American Academic Scientific Research Journal for Engineering, Technology, and Sciences
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402
http://asrjetsjournal.org/

Effectiveness of Adding a Salt Tolerant Crop to the Egyptian Crop Pattern to Adapt with the Water Salinity and Shortage Conditions

Dina El Demerdash[a]*, Mohamed M. Nour El Din[b] , Hesham El-Badry[c], Mohie El Din Omar[d], Essam Aly[e], Doaa A. El-Molla[f]

[a]PhD Student, Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt & Engineer, Ministry of Water Resources and Irrigation, Cairo, Egypt

[b,c]Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt

[d]Associate Professor, National Water Research Center (NWRC), Egypt & International Center for Agricultural Research in the Dry Areas (ICARDA), Egypt

[e]Doctor Agronomist, Planning Sector, Ministry of Water Resources and Irrigation, Egypt

[f]Assistant Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt

[a]Email: dinamamdouh@hotmail.com , [b]Email: mhmdnour@eng.asu.edu.eg, [c]Email: hesham_elbadri@eng.asu.edu.eg, [d]Email: mohie.omar@hotmail.com, [e]Email: essamohab62@gmail.com, [f]Email: doaa_anas@eng.asu.edu.eg

Abstract

The imbalance between the high water demand and the limited water supplies in Egypt makes water resources management a big challenge. The Mediterranean Sea water intrusion is predicted to increase, causing high water salinity at the Nile delta. A future reduction in the Nile's water supply is also expected to occur leading to further water stress. Such water shortage will increase the re-use of drainage water which leads to further increase in the water's salinity. This study aims at adding a salt-tolerant crop to the traditional Egyptian crop pattern. Using quinoa is suggested as an alternative for wheat crop in areas with high water salinity, where the wheat's productivity is negatively affected. The effectiveness of the proposed crop is evaluated by using the agriculture sector model for Egypt (ASME) which estimates the water demand and the agricultural productivity for different cropping patterns. The results show that quinoa is a good substitution that produces a reliable yield in the case of Nile flow reduction. A base case considering the current water supply conditions is first studied.

----

* Corresponding author.

Then, a 10% reduction in the Nile water supply and the population projection in the year 2030 are presented in two scenarios, one of which considers financial incentives for supporting quinoa. The results show that the Nile flow reduction adversely affects most of crops' yields, and accordingly, decreases the total crops' water productivity, but quinoa is found to have a potential high yield in case of water shortage. The total yield of both quinoa and wheat together decrease from 8,643 million tons to 8.223 million tons for the scenario of 10% Nile water reduction without economic incentives, while it jumps to 11.474 million tons under the same conditions but with incentives that encourage the farmers to cultivate quinoa.

Keywords: Agriculture Sector Model for Egypt (ASME); Crop pattern; Nile Delta; Quinoa; Water productivity; Water salinity.

1. Introduction

The world is facing an unprecedented water crisis, since the imbalance between the water demand and availability has reached critical levels in many regions. An increased demand for water and food production will likely occur in the future. Accordingly, a sustainable approach for agricultural water resources management is essential. The sustainable water management concept refers to all practices that improve the crops yield and minimize non-beneficial water losses. The effective water management of the agricultural sector is critical because it consumes the largest amount of freshwater and the water used in it tends to have lower net returns compared to the other uses. The concept of water productivity, which is defined as the crop yield per unit volume of the water used, started to gain more interest as it evaluates the benefits and costs of the water used for agriculture [1, 2] It is predicted that in the next three decades, the global food production systems will need 40 to 50 percent more freshwater than today. The municipal and industrial water demand is also estimated to increase by 50 to70 percent, while the energy sector's demand is expected to increase by 85 percent. In addition, the growing population, industrialization, inefficient agricultural practices, and urbanization oppose a heavy pressure on the limited available water resources. This causes most of the arid and semi-arid countries to be under severe water stress [3].

Egypt has recently reached a stage where the insufficient water quantity limits its economic development, food security, and national security. With the increasing severity of water scarcity and impacts of climate change, it is expected that the problems facing the water system will become aggravated unless a prompt action is taken to address and solve them. The imbalance between the increasing water demand and the limited water supplies is considered the main challenge of water resources management. The Mediterranean Sea water intrusion is also expected to increase leading to increasing the water salinity at the Nile delta. A future reduction in the Nile's water supply, which is the main source of fresh water in Egypt, is also expected to occur due to the climate change and upper stream countries dams' construction leading to further water stress. Such water shortage will lead to increasing the re-use of drainage water, which will subsequently increase the water's salinity. The Nile water reduction is expected to increase the irrigation water salinity and reduce the crops water productivity, the total cropped area, and self-sufficiencies of wheat, rice, cereal and maize, and socioeconomic indicators [4]. Achieving food security as well as a sufficient water quantity and quality is becoming crucial as it is strongly related to the United Nations sustainable development goals, especially goals number two (Zero Hunger) and six (Clean Water and Sanitation), respectively.

