how Egyptian crop farmers adapt to climate change, but rather try to get a better grasp of how crop farmers, that seek help from external organizations. adapt. Those are the pioneers of adaptations that ultimately will spread successful solutions with other crop farmers not represented in this research through lateral knowledge spread.

Second, the reliance on translators during interviews has surely led to the loss of some elements of information, especially within large group conversations. The reformulation, reinterpretation, or simplification of crop farmers' discussions were reduced by ensuring to work with researchers aware of the study's objectives of the study and the situation on the ground, such as professors at the Kafr El-Sheikh University (KFU) in the Faculty of Agriculture.

Third, the short timeframe of this study has allowed to only capture a snapshot of crop farmers' and relevant actors' experience. Abnormally high temperatures have shifted crop farmers' focus to this trend, and they might have forgotten to address other issues affecting them usually, as those concerns were buried under the threat of excessively high temperatures.

RESULTS

This section will investigate the results that emerged from the work with crop farmers. Those results will be put into perspective with comments from the second part of this research in the next section. The following results compile the discussions with 87 crop farmers, 76 of them located in the NRD, and the remainder located in El-Minya (see Table B1). One-fifth of the crop farmers interviewed were smallholders (i.e., land size below three feddans).

Perception of Adverse Environmental Impacts

When asked about what adverse environmental factors were affecting their crop production the most, 64% of crop farmers highlighted high temperatures and 55% indicated infections (nematodes, leaf miner, etc.).

Crop farmers located in El-Minya especially highlighted the adverse impacts of high temperatures, with 91% of them mentioning this issue during interviews (see Table B2 and Fig. B1). More than a third of crop farmers located in the NRD highlighted the impact of salinity (either in soils or irrigation water), while the problem of water shortage was most highlighted by crop farmers from El-Minya. Water shortage was mentioned as one of the least adverse environmental factors (in comparison to soil salinity, high temperatures, and infections) for crop farmers located in the NRD.

Leaf miner infection – The leaf miner larvae can be distinctly seen, as well as the trails left on the leaf surface.

Solutions to Adverse Environmental Impacts

In all locations, crop farmers highlighted the change of crop or variety to a more resistant one as the main way to adapt to decreasing crop yield (see Table 3 and Fig. B2). This was especially important for crop farmers in the NRD with 71.1% of them highlighting that they had changed crop or cultivar to deal with reduced yield. A quarter of the crop farmers interviewed in the delta mentioned the importance of transitioning from surface to drip or sprinkler irrigation to notably adapt to water scarcity (improved irrigation practices). More crop farmers in El-Minya compared to the NRD also emphasized the importance of using fertilization and pesticide programs to favour crop growth and limit crop infections by pests (approximately 50% in both cases).

Provenance of Information

To understand the way information was shared with and between them, crop farmers were asked the provenance of their knowledge on how to adapt to changing conditions. Collaboration is perceived as a key source of knowledge, with most crop farmers (92%) working with other crop farmers to discuss crop evolution and ways to adapt to changing conditions (see Table B4 and Fig. B3). Crop farmers in El-Minya highlighted the importance of working with agricultural engineers (91%), while crop farmers in the NRD mentioned the importance of finding knowledge on the internet, in books, academic articles or on television (51%). Overall, the government was the least sought-after source of information for crop farmers located in the NRD with only 6.6% of them considering that the government played a meaningful role in helping them adapt. Private companies, on the other hand, play an important role in helping crop farmers, especially in El-Minya where 90.9% of crop farmers mentioned them as a key component of their adaptation process. This assessment was not made in the NRD, with only 28.9% of crop farmers highlighting this aspect. Finally, the use of trial-and-error technique to adapt was mentioned by less than a fifth of crop farmers located in the NRD.

Limits to Adaptations

Fifty-seven percent of crop farmers highlighted the lack of financial support, which has been overall cited as the most important factor limiting adaptation (see Table B5 and Fig. B4). This problem seems most important in the NRD compared to El-Minya, with 62% compared to 27% of crop farmers mentioning it. In fact, crop farmers in El-Minya considered the lack of governmental support as being the most limiting factor to adaptation (47%). Crop farmers in the NRD also emphasized their lack of knowledge and the lack of external support to raise their knowledge on how to adapt (42% and 40% respectively). In the NRD only 10.5% of crop farmers interviewed highlighted the lack of more resistant varieties to counter yield reduction due to adverse environmental factors. Furthermore, 27.6% of crop farmers in that region hoped for more evidence that the solutions presented to them were reliable, which could notably be achieved through field experiments.

DISCUSSIONS

Results highlight a high diversity in what crop farmers perceive as affecting them. A fundamental aspect of this study that must be made clear before trying to interpret any results obtained is its focus on crop farmers' perceptions. Crop farmers were interviewed to understand their views on what may cause crop losses, on what could solve it, and on what could help them understand how to solve it. Therefore, results obtained above do not mean that crop farmers failing to mention, for example, salinity as one of the adverse environmental factors faced, are not affected by this problem. In fact, the NRD is affected by soil salinization, so all crop farmers in the region have, to different degrees, have adapted to it. However, understanding the way in which they perceive the problem is fundamental to understand the solutions they seek. Similarly, crop farmers who do not mention using a pesticide program do not mean that they are not using that solution. This research simply highlights that in their eyes, the fundamental solution might lie somewhere else. Understanding this distinction is key to avoid misinterpreting the percentages given in the results section, as well as acknowledging local perceptions of problems faced, their solutions and what is missing in crop farmers' eyes to adapt. This is key to help local actors work more efficiently alongside crop farmers to enhance local adaptations to climate change and avoid an agricultural crisis.

