Jordan Journal of Agricultural Sciences, Volume **9**, No. **4** 2013

Economic Efficiency of Water Use by Irrigated Crops in Al’Azraq Area

***Ahmad Moh'd Abu-Awwad*[1]✉ *and Stephen Blair*[2]**

ABSTRACT

Ever-increasing demands for water in Jordan have resulted in large-scale pumping from Al'Azraq groundwater reserves in Eastern Jordan. The level of exploitation significantly exceeds the proven annual natural recharge of 25 million m^3 per year. The purpose of this study is to identify existing cropping patterns, determine the crop water requirement, and perform an economic analysis to evaluate for alternatives for water usage. A review of the Ministry of Agriculture data suggests that the dominant crops in AL'Azraq area are: olive, grape, fruit trees, alfalfa, tomato, and barley, representing 96.3% of the total irrigated, cultivated area in AL'Azraq. The total irrigated, cultivated area is 114,995 dunum in 2011, of which 71.3% contain olive, 9.9% grape, 6.3% fruit trees, 4.3% alfalfa, 3.1% tomato, and 1.4% barley. Based on the existing cropping pattern, the annual agriculture water demands are estimated to be more than 172.3 million m^3 of water per year (about 7 times the sustainable yield of the aquifer) and the agricultural area continues to grow at an alarming rate. Farmer profits are found to be highly dependent on the cost of irrigation. Based on the information obtained from the Agricultural Credit Corporation, the cost in 2005 was estimated to range between 0.08 JD/m^3 for irrigation of olive trees to 0.4 JD/m^3 for irrigation of fruit trees. Based on these irrigation costs, estimated profits range from up to about 150 JD/du for field crops to in excess of 1600 JD/du for fruit trees (pomegranates). Olive farming was calculated to actually lose money despite accounting for more than 70 percent of the total agricultural area (and a similar percentage of the total agricultural water demand). Consequently, some farmers abandoned their olive farms. The existing situation reveals that the breakeven irrigation cost is the lowest with the largest crop cultivated area, while crops with the highest breakeven irrigation costs account for the lowest cultivated area.

Keywords: Al'Azraq, Irrigation, Water Use, Economic Efficiency, Breakeven irrigation cost, Cropping Pattern.

INTRODUCTION

Given the severe scarcity of water in Jordan, and in light of: (1) the decrease in groundwater resources from both a quantity (aquifer depletion) and quality (increase in the salinity of the groundwater) standpoint; (2) limited surface water resources; and, (3) the increasing demand for potable water due to growth, it has become a priority to dedicate considerable efforts to manage water resources, prioritize use and maximize its return. Throughout the arid regions of the world, irrigated agriculture is a major water user.

AL'Azraq basin is situated in Zarqa governorate, Jordan. Its geographical coordinates 31° 50’ 0” North, 36 ° 49’ 0” East. It is located about 110 kilometers east of Amman. AL'Azraq groundwater basin is one of the most water abundant, but ecologically sensitive and heavily used, providing a major share of Amman’s municipal water supply (Ali, 2010). Ever-increasing demands for water in Jordan, have resulted in large-scale pumping

[1] Land, Water and Environment Department; The University of Jordan; Amman 11942- Jordan.
✉ abuawwad@ju.edu.jo
[2] CDM International, Inc. No 17 Ahmad Al Arousi Street, Abdoun, Amman, Jordan.
Received on 15/1/2012 and Accepted for Publication on 26/3/2013.

from groundwater reserves in Eastern Jordan. The level of exploitation significantly exceeds the proven annual natural recharge, and the impacts of this over exploitation are becoming increasingly evident in declining groundwater levels and deterioration of water quality. Much of the AL' Azraq Oasis, which was once a rich habitat with its permanent fresh waters and springs, has dried out, and its soil quality has drastically deteriorated as a result of over abstraction of groundwater for irrigation (CEDARE, 2006).

The AL'Azraq basin has an area of 12,710 km^2 and is located in the heart of the Jordanian Badia. It is located in the Northeastern part of the country, extending northwards into Syria and Southwards into Saudi Arabia. Over 94% of the basin's area is located within Jordan, less than 5% in Syria, and about 1% in Saudi Arabia. Qa-AL'Azraq is the lowest point of the basin with an altitude of 500 m above sea level (Ali, 2010).

Agricultural activities constitute one of the major threats to water sources that must always be monitored, as the water status in Al'Azraq wetlands is affected by any change in the hydrological system within the basin. Studies reveal that the area of irrigated farms has increased a thousand fold since the early 1970s. By the end of 1991 there were approximately 14,000 du of olive groves and orchards, and 1,530 du of vegetable gardens, irrigated from private wells (Ghaith and Alia, 1998). By the year 1996, the irrigated, cultivated area in Al'Azraq was estimated at 24,616 du (UNDP, 1996), demanding over 20 million m^3 of water, nearly equivalent to the entire safe yield of the basin, which is 25 million m^3 per year (Ghaith and Ali (1998). Consequently, in November 1988, a Jordanian government decree proposed that the total abstraction should be reduced to 20 Million cubic meters (MCM) per year, with only 14 MCM/yr being supplied to Amman and 3.5 MCM/yr for agricultural irrigation (Jane Dottridge & Abu Jaber, 1999).

In general, Jordan experiences moderately cold winters and dry hot summers. Hot, dry summer from mid-May to mid-September and rainy, rather changeable winters from November to mid-March, and are separated by short autumn and spring seasons. The climate is characterized as arid to semi-arid climate (Mediterranean) and the potential evaporation is very high. AL'Azraq area is characterized by desert conditions, low rainfall, and a high evaporation rate (around 3,000 mm annually). Seasonal Khamasine winds blow into the area. The highest recorded temperature is 47^oC; the lowest is -5.7^oC (Jordan Metrological Department, 2011).

Water use efficiency in irrigation has various definitions. Whereas physical efficiency compares the volumes of water delivered and consumed, economic efficiency relates the value of output and the opportunity costs of water used in agricultural production to the value of water applied (Ximing, et. al., 2001). The measurements of water use efficiency are not straight-forward and interpretation of calculated values of water use efficiency need to consider factors such as crops grown, output and input prices, methods of irrigation and amount of net water used to irrigate crops, which tends to vary greatly from one year to the next (Robert Bewer, et al. 2010).

Howell (2001) has proposed that the main pathways for enhancing water use efficiency in irrigated agriculture are to increase the output per unit of water, reduce losses of water to unusable sinks, reduce water degradation, and reallocate water to higher priority uses. The differences of water values are heavily dependent on variables such as the crop selling price and the water productivity. In some cases the price of the crop is the critical element explaining the value of the water input, whereas in other cases the water productivity has the larger weight. The economic efficiency of on-farm water use is measured from the grower's perspective by comparing the marginal cost of the water to the marginal value of its use in producing a crop. Significant differences in the value of water were found for a same crop between countries, and between different crops within one country (Agudelo and Hoekstra, 2001).

Breakeven water pricing is defined as the strategy that yields zero profit, focuses on the relationship between fixed cost, variable cost, and profit. At breakeven water pricing the crop produce revenue equals expenses and is calculated by totaling the fixed and variable costs. Breakeven pricing may be used as an aggressive marketing tool for agricultural expansion. Understanding breakeven water price points gives management the tools to work towards generating profits or whether or not to even continue or expand particular crop cultivation.

In Jordan, irrigated agriculture is the highest water consuming sector being in the range of 65-70%, for the last two decades. Better understanding of the economic value of water will become an increasingly valuable in crop selection.

