Climatic changes and their impact on crop water productivity under limited water resources in Egypt

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Egypt generally has a hot desert climate. The climate is generally dry in most of the country except on the northern Mediterranean coast which receives more rainfall in winter. In addition to rarity of rain, extreme heat during summer months is also a general climate feature of Egypt although daytime temperatures are more moderated along the [northern coast of Egypt/northern coast].

Egypt's per capita water resources have dropped significantly in the last seven decades and could reach levels of absolute water scarcity by 2025, government statistics agency reports.
Egypt's annual water quota per capita has drastically declined by 60 percent in the last 66 years to reach 663 cubic metres, reported state-owned statistics agency CAPMAS (Central Agency for Public Mobilization and Statistics).

By 2025, an Egyptian's share in annual water will drop to 582 cubic meters as forecasted by CAPMAS. A level that approaches absolute water scarcity at 500 cubic meters according to the UN figures.
In 2012, the International Fund for Agricultural Development (IFAD) warned Egypt could face large-scale drought by the end of the century if it fails to make efficient use of its water. In addition, temperature fluctuations could prompt a 20 percent drop in rainfall. (Ahram Online, Wednesday 21 May 2014).

Water resources in Egypt

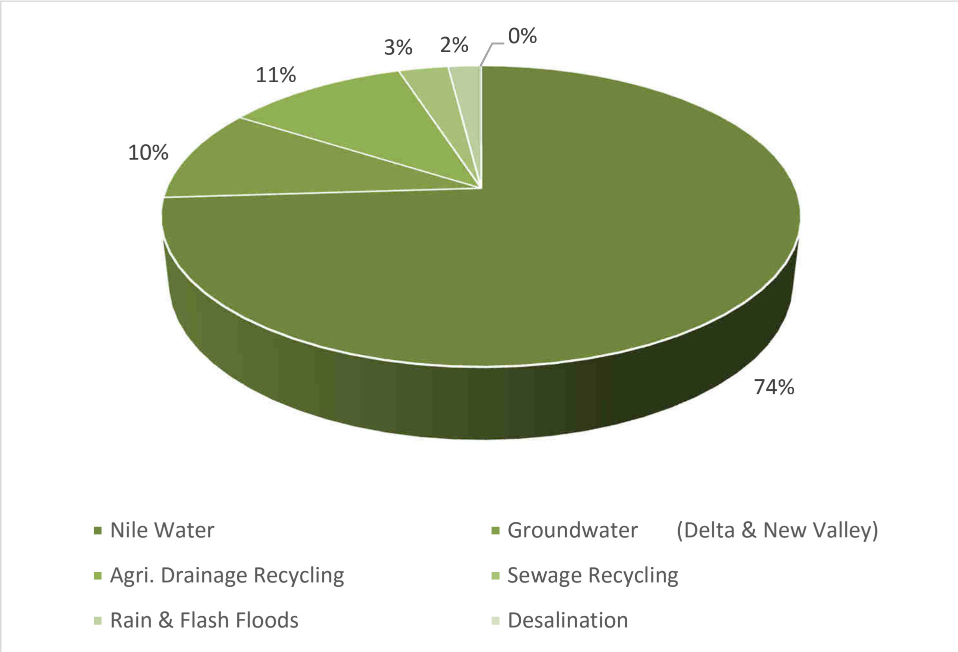
According to CAPMAS report (Abdel Aziz Bahgat, Director of Environment statistics section, CAPMAS, 2010) water resources in Egypt include Nile River, shallow ground water, deep ground water, flash floods, agriculture drainage reuse, sewage treatment and desalination.

Figure 1
Available water resources in Egypt

Resources	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008
Nile Water	55.5	55.5	55.5	55.5	55.5	55.5
Groundwater (Delta & New Valley)	7.4	7.4	7.4	7.4	7.4	7.5
Agri. Drainage Recycling	4.4	4.8	5.1	5.4	5.7	8
Sewage Recycling	1.2	1.4	1.6	1.8	2	2
Rain & Flash Floods	1.3	1.3	1.3	1.3	1.3	1.3
Desalination	0.06	0.06	0.06	0.06	0.06	0.06

