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Feasibility of some adaptation measures of on-farm irrigation in Egypt under water scarcity conditions

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Abstract. The aim of this investigation is to evaluate some proposed adaptation measures in order to overcome the projected impacts of climate change over on-farm irrigation system in Egypt. Improve irrigation systems efficiencies, change irrigation systems, and deficient irrigation were evaluated by using multi-criteria approach of evaluation. Adaptation measures were studied under current climate conditions and climate change projections of IPCC SRES scenarios for years 2025s, 2050s and 2100s, and evaluated regarding to the change in crop-water demands, change in crop-yield, change in water use efficiency, irrigation-energy requirements and the abetment cost. Improving surface irrigation efficiency was likely had a higher potentiality to overcome the negative impacts of climate change in old land. Deficit irrigation had negative effects on overcoming the impacts of climate change, but it could be acceptable for the conditions that the water saving is more important than crops reduction.

Keywords. Improved surface irrigation – Climate change – Irrigation efficiency – Deficit irrigation – Irrigation energy.

Faisabilité de certaines mesures d'adaptation d'irrigation à la ferme en Égypte en conditions de rareté de l'eau

Résumé. *L'objectif de cette enquête est d'évaluer certaines mesures d'adaptation afin de surmonter les impacts prévus du changement climatique sur le système d'irrigation des sols agricoles en Egypte. L'amélioration des efficiences des systèmes d'irrigation, le changement de ces systèmes et l'irrigation déficitaire ont été évalués en utilisant l'approche d'évaluation à multiples critères. Les mesures d'adaptation ont été étudiées dans les conditions climatiques actuelles et les prévisions du climat d'après les scénarios SRES de l'IPCC pour les décades de 2025, 2050 et 2100, et ont été évaluées en ce qui concerne le changement des demandes en eau des cultures, le changement du rendement des récoltes, le changement de l'efficience de l'utilisation en eau, les exigences en énergie de l'irrigation et le coût de modification des systèmes existants. L'amélioration de l'efficience de l'irrigation de surface a probablement eu une potentialité plus élevée pour surmonter les impacts négatifs des changements climatiques dans les anciennes terres. Le déficit en irrigation a eu des effets négatifs pour surmonter les impacts du changement climatique, mais cela pourrait être acceptable pour les conditions où l'économie de l'eau est plus importante que la réduction des cultures.*

Mots-clés. *Irrigation de surface améliorée – Changement climatique – Efficience de l'irrigation – Déficit d'irrigation – Énergie nécessaire pour l'irrigation.*

I – Introduction

The overall objective of effective on-farm irrigation management is to maximize crop yield per each unit of applied water (Buman *et al.*, 1983). Projected future temperature rises under climate change conditions are likely to reduce the productivity of the major crops, and increase its water requirements thereby directly decreasing crop water use efficiency (Bazzaz and Sombroek, 1996). On the other hand, it will cause a general increase of potential evapotranspiration (ET_o), this will lead to an increase in irrigation demands. Abou Zeid (2002) stated that agriculture water-demand is one of the serious pressures to water sector in Egypt. This is mainly due to several factors: (i) 85% from total available water is consumed in agriculture; (ii) 95% of the cultivated area is under fixed irrigation system; and (iii) most of the on-farm irrigation systems are low efficient irrigation systems coupled with poor irrigation management. The projected global warming and climate change is projected to add more pressures over the Egyptian on-farm irrigation system (Attaher *et al.*, 2006). The high vulnerability of on-farm irrigation system in Egypt is attributed to low irrigation system efficacy and irrigation management patterns (Attaher *et al.*, 2007). Figuring out adaptation strategies for on-farm irrigation system in Egypt, become one of the high national priorities.

Ornat and Morales (2002) stated that selection of adequate irrigation system is considered as a critical issue in agriculture water-use, and based on available water sources size and type, crop type, the society available technology and knowledge level, the existing infrastructure, and the devoted agricultural investment. Moreover, they asserted that using high-efficiency irrigation systems is one of the important adaptation options to reduce water used by agriculture, and switching from conventional irrigation systems to modern irrigation systems is an advisable strategy of the Mediterranean countries to improve water management.

The aim of this investigation is to evaluate some proposed adaptation measures in order to overcome the projected impacts of climate change over on-farm irrigation system in Egypt.