To face these problems, scientific, realistic, and feasible interventions must be developed. It is becoming necessary to change the culture of water abundance that has prevailed in the past, to the culture of water scarcity that is forecasted in the future. The need to produce more food with less water and improve the water productivity is a great challenge. The factors affecting the crop water productivity can be broadly categorized into four groups: the climate, the soil, the crop, and the management. There are interactions among these four groups. High water productivity can be achieved through promoting efficient water use techniques, adopting efficient water management methods, selecting a proper cropping pattern, and developing more efficient crop varieties [5, 6].

The main pillar of the agriculture strategy of Egypt is to rationalize the use of irrigation water. This is carried out through several measures such as, adjusting the cropping pattern by reducing the cultivated areas of crops that consume large amounts of water (such as rice and sugarcane), importing virtual water embedded in many food products (such as wheat), and enhancing the water-use efficiency in irrigated lands [7,8,9,10].

In Egypt, many previous studies have been carried out to evaluate the existing cropping pattern and adjust it based on the economic efficiency of the water used [11]. A cropping pattern that considers crops with high net yield and water productivity are the most favored [12]. Negm and his colleagues [13] investigated two scenarios for the Egyptian cropping pattern. The first scenario is associated with the local prices of crops while the second scenario is associated with the dynamic global conditions. Their study concluded that in order to reach an efficient use of the available water resources, the Egyptian cropping pattern needs to be modified. Fawzy [14] proposed a cropping pattern associated with three alternatives, maximizing the net return per Feddan using both financial and economic prices, maximizing the return per unit of water using both financial and economic prices, and minimizing the water requirements. Other researchers developed decision support systems to evaluate the efficiency of the different existing and proposed cropping patterns and water use strategies like in [15]. Multiple objective decision support systems were also presented. Such systems integrate the different physical, biological, management, and socioeconomic-policy factors to evaluate their influence on the crops' productivity and the system's sustainability and select the optimum decisions accordingly [15].

Quinoa (Chenopodium quinoa Willd.) is an ancient Andean crop that produces edible seeds and leaves. Quinoa is considered a unique halophytic seed-producing crop with great nutritional properties. It is cultivated in many different areas around the world, and accordingly, there is a wide range of its cultivars and varieties that adapt to each area's specific conditions. Hence, there is a broad genetic variability in quinoa's salinity and stress tolerance. Quinoa's tolerance to the salinity and other types of abiotic stresses gives it a high potential wherever water scarcity and increased soil salinization lead to crop failures. Quinoa is well known to grow successfully in poor soils (including pure sand) and in arid regions with very little rainfall. In recent years, quinoa has been receiving a worldwide attention as a multi-purpose agro-industrial crop that can grow in extreme soil and climatic conditions. The International Center for Biosaline Agriculture (ICBA) has been intensively working on evaluating the potential of quinoa as an alternative crop in salt-affected areas[16].

The agricultural sector model for Egypt (ASME) was designed by the Royal Veterinary and Agricultural University in 1980. The latest version of the model was launched in 2009 to make policy analysis. The ASME model simulates and optimizes the agricultural sector's crop patterns and livestock [16]. The objective function of ASME is to maximize the net consumer and producer surplus of agricultural commodities. The studied commodities include crop, crop-based, and livestock. In spite of the importance of the model, it has some limitations as its interface is not easy to handle and its objective function does not consider minimizing the use of water to ensure water saving.

All the previous studies did not consider introducing new adaptive crops to the traditional cropping pattern in Egypt. This study proposes adding a salt-tolerant crop to the traditional Egyptian crop pattern. Quinoa is suggested in this study as an alternative for wheat crop in areas with high water salinity, where the wheat's productivity is negatively affected. A base case considering the current water supply conditions is first studied. Then, a 10% reduction in the Nile water supply and the population projection in the year 2030 are presented in two other scenarios, one of which considers economic incentives for farmers. The effectiveness of the proposed crop is evaluated by using the (ASME) model which estimates the water demand and the agricultural productivity for the different studied cropping patterns.

The present study offers some policies that can help in the economic development of the agricultural sector in Egypt and attract some international agricultural investments as well. A policy is introduced for the production of alternative agricultural crops, which can contribute in solving the problem of water scarcity and food security in Egypt and similar nations and reduce the gaps of water stress and food poverty. The Egyptian water supply is fixed in the present study to be 55.5 BCM/year, the effective rainfall all over the country is also fixed to 1.3 BCM /year, the outflow at the end of the system depends on the water balance all over the country, the groundwater is fixed to 2.3 BCM /year, which is its maximum value in the recent time. The cultivated area is defined according to its real values in the base case. All the other factors are kept free in the ASME model to give it the chance to select the most economic crop pattern

2. Methodology

2.1. The Concept of Water Productivity

Water productivity is defined as the crop production (yield) per unit amount of water used. Although the concept of Water Productivity (WP) has existed since long ago, it only recently gained much attention, especially in the developing countries [17]. The concept of water productivity in the agricultural production system is focused on producing more food with the same amount of water supply (water resources) or producing the same amount of food with less water resources. It is the ratio of crop yield to the amount of water applied to produce it and is expressed in (kg/m^3 or ton/m^3). The water productivity of a crop can be improved by either reducing the water losses that occur during the water conveyance and irrigation practices or increasing the economic production (yield) of the crop through efficient water management techniques.

