Economic and Environmental Impacts of Supplemental Irrigation in Rain-Fed Agriculture: the Case of Wheat in Syria

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Abstract

Moisture stress coupled with the increasingly variable weather conditions experienced by farmers in the arid and semi-arid regions are leading to higher dependence on irrigation to supplement the meager rainfall received. Market and non-market valuation methods are employed in this paper to measure the economic and environmental impacts of the shift from traditional supplemental irrigation (TSI) to improved supplemental irrigation (ISI) of wheat farms in zones 1 and 2 of the Aleppo, Deraa and Al-Hassakah provinces in Syria. Even at the low level of its current adoption on wheat farms in three provinces(22.3%), ISI is preventing a total of 2995 tons of salt from being deposited annually in the three provinces on the top layer (0-20cm depth) of the soils alone. Even though ISI leads to marginal reduction in current profit, farmers' valuation of salinity prevention is found to be much greater. Simulation results show that the shift from ISI to TSI will extend the useful life of the wheat farms from 77 to 135 years substantiating farmers' high valuation of the salinity prevention. The conservative national estimate of all the environmental and economic benefits reaped so far due to the adoption of ISI on Syrian wheat farms is estimated at about SYP 994.2 million (US$ 21.6 million) per year.

Key words:

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I. Introduction

Over one third of the world's land surface (38 percent) is threatened with desertification, where eight out of the fifteen eco-regions fall in this category (Núñez et al., 2010). The immediate cause of desertification is the removal of vegetation which is driven by a number of factors, alone or in combination, which include tillage for agriculture; too many livestock on too little land; removal of crop residues for feed/construction use; deforestation for fuel wood and construction materials; and inappropriate irrigation practices that lead to salinity (Lund, A. 1999).

In Syria, about 27% of total agricultural land is irrigated (MunlaHasan, 2007). The demand for irrigation in the country has increased steadily over the decades, almost doubling since 1985 (FRMP, 1995).The main source of water for irrigation in Syria is groundwater. Over the years, excessive-pumping has led to the rapid depletion of groundwater, where current water deficit ranges between 2.85 and 4.70 billion m^3/year (MunlaHasan, 2007). Government policies also encouraged intensification through incentives such as input subsidies and crop area allotment that entitles farmers to sell their harvest to the government at premium prices. The government also provided loan to farmers for well drilling and pump installation (FRMP, 1995). These have put all the conditions for over irrigation in place.

The traditional surface canal gravity Irrigation system (TI) is the typical irrigation method at the field level in Syria (WB, 2001). TI in Syria leads to the loss of 10-60% of water due only to transpiration and seepage (Abdrabbouh, 2007). It also leads to over-irrigation especially in the absence of adequate land leveling. For instance, a study conducted in the Aleppo governorate of Syria showed that in 2007, the average water application rate for supplemental irrigation of wheat was 2658.3 M^3/ha - an amount which is over 300% higher than the recommendation by the Syrian Ministry of Agriculture and Agrarian Reform (MAAR). This shows that there is a large scope for reducing the amount of irrigation water used in Syria. When water is continually pumped from groundwater sources beyond its replenishment rate, there comes a time when the water table reduces all the way to saline brackish water layer. In such situations, poorly managed irrigation can lead to salinization (Nova, 2006).

II. Supplementary Irrigation in Syrian Wheat Farms

Wheat is the single most important food grain grown in Syria where in 2009, it was planted on 1.43 million ha (33% of the total cultivated land). It is a crop of strategic importance on food security grounds. Between 1980 and 1985, while the population of Syria grew at an annual average of 3.8 percent, wheat production registered a negative rate of -0.3 percent, with high fluctuations within (FAO, 2009). Syrian policy makers were aware that further production increases may not be achieved with traditional technology and by merely increasing land area under cultivation. Instead, there was a felt need for technologies that improve productivity and stabilize yield.

Supplemental irrigation was one of the technologies considered for boosting wheat production and achieving greater food security. In 2006, wheat was cultivated on nearly 1.8 million hectares, where 45% was irrigated and the remaining 65% rain fed, with agro-climatic[2] zones 1 and 2 accounting for more than 85 percent of total rain fed wheat land. In the same year, total wheat production amounted to 4.9 million metric tons (MAAR, 2007) with 72 percent coming from the irrigated lands. The disparity between irrigated land area under wheat cultivation and its contribution to total production indicates the importance of land and water resources management for wheat

[2] Syria is divided into five agro-climatic zones where: Zone 1 represents areas with average annual rainfall exceeding 350 mm but has 33% probability to be less than 300 mm. Zones 2-4comprise of areas with average annual rainfall of over 250, 250 and 200mm with more than 33%, 50% and 50% chances respectively of falling below the averages. Zone 5 refers to areas where average annual rainfall is less than 200 mm.

production, especially in the rain fed wheat zones 1 and 2. Although climatic conditions in these agricultural stability zones[3] are usually amenable to wheat production, rainfall is erratic and may cause low or highly variable yields.

The concept of SI is not new to the wheat growing regions of the Near East, and the practice dates 6000 years back (Perrier and Salkini, 1991). However, supplemental irrigation is understood by most farmers as the use of irrigation in addition to rain water – regardless of the amount applied. In its true essence, SI is the application of irrigation water only when rainfall fails to provide essential moisture for improved and stable production, and the amount and timing are scheduled to ensure that a minimum amount of water is available during critical stages of crop growth (Oweis, 1997). SI in low rainfall areas not only increases yield relative to purely rain-fed production, but also leads to optimal use of scarce water available from renewable resources and substantially improves the productivities of water from both irrigation and rainwater when applied conjunctively (Oweis et al., 1998 and 2000, Oweis and Hachum, 2004). To avoid confusion, we make distinction in this paper between improved supplemental irrigation (ISI), in which the recommended water application rates are used and traditional supplemental irrigation (TSI) where farmers use unnecessarily excessive irrigation over the recommended levels[4].

From 1986 to 1990, the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Syrian Ministry of Agriculture and Agrarian Reforms (MAAR) launched a project to promote and transfer ISI technologies to Syrian spring wheat farmers. The components of the ISI

[3] Wheat based systems are located in agricultural stability zones 1 and 2, an area that stretches from the outer margins of the Northeast to the Southwest of Syria. Total land area for Zone 1 is 2.7 million ha and that of Zone 2 is nearly 2.5 million ha.

