

# Approaches to increase the resiliency of Egyptian agriculture to climate change: An Overview

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Climate change is expected to affect agricultural production in direct and indirect pathways. The increase in mean temperatures directly accelerates crop development, the change in seasonal precipitation amounts together with increasing evaporative demand can indirectly lead to more drought stress for crops. In Egypt, the agricultural sector is highly vulnerable to climate change due to its dependence on the Nile River for irrigation, increasing soil salinity by sea water intrusion and soil deterioration as a result of decomposition of its organic contents. In this article, previous research carried out in Egypt on climate change assessments on water resources (the Nile River and rainfall on the north coast of Egypt), crop evapotranspiration, crop water requirements, crop yield, agricultural soils and national cultivated area are reviewed. Furthermore, the implemented actions to increase crop resilience to climate change were discussed. Additionally, the procedures used to reduce greenhouse gases emission were also reviewed.

**Keywords:** Water resources, soil resources, climate-resilient crops, greenhouse gases emissions, carbon sequestration, biogas production

## INTRODUCTION

Egypt is located on the Northeastern corner of Africa on the Mediterranean Sea between latitudes 22° and 32° N, and between longitudes 24° and 37° E. The total area of Egypt is 1,001,450 km<sup>2</sup>, with a land area of 995,450 km<sup>2</sup>. The Egyptian terrain consists of vast desert plateau interrupted by the Nile Delta and Valley, which occupy about 4% of the total area of Egypt. The Nile Delta and Valley divided the desert land of Egypt into the western desert (represents two third of Egypt territory) and the eastern desert. In addition, Sinai Peninsula located in the eastern part of Egypt represents 6% of the Egypt area and is located in Asia continent, which makes Egypt a transcontinental country. Water resources in Egypt are very limited, where more than 95% of it is received from outside of its international borders. It consists of Egypt's water share from the Nile River, ground water, effective rainfalls on the northern strip of the Nile Delta, and recycled agricultural drainage water.

Climate change is expected to affect agricultural production in direct and indirect pathways. The increase in mean temperatures directly accelerates crop development, the change in seasonal precipitation amounts together with increasing evaporative demand can indirectly lead to more drought stress for crops (IPCC 2012). Martins et al., (2019) indicated that increased temperatures are likely to shorten the crop cycle as a result of acceleration in crop development and phenological stages (Eyshi Rezaei et al., 2018), thus reducing crop production (Asseng et al. 2013). On the other

hand, alteration in precipitations will affect water resources and water availability for crops, so that crop yield will be severely affected and even crop failure could occur (Paymard et al., 2018). Reducing exposure to climate change and increasing the resilience of agricultural crops towards various biotic and abiotic stresses is a promising method for maximizing crop production under adverse conditions of drought, salinity and heat stress under climate change. Increasing the levels of biodiversity can help in improving the resiliency of agriculture to climatic shocks (Kozicka et al., 2020).

Emission of greenhouse gases (GHGs) from the soil results from the raise in air temperature that will lead to a raise in soil temperature, which will promote breakdown of soil organic matter and the release of CO<sub>2</sub> and CH<sub>4</sub> into the atmosphere (Kuzyakov et al., 2019). GHGs are also controlled by soil texture (Gaillard et al., 2016) and soil pH (Wang et al., 2010). Furthermore, rice cultivation is another sources of GHGs emissions including CH<sub>4</sub> and N<sub>2</sub>O (Zheng et al., 2004), where under low oxygen content (waterlogged soils), anaerobic decomposition of organic carbon compounds results in the emission of CH<sub>4</sub> to the atmosphere (Magdoff and Van, 2010). Another source of greenhouse gases is the burning of crop residues, which contributes to greenhouse gases emissions in the atmosphere, where it increase the content of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O and other trace gases (Smith et al., 2014).

In Egypt, the agricultural sector is highly vulnerable to climate change due to its dependence on the Nile River for irrigation, increasing soil salinity by sea water intrusion and soil deterioration as a result of decomposition of its organic contents. Therefore, in this paper, an overview of the previous researches done in Egypt on climate change assessments on water resources (the Nile River and rain fall on the north coast of Egypt), crops evapotranspiration, crops water requirements, crops yield, agricultural soils, and national cultivated area is presented. Furthermore, the implemented procedures used to increase crops resilience to climate change were discussed. Additionally, the procedures used to reduce the emission of greenhouse gases were also reviewed.

## **ASSESSMENT OF CLIMATE CHANGE EFFECTS ON AGRICULTURE IN EGYPT**

### **Climate change and water resources**

Egypt relays enormously on the Nile River as the main source of water, which contributes with about 95% of Egypt's water budget. Other water resources are precipitations and groundwater, which contribute with about 5% of the available supply. Sayed (2004) indicated that rainfall projection varies substantially in magnitude across the studied climate change models due to the highly non-linear relationship between precipitation and runoff. The uncertainty about the increase or decrease in precipitation near the sources of the Nile, as well as variations in temperature could have a larger than expected effect on Nile flows because these two factors are also interrelated which leads to moderate to extreme effects (Elsaeed, 2012). Furthermore, Nour El-Din (2013) reported that there is some uncertainty about the effect of future climate changes on Blue Nile (contributes more than 75% of the Nile flows), where roughly two-thirds of the studied general circulation models projected an increase in precipitation, whereas one-third of the studied models expected reduced precipitations.

It has also been suggested that Egypt's precipitations may decrease due to climate change, with an annual decline up to 5; 8 and 13% respectively by 2030, 2050 and 2100 (Barbi 2014). Ouda et al., (2016) projected that the amount of annual rainfall in northeastern coast of Egypt in 2030 will be the lowest than its counterpart values from 1997 to 2014, except for 1999 (Figure 1a). The value of rainfall deviation in 2030 from the average of 18 years was -27%, which is considered deficit according to the classification of Kumar et al., (2009). Similarly, in the northwestern coast of Egypt, the projected annual rainfall value in 2030 will be the lowest compared to the recorded values from

1997 to 2014 (Figure 1b) (Ouda et al., 2016). The value of rainfall deviation in 2030 from the average of 18 years was  $-95\%$ , which is considered scanty according to the classification of Kumar et al., (2009).