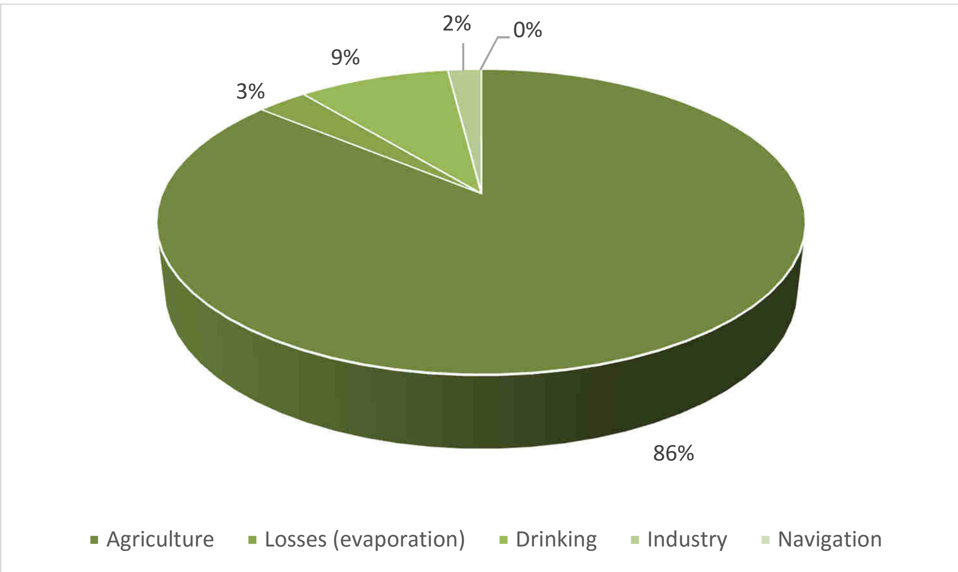
Source: Abdel Aziz Bahgat, 2010

Figure 2
Available water resources in Egypt (2007-2008)



Source: Abdel Aziz Bahgat, 2010

Figure 3
Water uses and losses in Egypt (2007-2008)



Source: Abdel Aziz Bahgat, 2010

The cropped area was 6.333 million ha in 2010, with an average cropping intensity of 175 percent. There are three growing seasons in Egypt: winter - from November to May; summer - from April/May to October; and "Nili" - from July/August to October. (FAO – Aquastat, Regional Report, year 2016).

Most crops are grown both in the Delta and the Valley, with the exception of rice (Delta mainly) and sugarcane (Valley). The main winter crops are wheat and clover or berseem (Trifolium alexandrinum). Berseem is grown either over 3 months with 2 cuts as a soil improver (short berseem), usually preceding cotton, or over 6-7 months, either with 4-5 cuts as a fodder crop or grazed by tethered cattle (long berseem). Minor winter crops are, amongst others, pulses, barley and sugar beet. The main summer crops are maize, rice and cotton, the latter being the most important Egyptian export crop.

Yields of most major crops have significantly increased within the 1980-2007 period: wheat yields have doubled from 3.24 tons/ ha in 1980 to 6.48 tons/ ha in 2007, rice yields increased by almost 70 percent from 5.86 tons/ ha in 1980 to 9.79 tons/ ha in 2007 being among the highest in the world, sugarcane and sugar beets yields increased respectively by over 40 percent and 80 percent reaching 121 tons/ ha and 52 tons/ha in 2007. Only clover and cotton have not seen their productivity increased as much, with only 17 percent increase for clover reaching 71 tons/ ha in 2007 while cotton yield remain stable at 2.6 tons/ ha (ARE, 2009).

Irrigated crops in Egypt do not only contribute to food security but also to the GDP, in particular with cotton and some 5 percent of the horticultural production, and to the preservation of the environment. Indeed, rice production is critical to prevent salt-water intrusion and maintain soil quality in the Northern Delta. In addition, the cotton industry is also a huge employer for rural population with the sector employing over one million people during most of the year and the textile industry half a million (MWRI, 2005).

Agriculture, even though contributing only 14.5 percent to GDP compared to 30 percent in the 1960s, is still a major economic activity in Egypt, as it plays an important role for many people as sustenance farming. Nearly all agriculture depends on irrigation water (MWRI, 2005). In 2010, the total irrigated area covers 98 percent of the cultivated area.