[4] Scheduling of SI is determined for each year using the water balance method. For instance, in zones 1 and 2 of Syria, which are the study areas for this research, optimum yields were obtained with SI of 600 to 1800 m3/ha. Hence, in this analysis, we used the higher end (1800 m^3) as the upper limit for the amount of water applied under ISI.

technology focused on irrigation scheduling: when to irrigate, how to irrigate, and how much water to use (Salkini, 1992). The ISI technology package for wheat farmers in Syria was also coupled with improved wheat varieties and organic fertilizers. The main objectives of the project for the introduction of ISI in Syria were to reduce yield instability, and increase water use efficiency. However, apart from the intended purposes, environmental benefits, such as water conservation, reduction of salinzation and the prevention of fertilizer leaching, can be considerable and hence became an important dimension in assessing the impact of ISI in Syria.

Currently, the zonal extension offices report that in addition to rainfall, all farmers in zones 1 and 2 use variable quantities of irrigation water depending on the depth and yield of wells and capacity of pumps installed. However, data from MAAR (2009) shows that out of 750,479 ha of total irrigated wheat area in the whole Syria, only 10.9% (81,802 ha) is under ISI.

III. Objective of the study

Several studies have been conducted to estimate the impacts of SI. For example, El-Shater (2009), Shideed et al (2005), Adary et al. (2002) and Salkini and Ansell (1992) reported almost twofold increases in wheat yield resulting from the adoption of SI and related technologies relative to exclusively rain-fed production.

ISI technology enhances water productivity (Ibeyie et al., 2006), leading to water conservation among farmers who switched from TSI practice. However, this may be countermanded by increased water use by farmers who switched from no irrigation under rain-fed conditions to ISI, although they would use less water than if they had switched to TSI techniques. Water use efficiency measurements in West Asia and North Africa revealed that wheat yield under rain-fed conditions ranges from 0.35 to 1.0 kg per m^3 of water (Oweis and Hachum, 2009). In comparison, appropriate management and optimum application of 1m^3 of SI in wheat produces additional gain of 2.0 to 3.5 kg over rain-fed wheat (Ilbeyi et al., 2006). Therefore TSI results in irrational and wasteful usage of scarce water resource as compared to ISI.

With TSI, soil salinization could be a major environmental threat. In low rainfall areas, ISI coupled with appropriate technologies such as sprinklers can reduce the pace of desertification by keeping soil salinity in check. ISI also have other environmental benefits which are not included in this analysis. Examples of these benefits include the prevented loss of fertilizer due to excessive irrigation through leaching and also the reduction in carbon emission from the reduced amount of fuel to pump water. The economic benefit to the farmer of the latter however is treated in this paper.

The shift from TSI to ISI reduces the amount of water pumped thereby helping to reduce the ever increasing speed of depletion, particularly of ground water. However, there are a number of possible outcomes of this shift: one possibility is that the excess water from the TSI will percolate into the same aquifer it was pumped from, thereby having only economic implications to the individual farmers who incur unnecessarily high cost to pump the excess water. Hence, as far as the irrigation source under consideration is well water, the percolating water cannot be considered as lost because it is going to be available for future use regardless of the user. Moreover it will have more or less the same salinity level when it goes back to the original aquifer for which it will not be considered as lost as with soft irrigation water that percolates into an aquifer of high salinity (USGS, 2010).

The second possibility is that the excess water may not necessarily percolate into the good aquifer from which it was originally pumped but dissipate into other protracted poor aquifers with such rocks as shale or solid granite, which do not allow for the free movement of water to recharge the ground water table (TEE, 1969). The probability of this happening will determine the outcome.

A third possibility is that, the excess water from traditional irrigation may not necessarily go all the way back to the aquifer from which it was pumped, especially when the well is very deep. However it may go to soil depths at which level it may not be available for the crop. With longer duration and increased temperatures, all or part of this moisture may dissipate in the soil which is eventually lost to either direct evaporation from the soil surface or to evapo-transpiration by weeds. The water in this case can be considered as lost because it may not rain back to the same place and recharge the particular aquifer (USGS, 2010). For instance, our sample survey results showed that the average depth of the wells used for irrigation is around 190m. This we believe consolidates the third possibility discussed above in that the excess water from traditional irrigation practice may not go all the way back to the same aquifer it was pumped from.

In this paper, we hypothesize that the shift from TSI to ISI reduces the pace of desertification via the reduction in the magnitude of soil salinity while at the same time leading to higher crop yields. Moreover, the increased water use efficiency and higher yields would lead to higher adoption of ISI by both types of farmers (those who have been using the traditional irrigation method where excessive irrigation water has been applied to supplement the rain water and also those who entirely depended on rain water). The net effect is that the widespread adoption of ISI to close the gap between optimal water requirement of crops and available water from rain will lead to ground water conservation.

The objective of this paper is therefore to provide empirical evidence from Syria to substantiate these arguments by making comparisons between ISI and the counterfactual (TSI). In this paper, attempts are made to estimate the environmental benefits (in terms of biophysical units) and also market and non-market valuation of on-farm profitability changes due to the shift from TI to SI. The farm-level economic savings from reduced fertilizer leaching and non-market valuation of the off-farm environmental impacts are however beyond the scope of this analysis. The specific aims of this paper are therefore to:

1. Empirically estimate the effect of the shift from TSI to ISI on the pace of soil salinity build up and ground water depletion in the region;
2. Quantify these environmental impacts (i.e., provide estimates of the amount of salt prevented from being deposited on the soil and the amount of water prevented from dissipating);
3. Make market and non-market valuations of on-farm benefits and costs of the shift from TSI to ISI;
4. Assess the impacts of different levels of water tariffs (user charges) on farmers' irrigation water application rates.

IV. Data

Owing to their relatively high share in total rain fed wheat land in the country and also the tremendous scope for SI, zones 1 and 2 of Syria have been chosen for this study. From among the total of 14 governorates in the country, 12 have areas which fall in zones 1 and 2 out of which the top three wheat producing governorates (Aleppo, Deraa and Al-Hassakeh) were chosen for this study. These three governorates account for about 66% of total wheat land and 61% of total wheat production in Syria.

For a 95% level of confidence for the estimation of the total number of adopters of supplementary irrigation, the minimum sample size needed is calculated to be 513. The total sample was then distributed proportionally using a stratified sampling procedure among the two zones where 241 and 272 households were drawn from Zones 1and 2 respectively. The distribution of these households into the three governorates and other details about the sample are provided in Table 1 below while the profile of the sample farm households in terms of the irrigation method and the amount of water used are presented in Table 2. Table 3 characterizes the sample farmlands.