In the present study, the water productivity is calculated for each scenario as a significant indictor of its efficiency. The crop's yield could be expressed as the weight of the crop, its seeds, or its grains. Hence, the water productivity of the quinoa crop is expressed as the weight of its seeds obtained per the unit volume of the applied irrigation water as referred in Equation (1).

$$WP\ (ton/m^3) = \text{seeds yield (ton/Feddan) / the applied irrigation water } (m^3/\text{Feddan}) \qquad \text{Equation (1)}$$

2.2. ASME Numerical model

In the present study, the ASME model is used to evaluate the effect of replacing the wheat crop at saline areas with the quinoa saline tolerant crop in the Egyptian crop pattern. It is used to solve what-if-questions which arise when new policies are proposed and evaluates the current agricultural problems. In order to use the ASME model, the input parameters should be accurately defined. The model is based on the recognized economic theory and it describes accurately the actual production possibilities. It also includes all the constraints that occur in the Egyptian agriculture. The ASME model can perform the following [18, 19, 20]:

- Create detailed calculations of the agricultural production on farm, regional and national levels.

- Use both the amounts and prices in its calculations (It includes old defined as well as new lands).

- Describe in detail the functions of major crops' production, using nonlinear response functions for cash, crops, fertilizers, manure, and pesticides as well as their interactions.

- Create a realistic model for crops rotation and use mathematical programming to simulate the distribution of crops.

- Include the livestock production functions and link them to crops in relation to feed demand and manure supply.

- Change the production technology over time and include the uncertainty in production and optimize it on the basis of the expected prices as a function of relative profitability.

The data in ASME is separated from the equations component of the model, and is imported to the model whenever needed which make it easy to update. The model is formulated as a set of smaller sub models, to reduce the solution time and make it possible to solve nonlinear problems and perform additional analysis if needed later. Figure (1) shows the interface of the ASME model.

The simulation in ASME is driven by maximizing the welfare which is expressed as the consumer-producer surplus along with the net revenues from international trade under the constraints of the land and water availability (Nile, deep groundwater and desalination).

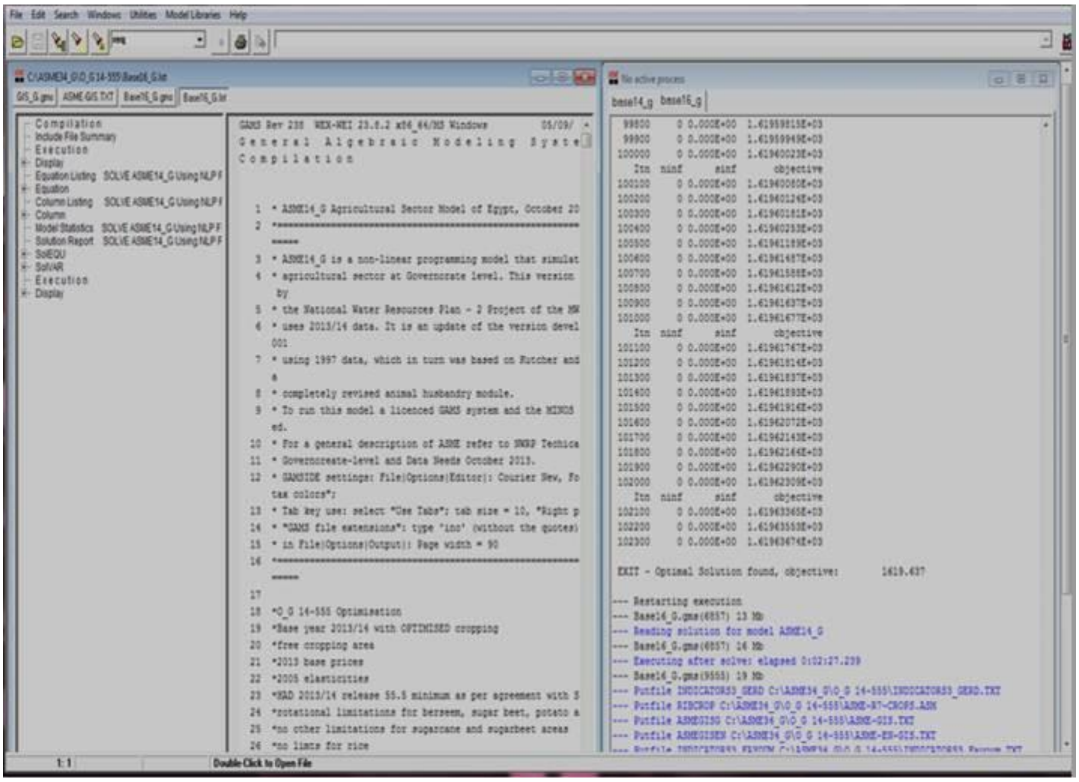

Figure 1: The Interface of ASME model.

