Ecological Engineering 70 (2014) 11–15

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Water saving scenarios for effective irrigation management in Egyptian rice cultivation

Harby Mostafa[a,*], Naoya Fujimoto[b]

[a] Agricultural Engineering Department, Faculty of Agriculture, Benha University, Moshtohor, Kalubia 13736, Egypt
[b] Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Ibaraki 305-8686, Japan

ARTICLE INFO

Article history:
Received 13 August 2013
Received in revised form 1 April 2014
Accepted 19 April 2014

Keywords:
Irrigation
Water
Management
Conservation
Rice
Egypt

ABSTRACT

Developing ideal irrigation management methods in rice production to lessen water consumption will free-up water for other users. Water use could be minimized with proper management techniques. It is necessary to highlight the threats of water scarcity and drought, and reiterate the importance of efficient water management for rice production and the urgent need to take action to solve the underlying problems in considering water security. From here, this study was designed to decide whether water can be preserved in rice production by surveying the successful water management techniques in the Egyptian Nile Delta. Management scenarios were suggested to save as much irrigation water as possible. The scenarios showed that water, which could be used in the agricultural land expansion, can be saved by 43–52% (4.7–5.7 billion m^3).

1. Introduction

Rice normally needs (under traditional methods in Egypt) a water application of about 2000 mm; an amount much higher than other crops. About 11 billion m^3 of irrigation water are being used in rice production in the Nile Delta. This amount represents about 20% of the whole quantity of irrigation water used in agriculture (55.5 billion m^3/year). Particularly water consumed under the conventional irrigation method is considered. Saving water is becoming a decisive reason for agricultural expansion. Limited water supplies and the remarkable increase in population (85 million capita, FAO, 2013) should force researchers to find ways to save more water without a significant fall in yield. Great efforts should be made with water management practices to find ways to save more irrigation water.

Water saving strategies in agriculture are not limited to irrigation practices. They extend into the other areas affecting on farm water application including varieties, cultivation methods and benefits of land leveling (Ichino & Kasuya, 1998; Hama et al., 2011; De Miguel et al., 2013). Water-saving methods are needed in rice to mitigate the effect of a lack of water, to increase water productivity, and to safeguard food security. At the same time, the salinity in the Northern Delta must be controlled. This article aims to take stock of and combine exercises of various water-saving technologies for rice in Egypt. First, it will produce an inventory, description, and a comparative analysis of farm-level water-saving technologies already done as individual research. Second, it will study novel technologies in detail and survey their adoption and impact on the saving of irrigation water. Finally, some scenario suggestions may help in irrigation management and water saving.

2. Materials and methods

To achieve the objectives, the study adopted both descriptive and quantitative analyses. As regards data, the study depended on published and unpublished data for the period until 2012, issued by the Ministry of Agriculture and Land Reclamation (MALR); Ministry of Water Resources and Irrigation (MWRI); Agricultural Research Center (Rice Research Program); the National Rice Program at Rice Research and Training Center (RRTC); and Food and Agriculture Organization of the United Nations (FAO). The influence of irrigation water saving in rice production was evaluated. The yield needed to meet the projected 2030 demand for rice was calculated for self-sufficiency. This demand was estimated from past trends in rice consumption per person. Legally and illegally cultivated rice

* Corresponding author. Tel.: +81 298386678; fax: +81 298386682.
E-mail addresses: harby.mostafa@fagr.bu.edu.eg, harby_sorour@yahoo.com (H. Mostafa).