The purpose of this study is to identify existing cropping patterns, determine the crop water requirement, and perform an economic analysis to evaluate for alternatives for water usage.

Approach and Major Activities

There are two ways to assess the value of water in irrigated agriculture: (1) the water-crop production functions, which model the relationship between irrigation water and crop yield. This approach is labor and data intensive; and limited to locations and crops where accurate up-to- date crop production functions are available. (2) the net return to water, which assess the value of water used for agriculture. It estimates the on-farm economic value of water in crop production. It is calculated by subtracting both variable and fixed costs of production (Young 2005). This represents the maximum amount that a grower could pay for water and just breakeven in producing a specific crop. Net return to water can be helpful in identifying a particular crop that a grower may grow or refrain. Also, farmers may refrain from planting a crop due to low crop prices and/or high input costs which make a specific crop unprofitable, or due to soil management and agronomic factors. The economic principles should be applied to guide the allocation of irrigation water between competing water uses in order to maximize profits (Grove, 2011)

To achieve the objectives of this study and to perform the economic analysis, the following activities were conducted, as follows:

- Meetings with various farmers to ascertain needs, preferences and gather data;
- Meeting with stakeholders including Ministry of Water and Irrigation, Ministry of Agriculture, Department of Statistics, and Agricultural Credit Corporation;
- Field reconnaissance;
- Literature review; and
- Data collection, including:
- Historical and existing cropping pattern;
- Crops cultivated areas, productions, values and costs; and
- Historical Weather data.

In the year of 2005, the Agricultural Credit Corporation published an Agricultural Costs and Returns Guide for major crops in Jordan, assuming a certain value for crop water requirement and irrigation cost. For detailed data and preliminary analysis of AL'Azraq groundwater use for irrigated agriculture, two methodologies were used for developing estimates of crop production costs.

- The first was adopted from the Agricultural Credit Corporation (2005) and is intended for application throughout Jordan.

RV = PV – PC

Return Percentage (%) = RV /PC

Where RV, PV and PC represent return value

(JD/du), production value (JD/du), and production cost (JD/du), respectively.

- In reviewing this methodology, it was noted that the crop water requirements appeared low for the AL'Azraq area, likely because the document was developed for application throughout Jordan. Therefore, independent estimates of crop water requirements were developed, specifically for AL'Azraq and incorporated into the analysis.

Detailed analysis for the relationship between irrigation cost and crop return for most crops existing in AL'Azraq area was performed. The analysis performed assumed:

(1) fixed and variable costs for all other inputs excluding irrigation water, in crop production, as estimated by the Agricultural Credit Corporation (2005);

(2) crop production and value as published by the Ministry of Agriculture and the Department of Statistics (2009 and 2010); and

(3) calculated crop water requirement based on prevailing climate and south AL'Azraq historical weather data (1981-2010).

Profit (JD/du) = PV – [BPC + (CWR x WF)]

BEWF = (PV – BPC) / CWR

Where BPC, CWR, WF and BEWF represent base production cost (JD/du), crop water requirement (m^3/du), water fee (JD/m^3) and break even water fee (JD/m^3) at 0.0 profit, respectively.

Crop water requirement for a certain crop is determined by summing crop potential evapotranspiration (an energy process governed by energy availability and prevailing climate); leaching requirement (which is function of irrigation water quality and crop sensitivity to salinity); and irrigation efficiency (which is function of application system and management). A comprehensive review of the existing data and local information related to crop water requirement, water demand, agricultural irrigation practices, and cropping pattern was performed. Potential and/or reference evapotranspiration was estimated on a monthly basis based on historical weather data using the most recent theoretical approach, Penman Monteith and Class A pan evaporation (Allen et al., 1998). Winters are moderately cold, while summers are moderately dry-hot (Mediterranean climate). Effective rainfall is expressed as that portion of total rainfall that becomes available for use by crops. The effective rainfall is negligible and has not been considered in crop water requirement calculations.

Crop water requirements were estimated for the existing crops. The components of the irrigation demands include: crop evapotranspiration, leaching requirement, and irrigation losses in the irrigation system.

The actual crop evapotranspiration was estimated as:

ETc = Kc x ETo

Where ETc represents actual crop evapotranspiration (mm/month); Kc represents mean monthly crop coefficient derived according to the guideline for computing crop water requirements-FAO Paper 56, (Allen et.al.1998); and ETo (mm/month) represents grass reference evapotranspiration calculated using Penman Montieth approach and Class A pan evaporation.

Average monthly climatic data were collected from South AL'Azraq weather station, from the Metrological Department. Data includes mean minimum and maximum temperatures, rainfall, relative humidity, wind speed, actual sunshine hours, and Class A pan evaporation for South AL'Azraq weather station (1981 - 2010).

The leaching requirement (LR) is the ratio of the net depth of leaching water to the net depth of water which must be applied for consumptive use. Leaching fraction was calculated (for sprinkler, trickle and surface irrigation application systems) as presented in the Sprinkler and Trickle Irrigation (Keller and Bliesner, 2001) and the FAO Irrigation and Drainage Paper No. 29 (Ayers et.al, 1994).

With good management, typical irrigation efficiency is about 75% on average for sprinkler irrigation, and around 85% for drip irrigation (Keller and Bliesner, 2001). Farm irrigation efficiency in Al'Azraq area was estimated at 80 percent.

Crop water requirement was calculated as follows:

$$CWR = ETc / Ei$$

Where CWR represents crop water requirement; ETc represents actual crop evapotranspiration; and Ei represents irrigation efficiency (estimated at 80%).

RESULTS AND DISCUSSION

The total area of tenure in Al'Azraq is 143,979 dunum, of which 125,954 dunum agricultural land potentially cultivable. Based on available data from the Department of Statistics; AL'Azraq Agricultural Directorate; Ministry of Agriculture; Jordan Water Authority; and other literature reviewed as part of this research, a significant increase in irrigated, cultivated land occurred in the last three decades (Figure 1). Agriculture activities started in the AL'Azraq area with one 40 dunum farm in 1957. After the speech of His Majesty King Hussein for a green desert as a motivation to invest in agriculture in the 1980s and because of the national land regulation dictating that proven activity in an acquired land is sufficient to grant the alleged owner right to this land, AL'Azraq underwent the development of large farms. Consequently, cultivated land increased dramatically from 7,566 dunum in 1980 (MOA, 1980) to 24,686 dunum (UNDP, 1996) in 1996 (more than 3 times), with a motivation of land speculation, prospect of cheap land, and free water. Irrigated, cultivated land almost doubled within two years, increasing from 24,686 dunum in 1996 to 48,230 dunum in 1998. Even with government prohibition of new expansion in irrigated agriculture in AL'Azraq region and water tariffs imposed by Ministry of Water and Irrigation, irrigated cultivation continued to grow being around 114,995 dunum in 2010/2011 (Al'Azraq Agricultural Directorate, 2011), but shifting from vegetables to orchards, mainly olive trees.

