Factors Affecting Agriculture Water Use in the Mafraq Basin of Jordan: Quantitative Analyses and Policy Implications

Jordan Component of the Sustainable Development of Drylands Project
Report# 7

New Mexico State University
College of Agriculture
Department of Agricultural Economics and Agricultural Business

and

The Badia Research and Development Center

By

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September, 2008

NM STATE UNIVERSITY

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Table of Contents

List of Figures

List of Tables

List of Appendix

List of Appendix Tables

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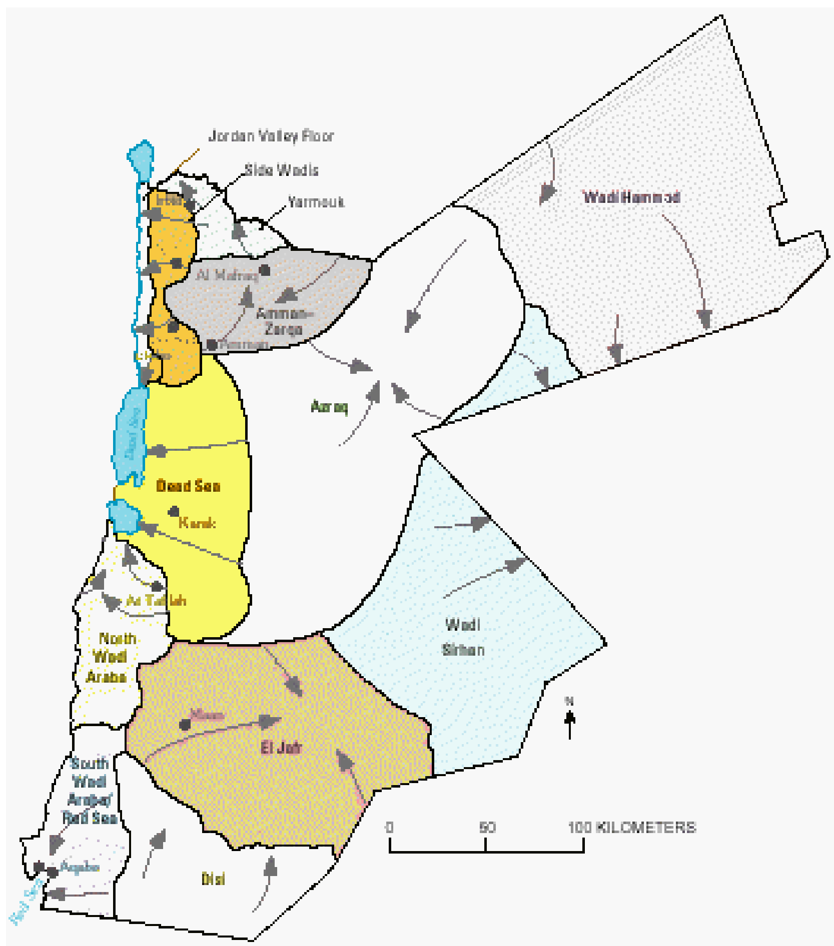
Introduction

With a land area of 91,971 square kilometers**,** a population of close to 6 million, a per capita GDP of nearly $3,000, and a real GPD growth rate of 6.4% (Jordan's Department of Statistics, 2008), Jordan is a relatively small but prosperous Middle Eastern country. This prosperity, however, is increasingly threatened by the prospect of reduced water availability for its main economic growth sectors, namely manufacturing, wholesale and retail trade, hotels and restaurants, transport, storage and communications, finance, real state, insurance and business services and construction. A significant share of this economic activity is in support of a thriving tourism industry.

It is estimated that Jordan's sustainable average annual supplies of water amount to 990 million cubic meters (MCM). Of these, 715 come from surface flows and 275 from sustainable groundwater extractions. In contrast, in 2005 water consumption reached 1,042 MCM, of which 679 were used for agricultural production. Under the status quo, the forecasted water requirement for 2020 is 1,647 MCM, with approximately half going to agriculture (WSPS, 2004). The contribution of agriculture to GDP, however, has stagnated at about 2.5% during the recent years (Central Bank of Jordan, 2005). In face of these irrefutable facts, the Jordanian Government is seriously considering various technological and policy alternatives to gradually transfer water supplies from agriculture to other industries.

The Mafraq/Azraq basin accounts for a significant proportion of the underground water resources available to Jordan. Although this aquifer is rechargeable, the current level of extraction of about 50 MCM exceeds its sustainable capacity. At present, most of this extraction is devoted to agricultural production through the pumping of water from wells that were sanctioned by the government in past decades. Although, legally, the government has the authority to rescind some or all of those pumping permits, farmers have come to think of them as long-term water "rights" and the political environment in the country makes it difficult to take action in this regard (Raed Al-Tabini, personal communication). In light of these reasons, policy makers are interested in understanding the factors driving water use and water use efficiency by farmers in this aquifer, and on gaining



Source: Halasah and Ammary

Figure 1. Jordan's Mafraq Region.

knowledge and information that help them make better decisions and justify actions to curtail agricultural water use in this basin.

Because of its proximity to Amman (Figure 1), the government's major policy objective in regard to the Mafraq basin is to gradually divert some of the water being used for agriculture to sustain economic growth in this city, which is home to more than half of the country's population and two thirds of its economic activity. Another key aspect of this objective, however, is to minimize the economic impact on farmers and the overall socioeconomic welfare of this region's inhabitants resulting from an eventual water transfer (personal communications with various government officials).

It is also important to point out those similar situations and policy dilemmas are found in most if not all other Middle Eastern countries, including Afghanistan and Iraq. Therefore, the objectives of this research are to enable Jordanian policy makers to make more informed decisions in regard to this major policy objective as well as to contribute to the overall understanding of the key determinants of water use and water use efficiency in the Middle East.

Data Collection

Data collection for this research took place in summer 2006, through a survey of 105 farmers scattered throughout the Mafraq basin. The survey sample was stratified by size to make sure that it was representative of the population of farmers in the region, which consists of approximately 300 Bedouin families. The survey instrument was administered by a team of three individuals of Bedouin descent with technical training in agriculture and strong ties with this area's population. Two of the individuals involved in the design of the questions in the instrument were also Jordanians of Bedouin descent with graduate degrees from British and Jordanian universities. Their advice was sought to make sure that the questions were framed in a culturally sound manner that was clear and understandable to the farmers and elicited reliable responses. These individuals were also instrumental on the training of the survey team, which was accomplished through a preliminary round of five interviews. The observation and information collected in these interviews was evaluated and used to refine the survey instrument and the manner in which it was administered.

