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Participatory research on irrigation water-use efficiency of wheat in a low-rainfall zone of Syria

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Abstract

The effect of irrigation and electrical conductivity (EC_w) on water-use efficiency (WUE_i) and net benefit (NIB) of wheat (Triticum aestivum L.) was studied in a farmer field located in a low-rainfall zone of Syria. Two trials were conducted: one using sprinkler irrigation (Trial A), and the other using basin irrigation (Trial B). Each trial had 4 replications of the treatments including full supplemental irrigation, farmer treatment and rainfed control. These treatments were compared with deficit irrigation (Trial A) and leaching (Trial B). Irrigation method, the treatment and EC_w accounted for 81% (88%) of variance of WUE_i (NIB). Under these trial conditions, an application level near full supplemental irrigation was most productive and profitable.

Keywords: supplemental irrigation, water use efficiency, irrigation benefit, irrigation water salinity, wheat (*Triticum aestivum* L.), low-rainfall zone, Syria

2 Introduction

Water use efficiency (kg/mm/ha) (Oweis and Zhang 1998a) and net irrigation benefit/cost (Syrian Lira/mm/ha) are indicators of irrigation performance. In supplemental irrigation, they are determined by dividing the differential yield or the differential (net) income by the irrigation. Both parameters can become negative if the rainfed yield (rainfed income) is higher than the irrigated yield (irrigation income).

In Agricultural Stability Zone 2 of Syria (annual precipitation: 300-350 mm), water is used most efficiently at about two third of full supplemental irrigation (FSI) if the water quality is good (Oweis et al. 1998b). By contrast, the research area (Figure 1) is situated in Zone 4 (200-250mm) at the border of the steppe. It is similar in terms of climate and land-use to a large part of the agriculturally used winter-rainfall areas in Western Asia and Northern Africa (de Pauw 2003). Rainfall (annual mean: 210 mm) is marginal for rainfed production. In Khanasser valley, groundwater is used for supplemental irrigation of winter crops. About 60 per cent of agricultural groundwater abstractions (50% of total abstractions) are applied to wheat, predominantly bread wheat (*Triticum aestivum* L.) by sprinkler irrigation (average EC: 5.8 dS/m) and basin irrigation (average EC: 10.0 dS/m) (SCHWEERS ET AL. 2004). Water levels have stabilized after cotton irrigation from groundwater in low rainfall areas was prohibited by the government, but the balance between recharge and abstractions is still delicate as the irrigated area (3-4% of cropping area) is expanding.

An experiment was conducted in two villages, Rahib-Roehib and Atshaneh. In the former, water resources are scarcer in the Paleogene limestone, but the water quality is relatively good (EC: 2 - 6 dS/m). Groundwater yields are better in Atshaneh, where most wells are situated in the alluvial Quaternary aquifer, but the water quality is worse (EC: 3 - 12 dS/m). The farmers in Rahib-Roehib have introduced sprinkler irrigation to cope better with the shortage, whereas the farmers of Atshaneh have mostly stayed with surface irrigation, which is better suited to higher salinity. To gauge the effect of salinity on yield, wells were selected to reflect a lower and a higher electrical conductivity level in each village.

The objectives of the experiment were:

1. To analyze the effects of supplemental irrigation and leaching on productivity and profitability of wheat production in marginal dry areas
2. To learn more about the irrigation practice in such areas as a precondition for developing farmer-oriented best practice guidelines