Even the small, more humid area along the Mediterranean coast requires water harvesting or supplementary irrigation to produce reasonable yields. Since 1992, farmers can select the crops they grow; previously the government selected the cropping patterns (Gersfelt, 2007). Smallholdings characterize Egyptian agriculture, with about 50 percent of holdings having an area less than 0.42 ha (1 feddan). Urbanization represents a serious threat to agriculture in Egypt. It is prohibited by law to construct any buildings on farmland without a licence from the Ministry of Agriculture and Land Reclamation, and violators are prosecuted and face serious penalties.

Agricultural policies also include some elements of water management. The 1980s Agricultural Development Strategy intended to fight salinization and improve irrigation in the newly reclaimed areas. The 1990s strategy aimed to improve water return and efficiency through improved irrigation techniques. The Sustainable Agricultural Development Strategy towards 2030 focuses on decentralization of water management through Water Users Associations (WUAs), irrigation operation and maintenance (O&M) cost recovery, and decrease of rice and sugarcane areas, which are crops consuming a large amount of water per ha (ARE, 2009). Its objective is to achieve a comprehensive economic and social development based on a dynamic agricultural sector capable of sustained and rapid growth while paying a special attention to vulnerable social groups and reducing rural poverty. (FAO – Aquastat, Regional Report, year 2016).

Climate change impacts on crop productivity, irrigation requirements and crop water productivity in Egypt

Climate change will put additional pressure on already limited natural resources, namely water and arable land, while rapid urbanization and population growth will impair the prospects for sustainable resource management.

The Intergovernmental Panel on Climate Change (IPCC) listed the Nile Delta as one of the area's most vulnerable to climate change globally. Climate change will affect Egypt mainly in three ways: temperature rise, sea level rise and decreased water availability. These impacts will have an adverse effect on existing environmental and natural-resource stresses faced by Egypt, namely pressures on irrigable land for food production and for human habitation along the Nile Delta. (Egypt Country Risk Brief-IPCC 2015.pdf).

The potential impact of climate change on some main strategic crops in Egypt was studied through the last three decades. Based on the mentioned previous simulation studies, climate change could decrease national production of many crops and increase in irrigation requirements. Yield of cotton would be increased in comparison with current climate conditions [see more details in Egypt's National Strategy for Adaptation (2011); El-Ramady et al (2013)]. As a result of reduced crop production and increased water needs the crop water productivity will decline accordingly.

On the other hand, we must note that the cotton crop is the only crop that will record an increase in crop water productivity due to increased productivity under climate change conditions.

Soil water balance has response to climate change and evaluation of soil water change is one of the most important items of climate change impact assessment. A change in temperature, for example, will affect conservation differently if that change primarily affects minimum, maximum, or mean temperature. A change in a climatic variable also may differ seasonally or geographically. The interaction between and among climatic variables and conservation outcomes is dynamic and often nonlinear. Climatic variables interact to magnify or dampen conservation effects. Likewise, conservation effects feed back into the system and modify the influence of climatic variables. Those interactions could have profound effects on soil, water, and related natural resources. Water budgets, stream flow, and frequency and severity of floods and droughts may be altered. Biotic communities, plant growth and development, and land use patterns may shift. Those changes, in turn, may have important implications for soil, water, and air quality, as well as fish and wildlife habitat. As the main constituent of terrestrial ecosystem, the functions and processes of soil changes in response to global climate change. Soil water reserve is one of the main sources of water that can be utilized by vegetation. The potential change of soil water induced by climate change may cause great change to ecological environment and agricultural production.

Globally, climate change affects average temperatures and temperature extremes; timing and geographical patterns of precipitation; snowmelt, runoff, evaporation, and soil moisture; the frequency of disturbances such as drought, insect and disease outbreaks, severe storms and forest fires; atmospheric composition and air quality; and patterns of human settlement and land use change. Ecosystems and their services (land and water resources, agriculture, biodiversity) experience a wide range of stresses, including pests and pathogens, invasive species, air pollution, extreme events, wild fires and floods. Climate change can cause or exacerbate direct stress through high temperatures, reduced water availability, and altered frequency of extreme events and severe storms.