The survey contained approximately 50 separate questions and took an average of two hours to administer. The reason for this long duration was that the survey team followed a protocol designed to set the stage for the farmer to become comfortable and answer the questions in an informal conversational environment. One of the team members was mainly in charge of asking and recording the answers to the questions, another was primarily tasked with maintaining the flow of the conversation with the farmer, and the third had a major responsibility for quality control, keeping an eye for unclear, ambiguous, or inconsistent responses. Appointments were made in advance for farmers to take the survey at a time of their choosing, and a conscientious effort was made not to rush the conversation. After the preliminary round of interviews, the survey team seemed to have achieved a high level of competence in the administration of the instrument (personal observation from the authors and Jordanian research collaborators) and, therefore, the authors are fairly confident on the reliability and validity of the data obtained.

Preliminary Analyses

Degree of Dependency on Farming

A first issue of interest being explored through this survey is the degree of dependency of the farmers on agriculture and, therefore, on the pumping of water from the Mafraq aquifer, for their sustenance. This issue was explored through several questions. When taken together, the responses to these questions shed much light on this issue. Responses to the first question indicate that only 36% of the farmers surveyed live on the farm, while 64% report living elsewhere. Of the 64% living elsewhere, 44% were found to reside in the city of Mafraq and

20% in Amman. The 36% of the individuals living on their farms pump 4.6 million m^3 (31%) of water from the aquifer each year. They use this water to irrigate 6,884 donums (26%) (1 donum = 0.10 hectares) of crop land and generate nearly JD 4 million (28%) in revenues from the sale of their agricultural products (Table 1). These individuals are most likely dependent on farming to support themselves and their families.

It is possible that many of the individuals living in the small city of Mafraq also depend on farming for their livelihoods. They pump close to 7 million m^3 (46.5%) of the water and use it to irrigate 12,628 donums (48%) of crop land and generate over JD 7.2 million (50.5%) in

Table 1. Production Characteristics by Farmers' Place of Residence.

	On-Farm (38 Farmers)		**Off-Farm (67 Farmers)**	
Description	*Total*	*Average*	*Total*	*Average*
Donum in production	6,884	181.2	19,483	290.8
Water used (m^3)	4.6 million	668.2[a]	10.36 million	531.74[a]
Revenue (JD)	4 million	581.1[a]	10.25 million	526.1[a]
Revenue per m^3 used		0.86[b]		0.99[b]

[a] per Donum
[b] Donum per m^3

agricultural sale revenues. The Amman farmers are the least likely to have to rely on their farm's revenues to make a living. These individuals irrigate 6,855 donums (26% of the area), use 3.36 million m^3 (22.5%) of the water, and generate JD 3.05 million (21.5%) of the sales.

A more direct question attempting to explore the degree of dependency of the farmers on agriculture was related to their income. About 62% of the respondents indicated that they derive the majority (75% to 100%) of their income from farming. Farming is the only source of income for 56% of them. At least 38% of the farmers earn the majority (50% to 100%) of their income from other sources (Figure 2). The 62% of the individuals that derive the majority of their income from farming hold about 50% of the area irrigated, use 61% of the water pumped from the aquifer each year and generate 63% of the total agricultural product sales. The 38% of the farmers that earn other sources hold the other 50% of the area irrigated, use 39% of the water and generate 37% of the total sales. A total of 5.75 million m^3 of water could be diverted to other uses each year if these individuals ceased to be involved in agriculture.

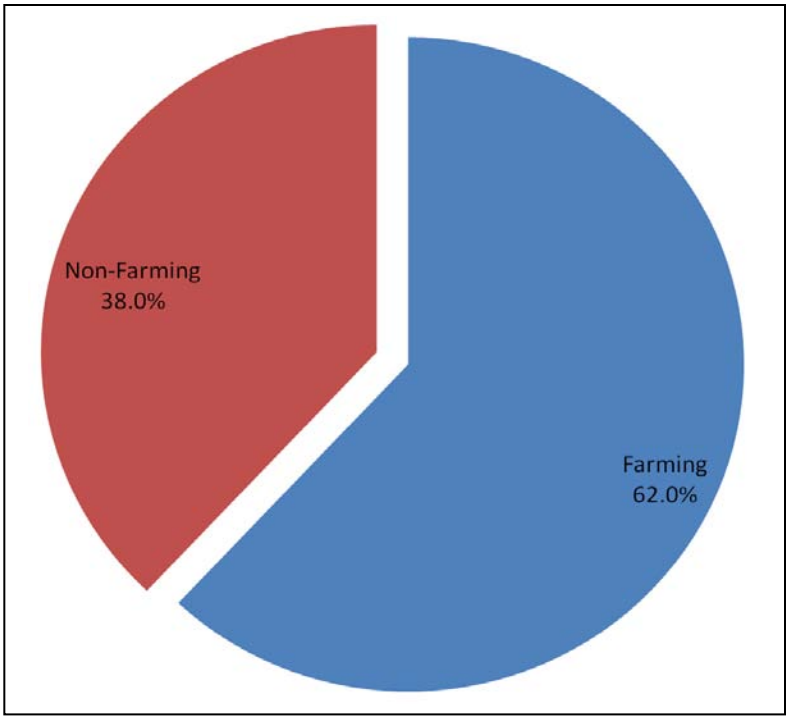


Figure 2. Farmer's Source Primary Source of Income

What farmers self-report to be their main occupation might also be related to their degree of dependency on agriculture to make a living (Figure 3).

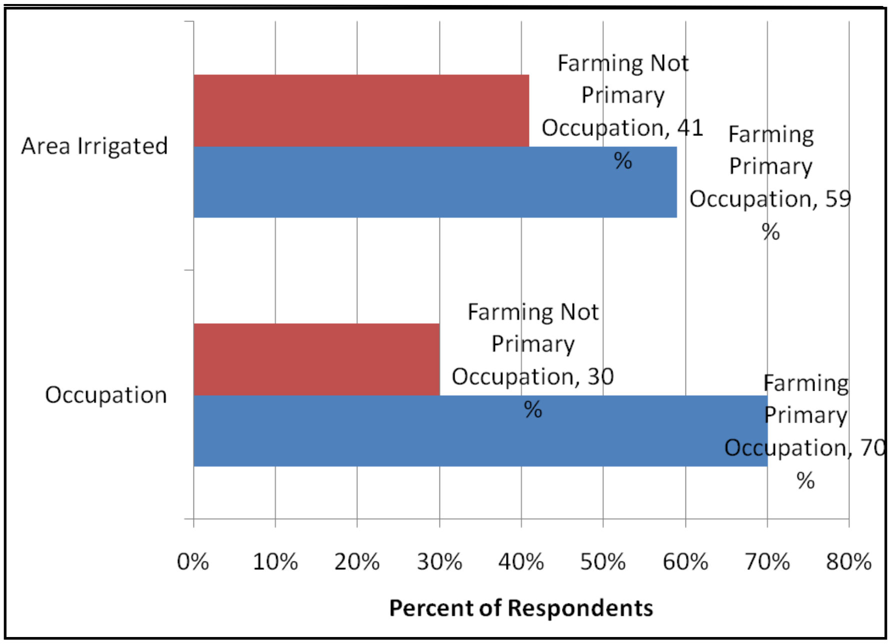


Figure 3. Occupation and Acres Irrigated

Nearly 70% of them report that farming is their primary occupation. Although these farmers only irrigate 59% of the area, they pump nearly 71% of the water and generate 69% of the crop sales. Farmers who indicated that farming was their main source of income generated only slightly more income per unit of water used compared with farmers for whom farming is not their primary source of income (Table 2).