Figure 1 Map of northwest Syria

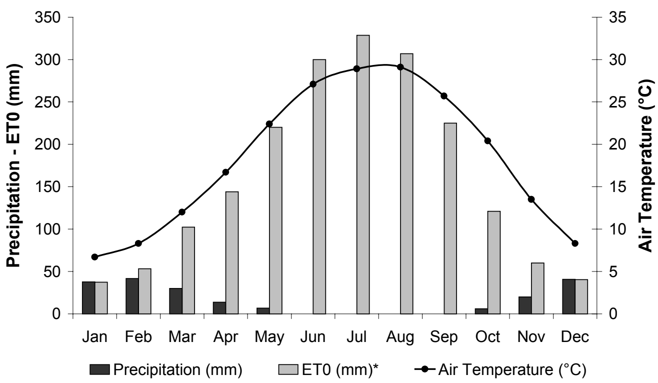

Figure 2 Climatic diagram for Khanasser (longterm data; *ET_0: 1980-1985)

3 Materials and methods

The experimental layout consisted of an incomplete block design with four replications, two in each field with two repetitions. The irrigation methods were sprinkler irrigation (Trial A) and basin irrigation (Trial B). The treatments *full supplemental irrigation* (S), *farmer practice* (F) and *rainfed control* (R) were compared with *deficit irrigation* (D) in Trial A and *leaching* (L) in Trial B.

Wheat was planted after cumin. Before planting, soil samples up to one-meter depth were taken at 0.2 m increments from three locations of each field to determine background soil fertility, texture, moisture holding capacity, and salinity. After harvest the same sampling procedure was used to determine soil salinity next to all soil moisture measuring points. The soil moisture was recorded by neutron probe. On every measurement occasion, core samples were taken for gravimetric soil moisture analysis from the first 15 cm; the remaining 15 cm increments were measured with the neutron probe. Installation depth was 105 cm. One access tube was installed in the rainfed control area. For each of the other three treatments, two access tubes were installed, the first at one third and the second at two thirds of basin row length or sprinkler line length. Access tube locations were surveyed to coincide with the center between four sprinklers. Colored rods were hammered below the sprinkler height in these locations to mark sprinkler positions. In Trial B, the access tubes were installed in the center of basins. Basins sizes were surveyed by measuring tape. Ditch infiltration was determined from the change in flow between 2 l/s capacity WSC-flumes, two in each location at 20-meter distance between them.

Climatic records were obtained from a meteorological station, about 2 (4) kilometers away from Trial A (B). The farmers took readings of manual rain gauges, positioned in one field of each trial. During irrigations, they recorded date, position or row, time of water application and flow meter readings. They were advised to adjust the application time in the "non-farmer" treatment locations following soil moisture measurements. Leaching was applied after the first irrigation in spring. The leaching ratio was calculated according to AYERS AND WESTCOT (1994). Crop evaporation was computed from the soil moisture balance and compared with ET_c (ALLEN ET AL. 1998). Above ET_c amounts were attributed to leaching and runoff.

Costs and benefits were assessed by interview. Singular distortions resulting from significantly higher discharge rates or fuel costs were eliminated to focus the economic comparison on immanent differences between the irrigation methods and water management practices. Irrigation-related costs i.e. fuel, irrigation labor hours and yield-related costs, i.e. loading and transporting of grain and shredding of straw were calculated dynamically for the irrigation/yield level of every observation. The statistical evaluation was carried out by fitting linear regression models and identifying the best model in terms of percentage variance accounted for using with GenStat® statistical software.

4 Results and Discussion

4.1 Trial conditions

Rainfall was above average (235 mm), but not well distributed. No rain fell between February 22 and April 16. The rainfall records of the farmers and the meteorological station showed no major differences. Therefore, the latter was taken as representative of all trial locations. Late frost occurred on April 4-6 and made more damage in one of the sprinkler-irrigated fields, but that was corrected on the basis of empty seeds and the 1000grain weight.

