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Water allocation strategies under drought and specific socio-economic and environmental conditions in the Central Jordan Valley

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Abstract. This work aims at analyzing different management practices for the improvement of the agricultural production in the Central Jordan Valley. The optimization of the cropping pattern has been done under different water scarcity and drought conditions and prevailing environmental and socio-economic constraints. The ISAREG model was used to estimate crop water requirements, net irrigation requirements and to develop the crop response to water curves under open field and greenhouse conditions, taking into account actual soil and water salinity level. A socio-economic model was developed in order to optimize the cropping pattern and to evaluate water productivity, land use and farmer's profit under different water availability and water prices scenarios. The overall results indicated that the reduction of water availability is the most limiting factor of the agricultural production in the region which might lead to the reduction of the cultivated land and profits. However, water productivity is not affected significantly neither by the restrictions of water supply not by the increase of water tariffs. The cultivation of less water demanding and salt tolerant vegetables, especially under greenhouse conditions, as well as the application of deficit irrigation practices are recommended to adapt to drought situations.

Keywords. Central Jordan Valley – ISAREG model – Irrigation requirements – Crop response to water curves – Salinity – Open field – Greenhouse – Mathematical socio-economic model – Water productivity – Water availability – Water tariffs.

Stratégies d'allocation de l'eau sous des conditions de pénurie et des conditions socio-économiques et environnementales spécifiques dans la Vallée Centrale du Jourdain

Résumé. *Ce travail vise à analyser les différentes pratiques de gestion pour l'amélioration de la production agricole dans la vallée centrale du Jourdain. L'assolement a été optimisé sous des conditions différentes de disponibilité d'eau d'irrigation et de précipitations, en tenant compte des contraintes socio-économiques et environnementales. Le modèle ISAREG a été utilisé pour estimer les besoins en eau des cultures, les besoins nets d'irrigation et pour produire les fonctions de réponse à l'eau en plein champ, dans des serres, en prenant en compte les conditions du sol et les niveaux de salinité de l'eau. Un modèle socio-économique a été développé pour optimiser l'assolement et pour évaluer la productivité de l'eau, l'utilisation de la terre et le revenu des agriculteurs sous différents scénarios de disponibilité et de prix de l'eau. Les résultats montrent globalement que la réduction de la disponibilité d'eau est le facteur le plus important pour la production agricole de la région, pouvant mener à une réduction de la surface cultivée et du revenu des agriculteurs. Par contre, la productivité de l'eau n'est pas affectée sensiblement par la restriction de la disponibilité d'eau ni par l'augmentation du prix de l'eau. Il apparaît recommandable de privilégier les cultures qui demandent moins d'eau et qui sont plus tolérantes à la salinité, surtout pour les cultures sous serre. L'irrigation complémentaire est aussi la mieux adaptée aux conditions de sécheresse.*

Mots-clés. *Vallée Centrale du Jourdain – Modèle ISAREG – Besoins d'irrigation – Fonctions de réponse à l'eau – Salinité – Plein champ – Serre – Modèle socio-économique mathématique – Productivité de l'eau – Disponibilité en eau – Tarifs de l'eau.*

I – Introduction

Water scarcity and fragility, unequal distribution in space and time and mismanagement of water resources are the main serious problems in most of arid and semi-arid countries of the Mediterranean. Agriculture sector is vital in most of the countries since almost 70% of the total available freshwater is used for that sector (EEA, 2003). Jordan is one of the world's countries that suffer from limited water resources where water supply is inadequate to meet water demand. Water in Jordan is considered not only the main factor of production but also a very crucial factor for survival and social development. The situation is particularly complex in Jordan valley that is of strategic importance for the country and represents essential area for agricultural production and economical development (Shatanawi, 2002).