II – Materials and methods

The study focused in evaluating the possible adaptation measures for on-farm irrigation system in old land which is referring to the agricultural system in Nile valley and the Nile Delta region, which characterized by heavy soil construction, traditional agriculture systems, surface irrigation system, poor management efficiency, small size land ownership, low available investments, and long list of environmental pressures at the current and future conditions.

The selection of the adaptation measure was based on experts' judgment and literature reviewing. Improve irrigation systems efficiencies, change irrigation systems and deficient irrigation were the three adaptation measures evaluated by using multi-criteria approach of evaluation. The improvement of surface irrigation system efficiency from 50 to 75% was based on the assumptions of improving surface irrigation design, improving land leveling, using control valves and using gated pipes instead of traditional surface irrigation systems.

Current and future ET_o data sets of the Egyptian governorates were used to determine crop water demands from Attaher *et al.* (2006). Table 1 presents the average increase in ET_o based on air temperature changes implication of IPCC SRES scenarios using HadCM3 climate model. "CropWat" program for Windows (version 4.3) of FAO, was used to calculate water requirements based on FAO modified Penman-Monteith method (Smith, 1992).

Table 1. The precent of the average increase in ET and CO_2 concentration in p.p.m. under A1 and B1 IPCC SRES scenarios for 2025s, 2050s and 2100s under Attaher *et al.* (2006) study conditions

	Current	2025s	2050s	2100s
Average increase in ET_o (%)				
A1	-	3.4	6.6	13.2
B1	-	3.2	5.2	6.0
CO_2 concentration in p.p.m.				
A1	370	433	542	732
B1	370	426	489	532

The change in crops yield due to climate change was determined through crop model simulations by DSSAT (Decision Support System for Agrotechnology Transfer), version. 4.0. The simulation models used for the studied crops experiments were CERES-Maize for maize crop, CROPGRO for tomato crop, and SUBSTOR-Potato for potato. Historical climate data (average of 10 years) from 25 satiation (EMA-CLAC-CAAE), and downscaled temperature data of A1 and B1 scenarios for 2025s, 2050s and 2100s (Attaher *et al.*, 2006) were applied as weather inputs of DSSAT experiments. The implications of IPCC's A1 and B1 scenarios to CO_2 concentrations were used to estimate the concentrations of years 2025s, 2050s and 2100s (Table 1). Adaptation measures were studied under current conditions and climate change worst and best case scenarios for the studied years and evaluated regarding to the change in crop-water demands, crop-yield, water use efficiency (WUE), energy requirements, energy applied efficiency (EAE) and cost analysis. Energy requirements and EAE were determined for the adaptation case studies according to Abdel-Aal (2000). Partial cost analysis was conducted according to Worth and Xin (1983). "Abatement cost", which is the additional cost to the total normal production costs in order to reduce vulnerability of the system of specific production system, was one of the economical measures. Extra-extension cost, extra-labour cost and extra-annual fixed cost were the three components of the abatement cost. The base estimated value of each of these items was referred to the current expanses and prices of extension service, labour requirements for each irrigation system and prices of the initial items of each irrigation system. Accordingly, extra-extension cost represented as 3% of total production cost. The change in labour cost due to the change from traditional surface irrigation system was 75% for improved surface irrigation, 200% for sprinkler irrigation, and 100% for drip irrigation. Extra-annual fixed cost was calculated as the difference between the fixed annual cost of current irrigation system and the improved irrigation system. The total annual cost was the summation of the ordinary cost and the abatement cost.

The results of the adaptation analysis included in this paper are representing the overall average of the studied crops for each evaluation parameter.

III – Results and discussion

Table 2 presents the simulated values of the overall average of evaluation parameters for the studied crops under traditional surface irrigation system with 50% efficiency in old lands (business as usual case). The general trends of total applied water, irrigation energy requirements, irrigation cost and irrigation-unit production cost were increased by temperature increase indicated under climate change scenarios. The observed increases in the previous parameters were coupled with general trends of decrease in crop yield, WUE and EAE.