http://dx.doi.org/10.1016/j.ecoleng.2014.04.005
0925-8574/

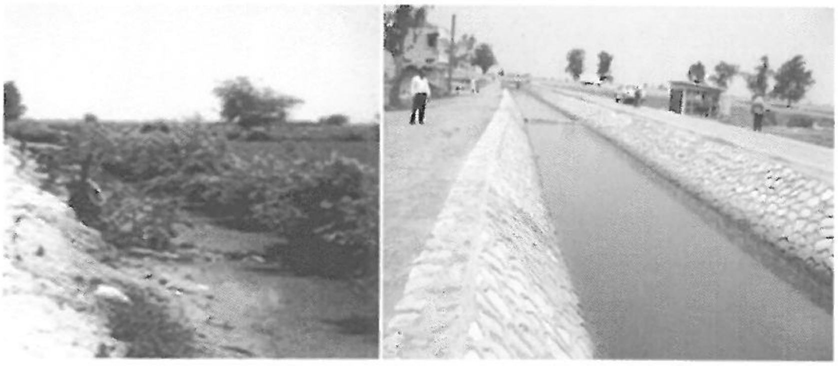

Fig. 1. Improved branch canal (Mesqa).

areas and their salinity levels wer surveyed and calculated. Finally, a plan was suggested and designed for the future to help in irrigation management and water saving.

3. Results

Several techniques have been developed for water management to improve water-use efficiency. For crop irrigation, ideal water efficiency means reducing losses because of evaporation, runoff or subsurface drainage while increasing production (Yang, 2012).

The Egyptian government has done successful efforts to develop the use of water resources. That strategy includes strengthening the awareness and community of people to control the use of irrigation water. It helps to save 10–15% of irrigation water and increase the crop production by 15–20%. This strategy has led to a plan for developing irrigation systems in several ways. The authors divided these ways into off-farm and on-farm improvements.

3.1. *Off-farm irrigation water management practices*

To achieve on-time water deliveries, Egypt started a national program to improve the main delivery system (Irrigation Improvement Project, IIP). Irrigation canals are classified into main canals (first level canals), branch canals (second level canals), and distribution canals (*Mesqas*, or third level canals which serving an area up to 50 ha). Improving the main delivery system through a rehabilitation of water structures such as intakes and tail escapes lessens water losses from canals end to drains. Replacement of the old structures with new ones with radial gates to provide automatic control for the downstream water levels to cope with farmers' demand and abstraction. Furthermore, turnouts and off takes are also planned for installation along the branch canals such as facilities at the head of each *Mesqa*, pumps, and pump sumps.

Improvement of *Mesqa* makes up the major part of the improving irrigation performance. It includes replacing the existing *Mesqa* with improved one. The old *Mesqa* is usually an earthen and low-level ditch with no organized water withdrawals through multiple pumping and lifting points along its length. Two types were recommended for improving the old *Mesqa*, open elevated *Mesqa* and buried low-pressure pipe. Normal water level in the elevated *Mesqa* was set to allow gravity flow to the field at 15 cm above the field level. Alternatives for elevated *Mesqa* include a rectangular concrete cast-in place section and precast concrete as shown in Fig. 1 (WMRI, 1996).

The IIP is concerned with improving the existing irrigation system in Egypt over a total area of 10^5 ha in the northern part of the Nile Delta. The overall objectives of the project were improving irrigation infrastructure, promoting more equable distribution of water, improving on-farm water management, minimizing different irrigation water losses and increasing water-use efficiency for different crops. The different field data were collected by the field staff day after day in the project's area. Data analysis was done for the rice cultivation area. Results showed increasing of rice crop yield of 11.4%. This increase due to the good conditions of water availability by the equity distributing between the head and tail of the Mesqa. Meanwhile the irrigation time for rice decreased in all Mesqas. The irrigation water was decreased on an average of 15.55%. In other words, since the crop yield increased and the irrigation water decreased, the water use efficiency increased (MALR, 1998).

According to the previous data, the irrigation water decreased from 20,000 to 16,900 m^3/ha for rice production.

3.2. *On-farm irrigation water management practices*

Several field experiments were conducted to rationalize water use. These experiments included (1) substituting the long-duration varieties with short-duration varieties, (2) using dry rice (3) using different planting methods with combining land preparations.

