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Optimization of the cropping pattern in Northern and Southern part of the Jordan Valley under drought conditions and limited water availability

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Abstract. Achieving balance between water demand and supply is crucial for sustainable agriculture in semi-arid countries. Many agronomic options and socio-economic measures can be applied to reduce water demand in agriculture sector without compromising its performance. This work investigated some specific management options for the improvement of the performances of the irrigated agricultural systems in Northern and Southern parts of the Jordan Valley under normal and dry year's conditions. An economic model was developed, calibrated and applied to evaluate farmer's income, water supply/demand balance and economic water productivity under different policy and water management scenarios. The overall results indicated that water productivity was lower in Southern than in Northern part of the Valley and that the improvement of the irrigated agriculture performance in the region can be achieved through the modification of cropping pattern (cultivating date palms and tomatoes instead of banana in the South) and the introduction of regulated deficit irrigation (for citrus in the North and for barley in the South).

Keywords. Jordan Valley – Water management – Drought – Deficit irrigation – Optimization model – Cropping pattern – Water productivity.

Optimisation du système de culture dans le nord et la partie méridionale de la vallée du Jourdain en conditions de sécheresse et avec disponibilité en eau limitée

Résumé. *Atteindre l'équilibre entre l'offre et la demande en eau est crucial pour l'agriculture durable dans les pays semi-arides. De nombreuses options agronomiques et socio-économiques peuvent être appliquées pour réduire la demande en eau dans le secteur de l'agriculture sans compromettre ses performances. Ce travail a enquêté sur certaines options de gestion spécifiques pour l'amélioration des performances des systèmes d'irrigation agricole dans les parties nord et sud de la vallée du Jourdain, dans des conditions d'années normales et d'années sèches. Un modèle économique a été élaboré, calibré et appliqué pour évaluer les revenus des exploitants, l'approvisionnement en eau et la demande et la productivité économique de l'eau au titre des différentes politiques et des scénarios de gestion de l'eau. Les résultats globaux indiquent que la productivité de l'eau était plus faible dans le sud que dans la partie nord de la vallée et que l'amélioration des performances de l'agriculture irriguée dans la région ne peut être atteinte par la modification du mode de culture (culture des dattiers et des tomates au lieu de la banane dans le Sud) et l'introduction de l'irrigation déficitaire réglementée (pour les agrumes dans le nord et pour l'orge dans le sud).*

Mots-clés. *Vallée du Jourdain – Gestion de l'eau – Sécheresse – Irrigation déficitaire – Modèle d'optimisation – Distribution des cultures – Productivité de l'eau.*

I – Introduction

Water scarcity and the misuse of land and water resources are serious problems in most of arid and semi-arid countries of the Mediterranean which varies from country to country (Hamdy, 2007). Jordan suffers water shortage more than any other country of the Middle East due to extremely unfavourable climatic conditions characterized by low precipitation and high evapotranspiration demand (Shatanawi, 2007). The situation is particularly complex in Jordan Valley (JV) which is of strategic importance for the country and represents essential area for agricultural production and economic development. About 70% of Jordan's total production of fruits and vegetables comes from Valley but the level of production is affected by water availability. The annual available water resource varies from less than 200 MCM in dry years to about 300 MCM in wet yeas. The occurrence of drought years has become more frequent in for almost three decades such as the years of 1999, 2000, 2005, 2006 and 2007 where winter rainfall was not enough to fill the dams and recharge the aquifers. The drought was consecutives more than once which forced the authority to impose restrictions on water for agriculture in the Jordan. Farmers are forced to reduce their demands and stopped the cultivation of summer vegetables to save scarce water for trees. Under such condition, the optimal control and allocation of water resources between different areas and among different crops have become an important question under limited water conditions. Considering these conditions, this research was initiated with the objective of improving agricultural production in the JV through a more efficient and sustainable use of land and water resources.

II – Materials and methods

1. Experimental site and climatic data analysis

This study focused on two areas in the Jordan Valley; the Northern Part (NP) which is extended from the Yarmouk River to the village of Kreymeh, at 212 m below sea level and Southern Part (SP) which is extended from the village of Muaddi to the north of Dead Sea at 400 m below sea level. The NP has semi arid climate, with the annual rainfall of 258 and 398.5 mm in dry year (2005) and wet year (2003), respectively. The maximum temperature is 39.2℃ and minimum temperature is 5.8℃. T he average relative humidity is 84% in winter and 28% in summer. The soil is fine clay-loam of high water holding capacity and low salinity. A typical farm of 9 hectares was selected for analysis. The cropping pattern in this farm is 3 ha of citrus, 3 ha of barley, and 3 ha planted with tomatoes, zucchini and pepper.