2.3. Defining the Studied Areas

One common problem of using ASME model is that there is no restriction on how much land is used when a shortage in water occurs. It is unlikely that an ASME model will allocate exactly the right amount of land. Therefore, the land allocation process will have to be manually corrected. This can occur by either changing the total amount of available land or changing the crop pattern with a new variety of crops using less amount of water. The two options are used together in the present study; the total amount of land in each region is reduced while introducing a new crop. Finally, the percentage of used agricultural land is calculated considering the new number of farms. To use all available land, the number of farms in all groups is divided by the available agricultural land, so that exactly 100 percent of the available land is used when the calculations are complete.

2.4. Adding Quinoa to the ASME Crop List

Water salinity and shortage affects the crop production in arid and semi-arid regions, including Egypt. This can be improved by diversifying the crop production and introducing new crops to the existing crop patterns. Wheat is considered one of the most strategic crops in Egypt. According to [21], the current average productivity yield of wheat is 2.73 ton/ Feddan, with a potential to increase up to 1.5 times compared to the international yields [22]. The wheat productivity in Egypt is affected by the high temperature, crop diseases, water salinity, and water shortage. There is a considerable gap between the annual production and the demand, leading to the importing of about 9 million tons of wheat yearly. The situation is further complicated by the food production shortfalls associated with the population growth and climate change.

New alternative salt tolerant crops should be cultivated in the areas affected by salinity. Quinoa is one of the most promising crops that can compete with wheat in its nutritional importance. Quinoa is a plant that produces a great amount of seeds and has been widely cultivated in the United States and Peru. It has been also given breeding programs in Argentina, Ecuador, Denmark, Chile, and Pakistan [23]. The current paper aims at investigating the effect of adding the quinoa crop to the existing crop pattern in Egypt on the water budget and productivity. Hence, the quinoa crop is added to the crop list in the ASME model through the following steps:

- The quinoa crop is added to the ASME cropping map by adding a new crop in the file which addresses the crops and the governorates where crops can be grown. Quinoa was allocated to the northern Delta governorates which are characterized by their high-water salinity concentrations.
- The land which ASME can include in the quinoa cultivation is selected.
- The economic incentives were provided for farmers as lowering the seeds' prices and purchasing the crop at competitive prices after the end of the planting season.
- Quinoa is included in the grain folder which defines the area of each grain crop in the studied region.
- An equation was developed in the present study to compute the area of quinoa in the studied region.

2.5. The Numerical Modeling Scenarios

Three scenarios were studied in the current paper. The base case, which considered the current water supply conditions, was first studied to verify the ASME numerical model by comparing its simulated crops' areas to the data of the actual areas. The other two scenarios assumed a 10% reduction in Nile flow to simulate the predicted water shortage due to the climate change by year 2030. For the two scenarios, quinoa crop is added to the cropping pattern in Egypt with one scenario without incentives while the other is with incentives to support and encourage farmers to cultivate quinoa.

Two constraints were added to the model, the current orchard cultivated areas, which were fixed in all three scenarios, and the minimum level of the country's self-sufficiency for certain commodities, which was achieved through limiting the importing of such commodities. The population was also included in the ASME simulation as it derived the demand for agricultural commodities. A distinction was made between rural and urban population, as recommended by the Central Agency for Public Mobilization and Statistics of Egypt (CAPMAS).

To alleviate the impact on the livelihood of rural farmers, the current version of ASME is used to include an additional constraint for rural production. It was assumed that the rural population of each governorate of the Old Lands produces at least half of their requirement for the commodities lentils, maize, onion, tomatoes, vegetables, sheep & goat meat, milk, poultry meat and eggs, plus at least a fifth of their wheat flour and a tenth of their fruits. Adding quinoa was proposed to be achieved through the support provided by the government and the incentives that help the farmer to cultivate quinoa, through lowering the prices of seeds and purchasing the crop at competitive prices after the end of the planting season. The cultivation of quinoa was on the expense of wheat cultivation in the areas affected by salinity.

3. Results and Discussion

3.1. Evaluation of Current Cropping Pattern

Since the model is an optimization model suggesting the optimal cropping pattern, the difference between the simulated crops' areas and actual areas in the base case scenario describes the status of current cropping pattern based on the available water resources. The difference between the simulated and actual values also indicates the reliability of the model in evaluating the tested scenarios under the Egyptian conditions. The accuracy of the numerical model is evaluated for the base case in terms of the root-mean square error (RMSE) statistical measure, which is frequently used to evaluate the magnitude of differences between the values predicted by the model and the actual observed values. A smaller RMSE means a better status of the current cropping pattern (close to the optimum) and a better performance of the model to test different scenarios. The RMSE is calculated as follows [24]:

$$\mathrm{RMSE} = \sqrt{\frac{\sum(\mathrm{Y_S}-\mathrm{Y_A})^2}{\mathrm{n}}} \qquad (2)$$

Where, n is the number of data points, Ys is the vector of the simulated values, and YA is the vector of the actual values.

Figure (2) shows the simulated areas using the ASME model for each crop compared to the actual data of those studied areas. The RMSE value was 716 Feddan, which was statistically considered low compared to the actual values of the results which ranged from 63,370 to 4,000,000 Feddan. This low RMSE value indicated that the current cropping pattern based on the current available water resources is close to the optimal pattern. The low RMSE value is moreover an indicator that the model can perform well in the evaluation process of the tested scenarios under the Egyptian conditions. It is also obvious that both the simulated and actual areas have almost the same trend with a tendency of over estimation from the ASME model.