Table 1 presents the cropping structure in 2010/2011 according to the Ministry of Agriculture records (Al'Azraq Agricultural Directorate, 2011). Noticeably orchards are the dominant crops acquiring 100,720 dunum, representing 87.6% of the total irrigated, cultivated area, of which 81.4% contain olive trees, 11.3% grapes, 7.1% fruit trees, and 0.2% citrus. Field crops and alfalfa accounted for 7,750 dunum, representing 6.7% of the total irrigated, cultivated area, of which 63.2% was alfalfa, 29.7% barley and wheat, and 7.1% corn fodder. Vegetables accounted for 6,525 dunum, of which 55.2% were tomatoes, 24% Melon and water melon, 9.9% onion and garlic, 5.4% cauliflower and cabbage, 4.0% eggplant, 1.2% okra and 0.5 peppers. Thus, in 2010/2011, the dominant crops were: **olive, grape, fruit trees, alfalfa, tomato, and barley**, representing 96.3% of the total irrigated, cultivated area in AL'Azraq. The total irrigated, cultivated area was 114,995 dunum, of which 71.3% contain olive, 9.9% grape, 6.3% fruit trees, 4.3% alfalfa, 3.1% tomato, and 1.4% barley.

Agriculture Economic Analysis

Agricultural Production and Costs

In 2010/2011 the dominant existing crops were: olive, grape, alfalfa, tomato, and barley, representing 90.0% of the total irrigated, cultivated area in AL'Azraq. These are discussed below:

Olive is the most dominant crop in AL'Azraq area. The irrigated area of planted olive trees (82,000 du) represents about 71.3% of the total irrigated, cultivated area (114,995 du) for the year 2011 (AL'Azraq Agricultural Directorate, 2011) in Al'Azraq area, which is more than any other.

Based on the Ministry of Agriculture records the total olive irrigated, cultivated area in AL'Azraq was 73,330 du in 2009, of which only 29,520 du was fruitful and 43,810 du was still not fruitful. The total olive fruit production of the fruitful olive trees was 11,218 ton, representing an average olive fruit production of 0.38 ton/du. Only 40% of the cultivated area was fruitful in 2009.

Production costs per one dunum of olive trees was estimated by the Agricultural Credit Corporation in 2005 for three time intervals (3 stages) from planting date, as follows: estimated cost for the first 3 years (1-3 years) from planting date was JD 82.2/du (assuming 200 m^3 crop water requirement, and JD 0.08/m^3 irrigation cost); JD 134.7/du for the next 4 years (assuming 250 m^3 crop water requirement, and JD 0.08/m^3 irrigation cost); and JD 236.1 for year 8 and thereafter (assuming 300 m^3 crop water requirement, and JD 0.08/m^3 irrigation cost).

Grape is the second most extensively cultivated temperate fruit crop in AL'Azraq (and in the world) after olive. The irrigated, cultivated area of planted grapes (11,350 du) represents about 9.9% of the total irrigated, cultivated area (114,995 du) for the year 2011 (AL'Azraq Agricultural Department, 2011) in Al’Azraq area.

Based on the Department of Statistics records, the total grape irrigated, cultivated area in AL'Azraq was 4,620 du in 2009, which produced 78,000 ton, with an average grape production of 1.69 ton/du.

Similar to olive, production costs per one dunum of grape was estimated by the Agricultural Credit Corporation in 2005 for three time intervals (3 stages) from planting date, as follows: estimated cost for the first 3 years (1-3 years) from planting date was JD224.2/du (assuming 300 m^3 crop water requirement, and JD 0.4/m^3 irrigation cost); JD415.7/du for the next 4 years (assuming 500 m^3 crop water requirement, and JD 0.4/m^3 irrigation cost); and JD 635.9/du for year 8 and thereafter (assuming 800 m^3 crop water requirement, and JD 0.4/m^3 irrigation cost).

Alfalfa is considered the third most cultivated crop in AL'Azraq area after olive and grape. The irrigated area of planted alfalfa (4,900 du, AL'Azraq Agricultural Department 2010/11) represents about 6.3% of the total irrigated, cultivated area (114,995 du) for the year 2011.

Based on the Department of Statistics records, the total irrigated, cultivated area in uplands was 62,036 du in 2010 produced 210,517 tons, with an average alfalfa production of 3.4 ton/du.

Based on the reconnaissance visit to AL'Azraq area in October 2011, production costs per one dunum of alfalfa was estimated based on interview with farmers at JD 411.3/du (assuming 1600 m^3 crop water requirement at JD 0.12/m^3 irrigation cost).

Tomatoes are among the most important vegetables grown in Jordan whether grown inside plastic houses or in open field. The irrigated area of planted tomato (3,600 du) represents about 3.1% of the total irrigated, cultivated area (114,995 du) for the year 2011 (AL'Azraq Agricultural Department, 2011) in Al’Azraq area, which is the fourth largest cultivated area after olive, grape, and alfalfa. In the highlands, the total irrigated, cultivated area accounts for 66,550 du, which produced 295,468 tons, with an average tomato production of 4.44 ton/du.

Production costs per one dunum of open tomato fields were estimated by the Agricultural Credit Corporation in 2005 being JD 423.7/du (assuming 500 m^3 crop water requirements at JD 0.12/m^3 irrigation cost). Despite nearly constant production costs and average production per one dunum, produce value varies significantly from one month to another and from one year to the other. In 2009 produce value was JD 113.6/ton at the farm gate, which nearly doubled in 2010 being about JD 197/du. This significant variation in tomato produce value makes economic analysis very difficult.

Barley and wheat are widely spread in Jordan, representing the main rain-fed crops in the highland areas. Both crops are winter crops. The irrigated area of planted barley (1,650 du) represents about 1.4% of the total irrigated, cultivated area (114,995 du) for the year 2011 (AL'Azraq Agricultural Department, 2011) in

Al'Azraq area, which is the fifth largest cultivated area after olive, grape, alfalfa, and tomato.

Based on the Ministry of Agriculture's Plant Production Annual Report 2009, the total irrigated, cultivated area in AL'Azraq was 3,400 du, which produced 952 tons, with an average barley production of 0.28 ton/du.

Production costs per one dunum of rain-fed barley was estimated by the Agricultural Credit Corporation in 2005 being JD 24.75/du. Adding the irrigation cost of about 240 m^3 water, (at JD 0.12/m^3irrigation cost), for supplemental irrigation based on interviews with local farmers, brings the production costs to JD 53.8/du.

The irrigated, cultivated area of planted **fruit trees**, excluding grapes, (7,200 du) represents about 7.1% of the total irrigated, cultivated area (114,995 du) for the year 2011 (AL'Azraq Agricultural Department, 2011) in Al'Azraq area. Based on the Department of Statistics and Ministry of Agriculture's records in 2009, fruit trees production varied from 1.0 ton/du for peach to 2.89 ton/du for pear.

Table 1. Agricultural Structure and Cropping Pattern in AL'Azraq Area, 2010/2011

Crops	**Area (du)**	**Percent of each crop in its category (%)**	**Percent of each crop of the total irrigated area (%)**
Field crops and Alfalfa			
Alfalfa	4,900	63.2	4.3
Barley	1,650	21.3	1.4
Wheat	650	8.4	0.6
Fodder Corn	350	4.5	0.3
Yellow Corn	200	2.6	0.2
Subtotal	**7,750**	**100**	**6.7**
Orchards			
Grape	11,350	11.3	9.9
Olive	82,000	81.4	71.3
Fruit tress	7,200	7.1	6.3
Citrus	170	0.2	0.1
Subtotal	**100,720**	**100**	**87.6**
Vegetables			
Tomato	3,600	55.2	3.1
Melon	1,080	16.6	0.9
Onion	515	7.9	0.4
Water Melon	480	7.4	0.4
Eggplant	260	4.0	0.2
Cabbage	200	3.1	0.2
Cauliflower	150	2.3	0.1
Garlic	130	2.0	0.1

Crops	**Area (du)**	**Percent of each crop in its category (%)**	**Percent of each crop of the total irrigated area (%)**
Okra	80	1.2	0.1
Pepper	30	0.5	0.03
Subtotal	**6,525**	**100**	**5.7**
Total	**114,995**		**100**

Similar to other orchards, production costs per one dunum of fruit trees was estimated by the Agricultural Credit Corporation in 2005 for three time intervals (3 stages) from planting date, as follows: estimated cost for the first 3 years (1-3 years) from planting date was in the range of JD 71.5 and 80.4/du (assuming 200 m^3 crop water requirement, and JD 0.4/m^3 irrigation cost); JD 177.5 and 192.9/du for the next 4 years (assuming 250 m^3 crop water requirement, and JD 0.4/m^3 irrigation cost); and JD 241.6 and 290.5/ du for year 8 and thereafter (assuming 300 m^3 crop water requirement, and JD 0.4/m^3 irrigation cost).