Table 1: Number of Villages and Households Selected Randomly by zone and Governorate

	Aleppo		Dara'a		Al-Hasakeh		Total	
	Z1	Z2	Z1	Z2	Z1	Z2	Z1	Z2
No. of villages selected	5	4	4	4	4	5	13	13
Total number of households in selected villages	30752	30647	12152	16383	23500	29500	66404	76530
No. of households selected by zone	111	109	45	59	85	104	241	272
No. of households selected by governorate	220		104		189		513	

Table 2: Profile of the Sample farm households in terms of Irrigation Method and Water Use

	Zone 1	Zone2	Total
		Traditional irrigation	
Households using the practice (%)	34	70	53
Average water used M^3 per ha	2,554	2,744	2,686
Av. Yield (Kg/ha)	5,384	4,892	5,040
		Sprinkler irrigation	
Households using the practice (%)	66	30	47
Average water used M^3	1,852	1,910	1,869
Av. Yield (Kg/ha)	5,840	5,460	5,733

Note: Some farmers who use surface irrigation methods are applying less than 1800M^3/ha while some farmers who use sprinklers apply excessive irrigation water (>1800M^3/ha).

Table 3: Characterization of Sample Farmlands

Attribute	level	%
	0 to 50 meters	41.6

Well Water Availability	51 to 100 meters	52.5
	100 to 200 meters	5.6
	Over 200 meters	0.3
Well Water Salinity	Low	87.5
	High	12.5
Soil Types	Shallow	10.9
	Deep red	89.1
Proximity to population centers	Close to an urban center	34.3
	Close to a rural population center	40.2
	Located in remote or unpopulated area	25.5

For various reasons, actual measurements of environmental variables such as soil and water salinity were not conducted in the survey discussed above. The survey was conducted between February-March, 2010 where data was collected for the previous calendar year (2009). However, in the course of writing this paper, there was a felt need to do these measurements so as to establish or complement existing data on the relationship between soil salinity and water salinity as well as their effect on yield. Moreover, in order to estimate the net water conserved due to the use of ISI, it is necessary to determine the amount of traditionally irrigated and rain-fed wheat land which was converted to ISI. The average irrigation water use for each irrigation type is also required. To this effect, a separate survey was conducted in July, 2010 on a random sample of 78 farm households drawn from among the 189 original sample households in the Al-Hassakeh governorate, the results of which are summarized in Table 4 below. Al-Hassakeh was deliberately chosen because it is one of the regions where there is wider adoption of ISI and hence the small sample is likely to have good size of adopters from which we can get adequate information about adopters.

V. Methodology

For the economic impacts, the cost-benefit analysis (CBA) method is used at the farm level, where on the benefit side, the yield gain, the value of water saved (if any) and the farm level benefits of avoiding salinity will be included. While on the cost side, direct farm level costs including cost of establishing and operating ISI and its related technologies will be included.

Mazid et al (2003) used proportionality to estimate land saved at current production levels, using a base production level and area of production. In a country like Syria, where there is not much land to which agriculture can expand, the land saving argument may not be justified. However, in a global context, the demand gap that has been closed in Syria due to the higher yield resulting from the use of ISI would have had to come from elsewhere, which would have required either more intensification or expansion of cultivated land both of which would have negative environmental impacts. The lack of land for agricultural expansion in zones 1 and 2 of Syria however makes it possible for ISI to potentially result in water conservation.

Table 4: Irrigation History – Summary of Survey Results from Al-Hassakeh

	Year						
	1980	1985	1990	1995	2000	2005	2009
Total land holding of the 78 sample households (ha)	2990	2990	2990	2990	2990	2990	2990
1. Total wheat area (ha)	1427	2228	2535	2535	2535	2535	2535
- Area under rain-fed wheat (ha)	787	208	0	0	0	0	0
- Wheat area under ISI (ha)	0	0	165	179	510	603	699
- Area of traditionally irrigated wheat (ha)	640	2020	2370	2356	2025	1932	1836
2. Total area under other crops (ha)	758	529	455	455	455	455	455
- Area under others Rain-fed crops (ha)	656	189	0	0	0	0	0
- Area under other traditionally Irrigated crops (ha)	102	340	450	444	444	444	444
- Area under other crops irrigated with ISI (ha)	0	0	0	0	0	0	0
3. Fallow	805	233	0	0	0	0	0
Total quantity of water used by the 78 sample households (in 000’ M^3)	2,726	6,847	11,723	11,634	11,098	10,856	10,814
- Quantity of water used on wheat fields (000’ M^3)	1,522	2,563	6,065	6,051	5,555	5,415	5,271
- Quantity of water used on cotton fields (000’ M^3)	1,204	4,284	5,658	5,583	5,543	5,441	5,543
- Quantity of water used for traditional irrigation (000’ M3)	2,726	6,847	11,456	11,350	10,312	9,931	9,746
- Total quantity of water used for ISI (in 000’ M3)	0	0	267	284	786	925	1,068

Note: For the years during and before 1985, other crops include cotton, lentil and chickpeas. After 1985 however, other crops include only cotton.

We use the regression approach to compute the value of water saved by ISI, if any. By regressing wheat yield against the amount of water used along with the quantity and quality attributes of other inputs, coefficients are derived and used to estimate values of marginal products, which should be equal to the factor prices at the profit maximizing levels of the inputs. The linear regression equation estimated is given below:

$$Yield_i = \beta 0 + \beta 1 * Area_i + \beta 2 * QW_i + \beta 3 * N_i + \beta 4 * P_i + \beta 5 * Seed_i + \beta 6 * Salin_i + \beta 7 * SoilT_i + B8 * Varty_i + \beta 9 * IM_i + \beta 10 * L1800_i + \varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where,

$Yield_i$ = Yield (Kg per ha)

$Area_i$ = Area in ha

QW_i = Quantity of irrigation water (m^3/ha) applied during the crop season

N_i = Nitrogen fertilizer (kg/Ha)

P_i = Phosphorus fertilizer (kg/Ha)

$Seed_i$ = seed (kg/Ha)

$Zone_i$ = Zone dummy (0= zone 1 and 1=zone 2)

$Salin_i$ = Soil salinity dummy (0= low and 1= high)

$SoilT_i$ = Soil type dummy (1=deep red and 0= otherwise)

$Varty_i$ = Wheat variety dummy (0= local and 1=improved)

IM_i = Irrigation Method dummy (0= traditional and 1=modern)

$L1800_i$ = Farmer applying less than 1800M^3/ha irrigation water? (0= No and 1=Yes)[5]

YS_i = Years of schooling

[5] QW_i, IM_i and $LI1800_i$ seem to be measuring the same thing but actually they are not. For instance, in our sample some farmers using traditional irrigation methods are found to apply less water than some others who are using modern irrigation methods (sprinkler). Likewise, two farmers could be identified as non adopters of SI but one could apply only 2000M^3 per hectare while another could use over 4000M^3 per hectare.