3.2.1. *Shorter season varieties*

The rice working group developed many rice varieties which express to reduce water consumption (Giza 177 and Sakha 102). The varieties reduce the time from planting to harvest by 40 days (120 days compared to 160 days for current longer-season varieties). A pilot program involved a package of agricultural practices and fulfilled water delivery for short-duration rice varieties until the rice-growing season of 1997 (RRTC, 1998). Measured reduction of water delivery to the canal for the period from May 1 to October 31 was estimated at 3×10^3 m^3/ha of applied water. That means when the short-duration varieties applied on all rice growing areas within the next two to three years to the 625×10^3 ha of rice, a decrease of about 2 billion m^3 of applied water could be expected.

During the 2000 summer season (after three years), it was noted that around 8×10^5 ha of rice was being cultivated because of the high yield and low applied water. However, all water savings because of substituting short duration varieties are exhausted (RRTC, 2001).

In summary, cultivating short-season rice does save about 18% (from 16,900 to 13,900 m^3/ha) of the water deliveries needed for long-season rice.

Table 1
Areas of rice cultivations in for all regions.

Regions	Planed area (ha)[a]	Actual area (ha)	Increasing (ha)	% of increasing
Legal	446,000	641,000	195,000	43.7%
Illegal	0	225,000	235,000	
Total	446,000	866,000	420,000	94.2%

[a] The area decided by MWRI and MALR (2012).

3.2.2. Land leveling and transplanting

Soil dry leveling by laser plays an important role in rice planting. It saves water by 25% (Badawi and Ghanem, 2007) because of the controlled water distribution in rice fields. This improved rice productivity compared with uncontrolled water distribution. On the other hand, using mechanical transplanting with land leveling could save about 3–5% water, which is used in seedling stage in the nurseries (Khattak et al., 2006).

In summary, mechanization management in soil preparation with transplanting could decrease the applied irrigation water by 29% (from 13,900 to 10,000 m^3/ha) and increase water use efficiency.

3.2.3. Planting methods

This method depends on reducing the irrigated area by the land division into furrows with 45 cm top and 35 cm bottom. The seedlings are transplanted in hills (4–5 plants) 10 cm at the bottom of the furrow with using the same plant density (25 hills/m^2) as recommended into two rows of plants. Planting irrigation was given with enough to reach puddling. Then the next irrigation were given for bottom only with a depth of 7 cm. Therefore, the flood area was less and thus increased water saving about 30–40%. This new method increased irrigation application efficiency and water productivity, however, it decreased percolation losses and decreased evaporation (Atta et al., 2006; Atta, 2008).

The results showed the applied water was reduced from 13,900 to 9000 m^3/ha with water saving about 4900 m^3/ha (35%). The comparison between the new and the traditional rice cultivation methods show the production increased about 5% and the water use efficiency can be reached to 75%.

3.2.4. Dry rice (aerobic)

A breeding rice program was done in RRTC for transferring prescription drought tolerance to some local high-yield and short season varieties. The varieties obtained were evaluated for three years, 2007–2010, as preliminary experiments under drought conditions (12–15-day irrigation intervals). The crop has reached those breeds 10 t/ha providing about 40% (13,900–8300 m^3/ha) of irrigation water comparing same varieties cultivated under conditions of continuous flood (RRTC, 2010). Another experiment at the department of genetics at the faculty of agriculture, Zagazig university, developed types of rice with standing drought. Two varieties were reached "Oraby 1 and 2", which consumes 50% of the water when grown in furrows compared to traditional rice varieties. Evaluating those breeds helped advances in the final stages of registration as new varieties consume less amounts of irrigation water (7×10^3 m^3/ha) without affecting productivity (Soliman and Saaid, 2010).

3.2.5. The hybrid rice

Egypt sits on the throne of rice productivity in the world (10 t/ha) and it is difficult to increase productivity more than that in the conventional varieties amended. The rice program has already achieved distinct high-yielding hybrids that meet all purposes, including hybrids bear conditions and lack of water and climate change (Ebaid and El-Mowafi, 2005; Gorgy, 2007). According to El-Mowafi (2010), Sakha "2034" has been registered to become the first hybrid rice class called Egyptian "1". This strain gives 14 t/ha with medium duration season not exceeding 130 days, is resistant to diseases and can be cultivated in all fertile and salt soils, while in addition having more than 20% water savings. Furthermore, tests were completed for the hybrid Sakha "2946" to be registered as the Egyptian hybrid "2". This strain gives the highest productivity with 16 t/ha.