Table 2. The average of evaluation parameters for the maize, winter and summer tomato, winter and summer potato, cultivated under traditional surface irrigation system with 50% efficiency in old lands, for current and climate change scenarios A1 and B1

Evaluation parameter	Current	A1			B1		
		2025s	2050s	2100s	2025s	2050s	2100s
Total applied water (m^3/fed)	4454	4577	4713	5001	4567	4651	4696
Total crop-yield (kg/fed)	7322	6948	6117	5322	6991	6455	6291
Field-WUE (kg/m^3)	2.0	1.9	1.6	1.4	1.9	1.7	1.7
Irrigation energy (kW·h/fed)	367	377	388	411	376	383	386
Energy applied efficiency (kg/kW·h)	24.7	22.6	19.5	16.3	22.8	20.9	20.3
Total irrigation cost (LE/fed)	789	876	965	1144	876	960	1119
Irrigation-unit production cost (LE/kg)	0.33	0.36	0.41	0.53	0.36	0.40	0.48

The first step in this investigation was the understanding the contribution of the adaptation measures in improving the current traditional system inside the same time step. Table 3 summarized the percentages of change in the evaluation parameters between the traditional surface irrigation system in old land and the adaptation measures under current climate conditions. Switching to drip irrigation system had the best impact on improving crop yield, and it could be strongly recommended as an efficient adaptation measure, under conditions of economical and power resources availability. Improving surface irrigation efficiency from 50 to 75% had the second highest effect in improving crop yield, and the highest effect on WUE, irrigation-energy requirements and EAE. This measure requires abatement cost almost equal to the required abatement cost required for drip irrigation. On the other hand, switching from traditional surface irrigation system to sprinkler irrigation system in old land had the worst effect in all evaluation parameters, especially for energy and economical parameters. El-Hessy and El-Kady (1996) indicated that the sprinkler irrigation of light soils is handled somewhat more efficiently than the heavy soils. Deficit irrigation measures were the best adaptation measures from the economical perception. Moreover these measures had a very good impact in water and energy saving with acceptable values of crop yield reduction (Pereira, 2000).

Table 3. The percent of change in evaluation parameters between the current system and the adaptation measures

Adaptation measures	Percent of change (%)						
	Applied water	Crop-yield	WUE	Energy	EAE	Abatement cost	UPC
I- Improve surface irrigation systems efficiencies from 50 to 75%	-25	+4	+30	-50	+97	38	+161
II- changing irrigation systems							
Surface to sprinkler	-13	-12	-4	142	-66	42	+755
Surface to drip	-23	+8	+27	10	-11	39	447
III- Deficient irrigation							
80% from ETc	-20	-3	+21	-20	+21	3	-3
60% from ETc	-40	-8	+20	-40	+52	3	-8

The contribution of the adaptation measures in mitigating the impact of climate change on the studied on-farm irrigation system is illustrated in Fig. 1. The general trend indicated by the overall average of the studied crops revealed a remarkable positive effect of improving surface irrigation system efficiency from 50 to 75% in reducing the impact of climate change conditions in the evaluation parameters, except the change in crop yield. Switching to drip irrigation system had the highest positive effect on overcome the harmful impact of climate change, and had the second positive effect for the rest of the evaluation parameters. The overall results of switching the traditional surface irrigation to sprinkler irrigation system present the highest contribution in intensifying the impacts of climate change over the evaluation parameters. This unfavourable effect indicated under sprinkler irrigation system, also indicated with applying deficit irrigation measures, but with lower values. Under water scarcity conditions projected under climate change, the Egyptian water annual resources withdraw is projected to face a fluctuation between +33 to -70% (Conway, 2005). Under the case of extreme water scarcity, deficit irrigation could be a key answer for the agriculture sector.

For all studied adaptation measures, the difference between the values of the evaluation parameters under current and future conditions was higher under A1 scenario than the difference indicated under B1 scenario.