Understanding climate impacts on each of these sectors requires monitoring many aspects of climate and a wide range of biological and physical responses. Therefore, it could be concluded that a changing climate has effects on soil and water resources in many ways. That means, climate change will affect soil and water conservation through multiple pathways because many climatic variables have important effects on conservation outcomes. Those variables include precipitation, temperature, wind, solar radiation, and atmospheric carbon dioxide, among others. (El-Ramady et al. 2013)

Maximizing crop water productivity under current and climate change conditions

According to FAO reports, water productivity means growing more food or gaining more benefits with less water. To feed a growing and wealthier population with more diversified diets will require more water for agriculture on an average annual basis. There is considerable scope for improving physical water productivity, but not everywhere. Increasing water productivity, especially the value produced per unit of water, can be an important pathway for poverty reduction in water productivity.

The adoption of techniques to improve water productivity requires an enabling policy and institutional environment that aligns the incentives of producers, resource managers, and society and provides a mechanism for dealing with tradeoffs. An assessment of the potential for reducing water needs and increasing production and values requires an understanding of basic biological and hydrological crop-water relations. Answering the question of how much more water will be needed for agriculture requires understanding the connections among water, food, and diets. The amount of water that we consume when eating food depends on diet and on the water productivity of the agriculture production system.

Figure 4
Crop productivity (ton/ ha) for some main crops in Egypt under current (data 2013) and climate change conditions.

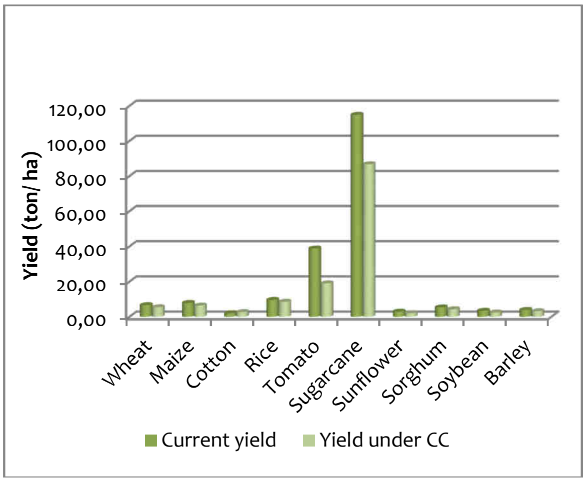


Figure 5
Irrigation requirements (IR) for some main crops in Egypt under current (data 2013) and climate change conditions.

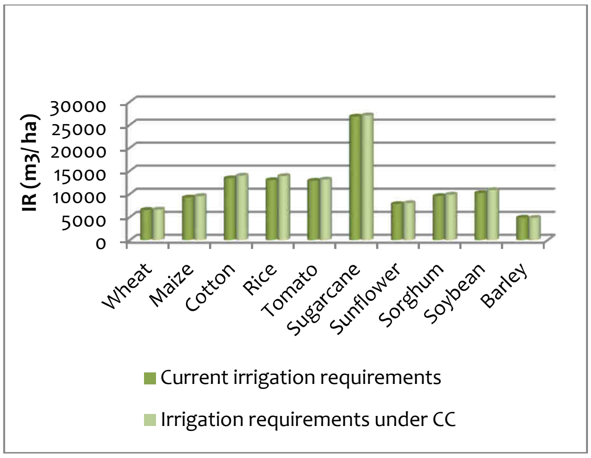


Figure 6
Crop water productivity (CWP) for some main crops in Egypt under current (data 2013) and climate change conditions.

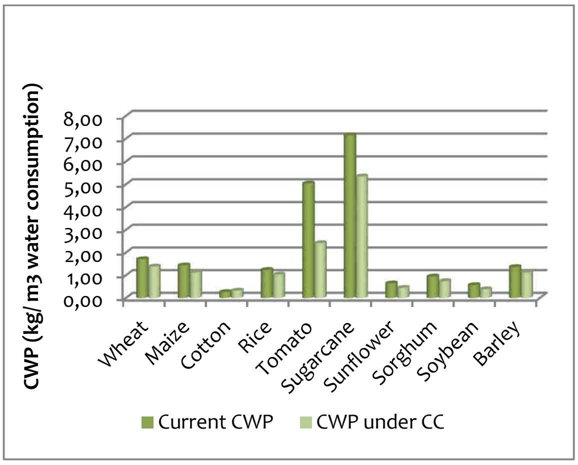
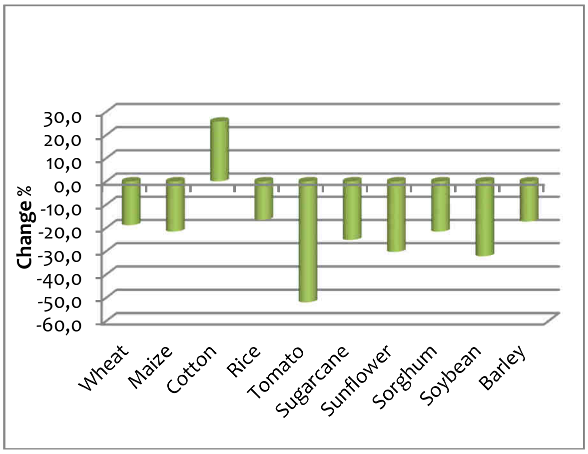