Crop Farmers' Perceptions of Adverse Impacts

Against expectations, crop farmers in the NRD did not emphasize the impact of salinity (either irrigation water or soil salinity) on their crops, even though scientific literature has highlighted its adverse impacts in the region. On the contrary, crop farmers mostly emphasized high temperatures and infections as problems, rather than water shortage, poor water quality and soil salinization. Still, soil salinity in particular is a fundamental problem affecting crop production in the NRD. Dr. Mohamed Sharaf, a professor at the University of Kafr El-Sheikh in the Faculty of Agriculture notably highlighted that high levels of soil salinity induce thinner plant roots, rendering them more vulnerable to pests (fungi, nematodes, etc.). This is not a particularity of soil salinity, as other environmental stressors on crops, such as high temperatures, or water shortage induce crop vulnerability to various diseases. So, while crop farmers in the NRD are affected by a multiplicity of factors, it is key to understand which one they perceive as being the most important to comprehend the way they adapt to climate change. Since infections and abnormally high temperatures are easily perceivable without the need for special measurement instruments, crop farmers will mainly focus on those aspects. With infections often being a symptom of deeper causes (poor water quality, soil salinity, high temperature), simply addressing them without addressing the root causes will become costly for crop farmers. This was proven by the fact that the majority mentioned experiencing costs increase to try to stabilize their crop yield (lessen losses), notably due to the necessity of buying more agricultural inputs (e.g. pesticides, fertilizers) to deal with infections.

Heat and Cold Waves

While the initial objective of this research was to mainly focus on how water scarcity and soil salinization impacted crop farmers in the NRD, some modifications came about. First, in the summer of 2023, crop farmers faced abnormally high temperatures early in the season, and the winter 2022-2023 brought especially harsh cold waves. Crop farmers in the NRD, normally used to cooler temperatures compared to Upper Egypt faced similar ranges of temperatures. Studies show that the intensity of heat and cold wave have increased in the past 20 years, as highlighted by the interviewed crop farmers (Aboelkhair & Morsy, 2024). This negatively impacts crop production and can increase water scarcity as high temperatures induce more crop evapotranspiration, increasing the water need of plants. With higher temperatures expected in the future, the Egyptian Ministry of State for Environmental Affairs (2010) expects that the national average irrigation requirements will increase by 7 to 12% by the year 2100. Despite this assessment, crop farmers in the NRD mentioned water shortage less than expected. In fact, the problem in the region is rather poor water quality than water shortage, as crop farmers have developed systems to ensure continuous supply of water: recycling of drainage water, infrastructure to divert water from canals further away, etc. The water recycled is often highly saline, which affects crop quality and growth, notably by rendering it more vulnerable to diseases.

Drip irrigation – The rubber drip irrigation tubing transports water directly to the crop, irrigating only the area of interest.

Irrigation

To deal with water scarcity, many crop farmers have switched to drip irrigation systems. While only a quarter of crop farmers located in the NRD mentioned improving their water irrigation systems, it was observed that close to all crop farmers had the new drip irrigation system. Sprinkler irrigation systems seemed less common, which is probably due to it being more expensive. Drip irrigation systems yield many advantages. Beyond saving water, fertigation allows using fertilizers efficiently by delivering them directly to

Crop farm using a drip irrigation system – The rubber drip irrigation tubing extends on the crop farm to transport water to each seed directly.

the crop through irrigation water. This saves on fertilizer use, as well as providing higher crop yield. Drip irrigation systems cost approximately 1,500 EGP per feddan (49 USD). This is a significant cost for crop farmers, but the Egyptian government does provide subsidies. In fact, in January 2017, the government launched a water-saving initiative based on a 20-year management plan. Most of the responsibility to switch to more efficient water management systems bears on crop farmers' shoulders, but the government does provide loans that can be paid off through farmers' instalments. Crop farmers that transition to more efficient irrigation systems can also receive subsidized seeds, fertilizers and pesticides (El-Aidy, 2023). The Egyptian government hopes to convert 2.1 million hectares to drip and sprinkler irrigation systems by 2037, a fivefold increase compared to 2017.

Soil Salinity

Drip irrigation systems do have disadvantages. In the long-term, they can induce an increase in soil salinity. Therefore, some crop farmers still use surface irrigation on their field once a year. The flooding of water allows washing the soils from the salts that may have accumulated due to the drip irrigation. This is especially necessary when irrigation water is highly saline, notably if coming from recycled drainage water.

Mango tree affected by soil salinity – The effect of soil salinity can be seen due to the leaf's depigmentation, or "burned" aspect.

Contrary to expectations, crop farmers in the NRD did not highlight soil salinization as one of the worst environmental factors faced. This might be explained by the fact that crop farmers have developed ways to counter this problem. Treatments notably exist to decrease salinity levels in the soils, such as sulfur, or humic acid application. Similarly, farmers have turned towards crops that are more resistant to high saline levels. Guava trees for example, are known for their high tolerance to high levels of soil salinity. However, a complete switch to a certain type of crop can be problematic and has revealed itself to be harmful in certain circumstances. One of the areas studied in this research, Baltim, had previously extensively switched to guava tree production to achieve high yield in saline conditions. The spread of a nematode affecting all guava trees in the region has forced crop farmers to switch to less salt-tolerant crops, notably mango trees. The effect of soil salinity can be observed on those trees, affecting yield and quality, but crop farmers have had to switch as guava trees were no longer profitable.