To estimate the on-farm non-market value of avoiding salinity, choice modeling is used. Following Morrison et al. (2002) we establish choice sets for the agricultural land including, among others, attributes such as water well depth[6] and salinity levels of the soil. There are two attributes (well depth and price of land) each of which has four levels, and three attributes (soil type, soil salinity level and proximity to an urban center) with three levels. As a result, we have a total of $4^2 x 3^3 = 432$ attribute profiles to be compared. In order to reduce the number of farmland profiles to a more manageable number, we used an orthogonal fractional factorial design (see Ehmke, Lusk and Tyner, 2008; Boyle et al., 2001) to generate 14 conjoint experiment profiles, randomly ordered and presented in Table 5.

Table 5: Conjoint Experiment Profiles Generated by the orthogonal fractional factorial design

No	Soil type (3-levels)	Well depth (4=levels)	Soil salinity level (3-levels)	proximity to population center (3-levels)	Price (mil SYP/ha) (4=levels)	Would you purchase 1 ha of land with these attributes? 1=Definitely purchase 5=Definitely not purchase				
						1	2	3	4	5
	Deep red	0 to 50 m	High	Rural	0.7					
2	Deep red	Over 200 m	Low	Rural	1.2					
3	Deep red	0 to 50 m	Medium	Remote	3.5					
4	Deep red	51 to 100 m	Low	Urban	3.5					
5	Deep red	100 to 200 m	High	Urban	10					
6	Deep red	Over 200 m	Medium	Remote	10					
7	Shallow	Over 200 m	Medium	Urban	0.7					
8	Shallow	51 to 100 m	High	Remote	1.2					
9	Shallow	100 to 200 m	Medium	Rural	3.5					
10	Shallow	0 to 50 m	Low	Rural	10					
11	Sandy	100 to 200 m	Low	Remote	0.7					
12	Sandy	0 to 50 m	Medium	Urban	1.2					
13	Sandy	Over 200 m	High	Rural	3.5					
14	Sandy	51 to 100 m	Medium	Rural	10					

[6] Well depth is a very good proxy for well quality. Because, the deeper the well, the higher the cost of pumping, the higher the salinity level of the water and also the higher the chance that water discharge level is low.

The results of the conjoint ranking experiment are then used to investigate farmers' willingness to pay for quality and proximity attributes in farmland options. The summary of farmers' ranking of individual farm land attributes are presented in Table 6. Due to ordering in the response variable (i.e., the ranks), model parameters are estimated using an ordered logit model. Parameter estimates from the resulting ordered logit model can be used to estimate the willingness to pay for acquiring one unit of a resource with specific attributes from which we can also compute the value of a unit change in environmental quality (for example a change in soil salinity from low to high).

Table 6: Summary of Sample Farmers' Ranking of Individual Farm Land Attributes

Attributes Ranking*	Percentage of farmers under the following rank-attribute combinations					
	Well depth	Soil salinity	Nearness to population center	Soil type	Price	Total
1	16.4	62.4	1.9	0	19.3	100
2	83.6	16.4	0	0	0	100
3	0	21.2	0	0	78.8	100
4	0	0	98.1	0	1.9	100
5	0	0	0	100	0	100
Total	100	100	100	100	100	100

* Farmers were asked to rank the different land attributes from 1 (most important) to 5 (least important)

For the measurement of environmental impacts, simple linear regression is used to determine the changes in soil salinity in response to marginal changes in the quantity of irrigation water applied. In this analysis, the level of soil salinity is regressed on the salinity and quantity of irrigation water and their cross-product to capture the interaction effect. Age and education level of farmers are also included in the model to capture the possible effects of differences in farmers' ability, skills and technology choice. The marginal increment in soil salinity due to a unit change in the quantity of irrigation water obtained from the regression will then be multiplied by the difference in the amount of water applied in the TSI vs. ISI to arrive at the magnitude of salt avoided due to the shift to ISI.

VI. Results

6.1 Benefits

6.1.1 Estimation and Valuation of Prevented Soil Salinization

Experimental data from Kshmo (2003) show that both the salinity and quantity of irrigation water applied have positive effects on soil salinity (Table 7). In another experiment, irrigation water with electrical conductivity (EC) measure of 4.8 dS/m was used for irrigation. One of the findings in this experiment is that when water application was increased from 120 to 300 mm, salinity of the top layer of the soil increased from initial values of 1.6-4.2 dS/m to 7.0-8.0 and 12.5-13.5 dS/m respectively (Plaut and Grava, 1999). However, such high salinity buildup on the soil is possible only in areas where there is low rainfall (See for example Costa, 1999).

Salts are added to the soil with each round of irrigation, where the extent to which the salts accumulate in the soil depends upon the irrigation water quality, irrigation management and the adequacy of drainage (Ayers and Westcot, 1994). Our sample survey shows that the average salinity measure (in terms of EC) for water from the wells in zones 1 and 2 of Al-Hassakeh is 1.24 ds/m, where in zone 2 salinity levels which are as high as 5.4 ds/m were observed. Plotting soil salinity against water salinity, we find that with the exception of few observations with high irrigation water salinity levels, the relationship is not strong (Figure 1). The quantity of water applied and the duration and frequency of application however have positive effect on soil salinity levels (Figure 2).

In figure 2, we see that not only that the quantity of water used but also the history of irrigation affects soil salinity. In hot and dry regions such as Al-Hassakeh where there is not adequate rainfall, when excessive irrigation water is applied in a crop field which does not have proper drainage, water that is not absorbed by the plants will ultimately evaporate leaving its salt content on the soil surface. Our observations from the smaller sample of 78 farms show that soil salinity decreases with depth (2.2 and 2.0 ds/m at depths of 0-20 cm and 20-40cm respectively). On the other hand, simulation results for 20 years using a CROPSYST model based on experimental data from ICARDA research station at Talhadiya (located in zone 2 of Aleppo province) show that salinity increases up to soil depth of 60cm and then declines as depth increases further.