Figure 7
Change percent in crop water productivity (CWP) for some main crops in Egypt under climate change conditions.



Results are shown in graphs compiled and computed from previous studies. Current crop productivity (2013) was obtained from Agricultural Economic Research Institute Bulletin (Volume 2013). Ministry of Agriculture.

Figure 8
Average crop water productivity (CWP) under different crop patterns in the Nile Delta region

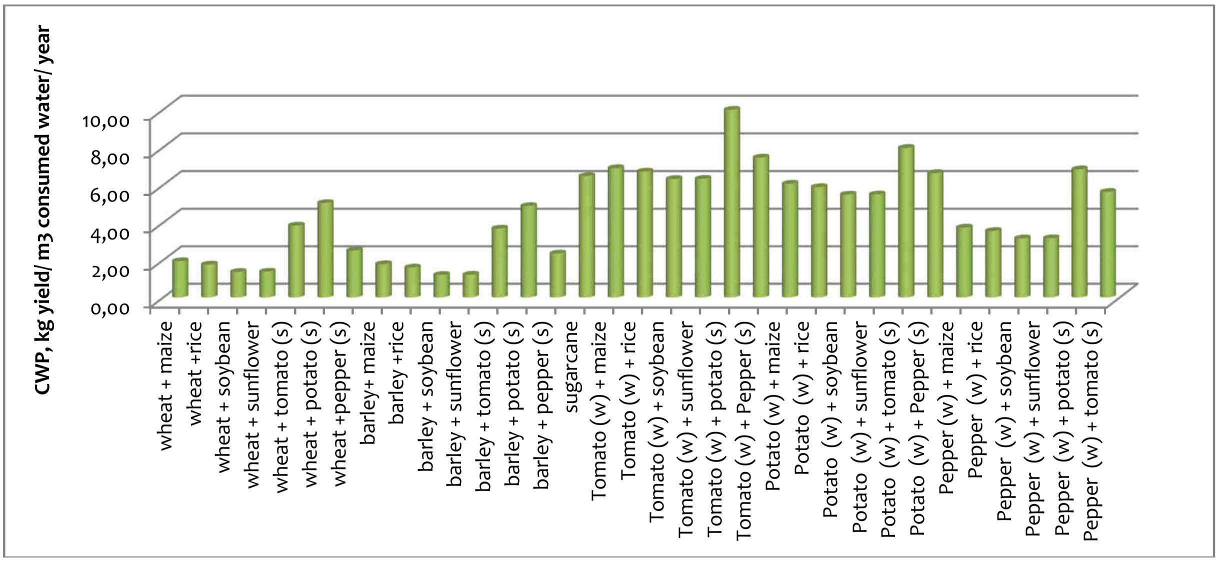


Figure 9
Average crop water productivity (CWP) under different crop patterns in Middle Egypt