The central part of Jordan valley is characterized by the extensive agricultural practices under open field and greenhouse conditions, limited water availability, low water tariffs and use of treated waste water for irrigation (JVA, 2004). For this reason most of agricultural land is affected by salinity problems that posed additional limits of agricultural development. In this region, the optimal control and allocation of water resources between different areas and water sectors have been important question for many years and especially for agriculture. Previous studies (Al-Weshah, 2000; Doppler *et al*., 2001; Shatanawi, 2002; Molle *et al*., 2008; Rawabdeh, 2008) indicated that water shortage is a serious problem in Jordan valley and an integrated approach should be applied to manage and optimize irrigation water use. This means the consideration of all parameters affecting the efficiency of agricultural production and including technical climatic, soil, socio-economic and environmental constrains. Accordingly, this work aims at the improvement of agricultural production in the central Jordan Valley by means of a more efficient land and water use optimizing the cropping pattern under limited water supply and existing environmental and socio-economic constraints.

II – Materials and methods

The overall methodology adopted in this study consists of the following main steps: data collection for both open field and greenhouse conditions, estimation of water requirements for the actual cropping pattern and generation of crop response to water curves under different soil and water salinity, set up of an optimization model for the evaluation of farmers' income, water demand and water productivity under different management scenarios.

1. Site description and data collection

Jordan Valley region is divided into three sub-region; Northern, Central and Southern Jordan Valley. The study focuses on the central part of Jordan Valley. Central Jordan Valley exhibits some variation in cropping pattern although this division between three sub-regions is based on micro climate conditions. Central Jordan Valley is irrigated with reclaimed water from King Talal Dam (KTD). Water of KTD is a mixture of reclaimed waste water from Khirbet es-Samra treatment plan and flood water of Zarqa basin, and it is characterized relatively by high salinity.

The average annual air temperature of study area is 25°C, whereas maximum and minimum air temperatures are 31°C and 19°C, respectively. The average relative humidity goes from 27 to 70%. The average annual wind speed is about 1.8 m/s while precipitation reaches 250-350 mm/years and it occurs almost completely during the winter season. Previous researches, done by NCARE (Agricultural Research Center), indicate that the maximum air temperature under confined agriculture is greater by 8°C for the all months except in December and January when the air temperature is 12°C greater with in respect to non confined agriculture and the average relative humidity is higher by 20% with incoming solar radiation of 76% of the incoming solar radiation under non confined agriculture (Mazahraih *et al.*, 2002).

The reference evapotranspiration was estimated under greenhouse condition using the above parameters in the Penman-Monteith equation, and the results have shown that ETo under greenhouse condition was in average about 71% of ETo under open field condition.

Two types of agricultural practices are present in the Central Jordan Valley: (i) open field (non confined) planted mainly by tomatoes, eggplant, zucchini, potatoes, beans, onion and cucumber irrigated by drip irrigation method using full irrigation technique or deficit irrigation technique; and (ii) greenhouse conditions (confined) mainly planted by tomatoes, cucumber, hot pepper and beans irrigated by drip irrigation method using both techniques full and deficit under a clay loamy soil with an effective depth of 150 cm and a salinity range between 2 and 2.4 dS/m.

The crop parameters, used in the study for open field conditions, were taken from the FAO database (Allen *et al.*, 1998) and checked up and adjusted during the field survey in June 2009. The crop parameters, used for greenhouse conditions, were collected during the field survey and direct contacts with local farmers and managers. The collected data for both open field and greenhouse conditions include the following parameters for each crop:

(i) Duration of four main crop growth stages (initial, development, mid and late season).

(ii) Root depth growth (initial and maximum) and maximum crop height.

(iii) Crop coefficient (Kc) values depending on the crop growth stages.

(iv) Yield reduction coefficient (Ky).

(v) Depletion fraction threshold (p) for optimum yield (OYT).

2. ISAREG model for agronomic parameters

The computation of crop water requirements (CWR), irrigation scheduling and the creation of crop response to water curves for the actual cropping pattern in the Central Jordan Valley was performed using the ISAREG model (Pereira *et al.*, 2003). The model computes crop evapotranspiration (ETc) and generates irrigation scheduling using the methodology proposed by Allen *et al.* (1998). The actual crop evapotranspiration (ETa) is lower than ETc when the soil water depletion exceeds the depletion fraction for no stress (p). ETa is estimated through the soil water balance as a function of the available soil water in the root zone as described by Teixeira and Pereira (1992), and depletion is limited to the management allowed depletion (MAD). When water stress is not admitted, then MAD ≤ p is adopted; when deficit irrigation is applied then MAD > p. The crop coefficients (Kc) and depletion fractions for no stress (p) were obtained from the calibration studies (Eholpankulov *et al.*, 2008). Different scenarios simulating soil and water salinity have been done using ISAREG to compute crop water requirements under different soil salinity, water salinity, irrigation techniques and management under both conditions open field and greenhouse.