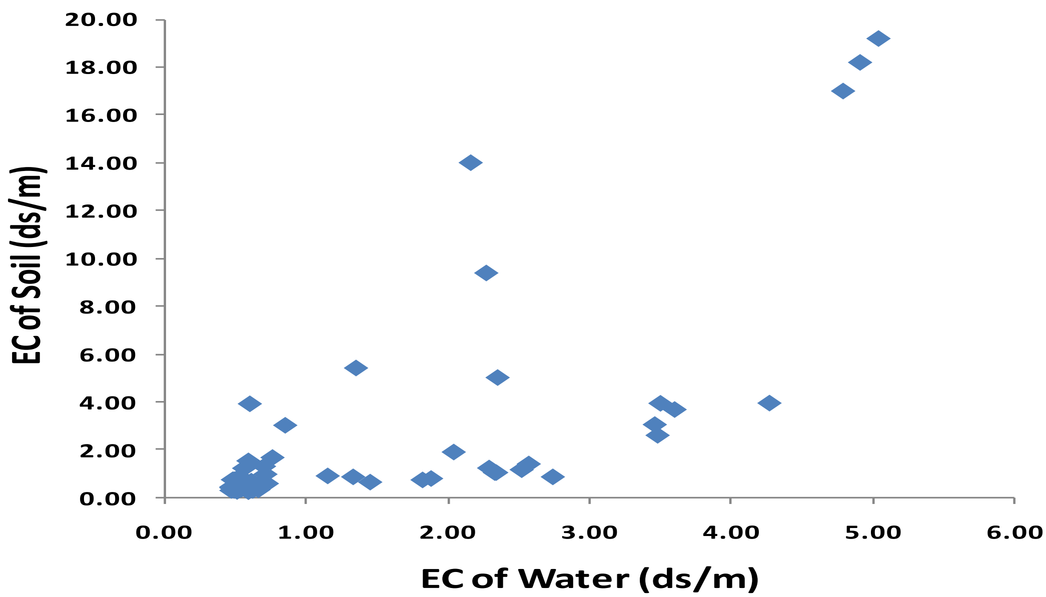

Figure1: Relationship between Salinity of Irrigation Water and the Salinity of Soil (survey results)

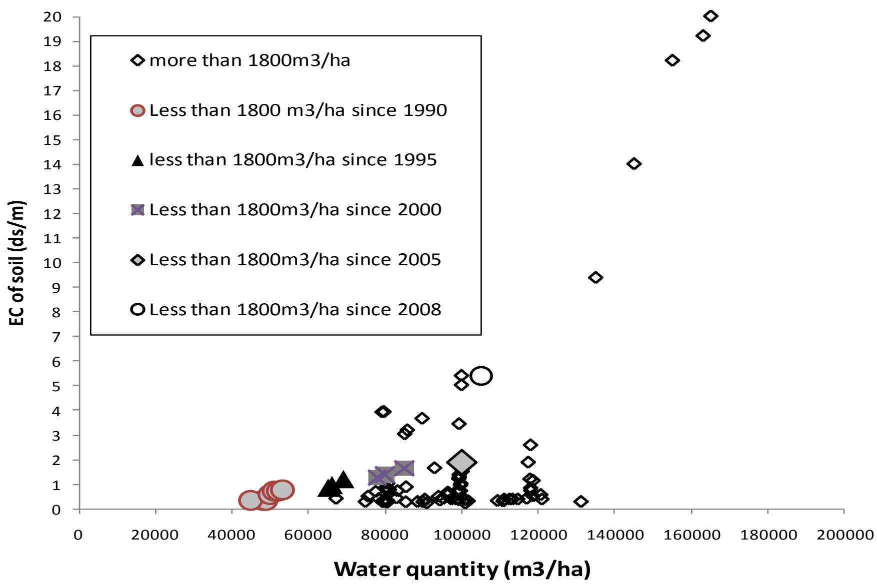

Figure 2: The Impact of Quantity of Water and Number of Years of Irrigation on Soil Salinity

Table 7: The Effects of Water Quantity and Salinity on Yield and Soil Salinity

				Accumulated salt based on leaching factor (L.F) (Kg/ha)									
Province	Location			97/98 Crop Calendar					98/99 Crop Calendar				
		Water Salinity EC (ds/m)	Yield (t/ha)	Quantity of Water Applied (M^3/ha)					Quantity of Water Applied (M^3/ha)				
				5155	6186	7217	8248	9279	5752.8	6903.4	8054.0	9204	10355
Aleppo	Ramleh	1.5	4.22	3124	3749	4374	4998	5623	4340	5207	6075	6943	7811
Hasakeh	Am-Hajarh	2.6	4.35	2888	3466	4043	4621	5198	8303	9964	11624	13285	14945
Hasakeh	Irrig. Res. Stn*	3.8	4.07	12930	15516	18102	20688	23274	13090	15708	18326	20944	23562
Hasakeh	Bab Al-Faraj	4.4	3.35	9996	11995	13994	15994	17993	14450	17340	20230	23120	26010
Hasakeh	Salmaseh	5.3	2.64	15626	18751	21876	25001	28127	19135	22962	26789	30616	34443
Aleppo	Am-Graf	6.6	3.35	20104	24125	28146	32166	36187	15657	18788	21920	25051	28183
Hasakeh	Tal-Brak	7	3.14	15392	18470	21549	24627	27706	16354	19625	22896	26166	29437
Aleppo	Khanaser	9.8	2.71	19758	23710	27661	31613	35564	31302	37562	43823	50083	56344

Source: Kshmo (2003).

*/ Irrig. Res. Stn = Irrigation research station

A linear regression estimated using the data collected in the second round (i.e., 78 farmers out of the initial 189 sample farmers in Al-Hassakeh) shows that the quantity of irrigation water applied as well as the interaction effect with its salinity are the major determinants of soil salinity (Table8). However, water salinity in and of itself is found to be insignificant. These results are consistent with the theoretical expectation especially in the study area where red clay type soils with low permeability dominate. With such soils, excessive application of irrigation water causes water logging which, upon exposure to high temperature levels evaporates leaving salt deposits on the soil surface.

Table 8: Determinants of Soil Salinity

Inputs/Attributes	B	Std. Error
(Constant)	0.211	0.195
Water quantity (M^3/ha)	1.40E-07	8.82E-08
Water salinity (ds/m)	1.6E-07	0.127
No of years of ISI practice	-0.021	(0.011)***
Water salinity Water quantity*	1.60E-07	(2.67E-08)***
R^2	0.912	

Dependent variable: Soil Electro conductivity (ds/m) (an indicator of salinity)

In Al-Hasakeh governorate, saline waters are largely observed in groundwater and are in proportions that are still within tolerance (Somi et al., 2002). As a result, unless it is coupled with high amounts of irrigation water, the moderate salinity of water in the study area is not expected to increase soil salinity at low levels of water application. Both high quantity and high salinity of irrigation water however create favorable condition for soil salinity buildup. Management skills and technology choices (as proxied by the age and education levels of farmers) however are found to have no effect on soil salinity. The justification for the insignificance of management skills is that apart from the adoption of ISI, construction of drainage structures is the most important management practice to control salinity. However, no drainage structures are built in the whole Al-Hassakeh governorate implying that education and experience are not helping in providing the minimum knowledge required to mitigate salinity problems through proper drainage.