3.2.6. Cultivating high-value crops instead of rice

One may conclude that there are positive results on water savings if a farmer grows high value crops such as yellow corn, sesame or vegetables instead of growing rice. According to the field records, the average water need for yellow corn and sesame were 4750 (furrow irrigation using gated pipes) and 3240 m^3/ha, respectively compared to 8000 m^3/ha for rice. Similar results were seen for income per ha for yellow corn and sesame where the average net income is 8000 LE (Egyptian Pound) compared to rice where it is about 5000 LE according to year 2010 prices (USAID, 2011) (1 US Dollar = about 7 LE).

4. Discussion

There is a clear constraint on lessening irrigation water in Egypt based on the need to control salinity in the Northern Delta. The salty aquifer which underlies the Northern Delta will cause soil salinity problems when the hydraulic pressure gradient allows because of upward migration. Periodic flushing with enough fresh water is required to reduce this upward migration. There is evidence that rice cultivation has improved some of the relatively salty soils in the Northern Delta. So rice cultivation is an important approach to conserve soil fertility and to reduce the salinity hazard. From here,

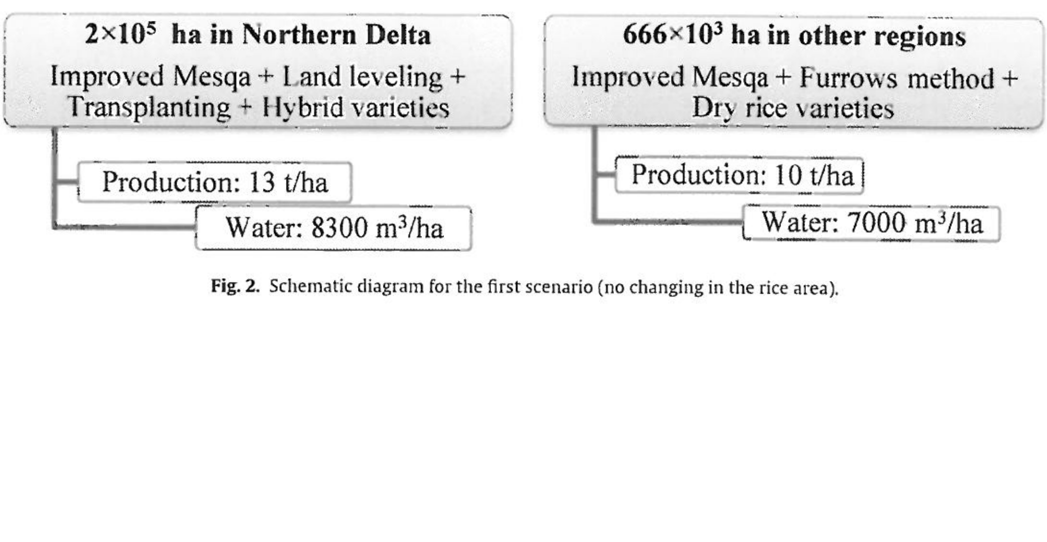

Fig. 2. Schematic diagram for the first scenario (no changing in the rice area).