Provenance of Information

Interestingly, crop farmers rely heavily on collaboration to adapt to adverse conditions. This can occur through one-on-one discussions between neighbour farmers, group discussions, or discussions through farmers' association meetings. Discussions are key to share about difficulties faced, expectations, potential solutions, etc. Crop farmers who might have found a good solution to a specific problem through trial and error may share their findings with others, expecting their help in the future. However, this type of knowledge sharing alone is not sufficient to face fast changing conditions. Crop farmers who want to maintain high crop yield and face challenges either seek help with private companies, university centres, their farmers' association's partners, online, or with the help of agricultural engineers. Let us take a deeper look at the different services those organisms offer.

Farmers' Associations

Farmers in the region of Sidi Salem were interviewed during a meeting at the El Nahda Society for Rural Development and Water Management, an organization established in 2007 by a group of 38 people highly educated in the field of agriculture. The current president of the organization, Abdallah Sahad Brahik, was interviewed to understand the work of the organization. The society works all around the Kafr El Sheikh governorate and has currently thousands of members and focuses on the development aspect of crop farmers' support. They notably (non-exhaustive list):

1- Distribute provisions (e.g.: meat, vegetables) to precarious crop farmers.

2- Help members with small agricultural projects by providing them with loans at low interest rates.

3- Arrange some extension services such as inviting agricultural experts to discuss with crop farmers and answer their enquiries.

4- Work alongside different organizations, such as the Food and Agriculture Organization (FAO) or the SAline AgricuLture for ADaptation (SALAD) project, providing them with technology and financial support in exchange of the right to conduct agriculture experiments (e.g.: testing new crop variety) on interested crop farmers' land.

5- Organize meetings with members thrice a year (before each growing season) to address any concerns, questions and provide recommendations.

6- Conduct their own research. For example, in 2007, the organization conducted a study on water quality in irrigation in partnership with researchers from the Netherlands and the CARE organization.

7- Organize workshops in the Kafr el-Sheikh Governorate to raise awareness on climate change and introduce small project ideas to crop farmers as a way to raise knowledge.

8- Develop a field school for small groups of crop farmers who have moved their fields to new areas. The aim is to transfer knowledge from expert scholars to crop farmers.

Those projects have been particularly efficient as local crop farmers are part of the knowledge creation process by working alongside researchers. Such a small-scale approach ensures crop farmers' empowerment by giving them the tools to adapt to climate change. Farmers have seen positive impacts on the crops. One of the association's projects (fully funded by the FAO) that started in 2021 to test different solutions to adapt to highly saline soils proved a rise in yield of crop farmers who adopted the solution. The association is especially powerful due to its collaboration with various actors, notably the Ministry of Agriculture, university centres (e.g.: KFU), governmental research centres, international organizations (FAO) and researchers (notably experts from the Netherlands, and China). Local and international exchange of knowledge is key to fuel research and development and support local crop farmers.

University Centres

Crop farmers may also work with local university centres through a mutually beneficial relationship. On one hand, crop farmers are provided with all required material for the experiment (e.g.: new fertilizer, cultivars, etc.) and can witness whether the adaptation is promising or not. On the other hand, researchers have access to free land to test a solution at a larger scale than within a laboratory, and ensure its real-life application, in the face of natural hazards.

KFU Field Experiment – Different irrigation system delivering chemicals to manage soil salinity are tested on a crop farmer field in the Kafr El Sheikh governorate.

Crop farmers interviewed especially appreciated these mutualistic relationships, and often highlighted that lack of adaptations in some cases was due to the lack of more of such initiatives. In fact, crop farmers, especially smallholders who lack the financial resources to recover from crop failure will avoid changing their production methods, without proof that the change will lead to a positive gain for them (ie. higher yield, better quality, reduction in cost, etc.). Working hand-in-hand with researchers ensures that all the experiments costs are covered by the university centre, which reduces the burden on crop farmers, and is highly beneficial in case of gains compared to their traditional methods. Having researchers coming regularly to once a field also allows crop farmers to seek free advice in case hardships are encountered in other parts of their field.

University centres may also organize workshops to efficiently spread knowledge to a higher number of crop farmers (compared to one-on-one discussions). The KFU has notably organized seven workshops in the year 2022, reaching 152 smallholders on topics including technical recommendations on crop cultivation, mitigation of adverse environmental conditions, and strategies for Managing Strategic Crops under climate change. Universities are thus key institutions to help crop farmers adapt to changing conditions, by being directly involved with them on their field. Such long-lasting relationships have built trust over the years and pushes crop farmers to follow recommendations and be potentially less risk averse as more trust is built into the suggestions given (especially as they prove to be successful when applied).

The Private Sector

Crop farmers who do not have special relationships with universities may turn towards the private sector to seek support. Interviewed crop farmers working with agricultural engineers appreciated their frequent visits and provision of valuable advice. Crop farmers who turn towards private chemical companies often receive free services to build trust and lasting relations. The Al Safwa Chemicals Company, specialized in the provision of agrochemicals, provides crop farmers (usually owning crop farms between five and 50 feddans) with free services, such as distributing free samples to build trust and confidence in the products offered. They also have eight agricultural engineers working for them to provide support and advice for free to crop farmers seeking help. In the worst cases, agricultural engineers may visit crop farmers' fields every two weeks to provide guidance. However, contrary to university centres or farmers' associations, private companies tend to work less with smallholders, who may not have the funds to buy quality agrochemicals for their field. Dr. Mohamed Sharaf, working both in the public and private sectors, highlighted that smallholder lacking financial means may turn towards cheaper agrochemicals, often illegal (not approved by the government), that provide results on the short-term but quickly backfire as their high concentrations in chemicals disturb the soils balance. Weakened crops and soils will lead the way for faster and stronger infections, which in some cases have forced crop farmers to leave their field due to loss of profitability.