### **Projected values of climate elements under climate change**

Table 1 shows the expected increase in the values of climate elements in 2030 using RCP6.0 scenario developed by CCSM4 model, in several governorates in Egypt from north to south. The table shows that it is expected that solar radiation will increase by an average of  $1.1 \text{ MJ/m}^2/\text{day}$ , temperature will increase an average of by  $1.1 \text{ }^\circ\text{C}$  and wind speed will increase by an average of  $0.9 \text{ m/sec}$  in 2030, compared to 2014 (Ouda, 2017).

### **Crop evapotranspiration under climate change**

The amount of crop evapotranspiration (ETc) is affected by reference evapotranspiration (ETo) and specific crop coefficients (Kc). Several studies showed an expected rise in the values of ETo under climate change in 2030 (Sayad et al., 2015; Ouda 2019b) (Figure 2).

Additionally, Ouda (2019b) found that the values of Kc of several crops will increase under climate change in 2030 (Figure 3). Consequently, a noticeable increase in ETc values in 2030 will be expected under climate change (Ouda, 2019b) (Figure 4).

### **Crops water requirements under climate change**

Several authors projected the values of water requirements for several crops and the percentages of increase in its values (Table 2).

Furthermore, Eid et al., (1992) indicated that climate change could increase crops water demand for summer and winter crops by 16 and 2%, respectively in the year 2050. Whereas Attaher et al., (2006) calculated national irrigation water demand in 2050 and 2100 and the percentage of increase could be up to  $+16\%$  (Table 3).

### **Projection of climate change impacts on crop production**

Assessment of climate change impact on crops production in Egypt started in the 1990s. Since that time, there was a large progress and improvement in the climate change scenarios developed by IPCC and the assessment analysis. These scenarios were used in a large number of studies in Egypt to assess its effects on crops yield. Examples of the IPCC scenarios and related studies were: IPCC (1990) used in Eid et al., (1993) and Eid et al., (1997a), IPCC (2001) used in Hassanein (2010) and Abou-Shleel and Saleh (2011), IPCC (2007) used in Khalil et al., (2009) and Ouda et al., (2013), and IPCC (2013) used in Sayad et al., (2015) and Ouda et al., (2016). All these studied concluded that the yield of the studied crops will be negatively affected by the stressful conditions of climate change.

### **Climate change and cultivated lands in Egypt**

#### **Effect of climate change on agricultural soils**

Only one study was done on the effect of climate change on the soil in Egypt. Muñoz-Rojas et al., (2017) applied the CarboSOIL model and global climate models to predict the effects of climate changes on soil organic carbon contents in 2030, 2050 and 2100 in Northern Egypt under different land use types. They projected an overall decreases of soil organic carbon contents in the topsoil soil layer and increases in the subsoil layers in the short, medium and long term. They also suggested that agricultural land relying on irrigation will be particularly vulnerable to losses of soil organic carbon stocks.

### **Effect of climate change on cultivated area**

Fawaz and Soliman (2016) calculated that the loss in total cultivated area of Egypt in 2030 will be 8%, compared to the current cultivated area. Furthermore, Ouda and Zohry (2018) calculated the loss of the cultivated area of several winter and summer crops, as affected by the increase in its water requirements. The overall losses on the national level will reach 8 and 16% respectively for the winter and summer crops, compared to its counterpart value in 2015 (Table 4).

## **CLIMATE CHANGE AND CROPS RESILIENCY**

Increasing the resiliency of cultivated crops to climate change was tackled in the context of reducing exposure, reducing sensitivity and increasing adaptive capacity.

### **Reducing exposure to climate change**

Reducing exposure to climate change can be achieved by implementing resilient farming systems based on increased levels of biodiversity which can help improving its resiliency to shocks, as well as to promote soil health of the farm and nutritional output (Kozicka et al., 2020).

### **Integrated farms systems**

To adopt diversity, farms should practice crops, and/or livestock production that lower reliance on external output (Lemaire et al., 2014). Eid et al., (2007) indicated that livestock and crops production is an excellent example of an integrated farm system, where feed crops and agricultural residues provide the feed for animals and, in turn, livestock manure is added to the soil to improve its fertility and reduce fertilizer use. It is a cheap way for society to conserve the environment and reduce pollution (El Sheikha, 2016). Ding et al., (2019) indicated that application of organic manure increased wheat yield grown in non-saline and saline soil under full irrigation by 18 and 11%, respectively.

Other integrated farm type is fish and crops farms, where fish effluents are used in irrigating the cultivated crops (van der Heijden, 2012). Integrated fish and crops farms attained similar sustainability as integrated livestock and crops farms. Irrigating crops with farm fish effluents improves soil quality due to organic matter that exists in fish water (Elnwishy et al., 2006). Isitekhale and Adamu (2016) reported that only 25% of N and 20% of P of fish feed is recovered in harvested fish and the rest is accumulated in farm effluent. Irrigation with fish farms effluents can substitute for 100% of fertilizer applied to winter crops (Zohry et al., 2020; Hefny et al., 2020) and for 50% of the applied fertilizer to summer crops (Zohry et al., 2020; Selim and Shams, 2019). AbdElMagid et al. (2018) reported that using fish farm effluent in irrigating onion and sugar beet increased yields by 16% for both crops without adding any chemical fertilizers.