Using the coefficient estimate for the number of years of ISI practice, the amount of salt prevented from being deposited on the top layer (0-20 cm) of the soil alone as a results of the adoption of ISI is 27.49Kg/ha per year[7]. As mentioned in section II above, a total of 108,920 ha of wheat fields in the three provinces studied are under ISI. Hence, at the current 22.3% level of adoption of ISI in the three provinces a total of 2995 tons of salt is being prevented from being deposited each year on the surface of the soil alone. Simulation results for Talhadiya – an area similar to the study areas using a crop simulation model shows that the highest salinity deposition is at about 0.6m depth. Hence, if we were to consider the total salt deposit up to 60cm, the amount of salt prevented from being deposited would be far greater. The salinity tolerance level for bread wheat is 6.0 ds/m (Allen et al., 2000). Starting from the current soil salinity level of 2.2 ds/m, wheat farms on which the traditional irrigation is practiced will have soil salinity above the tolerance level in 77 years. Whereas, the corresponding number of years for wheat farms on which ISI is practiced will be 135 years.

Apart from the environmental impact presented above, salinity has also negative effects on farm profitability. To conduct a contingent valuation of the prevented salinity at farm level, we build an ordered logit model, where the dependent variable has five levels. The first estimate in Table 9 is that of the log odds of a score one relative to scores greater than 1 (i.e., ln(prob(score =1)/prob(score >1)). The second estimate is that of the log odds of getting scores 1 or 2 relative to the odds of getting scores greater than 2 (i.e., ln(prob(score =1or2)/prob(score >2)) and so on. Note here that it is

[7] This figure is obtained using the conversion rate: Total Dissolved Salts (TDS) in mg percm^3 of soil= 0.6546xEC in ds/m (Forkutsa et al, 2009)

unnecessary to do the log odds for the fifth rank because the probability of a score of greater than 5 is by definition 0 making the ratio undefined.

For the wheat field attributes, a positive coefficient for a dichotomous factor means that higher preferences are more likely for the presence of the attribute. For a continuous variable, a positive coefficient tells that higher values of the variable increase the likelihood of higher preferences. Accordingly, the results of the ordered logit model show that the attributes deep red soil, shallow wells, low soil salinity and close proximity to urban centers lead to higher desirability of wheat fields in the land market. On the other hand, higher price, deep wells and shallow soils lead to relatively lower desirability of wheat fields (Table 9).

Table 9: Ordered logit parameter estimates of determinants of desirability for farmland attributes

	Variable	Level	Estimate	Std. Error
	[purchase = 1.00]		-16.07	(0.65)***
	[purchase = 2.00]		-7.83	(0.46)***
	[purchase = 3.00]		-1.18	(0.46)***
Threshold	[purchase = 4.00]		5.02	(0.56)***
	Price (mil SYP/ha)	(continuous)	-3.12	(0.08)***
	Soil type	Deep red	3.42	(0.71)***
	Soil type	Shallow	2.92	(0.32)***
	Water availability	0 to 50 m	2.63	(0.72)***
	Water availability	51 to 100 m	7.50	(0.63)***
	Water availability	100 to 200 m	-6.82	(0.162)***
	Salinity level	high	3.17	(0.43)***
	Salinity level	Low	10.89	(0.54)***
	Nearness to population center	Rural	2.80	(0.52)***
	Nearness to population center	Urban	10.54	(0.68)***

When a fee (unit price) for the asset is included as one of the attributes describing choice alternatives, the implicit price or the willingness to pay (WTP) for marginal changes in any attribute

m can be calculated as the negative of the ratio β_m / β_{fee} (Swait, 1993). Applying this formula to the estimates of the ordered logit parameters, the resulting implicit prices (i.e., the farmers' WTP for one hectare of land with the different quality attributes) are presented in Table 10 below.

Table 10: Estimates of Farmers' Willingness to Pay for Land Quality Attributes

Attribute comparison		Willingness to pay (mil SYP/ha)
Soil type	Deep red	1.1
	Shallow	0.9
Water availability	0 to 50 m	0.9
	51 to 100 m	2.4
	100 to 200 m	-2.2
Salinity level	high	1.0
	Low	3.5
Nearness to population center	Rural	0.9
	Urban	3.4

The estimated value of salinity prevention is then the difference between the willingness to pay figures for low and high salinity levels which is 2.5 million SYP/ha. This figure seems to be a little on the higher end, but given that a land with deep red soil, less than 50 m well, low salinity which is near an urban center could sell as high as 10 million SYP/ha, this estimate may not necessarily be too high. Hence, the value of ISI in terms of salinity prevention on a total wheat land of 108,920 ha in the three provinces of Syria is SYP 272.3 billion. This prevention however will yield streams of benefits for many years in the future. Suppose that ISI will prolong by 300 years the time required to reach soil salinity level of 32ds/m, the maximum level beyond which no crop can be cultivated. Then, average annual benefit of such prevention will be SYP809 million SYP.

Alternatively, we can also use the marginal value product approach to estimate the value of salinity reduction. The linear regression of yield on the different inputs and attributes (equation 1) shows that the amounts of irrigation water, nitrogen and phosphorus fertilizers and seed, the number of years of schooling and the use of modern irrigation techniques positively affect yield. Whereas being in zone 2 and having high soil salinity level are found to have negative impacts on yield. Soil type and farm size are found to have no significant effect on yield. The use of supplementary irrigation is found to have a positive effect on yield only at 10% significance level. This result makes good sense because the effect of ISI is cumulative and hence, we should not expect highly significant effect on a one-year analysis.

From the regression estimates, we find that the difference in marginal product due to the reduction in soil salinity from high to low is 255.816 kg/ha (Table 11). Using the average price of wheat (20 SYP/kg), the marginal value product of reduced soil salinity is 5,116 SYP/ha. Hence, the value of total salinity prevented in 108,920 ha of land under ISI is SYP 557.2 million per year. If the salinity prevention extends the useful life of the wheat field only by 15 years, then the total cumulative value of the prevented salinity will be about SYP 8.3 billion.