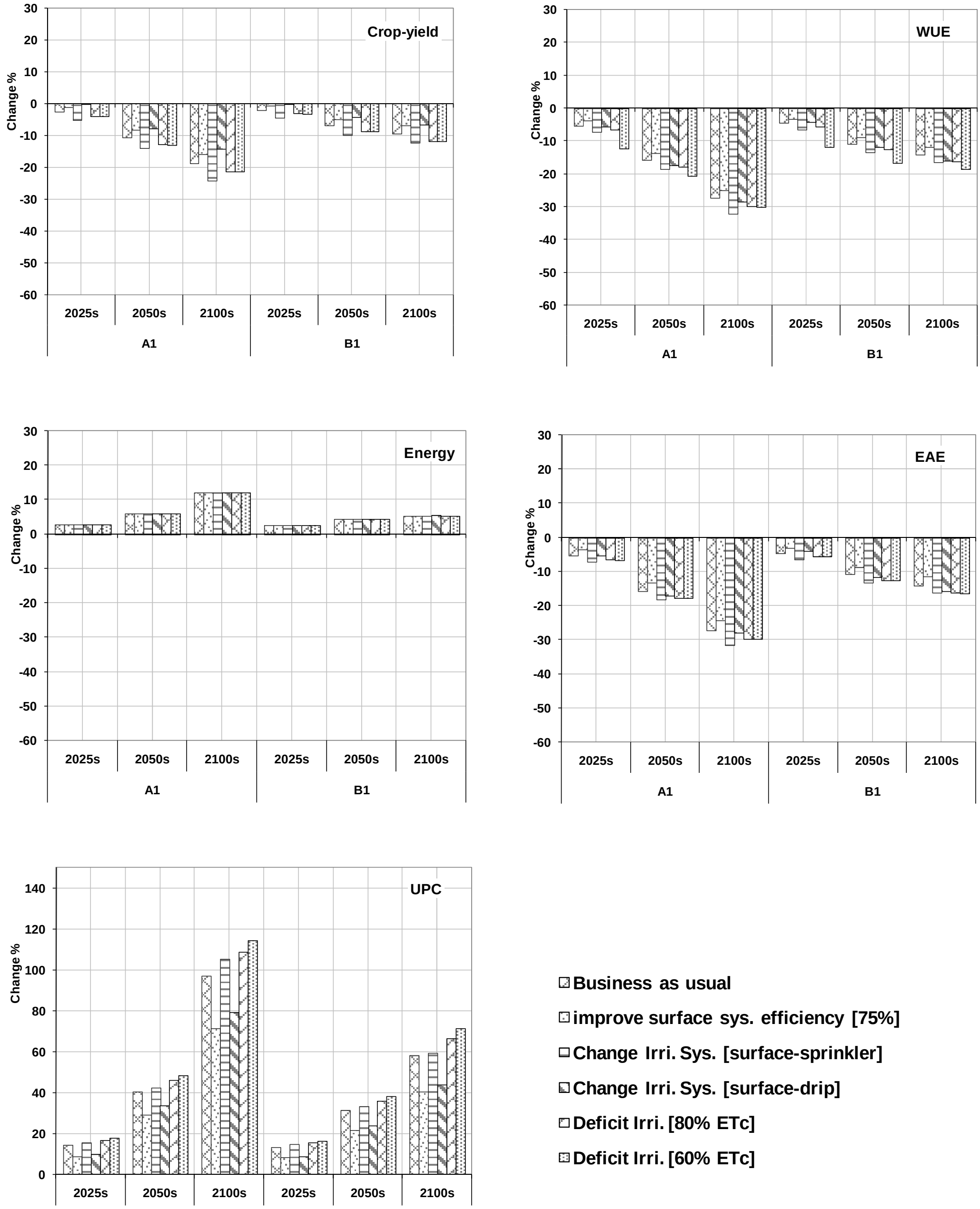

Fig. 1. The impact of climate change under A1 and B1 scenarios, on crop-yield, water use efficiency (WUE), irrigation energy, energy application efficiency (EAE) and unit production cost (UPC) under current traditional irrigation system (business as usual) and the studied adaptation measures (the overall average of the studied crops).

IV – Conclusion

The conclusion of the evaluation of the adaptation measures aims to overcome the projected impacts of climate change over on-farm irrigation system in Egypt, could be summarized in the following points:

(i) Improving surface irrigation efficiency was likely had a higher potentiality to overcome the negative impacts of climate change over on-farm irrigation system in old land. Whereas, this measure could be acceptable when power and economical resources are available and the reduction in the crop-yield is not favourable.

(ii) Although deficit irrigation measures had negative effects on overcoming the impacts of climate change on crop yield, these measures could be acceptable for application under the conditions that the water saving is more important than crops reduction.

(iii) Applying improved surface irrigation and deficit irrigation measures require limited structural modifications in the engineering design of the system, therefore it requires small economical resources.

(iv) Power consumption is projected to be critical issue under the projected changes in climate, even for agriculture sector; therefore low-power requirements irrigation systems could be better selections in the future.

(v) Using different combinations between different levels of improved surface irrigation system efficiencies and applying deficit irrigation could improve the capacity of surface irrigation system in old land to overcome the negative impacts of climate change.

(vi) The current adaptation analysis did not consider the long term reliability of the adaptation measures, the socioeconomic capacity for accepting the adaption measures, political considerations, and limitations associated to other systems and sectors.

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