### **Increasing crops diversification**

Crop diversification strategies simultaneously increase net crop production and also improve soil health by imparting interspecific interactions among different crop species both above and below ground (Rakshit et al., 2018). Aboveground diversification increases canopy heat and light capture, whereas belowground diversification assists in better utilization of water and soil macro- and micro-nutrients (King and Hofmockel, 2017). Increasing crops diversification can be done by cultivating three crops per year (winter, fall then summer crops or winter, early summer then late summer crops) instead of two crops per year. This system has many beneficial effects on soil fertility, if legume crop was cultivated in between the winter crop and the summer crop. Zohry et al., (2017) compared between the effect of conventional crop sequence, namely wheat then maize and cultivation of three crops per year, namely maize, short-season clover, then wheat on wheat yield. Their results indicated that wheat productivity was increased by 16 and 47% in the first and second

season, respectively when short-season clover followed maize, compared to maize fallowed by wheat sequence.

Furthermore, implementing intercropping systems can increase crop diversification and increase resilience to climate. Intercropping alters the microclimate of the soil by changing soil temperature and moisture: it changes the pattern of dispersal through wind, rain, or a vector that inclusively benefits the intercropped plants in one way or another. It increases nitrogen and carbon content in the rhizospheric soil, and therefore those resource pools can be further used by successive crops (Zang et al., 2015). Intercropping reduces water runoff and soil loss (Lithourgidis, 2011), increases nutrient availability and improves soil quality (Li et al., 2014). Furthermore, spatial arrangement and different pattern of roots exploit soil nutrients in this system minimize plants competition (Ijoyah and Fanen, 2012). Double benefits can be attained if these above mentioned were implemented in a crop rotation. Abou-Keriasha et al., (2012) implemented three crop rotations (prevailing, low intensive and high intensive rotations) and they reported that the yield of the cultivated crops, soil organic matter content were increased in the low intensive and high intensive rotations, compared to its counterpart values under the prevailing crop rotation.

### **Reducing sensitivity of crops to climate change**

Reducing sensitivity of crops to climate change can be implemented by either management practices or cultivation of climate-resilient crops.

### **Using improved management practices on farm level**

Several management practices were proven to be effective to reduce the sensitivity of the cultivated crops to water and salinity stress caused by climate change. El-Samnoudi et al., (2019) indicated that application of poultry manure and mulching to sorghum grown under deficit irrigation alleviated the effect of water stress and produced yield similar to the unstressed plants. Talaat et al. (2015) found that foliar application of 0.1 mg L<sup>-1</sup> 24-epibrassinolide (EBL) and 25 mg L<sup>-1</sup> spermine (Spm) to maize grown under drought stress conditions resulted in increasing in drought tolerance. Furthermore, Abdullah et al. (2015) found that the negative effects of late-season drought on growth and yield of wheat could be mitigated by application of an anti-transpirant, where it helped in increasing plants water use. Furthermore, Abd Allah et al., (2021) indicated that spraying faba bean intercropping system with sugar beet with 200 ppm potassium silicate positively affected the yield of both crops and water equivalent ratio under deficit irrigation. Baddour et al., (2017) reported that spraying maize plants with ascorbic and proline, in addition to application of chicken manure, increased maize yield under saline conditions.

### **Cultivation of climate-resilient crops**

Climate-resilient crops were defined by Dhankher and Foyer (2018) as “both crops and crop varieties with enhanced tolerance to biotic and abiotic stresses, which have the ability to maintain or increase crop yields under stress conditions such as drought, flooding, heat, chilling, freezing and salinity”. Examples of climate-resilient crops are quinoa, pearl millet and sorghum.

The quinoa plants are reported to be tolerant to heat stress (Hinojosa et al., 2019), drought (Garcia et al., 2007) and salinity stress (Adolf et al., 2013). Quinoa has been selected by Food and Agriculture Organization of The United Nations (FAO, 2013a), as one of the crops destined to contribute to food security in this century. It has nutritional advantage over major cereals of the world. Quinoa seeds contained 16.5 g protein, 6.3 g fat, 3.8 g ash, 3.8 g crude fiber, 69.0 g carbohydrate, and energy amount of 399 Kcal/100 g. All these nutrients are higher than what found in wheat, maize, and rice (Hulse et al., 1980; United States National Research Council). Although quinoa grains do not contain gluten, it can be mixed with wheat flour in the preparation of bread with high nutritional value. Substituting wheat flour with 20% quinoa resulted in elevating protein, fat and fiber percentages than that of wheat flour (Soliman et al., 2019).

Millets are one of the world's six major cereal commodities, and it is consumed by one-third of the world's population. It can tolerate heat stress (Sage and Zhu, 2011), salinity stress (Yakubu et al., 2010) and water stress (Sher et al., 2019). It is nutritionally superior to other major cereals as they are rich in vitamin B, folic acid, phosphorus, iron and potassium. (Gupta et al., 2011). Pearl millet seeds contained 11.8 g protein, 4.8 g fat, 2.2 g ash, 2.3 g crude fiber, 67.0 g carbohydrate, and energy amount of 363 Kcal/100 g. In addition, it contained 42 mg Ca and 11 mg Fe (Hulse et al. 1980; United States National Research Council). Pearl millet has been cultivated in Egypt as a forage crop. Further research should be done on including it in bread making in Egypt.

Furthermore, sorghum is also considered as a climate-resilient crop. It was documented that sorghum resiliency is expressed in it being heat tolerant (Chiluwal et al., 2019), salinity tolerant (Shakeri and Emam, 2017) and water stress tolerant (Surwenshi et al., 2010). It is gluten-free and can substitute for wheat flour in bread making (Ismail and El-Nakhlawy, 2019). Sorghum seeds contain 10.4 g protein, 3.1 g fat, 1.6 g ash, 2.0 g crude fiber, 70.7 g carbohydrate and energy amount of 329 Kcal. In addition, it contained 25 mg Ca and 5.4 mg Fe (Hulse et al., 1980; United States National Research Council). Sorghum is more common in southern Egypt and is cultivated for its grain, used in bread making.