Table 11: Coefficient estimates of the linear regression of yield on different inputs and their attributes

Inputs/Attributes	B	Std. Error
(Constant)	2443.749	(280.800)***
$Area_i$	1.945	(9.043)
QW_i	.307	(.057) ***
N_i	2.229	(.612) ***
P_i	5.562	(.813) ***
$Seed_i$	1.884	(.544) ***
$Zone_i$	-421.118	(77.062) ***
$Salin_i$	-255.816	(135.947) **
$SoilT_i$	66.593	(146.968)
$Varty_i$	119.469	(73.790) *
IM_i	659.386	(85.155) ***
$L1800_i$	122.866	(76.863) *

YS_i	51.193		(6.702) ***
R^2		70.6	

Dependent Variable: yield (kg/ha)

As compared to the willingness to pay approach, the marginal value product approach yields much less valuation of the prevented salinity. The explanations for the discrepancy are 1) the extremely high land quality attributes considered in the conjoint analysis have inflated the value of land to the farmers; 2) agricultural lands in the study area are used to produce multiple crops (including cash crops) within one year. Hence, using the opportunity cost of salinity on wheat production alone underestimates the value of salinity prevention to the farmer.

6.1.2 Estimation and Valuation of Water Saving

From the estimates of the linear regression (equation 1), the marginal yield of water is 0.307kg/ m^3 (Table 11). Multiplying the marginal product of water by the average price of wheat (20 SYP/kg), the marginal value product of water is found to be 6.14 SYP/ m^3, which is used as the implicit price of every m^3 of water saved due to ISI. From Table 4, we see that for the 78 surveyed farmers in Hassakeh, wheat area cultivated solely using rain water has disappeared in 1990 while only 165 ha have been cultivated using ISI. Over the years, farmers who have been using traditional irrigation have adopted ISI where in the 2010 crop calendar, the wheat area under ISI reached 699 ha. This increase in area under ISI has come at the expense of traditional irrigation, where the total area under traditional irrigation has dropped from 2370 ha in 1990 to 1836 ha in 2010.

To calculate the amount of water saved from shifting from TSI into ISI, consider the three scenarios discussed in section III. 1) All the excess water from the traditional irrigation percolates back to the same aquifer from which it was pumped. In this case the amount of water saved from shifting from TSI to ISI is zero. 2) All the excess water from the traditional irrigation dissipates to other protracted aquifers which are not accessible with the existing technology. This means all the excess water is lost. From our survey in zones 1 and 2 of Syria, wheat fields which are under ISI account for 27.6% of total wheat land. However, the corresponding data for the whole Syria is 10.9% (81,802 ha). As is the case with Al-Hasakeh, the majority of farmers adopting ISI in the rest of the wheat producing governorates of Syria (Aleppo and Deraa) are those who were using traditional irrigation. As a result, all fields which are now under ISI were at one time or another under TSI (El-Shater, 2010).

Using the 817 M^3 difference in the amount of irrigation water applied per hectare between TSI and ISI obtained from our survey, we calculate the total amount of water saved from wheat fields in Syria to be 68,928,000 m^3 per year. This means, 68,928,000 m^3 less of water is pumped from the ground every year, which reduces the pace of ground water depletion thereby reducing the pace of desertification in the region. For the economic valuation, we multiply the total quantity of water saved due to ISI by the implicit price of saved water and find the total value of the water saved due to the current level of diffusion of ISI in wheat fields in Syria to be 423,217,920 SYP per year. 3) All or part of the excess water that goes into deeper soil levels is lost due to evaporation and/or consumed by weeds. If we take a conservative estimate of 20% out of the total excess water as a loss to evaporation (Allen et al, 1998), then 13,785,600 m^3 of water is saved which has a value of SYP 84.6 million per year.

6.1.3 Estimation of Economic Benefits to Adopters

6.1.3.1 Yield Gain

Supplementary irrigation has a number of benefits to the adopting farmer. Our sample survey results show that higher measures of the EC levels of soil salinity lead to reduction of yield (Figure 3). The negative coefficient estimate from the regression equation (Table 11) also shows that higher soil salinity levels, *ceteris-peribus,* would lead to lower yield. Data from Kshmo (2003) also show the negative relationship between the salinity of irrigation water and yield (Table 7).

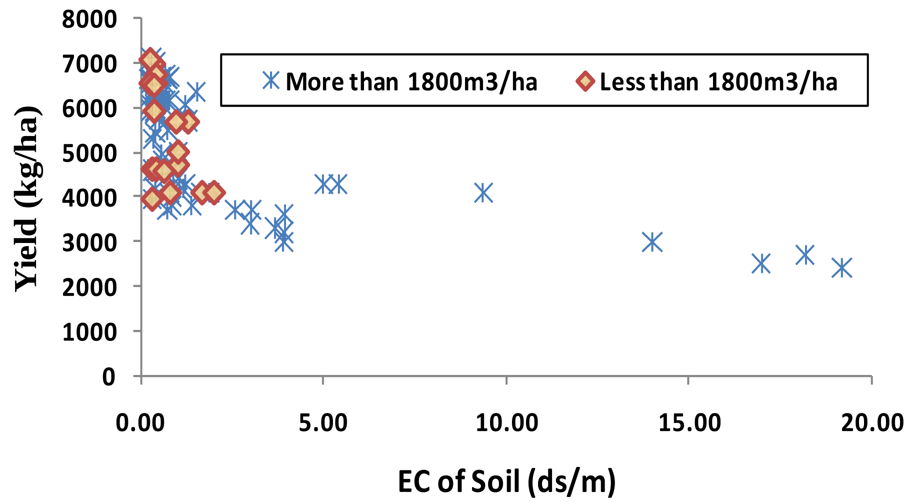

Figure 3: The Relationship between Soil Salinity and Yield

From our sample survey, the average yield difference between users of ISI and TSI is 429kg/ha. Given the current level of diffusion of ISI (57,440 ha) and wheat price of 20SYP/kg, the total value of the gain in yield due to the expansion of ISI in the country is estimated at 492,831,105 SYP per year.

6.1.3.2 Lower Pumping Cost

ISI by design reduces the amount of irrigation water applied as compared to the TI. As a result, there is reduction in the amount of fuel and other costs associated with pumping. Most of the pumps in Syria use diesel fuel. For a well of average depth (about 150m), the amount of diesel that is required to pump 1M^3 of water is 0.225 liters. Multiplying the total amount of water saved from the use of ISI in wheat production (68,928,000 m^3 per year) by 0.225, we find the estimated amount of diesel saved to be 15.5 million liters/year. Using an average diesel price of 20 SYP/liter, the estimated value of diesel saved from the use of SI in wheat field of Syria to be 310 million SYP per year.

6.2 Costs

The adoption of ISI may or may not have costs to the adopter. Suppose, prior to the adoption of ISI, a farmer has been using flood irrigation. If this farmer decides to use the same structures for ISI, then no additional investment may be needed and hence ISI can be adopted at no cost to the adopter. On the other hand, the farmer may decide to shift from flood (surface) irrigation to sprinklers. In that case the adoption of ISI entails an investment on sprinklers. Farmers in Syria who use sprinklers have an average of 35 sprinklers, which they use to irrigate all their wheat fields by shifting the devices. The unit cost of a sprinkler is 2500 SYP and hence the total cost of adopting ISI for all the 6409 adopters of ISI in this case becomes 560.8 million SYP, which is a onetime investment. Taking an average life time of 3 years for sprinklers, the annual cost of adopting ISI is estimated at 186.9 million SYP.