3. Description of optimization model

A non linear static mathematical programming model, written by GAMS language, was used with in an objective function to maximize the expected annual income by trying to minimize its variability by selecting the optimal cropping pattern under different constrains (land, water and crop rotation), water restriction and salinity condition.

A. Model calibration

Several runs have been done to calibrate the model in order to get the realistic results as compared to the actual situation. The model has been calibrated using the PAD measure. It is calculated as the average (over crops) absolute deviation between the model results and the data, divided by the average actual value (Hazell and Norton, 1986). The result for PAD in our study case is around 3%, which represents a very good result.

B. Scenarios simulation

Different scenarios simulations have been done in order to reconstruct farmers' behavior and try to improve and optimize water management under some possible future constraints. Two essential scenarios were applied, the first one by increasing water tariff 5 times more than the actual tariff and the second one by restricting the water availability to 50% of the actual water supply. These scenarios have been selected since they resemble the actual situation in the study area that is characterized by very low water tariffs and high water scarcity. Both scenarios have been analyzed and then after together in order to evaluate their combined impact.

III – Results and discussion

1. Estimation of CWR under different salinity condition

Different water and soil salinity scenarios have been considered in order to estimate irrigation water requirements using ISAREG model. Irrigation water salinity has been progressively increasing and it has reached actually about 2.0 dS/m that, together with predominant soil salinity of 2.4 dS/m, represent a serious obstacle for agricultural production in the study area. Tables 1 and 2 show the irrigation requirements respectively for open field and greenhouse conditions considering the actual water salinity (2 dS/m) and soil salinity levels (2.4 dS/m).

Table 1. Seasonal irrigation requirements of crops cultivated under open field conditions

Crop	Tomatoes	Citrus	Zucchini	Eggplant	Beans	Potatoes	Cucumber
Irrigation depth (mm)	777	1193	259	204	314	323	224

Table 2. Seasonal irrigation requirements of crops cultivated under greenhouse conditions

Crop	Tomatoes	Cucumber	Beans	Hot pepper
Irrigation depth (mm)	294	249	278	190

The results of estimation indicate that the crops, cultivated under greenhouse conditions, have lower ETc and irrigation requirements than the same crops under open field conditions. This can be explained by different growing seasons and weather conditions, different Kc values and longer growing cycle under open field conditions in respect to greenhouse conditions. The greatest irrigation water requirements were for tomato, as an annual crop, due to its sensitivity to salinity and for citrus, as a permanent crop. Under open field conditions, the lowest irrigation requirements (IR) were observed for typical autumn-winter crops, as they are eggplant and cucumber, whereas under greenhouse conditions the lowest IR was calculated for hot pepper.

2. Result of economic model

A. Scenarios resulting from limited water supply

The scenarios were simulated by reducing water supply by 10% each time until the amount of applied water reaches the half of the actually available water (WA), in order to study the farmer's behavior in optimizing cropping pattern. Table 3 shows the cultivated area under open field and greenhouses, profit and water productivity under different level of water deficit conditions.

The total cultivated area was decreased almost two times, from about 8500 to 4800 ha, when water availability was reduced by 50%. This means that water reduction could penalize the agricultural production in the study area leading to the abandonment of land rather than the application of non intensive management practices. Hence, the benefits from the cultivation become relevant only when optimal or close to optimal management practices can be applied. These findings are supported also by the results of some other studies (Doppler *et al.*, 2001; Rawabdeh, 2008).

Table 3. Cultivated area, profit and water productivity under different water restriction (1JD = 1€)

Scenarios	WA 100%	WA 90%	WA 80%	WA 70%	WA 60%	WA 50%
Open field area (ha)	5854	5777.3	5487.8	5062.2	4589.9	3625.1
Greenhouse area (ha)	2674.4	2751.1	2533	2103.8	1703.5	1074.7
Profit (JD/du)	578	560	520	476	430	352
Water productivity (m^3/JD)	1.85	1.83	1.81	1.82	1.82	1.83

B. Scenarios regarding the increase of water tariffs

There are no significant changes in cultivated land and profit when the management restrictions refer to the increase of water price up to five times. This is due to very low water tariffs which are actually applied in the study area (Table 4).