The SP has an arid to severe arid climate, with the annual rainfall of 129.5 for dry year mm and 180.6 mm for wet year. The maximum and minimum temperatures are 40.3 and 12.1℃, respectively. The average relative humidity is 73% in winter and 26% in summer. The soil is coarse loamy characterized with low water holding capacity and high salinity. A typical farm of 11 hectares was selected for analysis cultivated with barley, banana, date palm, eggplant, zucchini and tomato, respectively.

Climatic data for a period of 6 years was collected from two meteorological stations (Wadi al-Yabis in NP and Karamah in SP). The water resources for two study area comes from King Abdullah Canal (KAC). Water is distributed by the Jordan Valley Authority according to the crops cultivated in farm and on a monthly basis so the water availability. Data concerning soil and climatic as well as the structural and economic aspects of the farming system has also been collected.

2. Crop response to water curves generation

A software model [based on FAO 56 (FAO, 1988)] was developed for the simulation of soil water balance, estimation of crop water requirements and the creation of "crop response to water" curves (Todorovic, 2006) for different irrigation strategies and estimation of corresponding yield. Whenever possible, the outputs of the model regarding the irrigation requirements and production are checked with the field information before being used for the optimization purposes.

Deficit irrigation (DI) strategies deliberately allow crops to sustain some degree of water deficit and sometimes, some yield reduction with a significant reduction of irrigation water. The main strategy is classic deficit irrigation (DI) and the other two main DI strategies based on the physiological knowledge of crops response to water stress are regulated deficit irrigation (RDI) and partial rootzone drying (PRD) (Costa *et al.*, 2007). With regulated deficit irrigation water application is manipulated over time whereas, with partial rootzone drying irrigation, water is manipulated over space. DI strategies have emerged as potential ways to increase water savings in agriculture by allowing crops to withstand mild water stress with no or only marginal decreases of yield and quality (Costa *et al.*, 2007).

The relative yield, crop evapotranspiration (ET_c) and net irrigation requirement (NIR) are estimated for different levels of DI (10, 20, 30, 40 and 60%) and under rainfed conditions in order to draw the "crop response to water" curve for both relative ET_C and NIR. Then, it was possible to choose the suitable deficit level and to use it in the optimization model.

The variables for NP are: T0 – rainfed cultivation only for barley; T1 – full drip irrigation; T2 – slight DI fixing water supply to 0.8 for tomato, zucchini, pepper and citrus and to 0.7 for barley; T3 – moderate DI fixing water supply to 0.7 for tomato, zucchini, pepper and citrus and to 0.6 for barley; and T4 – regulated deficit drip irrigation considering the monthly water availability/supply, surface area covered by each crop and specific crop sensitivity to water stress for citrus, vegetables and barley.

The variables for the SP are: T1 – full surface irrigation only for barley; T2 – full drip irrigation; T3 – slight to moderate deficit surface irrigation fixing water supply to 0.7 for barley; T4 – slight to moderate deficit drip irrigation fixing water supply to 0.8 for palm, 0.6 for vegetables and to 0.9 for banana; T5 – moderate to severe deficit surface irrigation fixing water supply to 0.4 for barley; T6 – moderate deficit drip irrigation fixing water supply to 0.6 for palm and to 0.8 for banana; and T7 – regulated deficit surface irrigation considering the monthly water availability/supply and specific crop sensitivity to water stress for barley (stopping irrigation in April).

3. Building and calibration of optimization model

The optimization models attempt to find a suitable combination, out of many feasible combinations of resources and their allocations, which maximizes a benefit or minimizes a cost subject to given constraints expressed through simple linear algebraic expression or equations (Valunjkar, 2007). They use data on available land, water requirements per unit land area for different crops, and net revenue per unit of land area generated by the growing of those crops. The model takes prices or quantity allocations for water and generates a cropping pattern which maximizes agricultural income. The model used to be a non-linear single-year static mathematical programming model designed with GAMS language (General Algebraic Modelling System) and named JV-2008. The main constraints are related to the available land for each crop, the availability of the water for farm and existing rotations between different crops.