### **Increasing adaptive capacity**

Increasing adaptive capacity to climate can be done using early warning systems. The concept of the early warning system is used as a tool for planning before extreme weather events (Basher, 2006). In Egypt, Young et al., (2021) presented a practical approach of incorporating critical rainfall thresholds, historical flood data and precipitation forecast for forecasting extreme rainfall and flooding in Alexandria, North Egypt, which could help in improving decision-making especially in data-scarce regions or cities for developing early warning system. Furthermore, Baldi et al., (2020) studied the spatio-temporal evolution of selected episodes of heavy rainfall trend over Sinai Peninsula, Egypt to improve early warning systems. The study was based on the analysis of meteorological data from ground stations in Sinai and rainfall estimates derived from satellite images with the aim to help the decision-makers to plan the construction of flood water harvesting structures and flash flood protection works.

### **Reduction of the emission of greenhouse gases**

#### **Accurate application of irrigation water to crops**

The prevailing irrigation system in the old lands in Egypt is surface irrigation, which resulted in applying large amounts and that causes wasteful use of this valuable resource. Farmers used to pump water using diesel-powered pumps for irrigation, which have contributed in increasing greenhouse gases emission. Several practices were done to reduce the wasteful used of irrigation water:

- Application of the required irrigation amounts to crops, which will reduce the amount of fossil fuel used to pump water and consequently reduce the emission of GHGs.
- Land consolidation was done in several governorates of Egypt to unify irrigation dates, thus reduce the amount of fossil fuel used to pump the water (Ouda and Zohry, 2022).
- Implementing precise land leveling to reduce the applied water under surface irrigation, which improve crops productivity (Bahnas and Bondok, 2010), changing cultivation method from basins or furrows to raised beds proved to save applied irrigation water (Zohry et al., 2019). Farmers training on irrigation scheduling using simple scheduling technique was done in several governorates of Egypt to apply the required irrigation water to crops (Ouda and Zohry, 2022).
- Recently, the government of Egypt revealed a plan to change irrigation system from surface in

the Nile Delta and Valley to sprinkler or drip, which will reduce the applied irrigation to the crops and consequently reduce the use of fossil fuel and reduce greenhouse gases emissions.

### **Using solar energy in irrigation systems**

Lately, many farmers have switched to renewable solar energy in irrigation systems to pump water for irrigation, as an alternative to diesel or electric energy, which has lower operating cost, compared to using diesel or electricity (Taha, 2018 and 2019; Taha and Ghandour, 2021; Taha and Khalifa, 2022). the use of renewable solar energy in irrigation systems has also significant advantages, namely it requires minimal maintenance beyond cleaning the panels once a week. Furthermore, it eliminates any greenhouse gases emission as a result of using diesel pump.

The Farm-level Irrigation Modernization Project was implemented in Egypt to increased access to modern irrigation systems in the Mahmoudia, Manaifa and Meet Yazid canals in Egypt, primarily by phasing out diesel pumps and introducing electric ones, as well as by constructing an electricity grid to power the modernized pumping stations. A total of 197,633 water users (including landholders and tenants) benefited through improved irrigation and drainage services from this project (World Bank, 2020).

### **Soil carbon sequestration**

Soil carbon sequestration can reduce the magnitude of CO<sub>2</sub> release to the atmosphere. It implies the removal of atmospheric CO<sub>2</sub> by plants and stored as soil organic matter (Lal, 2004). Application of organic manure and compost can potentially sequester more carbon to the soils and thus convert the soils to a net CO<sub>2</sub> sink (Gattinger et al., 2012).

Intercropping can increase soil carbon sequestration. Recent studies suggest greater input of carbon into the soil through root residues in intercropping systems, as compared to sole crops (Li et al., 2014). It was reported that cover crops increased soil organic carbon stock by 9-10% (Bolinder, 2020). In Egypt, Zohry et al. (2020) stated that an increase by 8% in soil organic matter was observed when pea was intercropped with sunflower and the increase was 9% when pea intercropped with wheat.

### **Reduction of GHGs emission from rice fields**

Several field managements were documented to reduced emission of CH<sub>4</sub> and N<sub>2</sub>O from rice fields. Hadi et al., (2010) indicated that intermittent drainage could reduce greenhouse gases emission by around 14.7 to 68.5%, compared to continuous flooding. Whereas, alternate wetting and drying could reduce the emissions by 33-39%, compared to continuous flooding with no yield differences (Setyanto et al., 2017). Intermittent irrigation and saturated soil have less CH<sub>4</sub> emission (around 53-67%), compared to continuous flooding (Husin et al., 1995). Water savings techniques applied to rice field can largely contribute to reduction of the emission of CH<sub>4</sub> and N<sub>2</sub>O (Djaman et al., 2018). Furthermore, conversion from paddy rice cultivars to upland cultivars can contribute in reduction of greenhouse gases (Nishimura et al., 2008).

In Egypt, rice belt is located in the Northern Nile Delta, where CH<sub>4</sub> emission is representing about 53.3% of the agricultural greenhouse gases emissions (Farag et al., 2013a). Recently, the total CH<sub>4</sub> emissions from rice cultivation in Egypt are steadily decreasing due to switching from long-season traditional rice cultivars to early-maturing short-duration cultivars (Farag et al., 2013b). Furthermore, the cultivation of new upland rice cultivars is now expanding in Egypt.

### **Elimination of burning of crops residues**

In Egypt, it was estimated that about 3.1 Mt/year of rice straw are directly burned in open field (FAO, 2013b), as well as other crops residues (Abdelhady et al., 2014). These crop residues can be

used in production of biogas (Zayat et al., 2015). Biogas is produced from anaerobic degradation of organic materials. Biogas units can be installed in the farmers households and use crop residues and animal manure, which will be fermented in biogas digesters and a significant amount of methane is produced that could be used in cooking, heating and generating electricity (Zayat et al., 2015). Furthermore, the potential utilization of the digestate as fertilizers can also reduce dependence on mineral fertilizers (Pöschl and Owende, 2010), which will also reduce emission of greenhouse gases. Thus, biogas generation serves three important functions: waste removal, environmental management and energy production (Ford, 2007).