Crop production and economic data from the Department of Statistics, Ministry of Agriculture, and Agricultural Credit Corporation (2005), for 2009, 2010, and 2011, were compiled for the dominant existing crops in Al'Azraq and are summarized in **Table 2**.

Table 2. Production and Production value Statistics for the most dominant existing crops in AL'Azraq.

Crop	**Production**	**Production value**		**Production Cost**	**Profit (Return)**	
	tons/du	**JD/ton**	**JD/du**	**JD/du**	**JD/du**	**%**
Orchards(*)						
Olives	0.38	750	285	236.1(**)	48.9	20.7
Grape	1.69	520.7	880	635.9	244	38.4
Apple	2.5	544.8	1362	361.6	1000	277
Pear	2.89	633.8	1832	361.6	1470	407
Peach	1	633.8	634	410.5	223	54
Apricot	1.33	919.4	1223	410.5	812	198
Cherry	1.5	919.4	1379	410.5	969	236
Pomegranate	2	1250	2500	361.6	2138	591
Date Palm	1	1000	1000	410.5	590	144
Alfalfa and Barley						
Alfalfa	3.4	180	612	411.3	200.7	48.8
Barley	0.28	315	88.2	53.8	34.4	63.9

Vegetables						
Tomato	4.44	113.6(***) to 197(****)	504(***) to 875(****)	423.7	81(***) to 451(****)	19 to 106.4

Source: Ministry of Agriculture (2009, 2010, and 2011); Department of Statistics (2010); and Agricultural Credit Corporation (2005).

(*) Production costs assumes 300 m^3/du crop water requirement at 0.4/m^3 water price, for ≥ 8 years trees old from planting date (Agricultural Credit Corporation, 2005)

(**) Even though production costs estimated by Agricultural Credit Corporation (2005) based on JD 0.4/m^3, end results for olive water consumption cost indicates that it is calculated based on JD 0.08/m^3.

(***) Produce value in 2009

(****) Produce value in 2010

Based on crops' cultivated areas, the existing crops were divided into two groups and analyzed separately, as follows:

1) the most dominant crops including olive, grape, alfalfa, tomato, and barley; and

2) fruit trees including date palm, apple, pear, cherry, pomegranate, peach, and apricot

Based on the available data, of the most dominant crops (Olives, Grape, Alfalfa, tomato, and Barley) considered, grapes produce the highest return value per dunum at JD 244.1, followed by alfalfa being JD 200.7 (**Figure 2**). The return for olive was JD 48.9/du. The lowest crop return value was barley at JD 34.4/du, however it has the highest return per production costs per unit area being about 63.9%.

The return value on tomatoes varies from one year to another, mainly depending on the area cultivated, export, and diseases. In 2009, the tomato produce value per dunum was the lowest of the last five years, at JD 113.6/ton, resulting in a return value of JD 81.0/du. This was due to the fact that exports to Saudi Arabia were blocked accompanied by high production, and a disease free growing season. The opposite occurred in 2010, when the produce value was at a five year high, at JD 197.0/ton, resulting returns per dunum at JD 451.0/du. This was because of a disease problem growing season and resumed exports to Saudi Arabia.

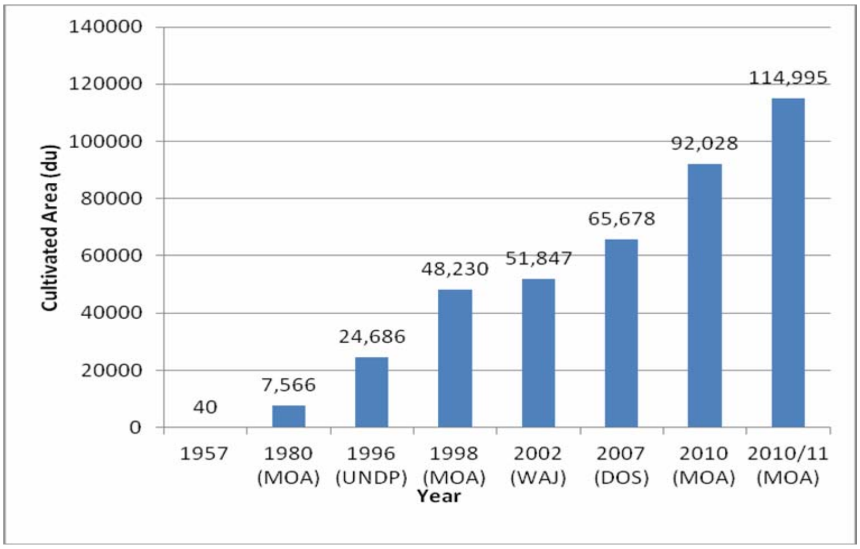

Figure 1 Irrigated Agricultural Development in AL'Azraq Area (1957-2011)

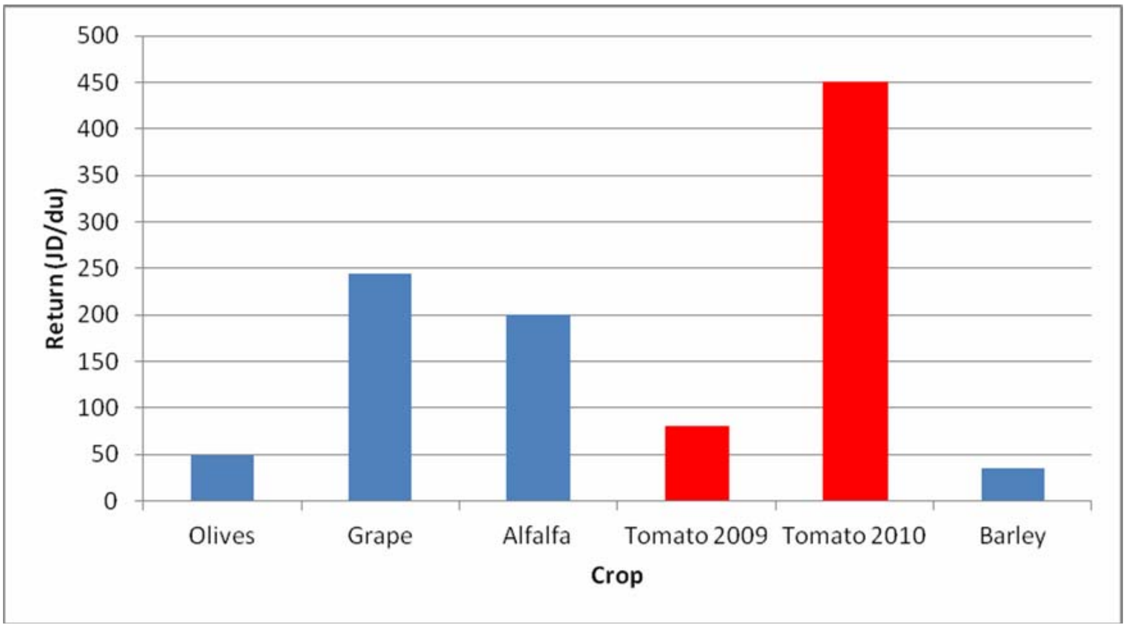

Figure 2. Crops Return Based on Agricultural Credit Corporation (JD/du)

Even though the return on barley per dunum (JD 34.4/du) was the lowest among crops considered, the return per unit production cost was the highest at 63.9%, followed by alfalfa at 48.8% (**Figure 3**). The return on olive was JD 48.9/du the second lowest after barley. Among crops of interest, olives have the lowest return value per unit production cost at 20.7%.