Many runs of the model were done using the data of a rainy year (and well water supply) in order to match the actual data (cropping pattern) observed in the fields. The mean absolute error (MAE) (Anderson and Woessner, 1992) is used to measure how close forecasts or solutions of the cropping pattern are to the actual situation. JV-2008 model has been calibrated using the MAE measure. It is calculated by the weighted average of the absolute errors, where the weights are the percentages of the land occupied by each crop. The result for MAE indicates that MAE for the JV-2008 model used is around 2.7, which represents a very good estimate. The optimisation model was built and calibrated using both agronomic and economic parameters derived from collected field data and from the Excel-based simulation tool.

4. Building and evaluation of the scenarios

The result of NIR and average yield from the agronomic model (coming from statistics and field experiments) for different crops according to the possible crop-irrigation technique combinations for NP and SP in wet and dry years were entered in the economic model together with the economic inputs. Different scenarios regarding agronomic practices of different water supply and climatic conditions have been defined and simulated in order to evaluate the farmers' decisions. For each area under study, 19 different scenarios were simulated by the model in order to reconstruct farmers' behaviour and try to improve and optimize water management.

The baseline scenario was adopted for 2003, a relatively rainy year in which programmed water supply can be guaranteed for the cropping pattern that resembles real conditions in the areas under study. There is no adjustment of irrigation scheduling and a regular irrigation scheme is adopted. Then, the scenarios regarding different water availability, irrigation management practices and cropping pattern variability limitations are elaborated for a dry year (2005) and grouped as indicated for NP and SP. Group A: refers to water supply according to the programmed availability for a year without restrictions, while group B and group C refers to limited water supply during the summer season (April-October) by 15% and by 30%, respectively. The groups A, B and C refer to water management practices and fixed water reduction during the whole growing season are taken into consideration. Nevertheless, the group A', B' and C' specified that more severe and crop-specific regulated deficit irrigation practices were applied considering not only the crop tolerance to water stress during the growing stages but also the availability/supply of water on a monthly basis.

Each group of scenarios according to different water availability comprehends 3 scenarios regarding to cropping pattern limitations as following:

(i) Scenarios 1, 4 and 7 refer to fixed cropping pattern obtained in 2003 in order to analyze the impact of management (techniques/deficit irrigation) under those conditions.

(ii) Scenarios 2, 5 and 8 refer to fixed cropping area for permanent crops (citrus in NP, and date palm and banana trees in SP) in order to understand what could be the acceptable cropping pattern for the rest of area and how the cropping area between date palm and banana tress could change.

(iii) Scenarios 3, 6 and 9 refer to a completely free distribution of crops over the study area in order to identify the most profitable cropping pattern under specific water availability and management practices independently of real/(initial) conditions as defined in the baseline scenario.

III – Results and discussion

1. Crop water requirement (CWR) and net irrigation requirement (NIR)

CWR and NIR are estimated on a daily basis and the overall results over the whole season (mm/season) and for both years (2003 and 2005) are given in Tables 1 and 2 for the crops cultivated in NP and SP of Valley, respectively.

In both areas under study, CWR does not differ substantially between a rainy and a dry year confirming that the weather difference is mainly in precipitation while other parameters (e.g. temperature) do not change significantly. In the NP of the Valley, NIR increases in a dry year are the lowest for perennial crops (citrus, 31 mm), then for vegetables (pepper 36 mm, zucchini 67 mm, tomato 70 mm), while the greatest variation was observed for barley (106 mm). In the SP, there is no significant difference in CWR and NIR in two year under study due to generally very low precipitation and stable arid conditions. In the South, for vegetables grown in autumn-winter season, both CWR and NIR were slightly greater in rainy than in dry year due to the fact that precipitation in dry year was concentrated mainly during the winter season. The greatest NIR was estimated for banana and it was 4-5 times greater than for vegetables and for almost 50% higher than for date palms.

Table 1. CWR and NIR estimated for NP of Jordan Valley

Crop	Growing season	Rainy year		Dry year	
		CWR (mm)	NIR (mm)	CWR (mm)	NIR (mm)
Tomato	Feb-June	593.2	444	609.6	514
Pepper	Mar-June	561.3	488	573.0	524
Citrus	Jan-Dec	1009.1	763	1011.9	815
Zucchini	Feb-May	308.6	168	318.5	235
Barley	Nov-June	584.4	264	585.8	370

Table 2. CWR and NIR estimated for SP of Jordan Valley

Crop	Growing season	Rainy year		Dry year	
		CWR (mm)	NIR (mm)	CWR (mm)	NIR (mm)
Tomato	Oct-Mar	353.7	236	334.4	223
Eggplant	Sept-Jan	329.5	247	310.7	239
Date palm	Mar-Feb	1392.1	1195	1414	1196
Banana	Mar-Feb	1741.2	1628	1768.3	1638
Barley	Nov-June	630.5	389	638.5	396
Zucchini	Oct-Feb	212.4	126	197.2	118