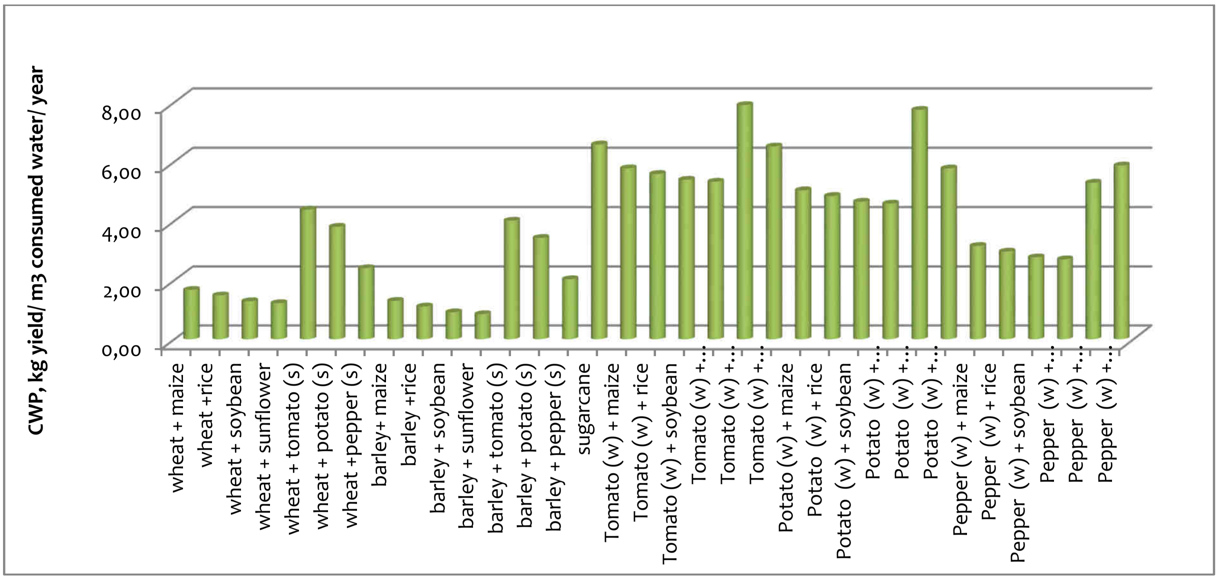
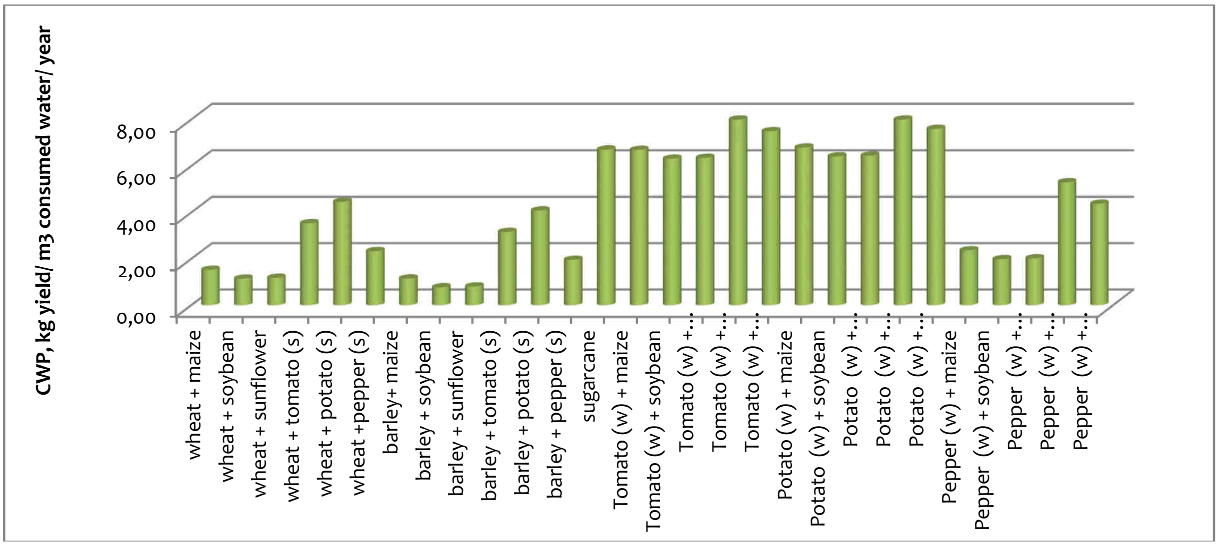


Figure 10
Average crop water productivity (CWP) under different crop patterns in Upper Egypt



In this regard, Agricultural Research Center has many experts in the field of application of good agricultural practices that would increase crop water productivity, some of these practices are:

Modification of cropping pattern

To determine the optimum cropping pattern which achieves the highest return from water unit, 33 scenarios were examined under different climatic zones in Egypt (Delta region - Middle Egypt - Upper Egypt). The results indicated that crop water productivity (kg/ m3 consumed water) can range from 1.21 to 9.99 in Delta, 0.85 to 7.91 in Middle Egypt and 0.78 to 9.63 in upper Egypt. For example, in the Delta region higher productivity of water unit (9.99 kg/ m3 / year) has verified the application of winter tomato followed by summer potato, however, the lowest scenario was registered for barley + soybean (1.21 kg/ m3 / year), El-Marsafawy et al. (2013). See more details in the three figures below.