## CONCLUSION

Assessments of the effect of climate change on water and soil resources in Egypt, as well as crops production and its water requirements are essential measures to increase its resilience to face the harmful effects. The sustainable use of natural resources under climate change entails its rational use that allow to maintain these resources for the future generation. With respect to water and soil resources, several procedures were reviewed in this paper to conserve without jeopardize the loss in crops production. Furthermore, methods to reduce the emission of greenhouse gases were also tackled. Thus, it could be concluded that these measures contribute in increasing food security.

## REFERENCES

- Abd Allah, A.M.M., Mohamed, M.S. and Noreldin, T. (2021). Water deficiency relief by application of potassium silicate to faba bean intercropped with sugar beet in sandy soil. *Zagazig J. Agric. Res.*, 48: 1-18.
- AbdElMagid H. A. A., Hala H. A. A., Mohamed A. M. M. (2018). Economic study the efficiency of water resource usage (Case Study). *Alex. J. Agric. Sci.*, 63: 149-155.
- Abdelhady S., Borellob D., Shabanb A., Rispolib F. (2014). Viability study of biomass power plant fired with rice straw in Egypt. *Energy Proc.*, 61: 211-215.
- Abdullah A.S., Aziz M.M., Siddique K.H.M., Flower K.C. (2015). Film antitranspirants increase yield in drought stressed wheat plants by maintaining high grain number. *Agricultural Water Management*, 159: 11-18.
- Abou-Keriasha M.A., Mohamed W.M.A., Eiasa N.M., Kamel A.S. (2012). Intensive crop rotations to improve agricultural production in Middle Egypt. *Egypt. J. Agric. Res.*, 90: 427-443.
- Adolf V.I., Jacobsen S.E., Shabala S. (2013). Salt tolerance mechanisms in quinoa (*Chenopodium quinoa* Willd.). *Environmental and Experimental Botany*, 92: 43-54.
- Abou-Shleel S.M.K., Saleh S.M. (2011). Sensitivity of tomato crop to air temperature under climate change conditions. *J. Biol. Chem. Environ. Research Sci.*, 6: 421-435.
- Attaher S., Medany M., AbdelAziz A.A., El-Gendi A. (2006). Irrigation-water demands under current and future climate conditions in Egypt. *The 14th Annual Conference of the Misr Society of Agricultural Engineering*, 1051-1063.
- Baddour A.G., Eman M. Rashwan, T.A. El-Sharkawy (2017). Effect of organic manure, antioxidant and proline on corn (*Zea mays* L.) grown under saline conditions *Env. Biodiv. Soil Security*, 1: 203-217.
- Bahnas O.T., Bondok M.Y. (2010). Effect of precision land leveling on faba bean response to compost application in sandy soils. *Misr J. Agric. Eng.*, 27: 465-481.





- Baldi M. (2019). Climate Change, Water availability, and Cultural Heritage in Egypt. In Sciences and Technologies Applied to Cultural Heritage—STACH 1. Baldi, M., Vittozzi, G.C., Eds.; CnrEdizioni: Roma, Italy.
- Barbi, V. (2014). Adaptation: Key Concepts, Strategies, and Practices. International Centre for Climate Governance. Available online: [www.iccgov.org/wp-content/uploads/2014/.../2014-05-22\\_Barbi.pdf](http://www.iccgov.org/wp-content/uploads/2014/.../2014-05-22_Barbi.pdf).
- Basher, R. (2006). Global early warning systems for natural hazards: Systematic and people-centered. *Philosophical transactions, Series A, Mathematical, physical and engineering sciences*, 364: 2167-2182.
- Bolinder M.A., Crotty F., Elsen A. (2020). The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agro-ecosystems: a synthesis of reviews. *Mitig. Adapt. Strateg. Glob. Change*, 25: 929-952.
- Chiluwal A., Bheemanahalli R., Kanaganahalli V., Boyle D., Perumal R., Pokharel M., Oumarou H., Jagadish S.V.K. (2019). Deterioration of ovary plays a key role in heat stress-induced spikelet sterility in sorghum. *Plant, Cell & Environment*, 43: 448- 462.
- Dhankher O.P., Foyer C.H. (2018). Climate resilient crops for improving global food security and safety. *Plant Cell Environ.*, 41:877-884.
- Ding Z., Kheir A.M.S., Ali M.G.M., Ali O.A. M., Aly, Abdelaal I. N., Lin. X., Zhou Z., Wang B., Liu B., He Z. (2020). The integrated effect of salinity, organic amendments, phosphorus fertilizers, and deficit irrigation on soil properties, phosphorus fractionation and wheat productivity. *Scientific reports*, 10: 1-13.
- Djaman K, Mel VC, Diop L, Sow A, El-Namaky R, Manneh B. (2018). Effects of alternate wetting and drying irrigation regime and nitrogen fertilizer on yield and nitrogen use efficiency of irrigated rice in the Sahel. *Water*, 10: 20-25.
- Eid H.M., El- Marsafawy S.M., Ainer N.G., El- Mowelhi N.M., El- Kholi, O. (1997b). Vulnerability and adaptation to climate change in maize crop. *Meteorology & Environmental Cases Conference* 2-6 March.
- Eid H.M., Ainer N.G., Rady M.A., Risk W.M. (1993). Impact of Climate change on simulated wheat yield and water needs. 1st Conf. Egypt. Hung. *Env. Egypt*, p. 309-312.
- Eid H.M., Ainer N.G., Yousef K.M.R., Sherif M.A., Miseha W.I., El-Sergany D.Z. (1992). Climate Change Crop Modeling Study on Maize.5th Egypt. Botan. Conf. Saint Catherina, Sianai, pp. 93-111.
- Eid H.M., El-Sergany D.Z. (1993). Impact of climate change on soybean yield and water needs. *Proc. First Conference on the Environment. Egypt.* pp. 313 -316.
- Eid H.M., Anton N.A., Tarrad A.M. (1994). Comparative study on Egyptian wheat cultivars and their response to high temperatures. *Annals of Agric. Sci. Moshtohor*, 32:143-154.
- Eid H.M., El-Mowelhi N.M., Metwally M.A., Ainer N.G., Abbas F.A., Abd El-Ghaffar M.A. (1995). Climate change and its expected impacts on yield and water needs of some major crops. Second ARC Field Irrigation and Agro-climatology Conference. Paper No. 17.
- Eid H.M., S.M El-Marsafawy, S.A. Ouda (2007). Assessing the economic impacts of climate change on agriculture in Egypt: A Ricardian Approach. Policy Research Working Paper No. WPS4293. The World Bank Development Research Group.