Table 2. Production Characteristics by Farmers' Income Source.

Description	Farming main source of income (65 Farmers) Total	Average	Farming is not main source of income (40 Farmers) Total	Average
Size (Donum)	13,183.5	202.8	13,183.5	329.6
Water used (m^3)	9.13 million	692.5 [a]	5.83 million[1]	442.2 [a]
Revenue (JD)	8.98 million	681.2 [a]	5.27 million	399.7 [a]
Revenue per m^3 water		0.98 [b]		0.90[b]

[a] per Donum
[b] Donum per m^3

Educational level can also help ascertain what proportion of farmers might be able to make a living outside of agriculture, if needed. About 69% of the farmers surveyed only have a secondary education or less. (Figure 4) These individuals hold 57% of the irrigated crop area, use 67% of the water and generate 66% of the agricultural sales. Unless they already have another occupation that provides for a sufficient source of income, taking water away from these farmers might jeopardize their ability to make a living. Less than 5 million m^3 of water are in the hands of farmers that are educated enough to potentially earning sufficient income outside of agriculture through their profession.

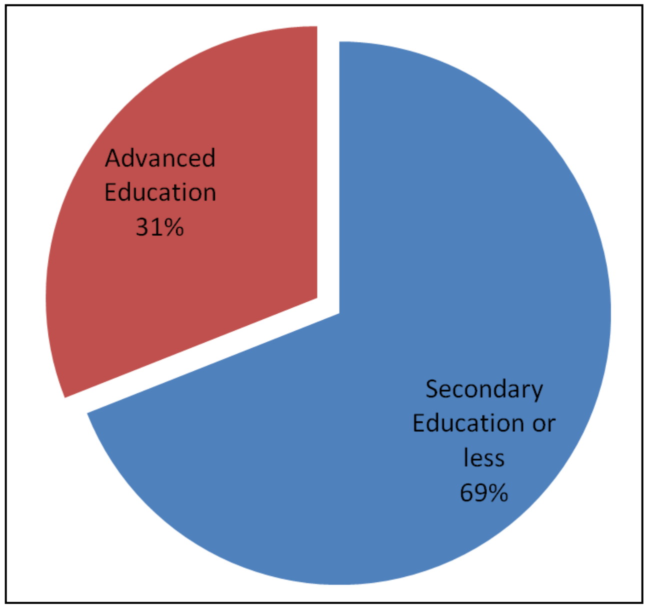


Figure 4. Educational Level

The last variable included in the survey that can shed some light on this first main issue of interest, i.e. the degree of dependency of the farmers on agriculture, is who is actually in

[1] Total values may vary slightly from other areas in the report due to donum assumptions.

charge of the day-to-day operation of the farm. It was found that most farms are managed by the farm owner himself (55%) or by one of his sons (17%). Only 21% are operated through a farm "agent" (Figure 5). On a per-farm basis, however, substantially more water is used when the farm is managed by an "agent" and these farms have larger average area. As a result, 8 million m^3 (54%) of the total amount of water pumped from the Mafraq aquifer each year is used in farms being operated by a contracted "agent."

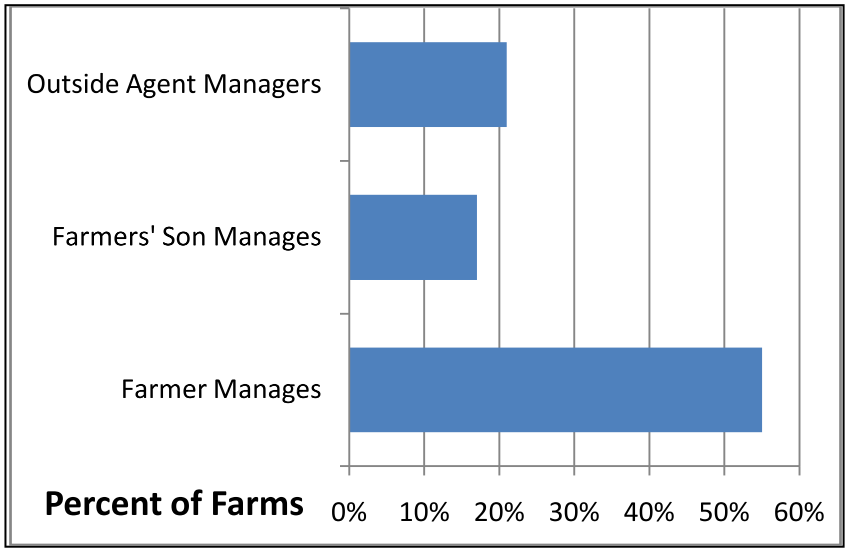


Figure 5. Farm Management

Since each of the five previously discussed variables might have some bearing on whether a farmer can survive and sustain his family without the income derived from irrigated agriculture, the surveyed farmers were also sorted by a combination of categories corresponding to these variables. Through this sorting it is found that 34 farmers (32%) live on farm or in the small city of Mafraq, report that farming is their main source of income, indicate that farming is their primary occupation, have a secondary education or less, and they themselves manage the farm. These individuals irrigate 6,346 donums (24% of the area), pump 4.67 million m^3 of water (31%) and generate 4.84 million JDs or 34% of the value of crop sales. Individuals fitting this profile are likely to have the most difficulty making a living outside of agriculture.

In contrast, it is found that only 8 (7.6%) of the farmers live in Amman, report that farming is not their main source of income and it is not their primary occupation, have a post-secondary education, and report that their farm is managed by an agent. These individuals irrigate 4,405 donums (16.7% of the area), pump 1.6 million m^3 of water (10.7%) and generate 1.36 million JDs or 9.5% of the crop sales value. These farmers are most likely able to make a living without reliance in agriculture. By extrapolating this amount of water to all 300 farms in Mafraq, it is estimated that close to million m^3 of water would be available for transfer each year if these individuals could be persuaded to stop pumping out of their wells.

Who is Influencing Irrigation and other Farm Management Decisions?

Knowledge about the agencies and individuals whose advice is sought and considered by the farmers when making irrigation and other farm management decisions is important for the design and implementation of future training and extension programs. Most farmers (80%) simply rely on self-experience for irrigation water use decisions. 20% receive guidance from an agricultural engineer and, interestingly, none cited the Ministry of Agriculture extension agents as a source of advice (Figure 6). The area irrigated by those who rely on self experience is 18,707 donums (71%), but they use 11,998,459 million cubic meters of water per year (81% of the total). The remaining 20% of the farmers who rely on an Agricultural Engineer for irrigation advice cultivate 7,590 donums of land (29% of the total) and use 2,887,800 cubic meters of water (19% of the total).