Is Knowledge Spread Efficiently?

We have seen that resources to spread knowledge to crop farmers directly does exist, but is it always efficient? During interviews, a crop farmer located in Baltim was working hand-in-hand with professors from the KFU, providing him with resources to improve his crop yield and reduce weed infestation. On their monthly visit, representatives of the KFU observed that the crop farmer was not following recommendations and the situation was worsening. Why would a crop farmer not follow expert recommendations? First, it was highlighted that the success rate of this kind of one-on-one work with crop farmers relied heavily on whether the crop farmer sought help or not. When experts arrive on a field to offer their services to help solve an observed issue, crop farmers are a lot less likely to comply with suggestions (even if an agreement was made between both parties). Second, the demand for advice is a lot higher than the supply of advice, and professionals are highly sought after. They are therefore unable to regularly go onto fields and must space their visits by usually a month, if not more. During this period, crop farmers may stop following recommendations, and trust is not as efficiently built as they do not see results as fast as they might have expected. The lack of supervision thus leads to a lack of willingness to comply with recommendations. Finally, crop farmers tend to be risk-averse and thus unwilling to try different growing techniques without proof that a change will lead to a potential gain[1]. Crop farmers especially like witnessing the success of a new growing technique, and many crop farmers

Crop Farmer Not Following Recommendations – A crop farmer located in Baltim failed to follow recommendations provided by professors from the KFU. The land is infested by weeds, as well as nematodes.

[1] Previous studies have investigated crop farmers' behaviour shaped by risk aversion, a tendency to avoid taking risks and prefer situations with low uncertainty (Menapace et al., 2013).

interviewed reiterated the need for more experiments being conducted on their field.

This tendency to prefer to witness the efficiency of a solution before adopting it explains a key aspect of lateral knowledge spread (farmer to farmer). Crop farmers will willingly adopt solutions that have worked for neighbour crop farmers, as they have the proof that the adaptation is profitable. However, this requires the presence of less risk averse individuals often becoming leaders within their community. This was notably the case of a crop farmer who gathered most of his knowledge online and tried different solutions to understand which one worked best. His online knowledge also allowed him to understand the market better and make informed decisions. He notably decided to export a part of its production to neighbour countries at a better price compared to the local market. Crop farmers in his community, witnessing his success, soon adopted similar techniques, positively contributing to the entire community's yield, and thus all smallholders' livelihood. Such pattern has been observed by the Desert Research Centre experts, who implement various agricultural projects in Egypt to find ways to tackle the adverse environmental factors affecting crop production and exacerbated by climate change. When selecting which crop farmers to work with, various factors are examined (e.g., income), including the crop farmer's leadership within his community. This ensures projects' long-lasting impact, as solutions adopted will laterally spread between crop farmers who follow leaders within their community[2]. Therefore, understanding the importance of working alongside the right crop farmers to maximize the efficiency of the limited supply of advice (due to a lack of experts in contrast with the multitude of crop farmers) is key to efficiently tackle adverse environmental factors affecting crop production.

Grand Renaissance Ethiopian Dam

Unexpectedly, few crop farmers have commented on their perception of the GERD's impact. Professors interviewed have mentioned their worries, deploring the GERD's "disastrous impacts" for the Egyptian water security and crop farmers' livelihood (A. El-Banna, personal interview, August 2023). Still, crop farmers might not have mentioned this problematic for different reasons, most likely due to the high concerns about warm temperatures, which might have overcome other concerns, especially those concerning the GERD, which impacts have not been felt in the NRD yet.

[2] The term "leader" in this case has nothing to do with political role, but rather with a farmer's reputation within his community, influenced by his knowledge, experience, character, etc.

Financial Support

The majority of crop farmers highlighted that the fundamental aspect lacking for many of them was financial support. The various solutions presented by crop farmers, such as pesticide and fertilization program, improved water management, or changing cultivars come at a cost. Crop farmers have seen an increase in their expenses to deal with exacerbated crop infections and reduced yield due to adverse environmental factors. Despite their efforts and financial investments, some have seen a decrease in their crop yield, in some cases by up to 60%. The problem is exacerbated for smallholders who lack funding and therefore cannot make long-term investments to plan for future changes. They must deal with problems as they appear, a season at a time. On the other hand, large-scale farmers tend to have the financial capacity to invest in the long-term and can thus invest in infrastructure supporting their crop farm. Despite this problem, when asked whether they would like to benefit from more governmental support, many farmers highlighted their distrust in governmental institutions and that they did not expect, nor seek, any help from the government. They prefer seeking help from local organizations, even though they would hope for more widespread extension services, to deal with the growing demand for advice and support. Still, resources are not sufficient to cover the costs of agricultural inputs and crop farmers interviewed that were strongly affected by high temperatures and water shortage decided to decrease the area of land cultivated in the future summers.