- Eid H.M, El-Marsafawy S.M., Ali M.A., Ainer N.G., Rayan A. A., El-Kholi O. (1997a). Vulnerability and adaptation to climate change in wheat crop. Meteorology & Environmental cases Conference 2-6 March.
- El Sheikha A.F. (2016.) Mixing Manure with Chemical Fertilizers, Why? and What is After? *Nutr. Food Technol.*, 2: 112.
- Elnwishi N., Salh M., Zalat S. (2006). Combating Desertification Through Fish Farming: The Future of Drylands. Proceedings of the International Scientific Conference on Desertification and Drylands Research, Tunisia 19- 21, June UNESCO.
- Elsaeed G. (2012). Effects of Climate Change on Egypt's Water Supply. H.J.S. Fernando et al. (eds.), National Security and Human Health Implications of Climate Change, NATO Science for Peace and Security Series C: Environmental Security, Springer Science&Business Media B.V.
- El-Samnoudi I. M., Ibrahim A. M., Abd El Tawwab A. R., Abd El-Mageed T. A. (2019). Combined Effect of Poultry Manure and Soil Mulching on Soil Properties, Physiological Responses, Yields and Water-use Efficiencies of Sorghum Plants under Water Stress. *Communications in Soil Science and Plant Analysis*, 50: 2626-2639.
- EyshiRezaei E., S. Siebert, H. Hüging, F. Ewert. (2018). Climate change effect on wheat phenology depends on cultivar change. *Sci. Rep.*, 8: 4891.
- FAO (2013a). Launch of the international year of quinoa: UN celebrates Andean super food. [http://www.fao.org/quinoa-2013/press room/news/detail/en/](http://www.fao.org/quinoa-2013/press%20room/news/detail/en/)
- FAO (2013b) Rice market monitor, Nov 2013.
- Farag A.A., Radwan H.A., Abdrabbo M.A.A., Heggi M.A.M (2013a). Inventory of the greenhouse gas Emissions from rice in the Nile Delta by using emission models, *Egypt. J Agric Res.*, 91: 917-937.
- Farag AA, Radwan H.A., Abdrabbo M.A.A., Heggi M.A.M., McCarl B.A (2013b) Carbon footprint for paddy rice production in Egypt. *Nat. Sci.*, 11: 36-45.
- Fawaz, M.M., Soliman, S.A. (2016). The Potential Scenarios of the Impacts of Climate Change on Egyptian Resources and Agricultural Plant Production. *Open Journal of Applied Sciences*, 6:270-286.
- Ford S. (2007). *Advances in Biogas*. Leatherhead, UK: Pira International Ltd; pp. 13-14.
- Gaillard R., Duval B.D., Osterholz W.R., Kucharik C.J. (2016). Simulated effects of soil texture on nitrous oxide emission factors from corn and soybean agro-ecosystems in Wisconsin. *J. Environ. Qual.*, 45: 1540-1548.
- Garcia M., Condori B., Castillom C.D. (2015). Agroecological and Agronomic Cultural Practices of Quinoa in South America. In: K. Murphy and J. Matanguihan (Ed.) *Quinoa: Improvement and Sustainable Production*", First Edition. John Wiley & Sons, Inc.
- Gattinger A., Muller A., Haeni M., Skinner C., Fliessbach A., Buchmann N., Mäder P., Stolze M., Smith P., Scialabba Nel-H., Niggli U. (2012). Enhanced top soil carbon stocks under organic farming. *Proc. Natl. Acad. Sci. USA*, 109:18226-18231.
- Hadi A., Inubushi K., Yagi K. (2010). Effect of water management on greenhouse gas emissions and microbial properties from paddy fields of Indonesia and Japan. *Paddy Water Environ.*, 8: 319-324.



Hassanein M.K. (2010). Climate change risk management in Egypt, Food Security FAO project UNJP/EGY022 report number 6.1.2.1. pp 92.

Hefny Y., Kassem E., El-Shenawy I. (2020). Effect of irrigation with fish farm effluent on two legume crops interplanted with orange trees in a sandy soil. *Mor. J. Agri. Sci.*, 1: 291-300.

Hinojosa L., Matanguihan J.B., Murphy K.M. (2019). Effect of high temperature on pollen morphology, plant growth and seed yield in quinoa (*Chenopodium quinoa* Willd.). *J. Agro. Crop Sci.*, 205: 33-45.

Hulse J.H., Liang E.M., Pearson O.E. (1980). *Sorghum and the millets: their composition and nutritive value*. New York Academic Press.

Husin Y.A., Murdiyarso D., Khalil M.A.K., Rasmussen R.A., Shearer M.J., Sabiham S., Sunar A., Adjuwana H. (1995). Methane flux from Indonesian wetland rice: the effects of water management and rice variety. *Chemosphere*, 31: 3153-3180.

Ijoyah M.O., Fanen F.T., (2012). Effects of different cropping pattern on performance of maize-soybean mixture in Makurdi, Nigeria. *Sci. J. Crop Sci.*, 1: 39-47.

IPCC (2007). Intergovernmental panel on climate change fourth assessment report: climate change 2007. Synthesis report. World Meteorological Organization, Geneva.

IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK and New York, 582 pp.

IPCC (1990). *IPCC Second Assessment: A Report of The Intergovernmental Panel On Climate Change*.

IPCC (1990). *Policymakers Summary Prepared by IPCC Working Group I*.