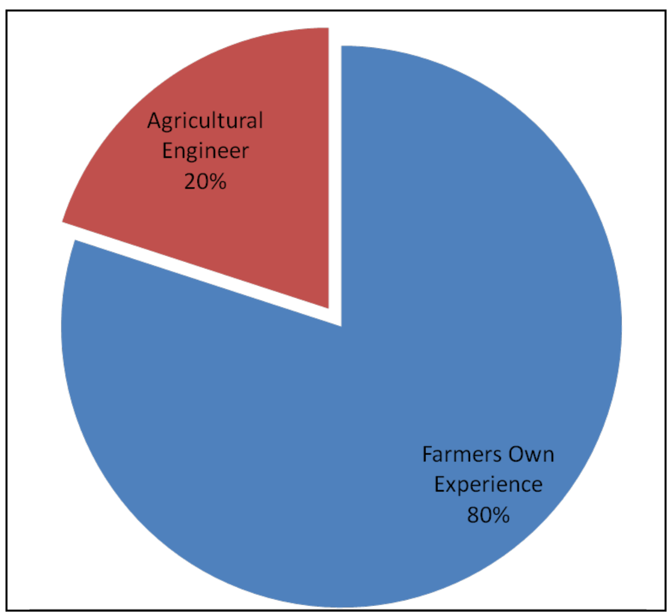


Figure 6. Information for Irrigation Decisions

The Age Effect

Age is often considered in survey analyses as, in many cases, the behavior and decisions made by individuals differ substantially according to this variable. In addition, the age variable might play a particularly important role in this research given the age-related policy decisions that could be implemented in regard to water use "rights." A full one-third of the farmers are 60 years old or older, while over 57% are at least 50 years old. About 36% (61%) of the water is pumped by farmers who are 60 (50) years and older,

This information is very pertinent for policy decisions involving possible water "right" buyouts. It is expected that older farmers can be persuaded to give up their implicit water use rights in exchange for a lower monetary compensation than younger farmers since, assuming the same life expectancy for all individuals, the present value of the expected stream of revenues from irrigated crop production is lower for older farmers. Even if the farmers assign some bequest value to their water "rights," this should be substantially lower than their own use value.

In short, retiring the water rights of all farmers over 60 would save approximately 5.5 million m^3, while capturing the rights of all over 50 would preserve nearly 10 million m^3 per year. An alternative policy to immediate buyouts would be to decree that the implicit water rights expire with the death of the current well owner. This policy has the obvious disadvantage that previously discussed annual water savings would only be slowly realized during the 15-25 years.

Employment and Income Generation

Employment and income generation are also critical variables for assessing the potential socioeconomic impact of a decline in agricultural production activities resulting in irrigation water use restrictions on Jordan's rural population and communities. The 105 farms surveyed in the Mafraq basin provide permanent employment for 729 individuals, 708 (97%) males, and 21 (3%) are females. Of these permanent workers, only 67 (9%) are Jordanians, while 650 (89%) are Egyptians, six (1%) are Syrians and six (1%) are of another nationality. About 25% of the Jordanian employees receive benefits, mostly in the form of housing. Less than 15% of the guest workers of other nationalities receive housing or any other benefit

The average daily salary for all permanent workers is JD 4.47. While, on average, Jordanian workers are paid JD 4.87 per day, guest workers of other nationalities are paid JD 4.43 per day. The total salaries paid to all 729 workers amount to JD 932,000 per year of which JD 93,318 goes to Jordanians and JD 838,741 accrues to guest workers of other nationalities.

In addition to permanent employees, 3,505 temporary workers are hired in these 105 farms. Nearly two-thirds of those workers are female. While 15% if the temporary workers are Syrian, most (77%) are Jordanians. The benefits received by temporary workers are negligible regardless of nationality. According to the survey, the temporary workforce is employed on these farms for an average of three months per year. Therefore, four temporary workers are approximately equivalent of one permanent worker and the 3,505 temporary employees are equivalent to about 876 permanent workers. This means that the 105 farms surveyed provide approximately 1600 full-time equivalent jobs, or about 15 jobs per farm. Each full-time equivalent job is associated with the pumping of 9,300 m^3 of water and JD 8,880 in total agricultural sales revenues. In addition to providing third-party employment, the income derived from these farms helps support a large number of dependents. The105 farms in the survey provide income for a total of 1129 individuals, based on an average of 10.75 family members per farm.

Well Ownership

Well “ownership” could be a critical variable not only affecting irrigation water use decisions but potential water pumping restriction policies as well. Curtailing or totally rescinding pumping “rights” on leased wells might be socially and politically more acceptable than on wells that are being used by the “owners” (i.e. the permit holders). Disappointingly, however, the survey data indicates that most (82%) of the farmers own the well from which they pump the water to irrigate their crops. These farmers use 85% (12.65 million m^3/year) of the water pumped each year versus 2.25 million m^3 from leased wells.

An interesting byproduct of the well information collected in the survey relates to the difference between well and water table depth. The average depth of the 105 wells included in the survey is 347.9 meters. The average depth of the water table at those wells is 267.3 meters, for a difference of 80.6 meters. Only three wells represented in the survey were within 20 meters of the water table depth, suggesting that few of the wells are in danger of becoming non-functional in the near future.

Cost and Value of Water

Some of the data collected in the survey can be used to make rough inferences about the cost and value of water for agricultural production in the Mafraq basin. The data indicates the maintenance and operation cost per m^3 of water pumped is higher in leased wells (JD 0.32) than in owned wells (JD 0.25). Well lease costs average JD 0.18 per m^3 pumped. Surprisingly, it was found that most farmers (29 out of 40) did not pay the mandated government fee for water pumped in excess of 150,000 m^3. Excluding any such government fees, the total average cost per m^3 of water pumped is JD 0.25 for owned-well farmers and JD 0.50 for leased-well farmers.

Since only 18% of the farmers lease wells, the average lease charge of JD 0.18 per m^3 of water yield can be considered a reasonable lower-bound estimate of the market value of water in this region. Most well owners value the water they pump for agricultural use at more than JD 0.18 per m^3, while potential well-renters might find it difficult to make a profit if paying more than JD 0.18 per m^3 of water. This suggests that well "owners" are receiving a substantial rent from holding a water pumping permit. At an average pumping rate of 142,550 m^3 per year, this rent amounts to at least JD 25,660 annually, on average across all 86 permit holders. Also note that, since the average sales revenues for the 105 farmer's surveyed amount to JD 0.96 per m^3 of water used, the total cost of the water input (including the opportunity cost or rent value of the water) represents approximately 50% of gross revenues. Unfortunately, poor record keeping by farmers makes it impossible to estimate other production costs, which would allow for a more refined analysis of this issue.