Governmental Support

While almost a half of crop farmers in El Minya mentioned the lack of governmental support (especially due to lack of infrastructure to support efficient crop production, such as cement roads), farmers in the NRD took a different approach, not mentioning the lack of governmental support due to mistrust in government institutions. The common refusal to seek governmental support was surprising, especially as the Egyptian government has developed a national agenda for the future, titled the Egypt Vision 2030 strategy to achieve sustainable development (Egypt MPED, 2016). The government notably highlighted its wishes to improve irrigation systems, high temperature tolerant crops, and drainage systems. To deal with water scarcity, the government is also building seawater desalinization plants and wastewater recycling facilities, as well as promoting water smart irrigation. The government is also funding the New Delta Project, a 2.5 million feddans project, with one of the goals being to develop micro-organisms helping plant resist to drought and saline conditions, funded by a 3 million EGP investment (approx. 97,000USD). Despite that, professors interviewed highlighted the need to speed the research and development process to adapt to the rapidly changing climate and provide adequate support to local crop farmers. Beyond that, crop farmers fail to see concrete government support on the ground, which combined with adverse environmental conditions affects the trust they put in government institutions. Crop farmers in El-Minya kept repeating their wish for better road infrastructure, or stable electricity to improve their crop production. A stable national grid is fundamental in months where high temperatures force crop farmers to irrigate at night to save water, and limit plant burn. This can however only be achieved through the reliance on public infrastructure. Crop farmers may bypass this requirement by investing in their own power grid, notably by installing solar panels, which is an important investment that cannot be achieved by all.

CONCLUSION

This research, through in-person discussions with crop farmers, as well as with representatives of various key actors of the adaptation process, has shed light onto crop farmers' perceptions of adverse environmental factors, as well as the dynamics behind their adaptation process. It has notably highlighted that crop farmers principally focus on tackling adverse environmental factors they can observe (e.g.: infections) and tend to prefer visual proof that adaptations are reliable, by either working with university centres, letting organizations work on their field for experiments, or collaborating with other crop farmers. Private companies play an important role in the adaptation process, and the main actor fundamentally lacking in crop farmers' support is the government. Despite that, government expectations to achieve food security are being implemented through the intermediary of private companies', agricultural engineers', and university centres' knowledge. For example, the Egypt Vision 2030 project aims to develop the greenhouse farming systems (increase protection from weather, reduced need for water, pesticides and other inputs, etc.), change sowing dates to cooler month, plant disease tolerant cultivars, change crop patterns, etc., which are all solutions being implemented locally, even by crop farmers that state their lack of governmental support. However, adaptations are costly, and the rapid investments required to limit crop losses and economic losses due to climate change cannot be met by all crop farmers (especially smallholders). It is thus key to develop an effective framework that can support all crop farmers through their transition, not just large-scale holders that can cover the costs. Farmers' associations are a great way to reach a large number of farmers with various cost saving initiatives and low interest loans, but many crop farmers do not seek those external services. Despite those few gaps, the current state of agriculture observed in the NRD is very promising as it relies on a framework of local, national, and international collaboration between a variety of actors (farmers' association, universities, agrochemical companies, etc.), working together to develop, test, present, and spread a multitude of solutions to ensure future food security and protect farmers' livelihoods despite the rising adverse environmental conditions. With financial support being a fundament aspect lacking for crop farmers, future research could investigate the development of service like microfinance programs to support crop farmers through their adaptation process.

ETHICS STATEMENT

This study was approved by the McGill University Research Ethics Board Office under file number 23-04-067 on June 9th, 2023. All participants provided oral informed consent prior to enrolment in the study.

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Appendix A

Form 1 Oral Consent Script

Consent Form

MUST BE GIVEN TO AND READ WITH THE PARTICIPANT BEFORE COMPLETING QUESTIONNAIRE

Adaptation of local farmers facing water shortage and soil salinization in the Nile River delta

Sponsor: McGill International Experience Awards

Fund title: Schull Yang International Experience Award

Purpose of the Study:

The purpose of this study is to understand the way you deal with issues of soil salinization and water scarcity. The focus is on the adaptations you have developed, and the process of how those adaptations have been developed. This study also aims to understand your relationship with academic institutions, notably researchers from the University of Kafrelsheikh, through the adapting process.

Study Procedures:

To fulfill the purpose of this study, you will be filling up a questionnaire. This should not take longer than 20 minutes. The questionnaire is anonymous.

Voluntary Participation:

Participation in this study is voluntary. You may decline to answer any question and may withdraw from the study at any time for any reason. If you decide to withdraw, the questionnaire will be torn apart, unless you allow me to keep it. Withdrawal after I have left with the questionnaire is not possible as it is anonymous, and I cannot trace it back to you.

Risk Assessment:

There are no anticipated risks to you by participating in this research. We will not address any potential sensitive topics and data will be completely anonymized.

Benefits:

Participating in the study will have little to no direct benefit for you; however we hope to learn more about the process of adaptation development and the cooperation between crop farmers and various institutions in this process.

Confidentiality:

Your confidentiality will be ensured as all data gathered on you is anonymized. There is nothing that can trace this research back to you.

Dissemination of Results:

Results of the study will be disseminated through an academic publication that will be available online. You will also be able to get a copy at the Kafrelsheikh University. Otherwise, I will share the results through some academic presentations in Canada.

Questions:

If you have any questions about the project, contact Prof. Farouk El-Aidy at this email address: felaidy@gmail.com or at this phone number +201006508305. He will translate your inquiries to me, and I will answer back through him.

If you have any ethical concerns or complaints about your participation in this study, and want to speak with someone not on the research team, please contact the Associate Director, Research Ethics at +1 514-398-6831 or lynda.mcneil@mcgill.ca citing REB file number 23-04-067.

Consent statement:

By completing the questionnaire, you consent to become an anonymous participant in this study. You understand that you may withdraw at any time until the researcher leaves with the questionnaire. You understand that you only must answer questions that you feel comfortable answering. Finally, by completing the questionnaire, you consent to have your anonymized data potentially shared with fellow researchers for future research.