IPCC (2013). *Summary for Policymakers*. In: *Climate Change. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2001). *The Third Assessment Report (TAR): Climate Change 2001. The Scientific Basis*. Cambridge University for the Intergovernmental Panel on Climate Change.

Isitekhale H.H.E., Adamu B. (2016). Effects of Effluents on soil chemical Properties in forest Derived savanna Transition. *IOSR Journal of Environmental science, Toxicology and Food Technology*, 10: 30 - 34.

Ismail S.M., F.S. El-Nakhlawy (2019). Optimizing grain sorghum (*Sorghum bicolor* L.) productivity under full irrigation and stress using humic acid in arid regions. *Assiut J. Agric. Sci.*, 50: 272 -288.

Khalil F.A., H. Farag, G. El Afandi, S.A. Ouda (2009). Vulnerability and adaptation of wheat to climate change in Middle Egypt. *Proceeding of the 13th International Conference on Water Technology*. Egypt. 12-15 March.

King A.E., Hofmockel K.S. (2017). Diversified cropping systems support greater microbial cycling and retention of carbon and nitrogen. *Agric. Ecosyst. Environ.*, 240: 66-76.

Kozicka M., Gotor E., Ocimati W., Jager T., Kikulwe E., Groot J.C.J. (2020). Responding to future



regime shifts with agrobiodiversity: A multi-level perspective on small-scale farming in Uganda. *Agricultural Systems*, 183: 102864.

Kumar N.M., Murthy C.S., SessaSai M.V.R., Roy P.S. (2009). On the use of Standardized Precipitation Index (SPI) for drought intensity assessment. *Meteorological application*, 16: 381-389.

Kuzyakov Y., Horwath W.R., Dorodnikov M., Blagodatskaya E. (2019). Review and synthesis of the effects of elevated atmospheric CO<sub>2</sub> on soil processes: No changes in pools, but increased fluxes and accelerated cycles. *Soil Biol. Biochem.*, 128: 66-78.

Lal R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123: 1-22.

Lemaire G., Franzluebbers A., Carvalho P.C. de F., Dedieu B. (2014). Integrated crop-livestock systems: strategies to achieve synergy between agricultural production and environmental quality. *Agric. Ecosyst. Environ.*, 190: 4-8.

Li Y., Zhang W., Ma L., Wu L., Shen J., Davies W.J., Oenema O., Zhang F., Dou Z. (2014). An analysis of China's grain production: looking back and looking forward. *Food and Energy Sec.*, 3: 19-32.

Lithourgidis A.S. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. *Aust. J. Crop Sci.*, 5: 396-410.

Magdoff F., Van E.H. (2010). *Building Soils for Better Crops*, 3rd ed.; SARE Outreach Publications: Brentwood, CA, USA.

Martins M.A., J. Tomasella, C.G. Dias (2019). Maize yield under a changing climate in the Brazilian Northeast: impacts and adaptation. *Agricultural Water Management*, 216: 339-350.

Muñoz-Rojas M., Abd-Elmabod S.K., Zavala L.M., De la Rosa D., Jordán A. (2017). Climate change impacts on soil organic carbon stocks of Mediterranean agricultural areas: A case study in Northern Egypt. *Agriculture, Ecosystems and Environment*, 238: 142-152.

Nishimura S., Yonemura S., Sawamoto T., Shirato Y., Akiyama H., Sudo S., Yagi K. (2008). Effect of land use change from paddy rice cultivation to upland crop cultivation on soil carbon budget of a cropland in Japan. *Agric. Ecosyst. Environ.*, 125: 9-20.

Nour El-Din M.M. (2013). *Climate Change Risk Management in Egypt: Proposed Climate Change Adaptation Strategy*. Ministry of Water Resources & Irrigation. Prepared for UNESCO-Cairo Office.

Ouda S., A. Zohry (2018). *Cropping Pattern to Face Water Scarcity*. In: *Cropping Pattern to Overcome Abiotic Stresses: Water, Salinity and Climate*. Springer Publishing House.

Ouda S. (2019a). *Accurate Estimation of Crop Coefficients for Better Irrigation Water Management in Egypt*. In: *Technological and Modern Irrigation Environment in Egypt: Best Management Practices & Evaluation*. Springer Publishing House.

Ouda S. (2019b). *Projected Crop Coefficients under Climate Change in Egypt*. In: *Climate Change Impacts on Agriculture and Food Security in Egypt*. Springer Publishing House.

Ouda S., Zohry A. (2021). *Water-smart Practices to Manage Water Scarcity*. In: *Climate-Smart Agriculture: Reducing Food Insecurity*. ISBN 978-3-030-93111-7.

Ouda, S. (2017). *Modeling and its Application in Crops Irrigation: Under Current Condition and Under Climate Change in the Future*. Noor Publishing. ISBN 978-3-330-85059-0. (in Arabic).



Ouda S., Noreldin T., Hosny M. (2016). Evapotranspiration under Changing Climate. In: Major Crops and Water Scarcity in Egypt. Springer Publishing House. pp 1-22. ISBN: 978-3-319-21770-3.

Ouda S., Noreldin T., AbouElenein R., Abd El-Baky H. (2013). Adaptation of cotton crop to climate change in salt affected soil. Proceeding of the 11th International Conference on Development of Dry lands. Beijing, China.

Paymard P., Bannayan M., Haghghi R.S. (2018). Analysis of the climate change effect on wheat production systems and investigate the potential of management strategies. *Nat. Hazards*, 91: 1237.

Pöschl M.S., Ward P. Owende (2010). Evaluation of Energy Efficiency of Various Biogas Production and Utilization Pathways. *Journal of Applied Science*, 87: 3305-3321.

Rakshit A., Sarkar B., Abhilash P.C. (2018). Soil amendments for sustainability: challenges and perspectives. CRC Press, Boca Raton, FL.

Sayad T., Ouda S., Morsy M., El-Hoseiny F. (2015). Robust statistical procedure to determine suitable scenario of some CMIP5 models for four locations in Egypt. *Global Journal of Advanced Research*, 2: 1009-1019.