2. Crop response to water curves

Analysing crop responses to different supply strategies, it was possible to develop the relationship between the relative evapotranspiration and the relative yield loss (RYL = $1-Y_a/Y_m$, with Y_a = actual yield and Y_m = potential yield) for different irrigation depths. The "Crop Response to Water" curves were developed initially for relative crop evapotranspiration and then after they are converted into yield losses with respect to NIR in order to quantify the effects of effective irrigation reduction and water stress on yield. Thus, formulation of the crop production function was sought for management of yield under conditions of deficit irrigation in respect to effective reduction of irrigation. For all crops under study, the relative yield and NIR were estimated for different levels of deficit irrigation (10, 20, 30, 40, 60, and 0%) in order to present graphically the relationships between relative yields with NIR and to choose the suitable deficit point without distinct effects on yield. Tables 3 and 4 show the levels of deficit irrigation applied for different crops in the Valley together with corresponding yield reduction.

It is important to underline that this yield reduction is strongly related to the precipitation pattern for the year under study and, accordingly, it has different impact on specific crops in the Valley. Therefore, it will be necessary to redo the calculations when the same approach has to be applied for some other years and climatic conditions.

Table 3. The data obtained from "Crop Response to Water" curves for each crop for NP in rainy (2003) and dry (2005) year

Crop	Rainy		Dry					
	Water reduction (%)	Yield reduction (%) T2	Water reduction (%)			Yield r eduction (%)		
			T2	T3	T4	T2	T3	T4
Citrus	20	12.83	30	20	11.00	23.92	14.88	7.2
Barley	40	8.89	40	30	65.95	15.37	10.03	27.8
Tomato	20	7.71	30	20	22.54	17.07	9.77	11.2
Zucchini	30	6.48	30	20	23.74	13.23	7.02	9.5
Pepper	20	12.82	30	20	23.15	22.86	13.95	16.7

Table 4. The data obtained from "Crop Response to Water" Curves for each crop for SP in rainy (2003) and dry (2005) year

Crop	Rainy		Dry					
	Water reduction %	Yield reduction % T3, T4	Water reduction %			Yield reduction %		
			T3, T4	T5, T6	T7	T3, T4	T5, T6	T7
Banana	10	10.04	10	20		10.12	21.81	
Date palm	20	11.25	20	40		11.31	24.22	
Eggplant	40	17.55	40			13.65		
Tomato	40	13.95	40			12.96		
Zucchini	40	10.64	40			9.04		
Barley	30	10.89	30	60	45	10.25	26.26	15.53

3. The results of the economic model

The baseline scenario was used for calibration of model's parameters aiming to achieve the best possible fitting between the cropping pattern obtained through the simulation and the real on-field observed cropping pattern. Then, in all other scenarios, all the input parameter were fixed in JV-2008 model except for the NIR for crops and water availability, in order to see the differences in cropping pattern, water use per month between a normal (rainy) year and dry year and profit.

A. Northern part

For cropping pattern in actual water supply, we observed increases in citrus in free distribution of cropping pattern instead of barley and pepper, while in 30% water reduction citrus remains stable and 50% of area is cultivated with rainfed barley. The highest profit is obtained in actual water supply with free distribution of cropping pattern and the lowest profit is observed in 30% reduction in water supply. Water productivity is stable for all scenarios however the highest water productivity is obtained by 30% reduction in water supply together with a free distribution of cropping pattern. If scenarios are infeasible that means the model can not give the solution without additional water deficit techniques because the water supply is lower than demand.

B. Southern part

For cropping pattern in actual water supply, date palm and tomatoes increase and banana and eggplant decrease. Under 30% water reduction, banana disappeared and date palm increased while eggplant decreased. Almost all scenarios are becoming infeasible without additional water deficit techniques and cultivation is possible with free distribution of cropping pattern. Therefore, the use additional deficit techniques becomes feasible. The highest profit is observed in actual water supply with free distribution of cropping pattern, and the lowest profit is observed in 30% reduction in water supply. Water productivity is quite different between scenarios, that means the water productivity changes are possible after modification in cropping pattern.

IV – Conclusion

The methodological approach combining agronomic and economic models, made it possible to manage and optimize irrigation water use considering climatic, soil, socio-economic and environmental constraints. It has, therefore, enabled the analysis of crop productivity under different water inputs and soil and climatic conditions.