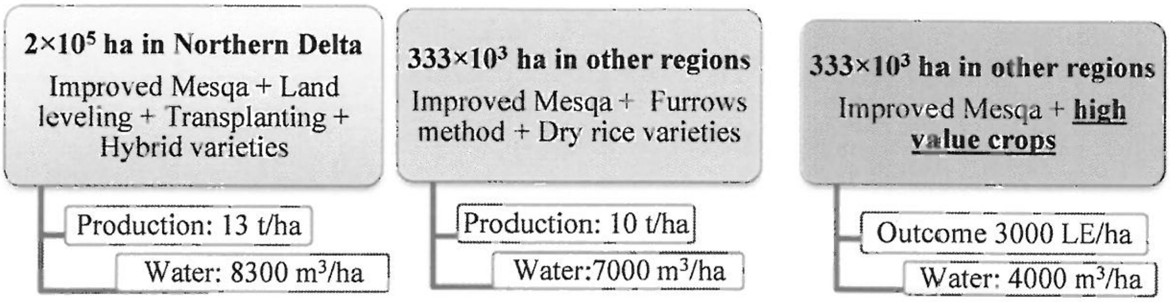

Fig. 3. Schematic diagram for the second scenario (38% decreases in the rice area).

the Northern Delta salinity problem has to be considered for any irrigation management method to reduce water consumption. Also, it should be reconsidered how much rice should be legally grown in Egypt bearing in mind future needs and constraints. According to the discussed and analyzed data, the actual cultivated rice area increased by 94% more than the legal area (Table 1). This area produced more than 8 million tons while the maximum local consumption is 5 million tons (Othman et al., 2011). The expected population will be 100 million by the year 2030 (FAO, 2013), meaning the local consumption will increase to 6.1 million tons.

Two scenarios were suggested, and irrigation water saving was calculated as follows:

4.1. Water savings if rice is cultivated according to the actual area in Table 1

This scenario suggested no changes in the rice area. According to MWRI and MALR reports (2012), the saline soil area in the Northern Delta is about 1.5×10^5 ha. To be on the safe side, the area in this scenario calculated as 2×10^5 ha (Fig. 2).

The total applied irrigation in the Northern Delta area is calculated at 1.66 billion m^3 while it was 4.66 billion m^3 for the other regions. So the irrigation water for the whole rice area will be about 6.32 billion m^3, leading to a 43% water saving (11 billion m^3 in traditional cultivation). On the other hand, total rice production will be more than 9 million tons.

4.2. Water savings from converting 333×10^3 ha of rice cultivation to other crops

In this scenario, the government has to pay more attention to cultivating alternative crops that not only use less water, but also give significantly higher returns, and in this way increase the added value per unit of water consumed. So if a plan is designed to cultivate about 333×10^3 ha of high value crops instead of rice (50% of rice area outside North Delta), the used water will be about 5.32 billion m^3, leads to 52% water savings (Fig. 3). The total rice production will be about 6 million t/year (4.2 million tons milled rice) which will be enough for consumption with the future needs (until the year 2030). Also, more than one billion LE returns from the high value crops (yellow corn and sesame) could be doubled if other high value crops are used (mint, chamomile, basil, golden sesame and marjoram).

The authors believe that both scenarios will appeal to farmers especially there are no more costs for using some techniques and rising labor wages. On the other hand, both scenarios will increase farmer income besides saving water. So the government can easily begin placement of scenarios, which it is expected to prevail all areas within three years.

5. Conclusion

A serious cultural problem dominates in the minds and actions of the Egyptian farmers' "culture of abundance of water". They deal with water as if it was inexhaustible resource, are wasteful in irrigation and non-compliant with regulations for the voracious water crops such as rice. Every year Egypt exports thousands tons of rice, and in fact we export water, where it is known that rice crops need much water, even with new varieties that consume less water than older varieties. Egyptian rice production is more than domestic consumption, and we export to countries without the scarcity of water. So the decision to decrease the current rice area gradually will be useful for Egyptian agriculture. It will contribute to a large extent in providing water and increasing other crop areas like corn. The study suggested two scenarios for the current and future rice cultivation areas.

The first scenario depends on redistributing the current area of the rice, where 23% is to cover all saline areas in North Delta (2×10^5 ha) using "improved Mesqa + land leveling + transplanting + hybrid varieties". The other 77% of rice area (666×10^3 ha) uses "improved Mesqa + furrows method + dry rice varieties". This scenario could help to save irrigation water by 43% of the currently applied water. The second scenario depends on the rice area could be reduced by 33×10^4 ha (38%) and cultivate with the high value crops like yellow corn and sesame. In that case the applied water can be reduced by 52% by increasing in the net return by 1 billion LE.