The physical characteristics of the deep alluvial soils in the trial locations were relatively similar (Table 1). According to AGB (1988), soil textures fell into the categories of sandy clay loam (location well No. 27, 68), clay loam (38) or loamy clay (116). The available soil moisture in the effective rooting depth was high, the infiltration rate medium (Figure 3). Ditch infiltration, partially plant-available, was 5-10% and deep percolation losses in the ditch were estimated at 2%. Differences in root-zone soil salinity before and after the trial were comparatively small. This indicates that rainfall leached salts and that it takes time for the soil salinity to built up again. Pre-trial supply with mineral nitrogen was predominantly medium (10-20 ppm), and high in the case of location 116 (MARX ET AL. 1999). Phosphorus concentrations were low (<10 ppm); potassium concentrations mostly high (250-800 ppm). The organic matter content of the soil was above 1 %, which is higher than typical for semi-arid rainfed areas (RYAN ET AL. 2001). This may have been caused by occasional manure applications.

Table 1 Average soil parameter (fertility: ~ top 0.3 m; physical parameter and EC: 1 m)

Well No	Min. N	Olsen P	Extr. K	OM	Mechanical Analysis			Soil moisture		EC (dS/m)	
	ppm	ppm	ppm	%	Clay %	Silt %	Sand %	FC (%)	PWP (%)	before	after
27	17.8	7.9	394	1.3	42.4	28.6	29.1	32.0	17.2	1.6	1.5
38	23.8	5.2	534	1.7	44.3	30.8	24.9	31.5	17.9	1.5	2.4
68	9.3	5.1	202	1.2	38.8	29.3	31.9	31.3	17.5	1.7	2.0
116	30.6	4.2	283	1.1	45.7	30.8	23.5	33.5	17.6	2.2	2.0

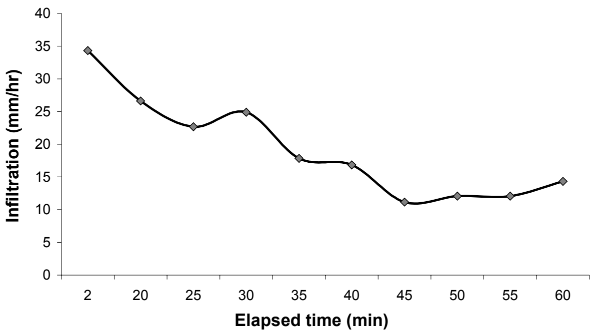

Figure 3 Ditch infiltration rate in field 27, Atshaneh

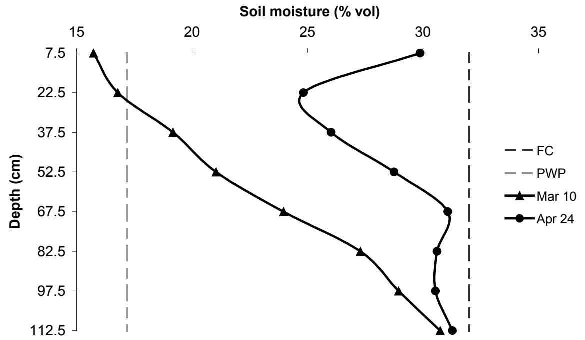

Figure 4 Soil moisture profiles at access tube No. 27_03 (Treatment F)

The farmers were informed about the soil fertility status of their fields, but their reaction was not as strong as anticipated to minimize differences in background fertility between the locations. Agronomic practices (Table 2) were representative of the area, including higher than recommended seed rates.

Table 2 Trial agronomy

Well/Field ID	27	38	68	116
Electrical conductivity (dS/m)	3.2	9.0	2.4	3.7
Irrigation method	Basin	Basin	Sprinkler	Sprinkler
Variety	Cham 6	Cham 6	Cham 6	Cham 6
Seed rate (kg/ha)	240	400	250	270
N-Total fertilization (kg/ha)	58	136	71	128
P-Total fertilization (kg/ha)	55	83	23	51
Date planted	02/12/03	12/12/03	03/12/03	27/11/03
Date harvested (samples)	31/05/04	01/06/04	25/05/04	27/05/04
No. of irrigations	3-4	3	3-4	3-5
Average irrigation (mm/ha)	230	362	196	171
Rainfed grain yield (kg/ha)	1170	1122	1012	1037
Irrigated grain yield (kg/ha)	4928	3935	2257	1935
WUE_i grain (kg/mm/ha)	21.4	10.9	11.5	11.3
Irrigated straw yield (kg/ha)	8127	8655	4248	4706
1000-grain-weight	34.3	32.2	33.5	43.9