The estimations of CWR demonstrated that in both areas under study (NP and SP of Jordan Valley), CWR do not differ substantially between a rainy and a dry year confirming that the weather difference is mainly in precipitation while other parameters (e.g. temperature) do not change significantly. In the Northern Part, the increase of NIR in a dry year is the lowest for perennial crops and vegetables than for barley confirming that most of precipitation occurred during the winter months. In a dry year, NIR ranges between 235 mm for zucchini and 815 mm for citrus. With the introduction of DI, the greatest water savings in terms of NIR are foreseen for citrus (247 mm under moderate DI) and for barley (244 mm under RDI) then after for tomatoes and peppers (about 100 mm) and for zucchini (about 50 mm). In the Southern Part, there is no significant difference in CWR and NIR in two years under study due to small difference in precipitation between dry and wet year. The NIR of vegetables are higher in NP than in SP of Valley, which is explained by the fact that vegetables in NP are cultivated in the summer season while in the SP they are grown during the autumn-winter season. The greatest NIR was observed for banana (more than 1600 mm) and it is almost 50% greater than for date palm and 4-5 times greater than for vegetables. Moderate deficit irrigation can contribute to water saving that could reach for date palm 478 mm and for banana 328 mm, while for barley is possible to save 180 mm ending the irrigation in April. Potential water saving in terms of NIR for vegetables is much lower, about 90 mm for tomatoes and eggplants and 50 mm for zucchini.

In NP, the cropping pattern optimization favours the citrus cultivation instead of barley and vegetables (peppers) under actual water supply, while suggest barley under rainfed as a solution in dry years. Date palm and tomatoes cultivation are favoured in the SP instead of bananas. Nevertheless, bananas are widely cultivated in the area and the substitution of bananas by some other crop could be a long term process with evident social implication and necessity for subsidies.

In general, the results of this work indicate several important points: (i) profit increases – with increased freedom to design/optimize cropping pattern; with greater water availability (i.e. when there is no water reduction); and with the introduction of new/additional deficit irrigation techniques; and (ii) water use increases – with increased freedom to design/optimize cropping pattern (except for the South in the case of actual water supply); and with the introduction of new deficit irrigation techniques (especially in the South). When additional deficit irrigation techniques are introduced, farm profit increases together with increase in total water use – a socio-economic implication. Second, more land is cultivated that on the contrary could be abandoned – an environmental implication. Also, the negative impact of reduction in available water is reduced – a socio-economic and environmental implication.

References

Anderson M.P. and Woessner W.W., 1992. *Applied Groundwater Modeling*. San Diego, CA: Academic Press, Inc.

Costa J.M., Ortuno M.F. and Chaves M.M., 2007. Deficit irrigation as a strategy to save water: Physiology and potential application to horticulture. In: *Journal of Integrative Plant Biology*, 49(10), p. 1421-1434.
FAO, 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. In: Allen R.G., Pereira L.S., Raes D. and Smith M. (eds). *Irrigation and Drainage*, Paper 56. Rome: FAO, p. 300.
Hamdy A., 2007. Water use efficiency in irrigated agriculture: An analytical review. In: Lamaddalena N., Shatanawi M., Todorovic M., Bogliotti C. and Albrizio R. (eds). Water Use Efficiency and Water Productivity. Proceedings of 4th WASAMED Workshop, Amman (Jordan), 30 September-4 October 2005. *Options Méditerranéennes*, Series B, no. 57, p. 9-19.
JVA – Jordan Valley Authority, 2004. Report on water availability and use in Jordan Valley.
Shatanawi M.R., 2007. Future options and research needs of water uses for sustainable agriculture. In: Lamaddalena N., Shatanawi M., Todorovic M., Bogliotti C. and Albrizio R. (eds). Water Use Efficiency and Water Productivity. Proceedings of 4th WASAMED Workshop, Amman, Jordan, September 30 – October 4 2005. *Options Méditerranéennes*, Series B, no. 57, p. 21-29.
Todorovic M., 2006. An Excel-based tool for real time irrigation management at field scale. In: *Proceedings of International Symposium on "Water and Land Management for Sustainable Irrigated Agriculture"*, Adana (Turkey), 4-8 April 2006.
Valunjkar S.S., 2007. Optimization of water resources for cropping pattern under sustainable conditions through fuzzy logic system. In: Third International Conference on Sustainable Development and Planning in Algarve, Portugal.