Revised Agricultural Production and Costs

In reviewing the details of the Agricultural Credit Corporation calculations, it was noted that the crop water requirements used were low. Other costs for labor equipment and manpower appeared reasonable. The sections to follow, include an independent evaluation of crop water requirements and crop production costs for use in this assessment.

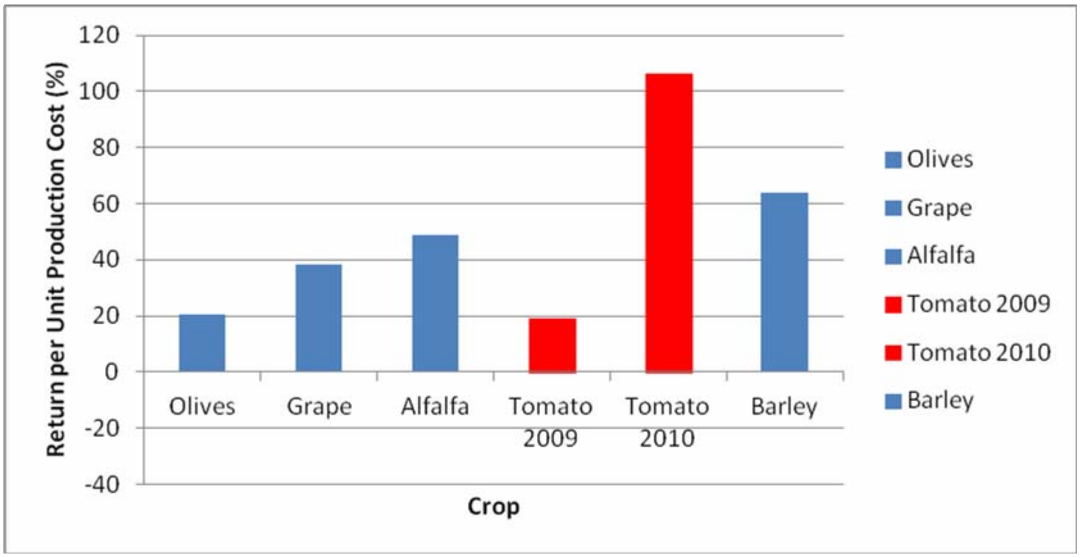

Figure 3. Percentage of Return Value per Unit Production Cost

Crop Water Requirements

The study area is characterized by high evaporative demand being about 3,278 mm/yearly (Class A pan evaporation, mean value for the last 20 years), consequently crop water demand is high. Average monthly climatic data were collected from South AL'Azraq weather station, from the Metrological Department. Data are summarized in **Table 3**, which illustrate the mean minimum and maximum temperatures, rainfall, relative humidity, wind speed, actual sunshine hours, and Class A pan evaporation for South AL'Azraq weather station (1981 - 2010).

The average daily mean temperatures measured at South AL'Azraq range from 8.9^{o}C in the month of January to 28.7 ^{o}C in the month of August, the average daily maximum temperatures range from 15^{o}C in January to 37.2^{o}C in August, and minimum temperatures range from 2.8 ^{o}C in January to 20.3 ^{o}C in August. The maximum evaporation at AL'Azraq region is about 15.3 mm/day in the month of August and the minimum of 2.9 mm/day in the month of January.

Most of the rainfall occurs between the months of November and April. Typical mean annual rainfall for the period 1981-2010 is very low, only 57.6 mm. Precipitation is not always a dependable quantity and may vary significantly from year to year and from one month to another. Forty percent of the annual rainfall occurs in December and January. The term dependable precipitation refers to that quantity of precipitation (monthly) which received a certain percentage of the time (example: 8 out of every 10 years). Given the high evaporative demand, and the very low total precipitation, dependable rainfall is negligible and will not significantly contribute in satisfying part of the crop water requirement. Dependable precipitation is considered negligible and is not considered in crop water requirement calculations.

Table 3. Climatic Data for South AL'Azraq (1981-2010)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Days	31	28	31	30	31	30	31	31	30	31	30	31
Mean daily, Tmean: °C	8.9	10.6	14.3	19.3	23.8	26.9	28.6	28.7	26.7	22.3	15.2	10.4
Mean daily, Tmax: °C	15.0	16.9	21.2	27.1	31.9	35.4	37.0	37.2	34.8	29.8	22.3	16.7
Mean daily, Tmin: °C	2.8	4.2	7.3	11.5	15.6	18.3	20.1	20.3	18.6	14.7	8.2	4.0
Mean daily, RH:%	70.2	63.9	56.5	48.1	43.7	44.9	48.2	51.3	52.5	54.1	60.9	68.9
Mean daily, Wind speed, m/s	2.34	3.30	4.16	4.52	5.04	5.92	6.06	5.52	4.85	2.92	2.07	1.78
Sun shine hours, n. hours	6.1	6.7	7.8	8.6	9.6	11.2	11.1	10.9	9.9	8.3	7.3	6.1
Class A pan Evaporation, mm	89.8	111.3	195.3	282.6	381.0	451.4	475.4	457.8	362.2	243.5	132.9	94.9
Rainfall: mm/Month	12.7	9.3	9.6	4.3	1.4	0	0	0	0.3	3.0	6.5	10.4

Latitude: 31°50"16' (0.556 radians)
Longitude: 36°47"54'
Elevation: 521 m

Source: Jordan Metrological Department (2011)

Reference Evapotranspiration

A review of the existing data and local information related to crop water requirement, water demand, agricultural irrigation practices, and cropping pattern was performed. Potential and/or reference evapotranspiration was estimated on a monthly basis based on historical weather data using the Penman Monteith method and Class A pan evaporation (Allen et al., 1998). **Figure 4** illustrates grass reference evapotranspiration for the South AL'Azraq area as calculated by the Penman-Monteith method and Class A Pan methods. Both values of calculated ETo are highly comparable and in excellent agreement. For the purposes of establishing an estimate for Crop Water Demands, the average of the two values was used for crop actual transpiration estimation.

Crop water requirements were estimated for the dominant crops in AL'Azraq, including olives, grapes, alfalfa, tomatoes, and barley. In general, the components of the irrigation demands include: crop evapotranspiration, leaching requirement, and irrigation losses in the irrigation system. With good management, typical irrigation efficiency is about 75% on average for sprinkler irrigation, and around 85% for drip irrigation. In calculating the crop water requirements, irrigation efficiency of 80% was adopted for the estimate.

Despite concerns about salination in the upper aquifer groundwater, water quality is generally good, except in the shallow sediments of Qa'a AL'Azraq, which contain hypersaline brines formed by evaporation. Elsewhere in AL'Azraq basin, the salinity is low. Total dissolved solids (TDS) increasing in the direction of flow from 200 ppm to 1000 ppm (Khresat and Qudah, 2006).