The ASME model suggests increasing the cultivated areas of soybeans and sunflower, fava beans, barely, sesame, and sugar beet. The model also suggests a small increase in the tomato and vegetables cultivated lands in all their seasons.

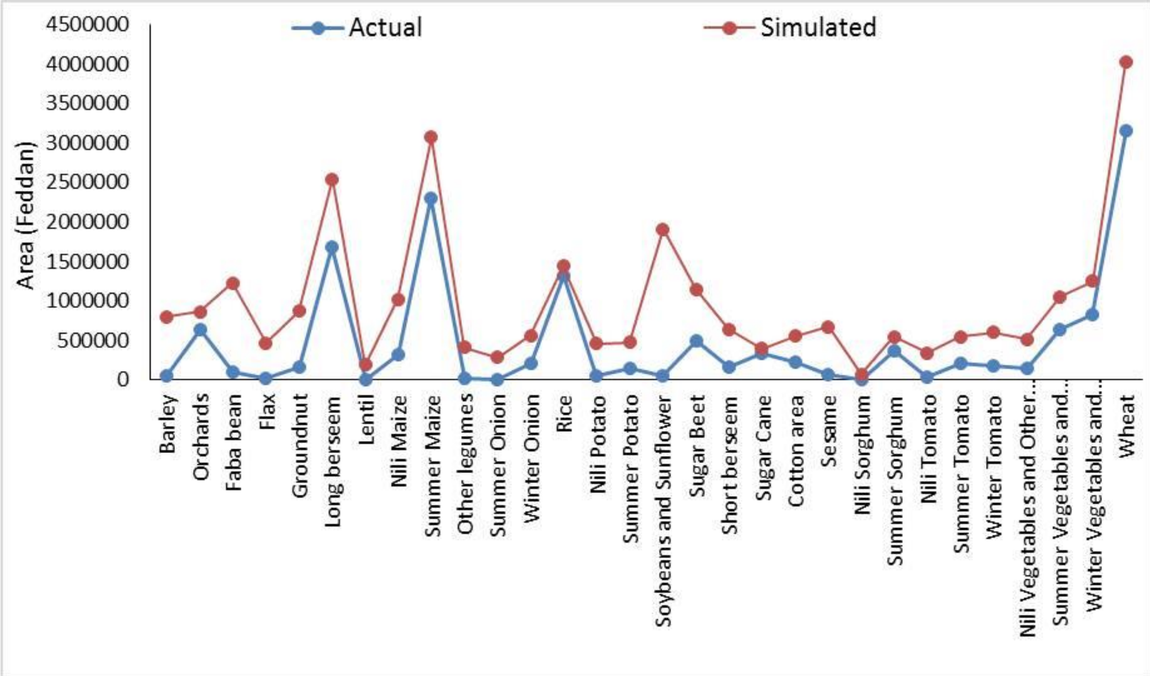

Figure 2: The actual data of crops' areas against those simulated using the ASME model for the base case.

3.2. The Effect of Using Quinoa on the Crops Yields

The most direct, cost-effective, and simple adaptation measure to water scarcity is changing the cropping patterns and bring new salt tolerant crops to the agricultural system of the country. However, changing the cropping patterns might have impacts on the food security and the water productivity. Figure 3 shows the areas of the crops cultivated in the three scenarios. There is no observed change in the areas of all crops except a noticeable decrease in the areas of rice and sugar cane. Among the three scenarios, the scenario that considers subsiding the seeds and purchasing the yield with fair prices have severely increased the cultivated areas of quinoa. It is worth to mention here that the total cultivated areas for all the studied scenarios were almost equal with about 13 million Feddan.

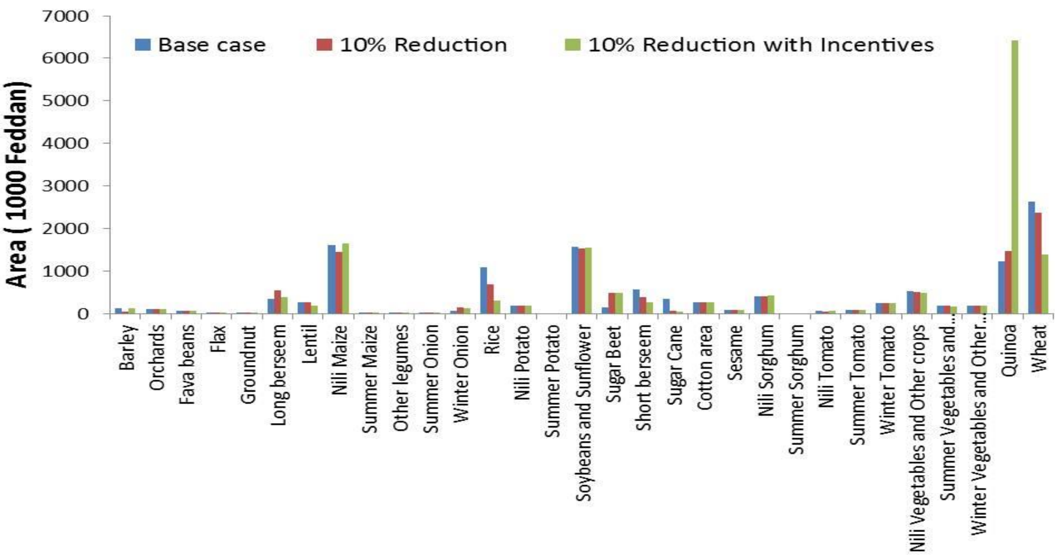

Figure 3: Crops' areas in the three tested scenarios.