Key Overall Statistics

The total amount of water pumped by the 105 farmers surveyed is nearly 14.9 million m^3, which is used to irrigate 26,367 donums of crops. As this survey is a sample of approximately 1/3 of the farmers in Mafraq, basin-level pumping is estimated at about 45 million m^3 to supply approximately 80,000 donums of irrigated agricultural production. A total of JD 14.24 million in gross revenues from crop sales are generated by the farmers surveyed, resulting on a basin-level estimate of JD 42.72 million. This represents close to 10% of the annual value of the total agricultural production of Jordan.

Agricultural activity in this basin is estimated to employ 3x729=2,187 permanent and 3x3,505=10,515 temporary workers paying over JD 6 million/year in salaries and supporting 3x1,129=3,387 dependent family members. Total water cost (including well rent or opportunity cost) is estimated at JD 0.5 per m^3 pumped, or JD 22.35 million for the entire basin. Labor costs and sales revenues are estimated at JD 0.15 and JD 0.96 per m^3 of water, respectively. Although data on other production costs was not collected, these are believed to be significant as well. Most farmers, for instance, use a tractor (99%) and apply fertilizer (100%), mulch (58%), herbicides (87%), insecticides (100%) and fungicides (100%); and either hire a farm operator or devote a significant proportion of their time (or a son's time) to manage the farm. Profitability for farmers that have to pay for the market value of the water used (i.e. lease a well), therefore, should be substantially less than JD 0.30 per m^3. For farmers that hold water pumping rights, those rights most likely represent the main source of profitability.

A more advanced econometric analysis of water use in the Mafraq basin is provided in the Appendix A. This analysis examines four different models to explain the variation in four key dependent variables observed in the survey. These variables include: the overall crop output of the farm, the amount of water per unit of area used by farmers, water use efficiency and the total amount of crop sales generated per unit of water used.

Conclusions

Key findings from the survey work reported here include:

- Fifty percent of farm land in the Mafraq basin is held by individuals who earn a majority of their income from off-farm sources. These individuals use 39% of agricultural water in the basin and account for 37% of total agricultural sales. A total of 5.75 million m^3 of water could be diverted to other uses each year if these individuals ceased to be involved in agriculture.
- A majority of the farmers in the Mafraq basin surveyed had a secondary education or less. These individuals hold about 57% of the land used in agriculture and account for 67% of agricultural water used in the basin. Unless these farmers already have another occupation that provides a sufficient source of income, taking water away from these farmers might jeopardize their ability to make a living. Less than 5 million m^3 of water are in the hands of farmers that are educated enough to potentially earn sufficient income outside of agriculture through their profession.
- While a majority of the farmers interviewed lived on- or near-the-farm (in the small city of Mafraq), a small number (7.6%) lived in Amman. These farmers are more likely to be able to make a living without reliance on agriculture. By extrapolating water used from these surveyed farmers to the entire Mafraq basin, is it estimated that close to one million m^3 of water would be available for transfer

each year if these individuals could be persuaded to stop pumping out of their wells.

- Age may play an important role in efforts to reduce agricultural water use. Fifty-seven percent of the farmers surveyed were at least 50 years old. These farmers pump about 61% of the agricultural water used in the basin. If these farmers could be persuaded to give up their implicit water use rights (in exchange for a lower monetary compensation that their younger counterparts) nearly 10 million m^3 of water could be saved each year.

Undoubtedly, whether water rights are real or perceived, issues related to them are politically delicate and complex. The culture and traditions of countries like Jordan make it all that more difficult to deal with these issues. Although the government, economic development interests, and academicians have been able to raise the level of awareness and achieve a political and social consensus on the need for a more sustainable and efficient use of the country's water resources the specifics on how to accomplish this objective are a work in progress.

In the case of the Mafraq basin, a decision has been made to revert extraction back to a sustainable level and transition from mostly agricultural into non-agricultural uses in order to help meet the long-term water needs of the capital city of Amman. It is hoped that the research results discussed in this paper will help policy makers, society, and the farmers in this basin come to an informed, rational, and economically efficient agreement on a feasible plan to achieve such transition. It is also hoped that the findings in this particular case are somewhat applicable to similar situations in other Middle Eastern and perhaps developing countries in general. Finally, the analytical modeling framework adopted and the lessons learned in this study could be useful in the planning of similar research in other regions and countries.

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Appendix A - Advanced Analysis

Modeling Methods and Procedures

Multiple regression models are developed to explain the variation in four key dependent variables that were observed in the survey: the overall crop output of the farm, the amount of water per unit of area used by farmers, water use efficiency and the total amount of crop sales generated per unit of water used.

The crop output model is used to ascertain the key factors affecting the overall technical productivity of these highly diversified farm operations. The dependent variable in this model is a yield-output index consisting of the sum, across all crops produced, of the standardized yield values times the number of donums planted of each crop, divided by the total amount of irrigated area. Standardized yield values are obtained for each crop by subtracting the mean yield from the actual yield and dividing the result by the standard deviation of the corresponding crop yield data. This index is designed to measure the overall level of output from the diversified, multi-product farms analyzed in this study.

Water use efficiency is defined at the farm level as the ratio of the amount of water that should be used per unit of area to the amount that is actually being used by the farmer. The amount that should be used is computed on the basis of the survey data on the areas of different crops being grown by the farmers times the recommended use amounts per unit of area for each of those crops (Alawayda, Aledwan, and Alkarakee, 2005). Water use efficiency has to be evaluated at the farm level rather than on a crop by crop basis because the farmers do not keep track and, thus, could not report the amount of water used to irrigate each of their crops.

The amount of water used per unit of area is measured in m^3 per donum (1 donum = 0.10 hectares), while the total crop sales per unit of water are measured in Jordanian Dollars (JD) (1 JD $\approx$ 0.70 U.S. dollars) per m^3. Gross value of sales was analyzed instead of net returns because the collection of detailed production and marketing cost data was beyond the scope and means of this survey. However, it is important to point out that promoting economic activity is a main policy objective of the Jordanian government, which often subsidizes non-profitable enterprises in order to secure jobs and provide economic opportunity for its disadvantaged populations.