Raised seed bed technique

According to Swelem et al., 2015, raised bed is used in developed countries as an improved system of crop productivity. The system was originally developed in Mexico's Yaqui Valley; where above 90 % of farmers have adopted the practice. It is broadly used in wheat growing areas in Mexico during the last decade (Meisner et al., 1992).

Abouenein et al. (2010) indicated that Egypt is facing many challenges in agricultural sector (scarcity of land and water resources; competitions between clover, the main forage crops, and wheat on available land, since both crops are planted during the winter season; rapid increase in livestock numbers due to the high demand of animal products), there are many opportunities available to fulfill the feed gap in a sustainable manner. The irrigation benchmark project introduced better alternative, known as simple water saving cost-effective technology for growing berseem on raised-seed bed (wide spaced furrow irrigation) instead of growing in flat basin in Egypt. The field has broader 'crop strips' and fewer water running. Over irrigation is automatically reduced because there are limited water running; but there are several other advantages as well, which is reflected on improving water productivity.

Wide-Spaced furrow irrigation, with its lesser water input per irrigation, has been shown to maintain crop yield and to reduce pumping costs (Stone et al., 1982, 1985). The authors added that results of growing berseem on raised seed bed indicated that the increase in green (fresh) yield ranged from 20 to 26 % being 34 to 38.3 t/ ha and the increase in dry yield ranged from 23 to 28 %, being 5.2 to 7.94 t/ ha as compared to farmer practice (flat method). This may be attributed to the increase in tiller number per plant (28 %) and the number of survived plant (more than 16 %). Hence, growing berseem on raised seed bed considered successful tool to save water which amounted to be 104 mm, being 18 %.

In the same direction, Swelem et al. 2015 clearly show that the raised bed systems are most profitable due to saving labour, time, water and energy costs and production costs. Using raised bed at width of 120 or 100 cm with 180 kg N ha-1 gave the highest significant averages of wheat grain yield and its components as well as nutrients uptake and grain protein content, also substantial water saving (15 %) over the raised beds at width of 75 cm with low N level treatments. Thus, in warmer areas where water resources are often limited and nutrient uptake and efficiencies are low, the use of raised beds with optimal nitrogen fertilizer level would be a distinct advantage.

Dry sowing method

Other tool could save irrigation water, increase yield and crop water productivity is using dry sowing method for berseem. This method can save irrigation water about 1000 m3 / ha. To calculate the benefit of this good agricultural practice on the national level we will find that :Egypt's agricultural area of clover according to statistics 2013 about 737,609 ha, so, the amount of water can be saved from this total area will reach 737,609,000 m3. This volume of water is sufficient to irrigate wheat area about 112,733 ha.

Optimum sowing date

Under climate change conditions, the results of studies conducted through the past three decades indicated that: change sowing date and identify the optimum date through adaptation strategies can make up the shortfall caused by the adverse impact of climate change on crop productivity or at least reduce the negative impact.

Precision land leveling

Allam et al. 2005 revealed that the main objectives of land levelling can be listed as follows:

- To achieve water application uniformity in the field to avoid having parts of water logging and parts of water stress. Uniformity of water application will thus contribute to increased crop production.
- Water losses could be minimized through reducing farm water run-off.

In Egypt, land levelling, particularly Laser levelling is practiced on a large scale in either by the governmental, public and/or private sector. The very pronounced example is that followed in the sugarcane fields where the government is subsidizing the laser levelling in these fields by about 50% of its cost. Another type of this land levelling is that implemented in rice cultivation areas, where this levelling is done under water by a wooden beam using animal traction. This is to minimize the water infiltration and losses by percolation through the soil profile.