Acknowledgments

The first author would like to present deep gratefulness and appreciation to Japan International Research Center for Agricultural Sciences (JIRCAS) and Benha university (www.bu.edu.eg) for giving him the financial support and the opportunity to fulfill this study through JIRCAS Visiting Research Fellowship Program.

References

Atta, Y.I.M., Meleha, M.E., Tallet, A., Gawish, U.M., 2006. Improving water productivity in rice cultivation with high potential for water saving. In: The 3rd Arab World Region Conference, Cairo, 4–11 December.

Atta, Y.I.M., 2008. Innovative Method for Rice Irrigation With High Potential of Water Saving. ICID Congress, Integrated Water Resources Management – From Concepts to Actions. Lahore, Pakistan.

Badawi, A.T., Ghanem, S.A., 2007. Integrated Water Management in Rice Fields. 4th INWEPF Steering Meeting and Symposium, Bangkok, Thailand.

De Miguel, A., Martínez-Hernández, V., Leal, M., González-Naranjo, V., de Bustamante, I., Lillo, J., Martín, I., Salas, J.J., Palacios-Díaz, M.P., 2013. Short-term effects of reclaimed water irrigation: *Jatropha curcas* L. cultivation. Ecol. Eng. 50, 44–51, http://dx.doi.org/10.1016/j.ecoleng.2012.06.028.

Ebaid, R.A., El-Mowafi, H.F., 2005. Effect of split-applied nitrogen on the productivity of two rice hybrids and Sakha 104 rice cultivar. J. Agric. Res. Tanta Univ. 31 (4), 760–774.

El-Mowafi, H., 2010. Egypt on Top of Global Rice Productivity. http://digital.ahram.org.eg/articles.aspx?Serial=1095486&eid=5764

Fao, 2013. http://faostat.fao.org/site/550/DesktopDefault.aspx?PageID=550#ancor
Gorgy, N., 2007. Performance of hybrid rice cultivars under different planting geometry and number of seedlings per hill. J. Agric. Sci. Mansoura Univ. 32 (1), 117–131.
Hama, T., Nakamura, K., Kawashima, S., Kaneki, R., Mitsuno, T., 2011. Effects of cyclic irrigation on water and nitrogen mass balances in a paddy field. Ecol. Eng. 37, 1563–1566.
Ichino, K., Kasuya, M., 1998. Nitrogen removal in paddy fields: an option for water quality improvement in rivers. Ecol. Eng. 10, 159–164.
Khattak, S.I., Usman, K., Khan, Q., Qayyum, A., 2006. Impact of various planting techniques on yield and yield components of rice. Ind. J. Plant Sci. 5 (1), 753–756.
MALR Agricultural Policy Reform Program, 1998. Assessment of Egypt's Rice Policy and Strategies For water Management. Report No. 6.
MWRI, MALR, 2012, August. Final reports on illegal rice cultivation areas.
Othman, A.Z., El-Agroudy, N.M., Hassan, M.B., Soliman, N.Y., 2011. Current situation and outlook for egyptian rice economics. Aust. J. Basic Appl. Sci. 5 (11), 1934–1941.
RRTC, 1998. The Annual Report of the National Rice Program.
RRTC, 2001, February. The 6th National Rice Program Workshop.
RRTC, 2010. Annual Report. Sakha, Kafr El-Sheikh, Egypt.
Soliman, Saaid, 2010. Dry Rice. http://digital.ahram.org.eg/articles.aspx?Serial=292651&eid=162
USAID, 2011. Integrated Water Resource Management II, High Value/low Water Consumption Crops Introducing to East Delta Farmers. Report 23.
WMRI, 1996. Rice Cultivation Strategy in View of Water Scarcity. Final Report.
Yang, C.-M., 2012. Technologies to improve water management for rice cultivation. Crop Environ. Bioinform. 9.