Three of the four previously mentioned models initially include the 19 explanatory variables listed in Table A1. The crop yield index model only includes the 14 variables listed in Table A2, which can be hypothesized to have a direct effect on water use. Although there is data on the areas of different crops planted by the farmers, the high number of crops being grown

Table A1. Descriptive statistics for the dependent and explanatory variables

	Average	Std Dev	Max	Min
Dependent Variables				
Total Water Use (m^3)	141,869	71,362	453,600	10000
Total Sales (JD)	135,578	153,939	920,975	4,500
Water Use (m^3/year)	141,869	71,362	453,600	10,000
Water/Area (m^3/donum)	756.84	498.28	3,000	75
Yield Output Index	-0.078	0.707	2.47	-1.87
Water Recommended/Water Used	0.814	0.753	5.750	0.100
Sales per Unit of Water (JD/m^3)	1.432	2.462	21.083	0.032
Explanatory Variables				
Farm Managed by Agent[1]	0.21	0.41	1.00	0.00
Farming is Main Profession[1]	0.70	0.46	1.00	0.00
Farmer Lives on Farm[1]	0.36	0.48	1.00	0.00
Farming is Main Income Source[1]	0.62	0.49	1.00	0.00
Expert Advice on Crop Selection[1]	0.30	0.46	1.00	0.00
Expert Advice on Irrigation[1]	0.20	0.40	1.00	0.00
Received Training on Irrigation[1]	0.27	0.44	1.00	0.00
Owns Well[1]	0.83	0.38	1.00	0.00
Well Discharge (m^3/hour)	64.10	20.75	150.00	0.00
Casing Size (inches)	7.00	2.82	16.00	4.00
Cost of Water (JD/donum)	0.30	0.47	3.43	0.02
Knows Water Table is Dropping[1]	0.70	0.46	1.00	0.00
Well Depth to Water Table (m)	80.64	50.49	260.00	10.00
Total Area Irrigated (donums)	251.11	181.77	820.00	30.00
% of Area Grown with Vegetables	0.54	0.48	1.00	0.00
% of Low Water Use Crops[3]	0.52	0.43	1.00	0.00
Uses Mulch[2]	0.51	0.47	1.00	0.00
Farmer's Age (years)	50.73	13.19	75.00	22.00
Univ. or Tech. Education[1]	0.31	0.47	1.00	0.00

[1] One if statement is true, zero otherwise. [2] One if in all crops, 0.5 if in some crops, zero otherwise. [3] Low water use means crops that require less that 500 mm per season.

makes it statistically unfeasible to include such variables in the models. Instead, the variables percentage of irrigated land planted with vegetables and percentage of crops that require less than 500 mm of water per season are included in hopes that they provide for an adequate summary of this information.

Econometric Results

The results from the estimation of the four models are presented in Tables A1, A2, A3, and A4. As the null hypotheses of homoskedasticity and normality are not rejected (α=0.20) in the case of the crop yield index model the results in Table A2 are obtained using standard OLS regression techniques. Interestingly this model shows an R^2 of only 0.092 and an adjusted R^2 of -0.049. Only one of the 14 slope parameters in this model is statistically significant (α=0.20) with a p-value of 0.04. However, the null hypothesis in the standard joint F test, that each and every one of the slope parameters in this regression is equal to zero, can not be rejected even at an α of 0.5. Therefore, the significance of the individual t-test for that one parameter is probably

Table A2. Results from the estimation of the crop output index model

Variable	Parameter Estimate	Standard Error	T-Value	P-Value
Intercept	-0.643	0.525	-1.226	0.223
Farmer's Age (years)	0.006	0.006	1.129	0.262
Farm Managed by Agent[1]	-0.212	0.229	-0.923	0.358
Farmer Lives on Farm[1]	-0.195	0.169	-1.154	0.251
Farming is Main Profession[1]	0.456	0.216	2.110	0.038
Univ. or Tech. Education[1]	-0.077	0.187	-0.414	0.680
Expert Advice on Crop Selection[1]	-0.072	0.185	-0.387	0.700
Expert Advice on Irrigation[1]	0.189	0.227	0.829	0.409
Received Training on Irrigation[1]	-0.086	0.169	-0.508	0.613
Well Depth to Water Table (m)	0.000	0.002	0.130	0.897
Total Area Irrigated (donums)	0.000	0.001	0.233	0.816
Water Use (m^3/donum)	0.000	0.000	0.167	0.868
% of Area Grown with Vegetables	-0.160	0.184	-0.869	0.387
% of Low Water Use Crops[3]	0.133	0.290	0.459	0.647
Uses Mulch[2]	0.086	0.261	0.328	0.744

[1] One if statement is true, zero otherwise. [2] One if in all crops, 0.5 if in some crops, zero otherwise. [3] Low water use means crops that require less that 500 mm per season.

due to the fact that, even if all parameters are equal to zero, it is not unlikely that one out of 14 parameters tested will turn out to be statistically significant at an α of 0.05. Standard procedures (Variance Inflation Factors and the Condition Number) indicate that the set of explanatory variables included in this model exhibits a low level of multicollinearity.

The total lack of significance of this crop yield index model has substantial policy implications as, even after accounting for all other factors that could potentially affect yields, the variable water use per unit of area can not be shown to have any effect on the yield index (p-value=0.84). This is evidence to the fact that farmers, in general, are applying irrigation water beyond its profit and even yield maximizing level. It is also interesting to point out that other factors that are generally assumed to affect yields, such as professional management, education, and access to expert advice do not appear to have a positive effect on this variable.

The average of the 19 standard error estimates from the heteroskedasticity-corrected version of Model 2 (Table A3) is 79.94 and the average p-value is 0.347, versus 29.90 and 0.170 after non-normality is accounted for. As a result, 13 parameters turn out to be statistically significant in the non-normal model (α=0.10) versus three at an α of 0.10 and seven at an α of 0.20 in the normal model. In the case of Model 3 (Table A4), the average of the WLS standard error estimates and p-values are 0.080 and 0.367, respectively, versus 0.050 and 0.326 for the non-normal model; however, the number of statistically significant parameters is about the same. This is due to the fact that the parameter estimates are generally higher in the non-normal model. In Model 4 (Table A5), the average of the WLS standard error estimates and p-values are 0.378 and 0.513, versus 0.0776 and 0.256 for the non-normal model. This results in only one statistically significant parameter at an α of 0.10 and two at an α of 0.20 under WLS versus nine (α=0.10) and 11 (α=0.20) in the non-normal model. In short, as expected, the use of the non-normal error estimation procedures substantially increases estimation efficiency. Therefore, the results form these models are presented in Tables A1, A2 and A3 and discussed next.

The first explanatory variable, whether the farm is run by an agent versus the farmer himself or one of his relatives, is statistically significant in all three models (α=0.10) indicating that agents use an estimated 110.18 m^3 of water per donum more that the family operators, but

Table A3. Results from the estimation of the water use per unit of area model

Variable	Parameter	Standard	T-	P-
Farm Managed by Agent[1]	110.180	34.113	3.230	0.002
Farming is Main Profession[1]	98.252	48.839	2.012	0.048
Farmer Lives on Farm[1]	80.455	39.084	2.059	0.043
Farming is Main Income Source[1]	-106.002	59.997	-1.767	0.081
Expert Advice on Crop Selection[1]	33.377	26.477	1.261	0.211
Expert Advice on Irrigation[1]	-84.615	35.651	-2.373	0.020
Received Training on Irrigation[1]	-27.620	30.504	-0.905	0.368
Owns Well[1]	-87.369	40.515	-2.156	0.034
Well Discharge (m^3/hour)	1.180	0.585	2.017	0.047
Casing Size (inches)	12.094	5.443	2.222	0.029
Cost of Water (JD/donum)	-360.492	56.346	-6.398	0.000
Knows Water Table is Dropping[1]	60.406	34.947	1.729	0.088
Well Depth to Water Table (m)	-0.914	0.301	-3.038	0.003
Total Area Irrigated (donums)	-0.868	0.099	-8.798	0.000
% of Area Grown with Vegetables	18.850	29.095	0.648	0.519
% of Low Water Use Crops[3]	46.083	51.905	0.888	0.377
Uses Mulch[2]	119.609	41.370	2.891	0.005
Farmer's Age (years)	-1.029	1.235	-0.834	0.407
Univ. or Tech. Education[1]	-0.719	12.541	-0.057	0.954

[1] One if statement is true, zero otherwise. [2] One if in all crops, 0.5 if in some crops, zero otherwise. [3] Low water use means crops that require less that 500 mm per season.