For the crops considered, there is no need for leaching until the irrigation water salinity exceeds 1000 ppm (1.56 dS/m). In this study, leaching is not considered necessary in the crop water requirements, since groundwater salinity in the upper aquifer of AL'Azraq basin, is in the range of 200 to 1000 ppm

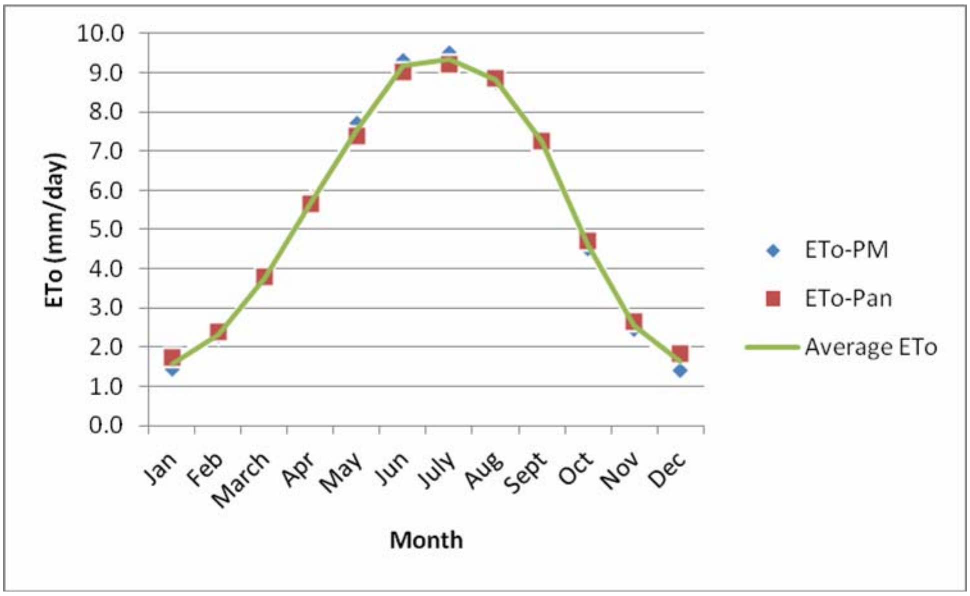

Figure 4. Grass Reference Evapotranspiration (ETo in mm/day)
ETo-PM and ETo-Pan represent ETo calculated using Penman Montieth 1998 and Class A pan evaporation, respectively.

Table 4 illustrates the expected mean monthly actual crop evapotranspiration for olives, grapes, alfalfa, tomatoes, barley, and fruit trees. These crops are the most dominant as of 2010/2011. The specific volume of water required for each month varies from crop to crop. Olive, alfalfa, and date palm have a continuous demand pattern with a summer peak being 203, 348, and 275 mm/month, respectively in July, and minimum demand being 19.6, 43.9, and 44 mm/month, respectively in January. Barley is an exception, showing increased demand in winter with a peak demand of 197 mm/month in April, and no irrigation demand in the summer months (June to September). Also, grape and tomato water demand extends from April to November/December, with its maximum demand occurring in July, at 246 mm/month and 331 mm/month, respectively, and no water demand from November/December to March. Thus, the determinate critical month is July.

Date palm has a continuous demand pattern with a summer peak being 275 mm/month in July, and minimum demand being 44 mm/month in January. The water requirement of date palm is high although it can withstand prolonged droughts. Irrigation is very essential in date palm because it is grown in hot and dry, low rainfall areas. Furthermore, like any other fruit tree, date palm needs sufficient water of acceptable quality to reach its potential yield. In the Jordan Valley, dates' water requirement varies from 2500 m^3/du to 3200 m^3/du (Liebenbag, P.J. and A. Zaid, 2002). An abundant water supply is important to the quality of the date crop. However, the date can tolerate long periods of drought, although for heavy bearing, it has a high water requirement. Dates require up to 2700 m^3/du for mature palms at ten years of age (FAO/RNE, 2008).

All other fruit tree water demands extend from April to October, with their maximum demand occurring in July, being 252-290 mm/month, and no water demand from November to March.

Table 4. Mean Monthly Actual Evapotranspiration (mm) for Existing Crops in Al'Azraq area.

Month	Olive	Grape	Alfalfa	Tomato	Barley	Date Palm	Apple/Pear/Cherry /Pomegranate	Peach/Apricot
Jan	19.6		43.9		28.3	44		
Feb	26.2		58.6		43.7	59		
Mar	55.6		116		104	110		
Apr	103	51.3	171	51.3	197	162	68	94
May	163	121	280	190	180	222	140	147
Jun	193	229	330	311		261	234	217
Jul	203	246	348	331		275	290	252
Aug	192	232	327	255		259	273	246
Sep	153	185	261			206	206	196
Oct	89.3	113	148		43	136	100	111
Nov	39.2	43.6	70		30.2	69		
Dec	24.4		45.7		24.6	45		
Total	**1260**	**1220**	**2199**	**1138**	**651**	**1851**	**1312**	**1263**

Based on the total crop areas obtained from the Ministry of Agriculture, Al’Azraq Department and the above calculated crop water requirements for dominant crops, assuming 80 percent irrigation efficiency, the current total agricultural demand is in excess of 178 MCM/yr (**Table 5**), more than 7 times the sustainable yield of 25 MCM/yr. Clearly the amount of agriculture in AL’ Azraq is not sustainable and it is only a matter of time before the livelihood of local inhabitants are severely impacted.

Revised Crop Production and Production Costs

Revised estimates of crop production costs and profitability were made to separate fixed costs associated with agricultural activities and water consumption, so that both costs and water usage could be used in assessing the viability of the existing crops in Al’Azraq area. Furthermore, as described above, the crop water requirements included in the Agricultural Credit Corporation in 2005 were much lower than the estimates above. The analysis performed assumed:

(1) Crop production and produce value as published by the Ministry of Agriculture and the Department of Statistics; and

(2) Calculated crop water requirement based on prevailing climate and south AL'Azraq historical weather data, as described above and assuming 80 percent efficiency in the irrigation system.

(3) Base costs for all other inputs excluding irrigation water, as estimated by the Agricultural Credit Corporation;

(4) Costs for pumping and distribution of irrigation water as per the Agricultural Credits Corporation

(5) Water tariffs calculated separately as described below

Table 5. Annual Al'Azraq Agricultural Water Demand for Selected Crops

Crop	Area	Annual Crop Water Requirement	
		Per dunum	Total
	du	m^3/du	m^3
Alfalfa	4,900	2749	13,470,100
Barley	1,650	814	1,343,100
Grape	11,350	1525	17,308,750
Olive	82,000	1575	129,150,000
Fruit tress	7,200	1640	11,808,000
Tomato	3,600	1423	5,122,800
Total			178,202,750

The results of the analysis are presented in **Table 6**. Due to the complexity of the water tariff structure, results are presented as a maximum and minimum, bounding the cases where water is obtained at no cost and at a water cost of 0.1 JD/m^3, based on the 2010 draft amendment pending approval. Also calculated is the total cost associated with irrigation (pumping, distribution and tariffs) necessary for the farmer to break even (zero profit) or the break even water fee. The base cost of the crop includes all the costs needed to produce the crop such as fertilizers, seeds, pesticides, distribution and harvesting, packaging and transportation and labor cost. It is important to note that the analysis is performed for the optimum irrigation conditions which will result in maximum yield from the crops and the fruit trees, actual conditions might be different and is related to individual farm conditions.