6.3 Summary

The economic benefits of shifting from TSI to ISI are multi pronged while the technology could be adopted at no or minimum cost. In this paper, we investigated only two environmental benefits and two farm-level economic benefits. Taking a conservative estimate for the amount of excess water from TI lost (20%) and combining the benefits and costs, the total farm-level net benefits from shifting from traditional irrigation to supplementary irrigation at the current level of adoption (10.9%) for all wheat farmers in Syria is 994.2 million SYP per year (Table 12). In addition, the adoption of ISI leads to environmental benefits of 4.18 tons of salt prevented from being deposited on the soil and 68.9 million m^3 of ground water saved. This shows that there is scope for wider adoption of ISI in wheat fields of Syria.

Table 12: Summary of Benefits and Costs of ISI

Benefits		Environmental benefits measured in physical units		Farm-level benefits (losses) in million SYP per year	Costs (SYP per year)	
		Tons per year (for 0-20 cm depth alone)	Million M^3/year		Using Surface	Using sprinklers
Yield loss		NA	NA	(869.8)	0	186.9
Saving from less diesel and other costs		NA	NA	752.8		
Salinity prevention		2,995	NA	293.8		
Water conservation	If all (95%) excess water from TI is lost due to ET	NA	114.8*	0		
	If only 50% of the excess water from TI is lost due to ET	NA	60.4*	NA		
	If only 20% of the excess water from TI is lost due to ET	NA	24.2*	NA		
Total				1,096.631,105	0	186,900,000

*/ Using the marginal value product of water (6.43 SYP/M^3) estimated at the average irrigation water application rate for ISI, the environmental values of water saved under the 95% 50% and 20% water loss scenarios are 777 million, 388 million and 155 million SYP per year respectively.

VII. Conclusions and Recommendations

The development of groundwater resources to boost agricultural production in dry areas has in many cases led to continuous decline in groundwater levels (Luijendijk and Bruggeman, 2008). Previously, farmers employed flood irrigation techniques which were not amenable to scheduling. This resulted in significant water use per unit land area, causing over-irrigation and wastage of scarce water resources. ISI reduces the amount of irrigation water used per unit land area through scheduling, modern irrigation methods and the use of water balance methods to estimate crop water needs. This helps farmers to enjoy lower pumping costs and higher land and water productivity. The stabilizing effect of supplemental irrigation has also been widely documented. For example, from farm surveys, Salkini and Ansell (1992) found coefficient of variation (CV) values of 51% for rain-fed wheat and 20% for wheat under SI. The corresponding figures for on-farm demonstrations are 71% and 8% respectively. ISI also has other environmental impacts such as the reduction of the pace of soil salinity buildup and reduction in the amount of excess water that dissipate in various ways such as evaporation. ISI can also help to maintain the quality of irrigation water and availability to other farmers in the future.

In Syria, the introduction of ISI targeted wheat farms which are mainly concentrated in stability zones 1 and 2 which are areas of relatively high rainfall (250mm – 650mm). This amount of rainfall however is not sufficient for which farmers use some form of irrigation on their wheat fields to supplement rainfall. Before the introduction of ISI, farmers used to apply unnecessarily high amount of irrigation water (on the average 3000M^3/ha). This caused concern about the future of ground water in the country. As a result, ICARDA and its local partners launched a project to introduce ISI, where only small amount of water (<1800 M^3/ha) was recommended along with other complementary inputs. This paper attempted to identify, quantify and attach monetary values to some of the benefits and costs of ISI for the Syrian wheat growers.

Irrigation using highly saline water from deep wells poses high risk of increasing soil salinity, especially when excessive irrigation water is applied. Our results show that by moderating the amount of water applied, ISI is indeed reducing the pace at which salinity is building up in the soil and hence the pace at which desertification is advancing. It is also found that the amount of salt deposited in the soil increases with duration of irrigation at differing rates depending on the method of irrigation. In this study, we find that the average soil salinity level in terms of EC (at 0-20 cm depth) among wheat fields which are irrigated traditionally to be 2.5 ds/m while the corresponding value for the wheat fields under ISI for at least two years is 1.1 ds/m. Syrian wheat farmers are also aware of the problem. For instance, 62% of farmers from our sample survey put soil salinity as the most important land quality attribute. Estimates of farmers' willingness to pay and the marginal value product of a low salinity land are found to be high. Consequently, the value of salinity prevented in the wheat lands of Syria is estimated to be at least SYP 293.8 million per year.

A number of possible fates are also considered for the unnecessarily excess water applied under the traditional irrigation. From among all the possibilities considered, the line of argument that suggests that all or part of the excess water applied is lost due to direct evaporation from the soil and evapo-transpiration from weeds is more relevant to the situation in Syria. Taking a conservative estimate of 20% for the total excess water applied as a loss due to evaporation or through weeds, the value of water saved due to the use of ISI has been estimated to be at least SYP 84.6 million (about mil $1.8 million) per year.

Syrian wheat farmers who adopted ISI have also benefitted from higher yields and also lower pumping costs. The total benefit due to higher yields among all wheat farmers is estimated at about

SYP 492 million ($10.7 million) per year while the cost savings from using less fuel is estimated at SYP 310 million ($6.7 million) per year. Even though there are farmers who adopted ISI without any additional cost – just using their existing surface (flood) irrigation systems, the most common and more effective method is to use sprinklers. The use of sprinklers on the average leads to a onetime in three years cost of 87,500 SYP per farmer. Hence, at the current level of adoption of ISI in Syria (10.9% of all irrigated wheat growers), the conservative estimate of national net benefits of shifting from traditional surface irrigation to supplementary irrigation using sprinklers is SYP 994.2 million ($21.6 million) per year. In addition to

Given the tremendous potential for ISI to benefit individual adopter farm households as well as the environment, we recommend that the government intensifies its extension service to raise the awareness about ISI among farmers. If all benefits were to be included and also better estimates of water conserved due to the use of ISI were available, the net benefits of ISI would be much higher. This calls for future research on estimating the amount of water saved due to the use of technologies that monitor soil moisture and provide farmers much more accurate estimates of water requirement by crop type. Given the economic and environmental benefits estimated in this report and given the increasing water scarcity in the dry areas, such technologies currently used in the developed countries (for example in California) may be feasible in Syria, and hence need to be studied.

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