Form 2 Crop Farmers' Questionnaire and Semi-Structured Interview Guide

QUESTIONNAIRE FOR CROP FARMERS

1- CURRENT SITUATION

a. Crop farm size : ____________

b. Type of crops and % (e.g.: rice – 25%)

c. Has there been any change in the type of crops you have been cultivating in the past two years? **Yes / No**

- What are the old and new crop types? (e.g.: Al-Basha 1077 tomatoes to Sama tomatoes)

- Why did you make this change?

____

____

____

____

d. Do you perceive negative impacts on your cultivation caused by environmental factors (e.g.: lack of available water)? **Yes / No**

- How so? (e.g.: decrease in crop yield,…)

____

____

____

____

2- ADAPTATIONS – This section applies to you if you have adopted any adaptations (e.g.: change in cropping pattern, water management, etc.).

a. What has motivated you to adapt?

b. What adaptations have you adopted? (e.g.: new crop patterns, new crop types…)

c. What were the resulting changes in crop production/quality? (e.g.: in terms of crop productivity, water demand, etc.)

d. Do you share knowledge about efficient adaptations with other crop farmers? **Yes/No**

- If yes: where and how often? (e.g.: union meetings, one-on-one discussions, events, …)

3- RELATIONSHIP WITH ACADEMIC CENTRES

a. Where do you get your knowledge on efficient adaptations?
   - ☐ Internet
   - ☐ TV
   - ☐ Other crop farmers
   - ☐ Newspapers
   - ☐ Academic articles
   - ☐ Researchers from academic centres
   - ☐ NGOs
   - ☐ Government
   - ☐ Trial and error
   - ☐ Other, please describe ;

   ____

b. The following questions apply if you are working hand in hand with academic institutions (such as the University of Kafrelsheikh), NGOs, or other organisms working to spread adaptations.
   - Who are you working with?____________________________________
   ____
   - On what kind of adaptations are you working?
   ____
   ____
   ____
   - What is the purpose of this/those adaptation(s)?
   ____
   ____
   ____
   - Since when are you working together? _____________
   - What evolution have you seen in your crop production since working together? (e.g.: less/more irrigation, improved/reduced crop production, etc.)
   ____
   ____
   ____

4- FUTURE WORK

a. This question applies if you haven't adopted any adaptations to soil salinization and/or water scarcity, but still have witnessed a decrease in crop productivity or other negative impacts on your crop production.

- What negative impacts are you observing on your crop production?

____

____

____

- What is preventing you from adapting?
  - ☐ Lack of knowledge on existing adaptations
  - ☐ Lack of financial means
  - ☐ Lack of confidence in existing adaptations
  - ☐ Belief that negative impacts are temporary
  - ☐ Other, please specify;

____

____

____

- What would affect your decision to adapt?
  - ☐ More accessible information on existing adaptations
  - ☐ More proof that the adaptation is reliable
  - ☐ Financial support
  - ☐ More support from external organizations like farmers' union, NGOs, academic centres, etc.
  - ☐ Other, please specify;

____

____

____

b. This last question applies only if you have adopted adaptations.

- Do you think there are means lacking for you to efficiently adapt? If yes, which ones?

____

____

____

Appendix B

Table 1. Research sample

Location	Sample Size	Smallholders (<3 feddans)
Mansoura	30	6
Baltim	31	6
Sidi Salem	11	6
Alexandria	1	0
Tanta	3	2
Nile River Delta	76	20
El-Minya	11	0
Total	87	20

Table 2. Adverse Environmental Factors Perceived by Crop Farmers

Location	High Temperature	Salinity (Soil or Irrigation Water)	Water Shortage	Infections
Mansoura	25	9	6	18
Baltim	11	12	7	16
Sidi Salem	6	6	6	5
Alexandria	1	1	0	1
Tanta	3	1	0	1
Nile River Delta	46	29	19	41
El-Minya	10	3	5	7
Total	56	32	24	48
Percentage of total	**64,37**	**36,78**	**27,59**	**55,17**

The table displays the full data, instead of summarizing values into the Western Delta category (displayed on the graph).

Fig. 1 Percentage of Crop Farmers Perceiving Different Environmental Impacts in Five Locations