Sayed M.A.A. (2004). Impacts of climate change on the Nile Flows. PhD thesis. Ain Shams University, Cairo, Egypt.

Selim M.A.F., Shams A.S. (2019). Maximizing efficiency of land and water utilization and profitability of interplanting maize with mandarin trees using irrigation with fish waste water between sandy soil and drip irrigation conditions. *Middle East Journal of Agriculture Research*, 8: 1240-1252.

Setyanto P., Pramono A., Adriany T.A., Susilawati H.L., Tokida T., Padre A.T., Minamikawa K. (2017). Alternate wetting and drying reduces methane emission from a rice paddy in Central Java, Indonesia without yield loss. *Soil Sci. Plant Nutr.*, 64: 23-30.

Shakeri E., Emam Y. (2017). Selectable traits in sorghum genotypes for tolerance to salinity stress. *J. Agric. Sci. Technol.*, 19: 1319-1332.

Sher A., A. Nawaz, M. Sarfraz, M. Ijaz, S. Ul-Allah, A. Sattar, S. Hussain, Sh. Ahmad (2019). Advanced Production Technologies of Millets. In *Agronomic Crops* Springer Nature Singapore Pte Ltd.

Smith J.B., McCarl B.A., Kirshen P., Jones R., Deck L., Abdrabo M.A., Borhan M., El-Ganzori A., El-Shamy M., Hassan M., El-Shinnawy I., Abrabou M., Hassanein M.K., El-Agizy M., Bayoumi M., Hynninen R. (2014). Egypt's economic vulnerability to climate change. *Int. Res. Clim. Res.*, 62: 59-70.

Soliman A.H., Abbas M.S., Abol-Ella M.F., Eassawy M.T., Mohamed R.H. (2019). Towards bridging wheat gap in Egypt by using cassava, quinoa and guar as supplements for the production of balady bread. *Journal of Food Measurement and Characterization*, 13: 1873-1883.

Surwenshi A., V.P. Chimmad, B.R. Jalageri, V. Kumar, M. Ganapathi, H.T. Nakul (2010). Characterization of sorghum genotypes for physiological parameters and yield under receding soil moisture conditions. *Res. J. Agric. Sci.*, 1: 242- 244.

Taha A.M. (2018). Assessment of different ETO-dependent irrigation levels for pomegranate on saving water and energy and maximizing farm income. *J. Soil Sci. Agri. Eng.*, 9: 665-673.

- Taha A.M. (2020). Response of mango (Keitte var.) productivity to deficit irrigation in sandy soil. *Soil Crops J.*, 30: 14- 25.
- Taha A.M., Khalifa H. E. (2022). Productivity of Date Palm (Barhi var.) as Affected by Irrigation Treatments in Sandy Soil. *Mor. J. Agri. Sci.*, 3: 85-98.
- Taha A.M., Ghandour A. (2021). Pearl millet forage productivity under sprinkler irrigation system in sandy soil. *Mor. J. Agri. Sci.*, 2: 194-203.
- Talaat N.B., Shawky B.T., Ibrahim A.S. (2015). Alleviation of drought-induced oxidative stress in maize (*Zea mays L.*) plants by dual application of 24-epibrassinolide and spermine. *Environ. Exp. Bot.*, 113: 47-58.
- van der Heijden P.G.M. (2012). Water Use at Integrated Aquaculture Agriculture Farms. Experiences with Limited Water Resources in Egypt. Wageningen University and Research Centre for Development Innovation.
- Wang L., Han Z., Zhang X. (2010). Effects of soil pH on CO<sub>2</sub> emission from long-term fertilized black soils in Northeastern China. In: Proceedings of conference on environmental pollution and public health (CEPPH 2010). Wuhan, China.
- World Bank (2020). Modernizing Irrigation Improved Water Security for Farmers in Egypt. <https://www.worldbank.org/en/results/2020/04/01/modernizing-irrigation-improved-water-security-for-farmers-in-egypt>.
- Yakubu H., Ngala, A.L., Dugje I.Y. (2010). Screening of millet (*Pennisetum glaucum L.*) varieties for salt tolerance in semi-arid soil of northern Nigeria. *World J. Agric. Sci.*, 6: 374-380.
- Young A., Bhattacharya B., Zevenbergen C. (2021). A rainfall threshold-based approach to early warnings in urban data-scarce regions: A case study of pluvial flooding in Alexandria, Egypt. *Journal of Flood Risk Management*, 14: e12702.
- Zang H., Yang X., Feng X., Qian X., Hu Y., Ren C., Zeng Z. (2015). Rhizode position of nitrogen and carbon by mungbean (*Vigna radiata L.*) and its contribution to intercropped Oats (*Avena nuda L.*). *Plos One*, 10 :e0121132.
- Zayat M.E., Hassan M.G., Taylor C., Hagggar S.E. (2015). Feasibility of biogas utilization in developing countries: Egypt a case study. *Austin Chem Eng.*, 2: 1017-1028.
- Zheng X., Han S., Huang Y., Wang Y., Wang M. (2004). Re-quantifying the emission factors based on field measurements and estimating the direct N<sub>2</sub>O emission from Chinese croplands. *Glob. Biogeochem. Cycle*, 18: GB2018.
- Zohry A.A., Ouda S., Hamd-Alla W., Shalaby E. (2017). Evaluation of different crop sequences for wheat and maize in sandy soil. *Acta Agriculturae Slovenica*, 109: 383-392.
- Zohry A., Hefny Y., Ouda S. (2020). Evaluation of different crop sequences and water qualities treatments on orange yield under intercropping conditions in sandy soil. *Proc. 16th Inter. Conf. Crop Sci. 16th of October. Cairo, Egypt*: 315-340.
- Zohry A., S. Ouda, Abdel-Wahab T. (2020). Sustainable intensive cropping to reduce irrigation-induced erosion: I. Intercropping systems under surface irrigation practice. *Moroccan Journal of Agricultural Science*, 1: 63-71.



## References