Figure 4 compares the yields of quinoa and wheat in the base case scenario with both 10% Nile flow reduction scenarios. The results show that the quinoa yield increased from 1.465 million tons in the base case scenario to 1.747 million tons in the 10% of Nile flow reduction scenario without incentives. This affected the wheat's crop yield, which decreased from 7.178 million tons in the base case to 6.476 million tons in the case of 10% reduction in the Nile flow without incentives. In case of applying economic incentives with the 10% Nile flow reduction, the yield of quinoa severely jumped to 7.701 million tons but the wheat's yield decreased to 3.773 million tons. The total yield of wheat and quinoa crops together decreased from 8.643 million tons in the base case to 8.223 million tons in the case of 10% Nile flow reduction. On the other side, their total yield increased to 11.474 million tons when incentives were used with the case of 10% Nile flow reduction. These results prove that setting economic incentives is essential to motivate farmers to plant quinoa. The incentives can increase the total yields of wheat and quinoa crops together by almost 1.5 times for the case of 10% Nile flow reduction. This gives rise to the high efficiency of quinoa crop in increasing the total crops yield in water stressed and saline areas. Also, the results highlight the importance of motivating the farmers to change the traditional crop pattern in order to face the future climate and water challenges.

Several farmers in Egypt have previous knowledge about quinoa from their neighbors. Many farmers indicate that when they consider the introduction of a new crop in their production system, they make some sort of comparison between the crops that they already produce and the new crop. They also look at the market's availability, products' prices, crop's yield, crop's production costs, and the ease of crop's production. A noticeable number of farmers will perceive quinoa as a likely crop to be included in their crop rotation if its current prices on the market encourage them. On the consumers' side, quinoa has many health benefits and is especially good for people who are intolerant to gluten. This could be an important market segment for quinoa both nationally and for exportation.

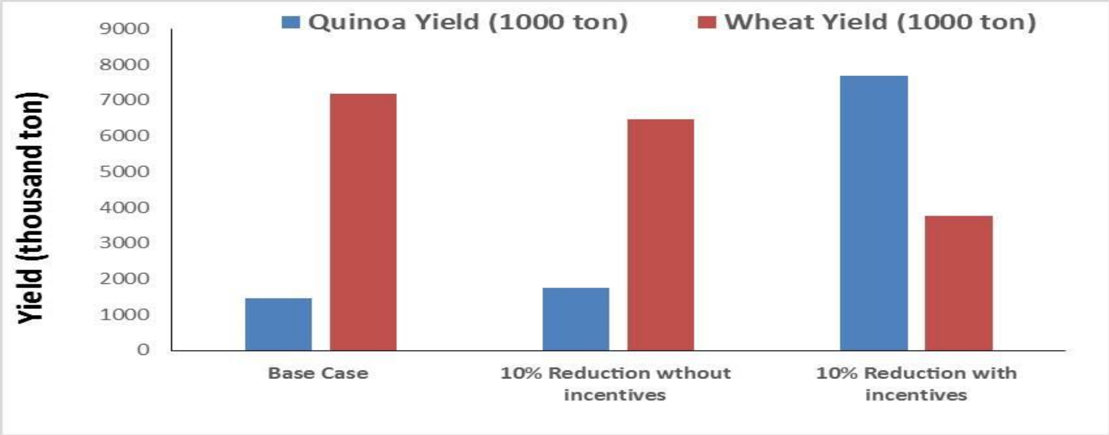

Figure 4: Yields of wheat and quinoa in the three tested scenarios.

3.3. The Effect of Using Quinoa on the Water Productivity

The yields of all the crops decreased because of the Nile flow 10% reduction. Consequently, the ASME model identifies the best crop pattern that makes up for this flow reduction. The model fixed the areas of some cultivated crops in the winter and Nili seasons like groundnut, flax, winter onion, Nili potato, winter tomato, and winter vegetables. This can be attributed to the low water requirements of these seasons compared to the summer season. The results also showed that the cultivated areas and crop yields of barley and Nili maize increased, while the areas and crop yields of long berseem, short berseem, lentil, rice, winter onion, and wheat decreased.