In the same direction, El-Ramady et al. 2013 indicated that precision land leveling using laser assisted land leveler equipped with drag scrapper is a process of smoothening the land surface within ± 2 cm of its average micro-elevation. It is contemplated that laser levelers may play a significant role in improving resource use efficiency under surface irrigated systems. Improvement in operational efficiency (Rajput et al. 2004), weed control efficiency (Jat et al. 2004), water use efficiency (Jat et al. 2009), nutrient use efficiency (Choudhary et al. 2000), crop productivity and economic returns (Rickman, 2002), and environmental benefits (Jat et al. 2006) been reported as a result of precision land leveling when compared to traditional practice of land leveling. Significant increase in water use efficiency (WUE) on laser level fields has been reported by several researchers under different soil and climatic conditions (Jat et al. 2011).

El-Ramady et al. 2013 added that irrigation application efficiency (%) increased from 66 % (for control) to 75.4 % for cut off 75 % of stream irrigation and land leveling with 0.01 % slope. Thus, about 30.8 % from the applied water for irrigation is saved by the previous treatment.

Surge flow irrigation technique

Surge irrigation is defined as the intermittent application of water to furrow or borders…… creating a series of on and off modes of constant and variable time spans, Bishop et al. 1981. Abdel-Maksoud et al. 1999 reported that surge irrigation resulted in reduction in quantities of water applied to wheat and maize plots. The reduction under surged-wheat plots was insignificant and reached about 14.5 %, while, it was significant under maize crop and amounted to 18.6 % less than continuous irrigated plots. The authors added that, grain yields for both wheat and maize crops were significantly increased under surge irrigation more than continuous one and the relative increases amounted to 7.00 and 7.87 %, respectively.

Osman et al. 1999 illustrated that surge flow irrigation technique and irrigation every 14 days are considered a suitable practices to optimize water use and increase the surface irrigation efficiency in calcareous soil. The best treatment surge flow (5 min. on and 15 min. off) reduces water requirement of corn by about 39.25 % (2713 m3l hectare) compared with conventioned continuous irrigation for irrigated every 14 days. The average increments of the two seasons in grain yield were about 11.4 %. The surge flow irrigation system can be used efficiently in calcareous soil by using conventional or concrete channels with siphon tubes or automatic gate pipes for distributing irrigation water.

In addition, there are many other good agricultural practices that have been drawn from researches conducted at the agricultural research center. Some of these practices are already implemented by farmers.

- Breeding new varieties that can tolerance to drought, salinity and high temperature
- Breeding of new varieties short growth season to reduce water needs.
- Alternate furrow irrigation
- Improve both the technical water application efficiency and the agronomic water use efficiency
- Modern methods of irrigation (sprinkler and drip)
- Lining irrigation canals
- Use anti- transpiration
- Scheduling of irrigation for different crops using the evaporation pan method (accumulative evaporation)
- Scheduling of irrigation through the computer software programs
- Reduce the area of crops that consume large amounts of water or at least not increase agricultural area of these crops (such as rice and sugarcane).
- Rapid response and address the fundamental problems of agricultural land degradation and low productivity
- Promote the use of agricultural equipment and machinery.
- More efficient use of groundwater in agricultural uses
- Supplementary irrigation and improvement of rain harvesting techniques
- Use compost or mulch where it increases water retention capability of soil
- Establishment of Water Users Associations (WUA's)
- Night irrigation
- Weather forecasting and early warning systems
- Supporting scientific and applied research and technology transfer
- Raise water awareness at all levels

Conclusion

Currently, about 86% of water in Egypt is used in agricultural sector. With expected population increase, water share for capita will decrease. This would mean less food to feed the growing population. Irrigated crops in Egypt do not only contribute to food security but also to the GDP. In 2010, the total irrigated area covers 98 percent of the cultivated area. Even the small, more humid area along the Mediterranean coast requires water harvesting or supplementary irrigation to produce reasonable yields. Climate change will put additional pressure on already limited natural resources, namely water and arable land, while rapid urbanisation and population growth will impair the prospects for sustainable resource management.

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According to FAO reports, water productivity means growing more food or gaining more benefits with less water. Increasing water productivity, especially the value produced per unit of water, can be an important pathway for poverty reduction in water productivity. Agricultural Research Center has many experts in the field of application of good agricultural practices that would increase crop water productivity, some of these are: modification of cropping pattern, raised seed bed technique, dry sowing method, optimum sowing date, precision land leveling and surge flow irrigation technique. Some of these practices are already implemented by farmers.

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