The results suggest that out of all the crops, grapes provide the highest profit per dunum of 149 JD/du at zero water fees. Grapes represent the second largest cultivated area, in 2011, and have increased by 1.5 times the cultivated area in 2007. Olive represents the most dominant crop in the AL'Azraq area and accounts for 71.3% of the total irrigated, cultivated area (2010/2011). The calculations suggest that growing olives is not profitable. Farm owners may not be fully aware of this issue. Sometimes a farmer will confuse irrigation practices for rain-fed crops and irrigated crops resulting in not providing the olive trees with as much water as they need. Such deficit farming techniques provide crops with less water than is optimal in order to achieve a marginal profit, however such a practice result in a lower yield and hence affects the profitability of the investment. Supporting the conclusion that such practices are being implemented in AL' Azraq, a recent study in the highlands has found that olive trees orchard are much smaller than would be expected for their age (German-Jordan Programme, 2010). This is attributed to the fact that the trees are not being provided with their actual demand needs. Similar observations are made with respect to other crops in AL'Azraq such as alfalfa and barely.

Fruit trees (including apple, pear, peach, cherry, apricot, pomegranate, and date palm) account for only 7,200 du of irrigated area, representing only 6.3% of the total. For fruit trees, profits range even higher with maximum profits for farmers at 1602 JD/du, if water tariffs are not paid as the case with Pomegranate.

Irrigation water availability and cost are the most determinative factors in agricultural production and expansion. Even though groundwater of good quality in AL'Azraq basin is shallow, easily reachable and pumped from depths ranging from 20 to 50 m, the source of energy used in water abstraction is the determinant factor for water unit cost and produce return. Management of Water Resources by German-Jordan program (2010) estimated olive seasonal water consumption in the range of 900 to 1300 m^3/du. The report shows that 1/3 of visited farms use diesel pumps and 2/3 use electricity. Energy costs represent an average of 19% of the production costs for farms connected to electricity, and 52% for farms using diesel. Even though the olive cultivated area, in 2011 is 1.9 times that in 2007, some of the olive farms were abandoned because of the high water abstraction costs, using diesel. Olive cultivated area expansion occurred in farms connected to electricity. It is reported that, farmers using diesel for water abstraction are hardly sustaining their olive farms, if not losing money. The German-Jordan Programme "Management of Water Resources in their draft report (2010) stated that "most of the farmers are just sustaining or even losing money (on average profit is 9 JD/du).

The calculations suggest that barley provides a negative return on investment, accordingly the area of cultivated barley is decreasing. For date palm, the return on investment is also negative, despite expansion in AL'Azraq. Possible reasons for this as noted previously could be the extension of electrical service into these areas reducing irrigation costs, or the practice deficit irrigation as described above for olives. Peach also returns a negative profit. Consequently, peach is the least cultivated in terms of area and has not undergone expansion in recent years. Thus, in addition to climate suitability, crop selection should be based on water value and availability, land value and availability, production costs, and produce value.

Table 6. Return on Crop Production in Al'Azraq

Crop	Crop Production ton/du	Crop Value		Base Production Cost JD/du	Water Requirement m^3/du	Irrigation Cost		Base Production Cost with Irrigation JD/du	Water Fee (JD/du)		Profit		Break Even Water Fee
		JD/ton	JD/du			JD/m^3	JD/du		Max (Free)	Min (0.1 JD/m^3)	Max JD/du	Min JD/du	JD/m^3
Olive	0.38	750	285	212	1575	0.08	126	338	0	158	-53	-211	0.05
Grape	1.69	636	1075	316	1525	0.4	610	926	0	153	149	-4	0.50
Alfalfa	3.4	180	612	211	2749	0.12	330	541	0	275	71	-204	0.15
Tomato	4.44	155	690	364	1423	0.12	171	534	0	142	155	13	0.10
Barley	0.28	315	88	25	814	0.12	98	122	0	81	-34	-116	0.08
Apple	2.5	545	1362	242	1640	0.4	656	898	0	164	464	300	0.68
Peach	1	634	634	291	1579	0.4	632	922	0	158	-288	-446	0.22
Apricot	1.33	919	1223	291	1579	0.4	632	922	0	158	301	143	0.59
Pear	2.89	634	1831	242	1640	0.4	656	898	0	164	933	769	0.97
Cherry	1.5	919	1379	291	1640	0.4	656	947	0	164	433	269	0.66
Pomegranate	2	1250	2500	242	1640	0.4	656	898	0	164	1602	1438	1.38
Date Palm	1	1000	1000	291	2314	0.4	926	1216	0	231	-216	-448	0.31

Results of the most dominant existing crops (olive, alfalfa, grape, tomato, and barley) and fruit trees (apple, pear, peach, cherry, apricot, pomegranate, and date palm) reveal that the largest irrigated, cultivated area is olive accompanied with the lowest breakeven water price, and the minimum irrigated, cultivated area is pomegranate accompanied with the highest breakeven water price (**Figure 5**). This might be attributed to the traditional farmers who used to grow olive and field crops, such as wheat and barley. Now a day's investors are trying to get benefit from low land value and shallow ground water to invest in high value crops such as orchards. In the last few years most of the expansion occurred in grapes, alfalfa, and orchards.

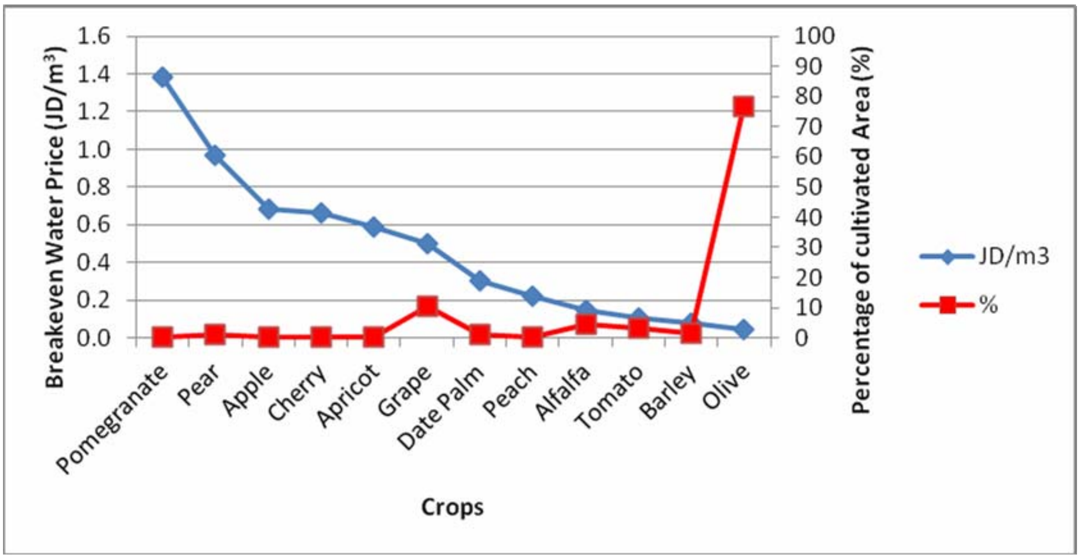

Figure 5. Breakeven Water Price vs. Cultivated Area for most Crops existing in AL'Azraq

Conclusion and Recommendation

Based on the existing cropping pattern in Al'Azraq, the annual agricultural water demands are estimated to be more than 172.3 MCM/year (about 7 times the sustainable yield, 25 MCM/year, of the aquifer). The agricultural area continues to grow at an alarming rate. Olive farming was calculated to actually lose money despite accounting for more than 70 percent of the total agricultural area (with a similar percentage of the total agricultural water demand). The existing situation reveals that the breakeven irrigation cost is lowest with the crop having the largest cultivated area, while crops with the highest breakeven irrigation costs account for the lowest cultivated area. In addition to the climate suitability, crop selection should be based on water value and availability, land value and availability, production costs, and produce value. Irrigated agricultural expansion should be stopped, as well as prioritizing water use and maximizing its return.