The total cultivated areas decreased from 12.27 million Feddan in the base case to 11.73 million Feddan in the 10% flow reduction scenario without incentives. On the other side, it increased to 15.22 million Feddan for the case of 10% flow reduction with incentives. The incentives were found to increase the area of quinoa severely. On the other side, the total yield of all crops decreased in the case of incentives, because the yield of quinoa is relatively low compared to the remaining crops as shown in Table 1, which presents the average yield (ton/Feddan) for each crop. The crop yield is calculated by multiplying the crop area by the crop yield from Table 1. The total crops' yields decreased from 76,934 million ton in the base case to 73,965 million ton (without incentives) and 69,116 million ton (with incentives) in case of Nile flow reduction. The total crops' yields decrease because quinoa yield from one Feddan is only 1.2 ton, while wheat yield is 2.7 ton / Feddan. As a result, the total water productivity increased from 1.357 for the base case to 1.507 and 1.448 kg/m3 for the cases of 10% Nile flow reduction without and with incentives, respectively (refer to Figure 5). Again, the results show the high effectiveness of changing the Egyptian crop pattern an introducing salt tolerant crops to enhance the water productivity, especially, when accompanied by motivating farmers and raising their awareness about such strategies.

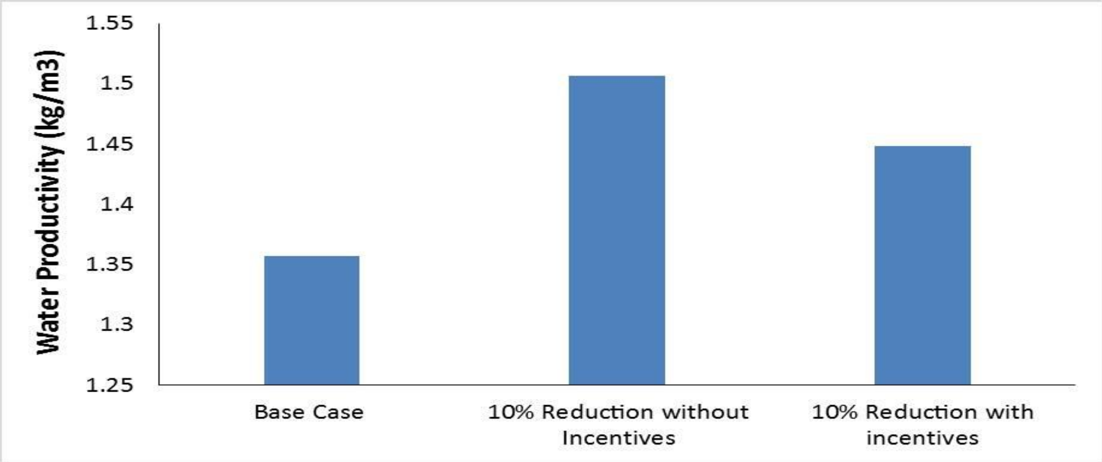

Figure 5 : Total water productivity for all crops in the three tested scenarios.

Table 1: The average crop yield of each crop in the Egyptian cropping pattern as it is saved in ASME database.

The crop	The crop yield (ton/Feddan)	The crop	The crop yield (ton/Feddan)
Barley	1.572	Sugar Beet	20.235
Orchards	12.54	Short berseem	11.351
Fava beans	1.775	Sugar Cane	46.587
Flax	4.217	Cotton area	7.480
Groundnut	1.393	Sesame	0.519
Long berseem	32.992	Nili Sorghum	2.199
Lentil	0.994	Summer Sorghum	2.104
Nili Maize	2.699	Nili Tomato	11.623
Summer Maize	3.249	Summer Tomato	16.623
Other legumes	1.222	Winter Tomato	17.649
Summer Onion	14.233	Nili Vegetables and Other crops	8.533
Winter Onion	14.989	Summer Vegetables and Other crops	10.332
Rice	3.681	Winter Vegetables and Other crops	11.950
Nili Potato	12.23	Quinoa[1]	1.200
Summer Potato	12.305	Wheat	2.730
Soybeans and Sunflower	1.228		

[1] [23]

4. Conclusions

This study investigates the effect of adding the quinoa crop to the Egyptian cropping pattern using the ASME numerical optimization model. Quinoa is a promising crop that can withstand difficult conditions such as water shortage and salinity with a high degree of tolerance, and also has high nutritional specifications. This makes it a good replacement for wheat in saline areas where wheat's crop yield and water productivity are negatively affected. Economically quinoa consumes almost one third of the amount of water required for wheat production and produces about half of the wheat's yield.

A base case considering the current water supply conditions was first studied, then two scenarios considering a 10% reduction in the Nile water supply. The Nile flow 10% reduction scenario adversely affected most of the crops' and decreased their yields leading to a reduction in the total crops' water productivity, but quinoa crop was found to have a potential high yield in such case of water shortage. Economic incentives were found to motivate farmers to plant quinoa and can increase the total yields of wheat and quinoa crops together by almost 1.5 times for the case of 10% Nile flow reduction. The total water productivity increased from 1.357 for the base case to 1.507 and 1.448 kg/m3 for the cases of 10% Nile flow reduction without and with incentives, respectively. These results show that quinoa is a good addition to the cropping pattern as it produces a reliable yield and adding it enhances the water productivity in the cases of 10% Nile flow reduction. This study was performed to evaluate the Egyptian crop pattern and water supply conditions. Similar future studies are recommended to be performed on other countries suffering from water stress and salinity problems.

References

[1] D. Molden, D., Bin, R., Loeve, R., Barker, TP., Tuong, 2007. Agricultural water productivity and savings: policy lessons from two diverse sites in China. Water Policy, 9(1):29-44.