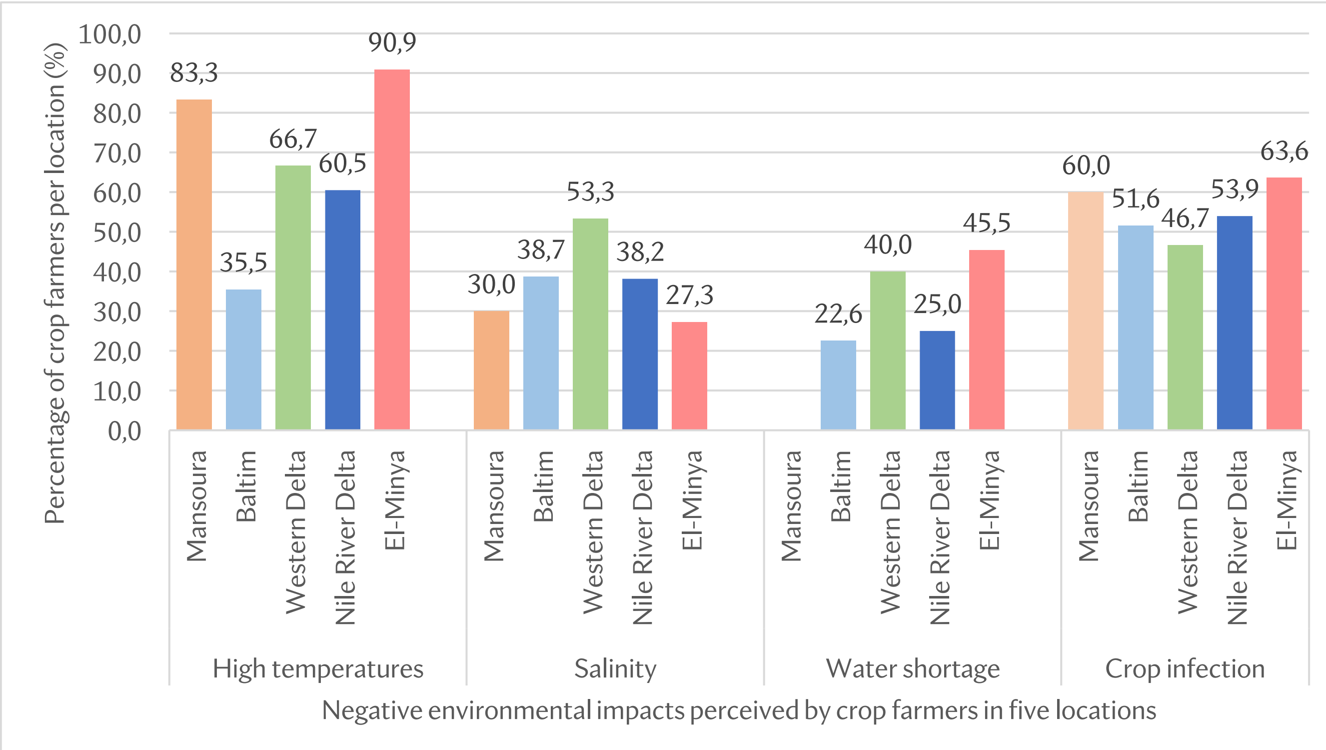

Table 3. Adaptations Discussed by Crop Farmers

Location	Change crop/variety	Pesticide program	Fertilization program	Improved irrigation practices
Mansoura	18	12	8	5
Baltim	23	2	5	13
Sidi Salem	10	0	0	0
Alexandria	1	0	0	0
Tanta	2	0	2	1
Nile River Delta	54	14	15	19
El-Minya	7	5	6	4
Total	61	19	21	23
Percentage of total	**70,11**	**21,84**	**24,14**	**26,44**

The table displays the full data, instead of summarizing values into the Western Delta category (displayed on the graph).

Fig. 2 Adaptations Discussed by Crop Farmers in Five Locations

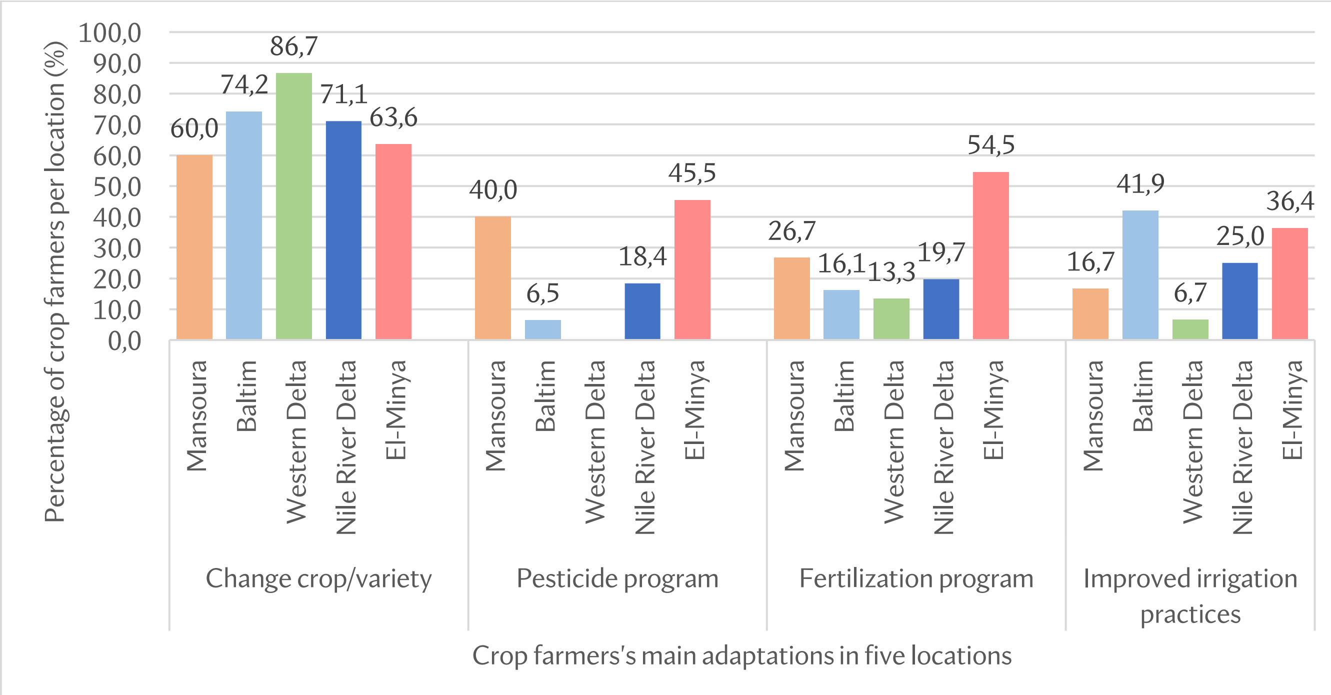

Table 4. Provenance of Information on How to Adapt for Crop Farmers

Location	Trial & Error	Academic Institutions	Internet, Books, Articles, TV	Private Companies	Government	Other Crop Farmers	Agricultural Engineers
Mansoura	5	2	17	10	3	29	22
Baltim	5	8	19	8	1	30	3
Sidi Salem	2	0	3	1	1	9	1
Alexandria	1	0	0	0	0	1	0
Tanta	0	0	0	3	0	2	0
Nile River Delta	13	10	39	22	5	71	26
El-Minya	4	2	5	10	1	9	3
Total	17	12	44	32	6	80	29
Percentage of total	**19,54**	**13,79**	**50,57**	**36,78**	**6,90**	**91,95**	**33,33**

The table displays the full data, instead of summarizing values into the Western Delta category (displayed on the graph).