REFERENCES

Agricultural Credit Corporation. Agricultural Costs and Returns Guide. 2005

Jose Agudelo I. and Arjen Hoekstra Y.. 2001.Valuing water for agriculture: application to the Zambezi basin countries. ***AWRA/IWLRI- UNIVERSITY OF DUNDEE INTERNATIONAL SPECIALITY CONFERENCE***.

Ali El-Naqa. 2010. Study of salt water intrusion in the upper aquifer in Azraq Basin. Final report. ***IUCN***,. http://cmsdata.iucn.org/downloads/final_report_azraq_2011.pdf

Allen Richard, , G., Luis S., Pereira, Dirk Raes, and Smith Martin. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Rome.

Ayers, S.R., and Westcot D.W.. 1985, 1989, 1994. Water Quality for Agriculture FAO Irrigation and Drainage Paper 29 Rev. 1.

CEDARE. 2006. Water conflicts and conflict management mechanisms in the Middle East and North Africa region. Centre for Environment and Development for the Arab Region and Europe.

Department of Statistics. Agricultural Prices. 2010

Department of Statistics. Agricultural Statistics Newsletter. 2009

Department of Statistics. Statistics of Plant Production. 2010

FAO/RNE. 2008. Proceedings: Workshop on "Irrigation of date palm and associated crops. Damascus, Syrian Arab Republics.

German-Jordan Programme "Management of Water Resources".2010. Farming in the Desert: Analysis of the Agricultural Situation in the AL'Azraq Basin.

Ghaith Fariz and Alia Hatough-Bouran. 1998. Population Dynamic in Arid Region. The Experience of the Azraq Oasis Conservation Report.

Grove, B. 2011.Review of while-farm economic modeling for irrigation farming. Water Research Commission 40-Year Celebration Conference. Kempton Park.

Keller J. and Bliesner D. R.. 2001. Sprinkle and trickle irrigation. The Blackburn Press, New Jersey, USA.

Khresat, S.A. and Qudah E.A. 2006.Formation and properties of aridic soils of Azraq basin in northeastern Jordan. ***Journal of Arid Environments***. 64:116-136.

Howell T.A. 2001.Enhancing water use efficiency in irrigated agriculture. ***Agronomy Journal***. 93:281-289.

Jane Dottridge, and Nizar Abu Jaber.1999. Groundwater resources and quality in northeastern Jordan: safe yield and sustainability. ***Applied Geography*** 19,313–323

Liebenbag, P.J. and Zaid A. 2002. Date palm irrigation. FAO Plant Production and Protection. Papers- 156 Rev. 1.

MOA. 2011.Ministry of Agriculture. AL'Azraq Agricultural Directorate, internal Records.

MOA.1980. Ministry of Agriculture. Annual Statistical Report.

MOA.1998. Ministry of Agriculture. Annual Statistical Report.

MOA. 2009.Ministry of Agriculture. Annual Statistical Report.

Ministry of Transport and Communication. 2011. Jordan Metrological Department files.

Robert Bewer, Md. Kamar Ali, Klein K. K. and Kulshreshtha S. N. 2010. Water use technical and economic efficiency in Southern Alberta irrigated agriculture. ***SAREC Report*** .

UNDP. 1996. The Azraq Oasis Conservation Project: JOR/1992/G31.

Young, R. A. 2005. Determining the Economic Value of Water: Concepts and Methods. Resources for the Future, Washington, D.C.

Ximing Cai, Claudia Ringler, and Mark W Rosegrant. 2001. Physical and economic efficiency of water use in the river basin. EPTD DISCUSSION PAPER NO: 72.

الكفاءة الاقتصادية لاستغلال المياه في الزراعة المروية لمنطقة الأزرق

أحمد أبو عواد[1]، ستيفن بلير[2]

ملخـص

أدى الطلب المتزايد على المياه في الأردن، الى الضخ الجائر من حوض الأزرق المائي الجوفي في الصحراء الشرقية للأردن، بمستوى يتجاوز كثيرا التغذية الطبيعية الآمنة السنوية المقدرة بخمسة وعشرين مليون متر مكعب سنويا. تهدف هذه الدراسة الى تقدير الاحتياجات المائية للمحاصيل؛ بناء على النمط الزراعي القائم في منطقة الأزرق، وتقدير الإنتاجية والربحية للمحاصيل المزروعة. وبمراجعة بيانات وزارة الزراعه الزراعية لمنطقة الأزرق تبين أن المحاصيل السائدة، التي تمثل ما نسبته 96.3% من مجموع المساحات الزراعية المروية للعام 2011/2010، هي: الزيتون، العنب، الأشجار المثمرة، البرسيم، البندوره، والشعير. كما بينت الدراسة أن مجموع المساحات الزراعية المروية للعام 2011/2010 هي 114995 دونما، منها 71.3 ٪ تحتوي على الزيتون و 9.9% العنب، و 6.3% أشجار فاكهة، و 4.3 ٪ البرسيم، و 3.1 ٪ بندورة، و 1.4 ٪ الشعير. وتقدر الاحتياجات المائية لهذه المساحة من المحاصيل بـ أكثر من 172 مليون متر مكعب من مياه الري سنويا، أي ما يعادل أكثر من 7 أضعاف العائد الأمن للحوض. كما بينت الدراسة أن ربحية المزارع تعتمد بشكل أساسي على تكلفة الري. وفقا" لتقديرات مؤسسة الإقراض الزراعي للعام 2005، تراوحت تكلفة الري ما بين 0.08 دينارا للمتر المكعب لري أشجار الزيتون و 0.4 دينارا للمتر المكعب لري أشجار الفاكهة. وبحسب هذه التقديرات لتكلفة الري، تراوحت الربحيه ما بين 150 دينارا لدونم المحاصيل الحقلية و 1600 دينار لدونم أشجار الفاكهة (الرمان). وقد بينت الدراسة انه على الرغم من أن المساحة المزروعة باشجار الزيتون تزيد على 70% من المساحة الكلية المزروعة (التي تستهلك النسبة نفسها من الاحتياجات المائية الكلية للمساحة المزروعة)، فإنه في الواقع تتسبب في خساره. وقد تعود الربحية المتدنية للزيتون الى أن كمية مياه الري المضافة أقل من الاحتياجات المائية المثلى، بغض النظر عن تدني الانتاجيه. ومما يدعم ذلك هجر بعض المزراعين لمزارعهم. كما بينت الدراسة أن نقطة التعادل (الربحية = صفر) لتكلفة الري هي الأقل للمحاصيل المروية المزروعة بالمساحات الكبيره، بينما المحاصيل التي لها نقطة تعادل مرتفعة مساحتها المزروعة هي الأقل.

الكلمات الدالة: الأزرق، ري، استخدام المياه، الكفاءة الاقتصادية، سعر التعادل، النمط الزراعي.

---

1) قسم الأراضي والمياه والبيئة، الجامعة الأردنية، الأردن.
abuawwad@ju.edu.jo

2) CDM International، الأردن.

تاريخ استلام البحث 2012/1/15 وتاريخ قبوله 2013/3/26.