[2] S.M., Scheierling, D.O.,Tréguer, JF ,Booker, E., Decker, 2014. How to assess agricultural water productivity looking for water in the agricultural productivity and efficiency literature. Washington, DC, USA: World Bank Group. (World Bank Policy Research Working Paper 6982), p44.

[3] Kevin,Watkins, 2006. Beyond Scarcity: Power, Poverty and the Global Water Crisis (November 9,). UNDP Human Development Reports 2006, Available at SSRN: https://ssrn.com/abstract=2294691.

[4] M.E.D.M., Omar, **A.M.A.,** Moussa, R. Hinkelmann, 2021. Impacts of climate change on water quantity, water salinity, food security, and socioeconomy in Egypt, Water Science and Engineering, https://doi.org/10.1016/j.wse.2020.08.0 14 (1): 17 – 27.

[5] D., El Quosy, T.A., Ahmed, 1999. **"**Water conservation for reclamation projects in Egypt**"**. IN: Pickford, J. (ed). Integrated development for water supply and sanitation: Proceedings of the 25th WEDC International Conference, Addis Ababa, Ethiopia, 30 August-2 September 1999, pp.415-417.

[6] A., Hamdy, G., Trisorio Luizzi, 2003. Water Scarcity Management Towards Food Security In The Middle-East Region.

[7] G., Siam, H., Moussa, 2003. Food security in Egypt under economic liberalization policies and WTO agreement. In: International Conference Agricultural Policy Reform and the WTO: Where are we Heading, Capri, Italy, 23–26 June 2003.

[8] MALR ,2005 Ministry of Agricultural and Land Reclamation. Strategy of agricultural development in Egypt until 2017, Cairo, Egypt.

[9] MALR, 2009. Strategy of agricultural development in Egypt until 2030, Ministry of Agricultural and Land Reclamation Cairo, Egypt.

[10] M., Amer, S., Abd El-Hafez, M., Abdel Ghany, 2017: Water Saving In Irrigated Agriculture in Egypt (Case Studies and Lessons Learned), LAP LAMBERT Academic Publishing.

[11] I., El-Gafy, A,El-Ganzori, I. Mohamed, Ali,2013: Decision support system to maximize economic value of irrigation water at the Egyptian governorates meanwhile reducing the national food gap, , Water Science, Volume 27, Issue 54, October, Pages 1-18.

[12] I., Salah, 2002. **"**The economic efficiency of the water resources use in the agricultural sector**"** .M.Sc, Thesis. Agricultural Economics Department, Faculty of Agriculture, Monofia University, Egypt.

[13] A., Negm, K., El-eshmawiy, H., Abd El fatah, L., El-shiraif, 2006. The optimal Egyptian indicative cropping pattern using nonlinear fractional programming. J. Appl. Sci. Res. 2 (2),pp 91–99 (INSInet Publication).

[14] G., Fawzy, 2009. The impact of optimizing the irrigation water use on the economics of agriculture production and water saving. WSJ 45, 43–56.

[15] K., Abu-zeid, 1999. Multiple objective decisions making for land, water, and environmental management. In: S.A., El-Swaify, D.S. Yakowitz, (Eds.), A Multi-criteria Decision Support System for Evaluating Cropping Pattern Strategies in Egypt. Lewis Publishers, USA, pp. 105–120.

[17] MWRI, 2012. Agricultural Sector Model of Egypt (ASME) 2011 Version at Governorate Level with 2007 Database and Update Instructions. Ministry of Water Resources and Irrigation – Planning Sector, National Water Resources Plan, Coordination Project (NWRP-CP).

[18] R., Barker, J., Kijne, D., Molden, 2003. Improving Water Productivity in Agriculture: Editors' Overview, in Jacob Kijne et al. (Eds.) Water Productivity in Agriculture: Limits and Opportunities for Improvement, Comprehensive Assessment of Water Management in Agriculture. UK: CABI Publishing in Association with International Water Management Institute.

[19] MWRI., 2013. NWRP for 2037, ASME the Agriculture Sector Model for Egypt, Technical report No.37, Ministry of Water resources and Irrigation.

[20] MWRI, 2005, Technical Report NO. 34, National Water Resources Plan for 2017, Ministry of Water resources and Irrigation.

[21] MWRI, 2001, NWRP for 2017, 2001b. ASME: The Agriculture Sector Model for Egypt, Technical

report No.19, Ministry of Water resources and Irrigation.

[22] MALR, 2019. Bulletin of the Agricultural Statistics, published by the Economic Sector of Egyptian Ministry of Agriculture and Land Reclamation.

[23] M., Langemeier, E., Yeager, 2016. "International Benchmarks for Wheat Production. " Farm doc daily (6):182, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, September 23.

[24] S.E., Jacobsen, S., Shabala, 2013.Ionic content of two hydroponically grown quinoa cultivars contrast in salinity tolerance. Journal of Agronomy and crop Science.

[25] T.,Chai, R.R., Draxler, 2014: " Root mean square error (RMSE) or mean absolute error (MAE)– arguments against avoiding RMSE in the literature". Geoscientific model development 7(3), 1247–1250.