Table A4. Results from the estimation of the water recommended over water used model

Variable	Parameter Estimate	Standard Error	T-Value	P-Value
Farm Managed by Agent[1]	0.108	0.066	1.639	0.105
Farming is Main Profession[1]	0.094	0.096	0.978	0.331
Farmer Lives on Farm[1]	-0.026	0.033	-0.781	0.437
Farming is Main Income Source[1]	-0.079	0.082	-0.957	0.342
Expert Advice on Crop Selection[1]	0.092	0.053	1.732	0.087
Expert Advice on Irrigation[1]	-0.043	0.057	-0.746	0.458
Received Training on Irrigation[1]	0.075	0.048	1.577	0.119
Owns Well[1]	0.058	0.051	1.129	0.262
Well Discharge (m^3/hour)	-0.001	0.001	-0.994	0.323
Casing Size (inches)	-0.010	0.007	-1.510	0.135
Cost of Water (JD/donum)	0.785	0.104	7.551	0.000
Knows Water Table is Dropping[1]	-0.037	0.054	-0.687	0.494
Well Depth to Water Table (m)	0.000	0.000	0.546	0.587
Total Area Irrigated (donums)	0.079	0.011	7.327	0.000
% of Area Grown with Vegetables	0.047	0.056	0.841	0.403
% of Low Water Use Crops[3]	-0.110	0.080	-1.373	0.174
Uses Mulch[2]	0.019	0.096	0.197	0.844
Farmer's Age (years)	-0.002	0.002	-0.886	0.378
Univ. or Tech. Education[1]	-0.019	0.053	-0.353	0.725

[1] One if statement is true, zero otherwise. [2] One if in all crops, 0.5 if in some crops, zero otherwise. [3] Low water use means crops that require less that 500 mm per season.

Table A5. Results from the estimation of the sales per unit of water used model

Variable	Parameter Estimate	Standard Errot	T-Value	P-Value
Farm Managed by Agent[1]	0.282	0.105	2.680	0.009
Farming is Main Profession[1]	-0.098	0.137	-0.714	0.477
Farmer Lives on Farm[1]	0.097	0.067	1.451	0.151
Farming is Main Income Source[1]	-0.060	0.100	-0.600	0.550
Expert Advice on Crop Selection[1]	0.071	0.088	0.812	0.419
Expert Advice on Irrigation[1]	0.252	0.128	1.967	0.053
Received Training on Irrigation[1]	0.052	0.054	0.965	0.338
Owns Well[1]	0.324	0.136	2.374	0.020
Well Discharge (m^3/hour)	-0.001	0.002	-0.374	0.709
Casing Size (inches)	0.021	0.011	2.005	0.048
Cost of Water (JD/donum)	2.032	0.089	22.825	0.000
Knows Water Table is Dropping[1]	-0.169	0.065	-2.584	0.012
Well Depth to Water Table (m)	-0.001	0.001	-1.178	0.242
Total Area Irrigated (donums)	-0.025	0.015	-1.685	0.096
% of Area Grown with Vegetables	0.210	0.080	2.622	0.010
% of Low Water Use Crops[3]	-0.070	0.190	-0.370	0.712
Uses Mulch[2]	-0.217	0.098	-2.221	0.029
Farmer's Age (years)	0.004	0.003	1.285	0.202
Univ. or Tech. Education[1]	0.030	0.106	0.283	0.778

[1] One if statement is true, zero otherwise. [2] One if in all crops, 0.5 if in some crops, zero otherwise. [3] Low water use means crops that require less that 500 mm per season.

they exhibit a higher water use efficiency ratio and generate a superior value of sales per unit of water. Evidently agents are planting crops that require more water but are more technically and perhaps economically efficient in the use of this resource. Therefore, although farmers could benefit from the agents' expertise, this might increase overall water use. In addition, targeting the operations managed by agents for water use restrictions or "rights" buyouts might be more politically and socially acceptable but it will take the most efficient farms out of production.

Interestingly a related variable, whether or not the producer identifies himself as a "professional" farmer, is estimated to increase water use per unit of area by nearly the same amount (about 100 m^3 per donum) as the "managed by agent" variable. However, this variable does not show a statistically significant effect on the water efficiency or the sales to water ratio. Thus, "professional" farmers seem to be using more water but not in a technically or economically efficient manner. Perhaps these farmers could benefit from the agents' expertise in regard to these two key issues.

In regard to the variable indicating whether or not the farmer lives on farm, it is important to note that the families that live on farm likely devote a non-negligible share of their total water use for household consumption, particularly in the case of small farms. This might explain why their overall water use per unit of area is higher than those who do not live on farm. However, note that their ratio of water recommended to water used and value of sales per unit of water are not statistically different from those who do not live on farm. Therefore, these findings would not hinder a policy case to allow these family farmers to continue making a living of agriculture.

Although the individuals for whom farming is the main source of income appear to be as efficient in the use of water from a technical and sales revenue standpoint, they tend to use less water per unit of area (106.00 m^3/donum with a p-value of 0.081). Given that water is being generally over used and that pumping water for irrigation is costly (average variable cost of operation of JD 0.30), it is possible that those who derive their main source of income from farming are more cost-conscious and thus apply less water per unit of area. In any event, this finding could support a policy decision to allow individuals who derive the majority of their income from farming to continue growing irrigated crops in the Mafraq basin, especially if the Jordanian government invests in training on crop selection and marketing for this group of relatively disadvantaged farmers.

Another interesting explanatory variable included in these models is whether or not the farmer receives expert advice on crop selection. Statistically, this variable is only found to have moderately significant positive effect on the water use efficiency ratio. This could be due to the fact that guidance on the recommended amount of irrigation is provided as part of the crop selection advice. However, there is no evidence that such advice reduces the amount of water used per unit of area or the value of sales generated per unit of water. Therefore, it is concluded that the current sources of expert advice on crop selection are not as sound as they could be.

In addition, while it can not be concluded that receiving expert advice on irrigation increases the water use efficiency ratio, this is found to reduce the amount of water used per donum by 84.62 m^3 (p-value of 0.020) in comparison with the average use of 757 m^3/donum and increase the value of sales per unit of water applied by JD 0.252 per m^3 (p-value of 0.053) versus the overall sample average of JD 1.432/m^3. In short, although they can perhaps be improved, the current sources of irrigation advice seem to be having a positive impact. In contrast, producers who at some point received training on irrigation seem to exhibit a somewhat higher (0.075 versus the sample average of 0.814) water use efficiency ratio (p-value of 0.119) but do not appear to use less water per unit of area or generate more sales per unit of water. This suggests that these two sources of irrigation information might complement each other quite well.