Table 4. Actually applied water tariff scheme in the Central Jordan Valley

Water tariff	Level (JD/m^3)	Water quantity (m^3/ha/month)
W1	0.008	0-714
W2	0.015	714-1000
W3	0.020	1000-1280
W4	0.035	More than 1280

C. Combination between both scenarios water tariff and water restrictions

Figure 1 represents the synthesis of the results obtained from the combination of different water availability and water pricing constraints giving the difference in profit, cultivated area and water productivity. Profit and total cultivated area decrease as the restriction and water price increase but the decreasing is more significant with the restriction on water availability than with the increasing of water tariff. Similarly, it can be concluded that water productivity remains almost the same for all scenarios except for those with a significant water restriction combined with the increase of water prices.

IV – Conclusions

This work analyses several management options that could be applied to sustain farmer's income, agricultural production and efficient use of resources in the Central part of Jordan Valley under eventual reduction of water supply and increase of water tariffs in the future years. The simulation results indicated that cultivated land and total profit of farmers could decrease almost in a linear way by the reduction of water availability. With the decrease of water supply, the farmers would adopt more efficient irrigation techniques, such as deficit irrigation, and cultivate crops with lower water requirements such as early potato and eggplant. The increase of water tariffs up to five times could decrease the profit only by 2% while the cultivated area would remain the same. The overall results indicate that water availability rather than water price is the most limiting factor of agriculture production in the Central Jordan Valley which is due to the low water pricing scheme. The results pointed out that water productivity (Wp) would remain almost the same (around 1.85 JD/m^3) by introducing different restrictions on water availability and price scheme. A more significant drop of Wp, down to 1.75 JD/m^3, was observed when water availability was reduced to 50% of the current supply and water prices were increased 5 times. The actual cropping pattern reflects the constraints imposed by soil, climatic and environmental conditions and will not be changed easily unless a major drop of water availability comes out.

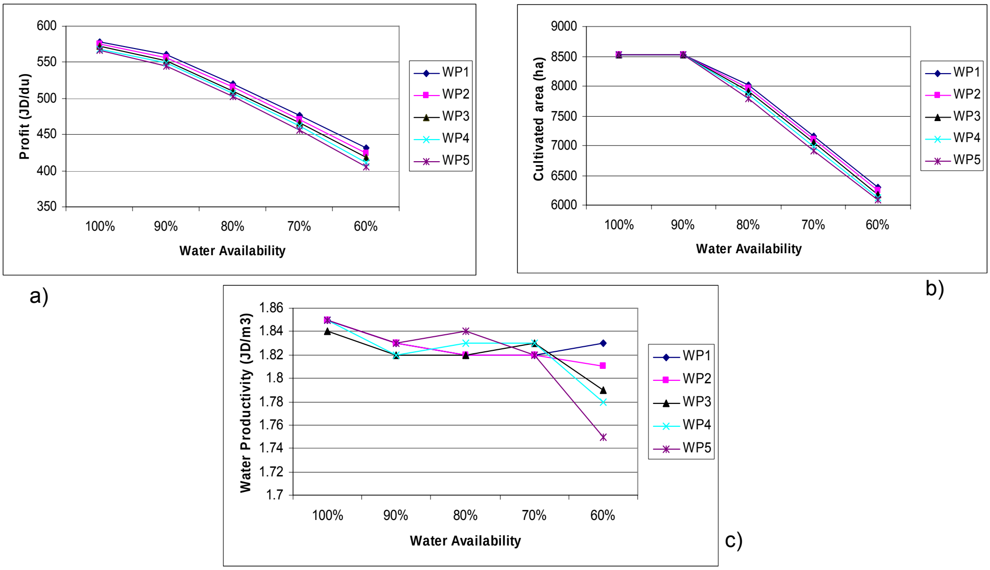

Fig. 1. Profit (a), cultivated area (b) and water productivity (c) of different scenarios combining water availability and water pricing constraints.

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