Fig. 3 Provenance of Information on How to Adapt for Crop Farmers in Five Locations

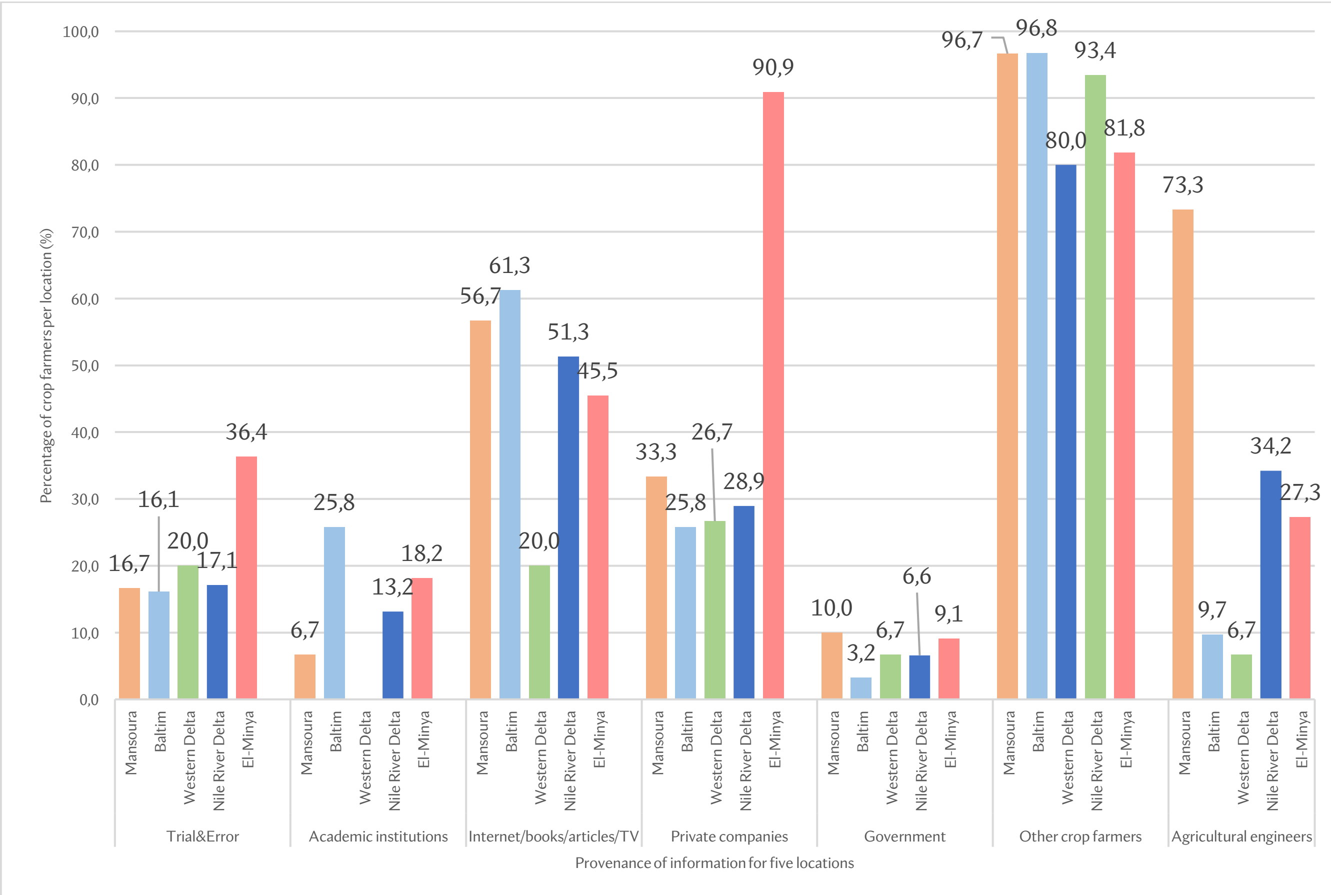

Table 5. Limitations to Adapt Perceived by Crop Farmers

Location	Financial Support	Lack of Knowledge	Governmental Support	External Support	Proof that Adaptation is Reliable	Resistant Varieties
Mansoura	20	14	5	11	5	6
Baltim	19	14	3	15	15	2
Sidi Salem	7	4	1	3	1	0
Alexandria	0	0	0	0	0	0
Tanta	1	0	1	1	0	0
Nile River Delta	47	32	10	30	21	8
El-Minya	3	0	5	0	1	0
Total	50	32	15	30	22	8
Percentage of total	**57,47**	**36,78**	**17,24**	**34,48**	**25,29**	**9,20**

The table displays the full data, instead of summarizing values into the Western Delta category (displayed on the graph).

Fig. 6 Limitations to Adapt Perceived by Crop Farmers in Five Locations