Several other policy implications can be drawn from the previously discussed results, which have to be framed on another key finding of the survey that all this advice is being provided by pesticide company salespersons and privately hired experts, not the Ministry of Agriculture and Irrigation (MAI) extension agents. Given that the advice is found to have important effects in certain cases, the MAI agents could have a significant impact if they are supported and make more efforts to work with and earn the trust of the farmers. Second, while the guidance and training on irrigation being provided by these private parties seems to be generally having positive impacts, it appears that the advice on crop selection is focused on technical aspects and ignores the economic and marketing consequences of such decisions. MAI agents should play a role on addressing this deficiency.

Since nearly 20% of the farmers irrigate from a leased well, it is important to analyze the effect of whether or not the farmer owns the well on the three dependent variables of interest. Farmers who own the wells from which they are pumping appear to use substantially less water per unit of area (87.37 m^3/donum) and generate a markedly higher value of sales per unit of water applied (JD 0.324/m^3). The effect of well ownership on water use efficiency is also positive but statistically insignificant (p-value of 0.262). The water use result is perhaps due to the fact that the farmers who own the wells have a longer-term planning horizon and are thus more inclined to make a judicious use of this finite resource. Unlike the lessees, they are also concerned about the depreciation of their well equipment. And, everything else being constant, a lower water use will result in higher sales per unit of water. This relative technical and economic inefficiency in the use of water by farmers leasing wells could be a factor to justify the rescinding of water “rights” to those that are not directly making use of them.

Both explanatory variables related to well pumping capacity, discharge and casing diameter, are found to have positive statistically significant effects on the amount of water used per unit of area. This finding suggests that water use in the Mafraq basin could be curtailed by limiting the discharge and/or casing capacity of the wells as a condition for the farmers to maintain their pumping “rights.” In light of the previously discussed results, it is unlikely that such action would hinder their overall yields and revenues. In fact, it might increase farm profits by reducing the total water pumping costs.

Perhaps the most important result of this analysis is the fact that the cost of water (specifically the average variable cost of well operation) is found to have statistically significant and empirically relevant effects on the use of water per unit of area (-360.50 m^3 per donum with a p-value of 0.000), the water use efficiency ratio (0.785 with a p-value of 0.000) and the value of sales generated per unit of water (JD 2.032 per m^3, with a p-value of 0.000). Note that the magnitudes of these parameter estimates have to be assessed in light of the fact that the cost of water is measured in JDs and averages about JD 0.30 per m^3. Thus, a doubling of the cost of water is predicted to reduce water use by about 108.15 m3 per donum, increase the water recommended to water used ratio by 0.236 and boost the value of sales generated per unit of water used by over JD 0.60 per m^3. These results could be used in support of a policy to charge farmers for the water that they pump to irrigate their crops.

Another interesting result is that farmers who know that the water table is dropping appear to use more water per unit of area (60.41 m^3 per donum with a p-value of 0.088) and, perhaps as a result, exhibit a lower value of sales per unit of water applied (JD -0.168/m^3 with a p-value of 0.011) than those who do not. Although to a policy maker this might seem counterintuitive, these results are expected since water is a common resource to all producers in the Mafraq basin. Therefore, knowledge that the resource pool is finite and might not be available in the near future motivates these farmers to use more of it, i.e. to act in a manner that they believe will maximize their returns in the short-run before the actions of others exhaust the common pool. Thus, policy makers are advised not to follow their intuition and publicize the fact that the water table is dropping in hopes that the producers will be more judicious in their use of this resource. Instead, it is recommended that they undertake actions that individually motivate farmers to reduce water use to more efficient levels.

Interestingly the variable “depth to the water table” is found to have a negative effect on water use per unit of area. In regard to this result, it stands to reason that if they know that the water table is dropping, farmers whose wells are relatively deep in relation to the location of the water table would be less motivated to overuse this resource than those whose wells are about to run dry. This, again, is due to the fact that water is a common resource.

Another policy-relevant variable that shows strong statistical and empirical significance is the total area irrigated. Evidently, larger farms use less water per unit of area (-0.869 m^3/donum with a p-value of 0.000), exhibit a higher water efficiency use ratio (0.079 with a p-value of 0.000), but generate a slightly lower crop sale value per unit of water (JD -0.025/m^3 with a p-value of 0.096) for each additional donum of irrigated land. Generally in developing countries larger farms tend to use more efficient technologies and have access to a better knowledge base and management and marketing resources. In this particular case, however, it is believed that these results are due to the fact that larger farms simply have less water availability per unit of area than smaller farms, as all producers surveyed have a single well and there is a limit to amount of water that can be pumped from it. Thus, farmers with more land will tend to stretch their available water to be able to crop all of their land and, because of it, make a more technically efficient use of this valuable resource. The fact that these farmers generate a slightly lower value of sales per unit of water could be explained by the counter-balancing effect that large farms tend to grow field crops, rather than fruits and/or vegetables, which obviously have a lower market value.

Policy-wise this represents a dilemma since larger land-holders are generally less likely to rely on agriculture for making a living. The average area irrigated by the 64 producers for whom agriculture is the main source of income, for instance, is 2.05 donums, versus 3.25 for the 41 for whom it is not. The average area irrigated by the 33 producers who have a technical or university education is 3.44 donums, versus 2.09 for the 72 who do not. Policy makers in Jordan thus have a challenge in finding the right balance between basic income support and water use efficiency objectives.

Disappointingly, only one statistically significant parameter turns out to be associated with the two explanatory variables included in an attempt to capture the effects of the crop mix on the dependent variables of interest, that is, the percentage of irrigated land planted with vegetables and the percentage of crops that require less than 500 mm of water per season. Specifically, the percentage of vegetables grown is found to increase the value of sales generated (p-value of 0.010). This could indicate that vegetables are generally more valuable than field and fruit crops, but might also be due to the fact that vegetable prices were relatively higher during the year of the survey.

Interestingly, it is found that those farmers who use mulch seem to apply more water per unit of area and generate a lower value of sales per unit of water. This result also has to be evaluated in light of the fact that, in Model 1, the use of mulch did not show a statistically significant effect on overall yields (p-value of 0.733) and that farmers are generally are applying much more water than what is actually needed (average water recommended to water used ratio of 0.814). Since the models did not include the percentages of the areas of different crops being planted, it is possible that the use of mulch is acting as a proxy variable for crops grown in which the farmers tend to apply lots of water. Given that mulch use does not seem to affect yields, the apparently lower sales values might be due to lower prices for those crops during the particular year of the survey. Finally, it is noted that the farmer's age and his educational level do not show a statistically significant effect on any of the previously discussed dependent variables.