4.2 Water use efficiency and irrigation benefit

With around 11 kg/mm, the irrigation water use efficiency (WUE_i) was more than twice the rainwater use efficiency (~ 5 kg/mm). The WUE_i of basin-irrigated Field 27 was outstanding (21 kg/mm) and the irrigation was little more than needed to satisfy the crop water requirements. During the crucial jointing/booting stage (LIANG ET AL. 2003) it coincided with flag leaf appearance (end of jointing stage). Since rain had stopped early, it was important not to wait too long with the first mid-stage irrigation. The moisture profile just before irrigation on March 25 is shown in Figure 4. The next profile was taken after another irrigation on April 11. The neutron probe calibration (r^2 = 0.85) displayed a good fit in relation to field capacity and permanent wilting point.

On average, the net irrigation benefit of basin irrigation was about 5 times higher than that of sprinkler irrigation. According to WANG ET AL. (2002), the toxic ions Na^+ and Cl^- are accumulated by foliar absorption at the expense of the structural component Ca^{++} under sprinkler irrigation with saline water. Foliar absorption of salt ions has been found to be a significant mechanism of salt accumulation in maize (Zea mays L.) and barley (Hordeum vulgare L.) (BENES ET AL., 1996). Intermittent absorption of rainwater might dilute the salts and normalize the salt composition in the plant tissue. In 2002/03 with 298 mm annual rain and a better distribution, the relationship between the NIB of basin irrigation and sprinkler irrigation was roughly the inverse of the outcome in the trial season. The observation time of sprinkler operation was accounted as 50% of irrigation hours and changes in sprinkler positions as 2.5 labor hours or 15 hrs per hectare and irrigation. The labor requirement per hour of sprinkler irrigation turned out to be nearly the same as of basin irrigation (~1 manhour/hr).

Table 3 Wheat budgets for the trial locations (Syrian Lira per hectare; 51.5 SL = 1 US$)

	Well No	Formula	27	38	68	116
A	Grain income		54205	43284	24824	21283
B	Straw income		16255	17309	8496	9411
C	**Gross income**	**A + B**	**70460**	**60593**	**33321**	**30694**
D	Fuel costs		2802	4734	1524	1891
F	Irrigation labour costs		1868	3156	1134	1178
G	Yield related operation costs		7968	6363	3649	3129
H	Other operation costs		10945	12698	9240	11612
I	Capital costs		4200	4200	6400	6400
J	Total costs [excl. family labour]	D + G + H + I	25915	27994	20813	23032
K	**Net income**	**C - J**	**44545**	**32600**	**12508**	**7662**
L	Rainfed gross income		20539	18737	17085	18720
M	Rainfed yield-related costs		1891	1814	1636	1677
N	Rainfed other operation costs		10945	12698	9240	11612
O	Rainfed net income	L - M - N	7702	4225	6209	5431
P	**Differential income**	**K - O**	**36843**	**28374**	**6299**	**2231**
Q	Average irrigation (mm/ha)		230	362	196	171
R	**Net cost/benefit of irrigation (SL/mm/ha)**	**P/Q**	**160**	**78**	**32**	**13**
S	Irrigation labour (hrs/ha)		149	252	91	94
T	Other family labour (hrs/ha)		73	99	121	91
U	Total family labour (hrs/ha)	S + T	222	351	211	185
V	**Labour income from irrigation (SL/hr)**	**P/U**	**166**	**81**	**30**	**12**

4.3 Statistical evaluation

With five degrees of freedom, irrigation method, treatments and EC_w accounted for 81% (88%) of variance of WUE_i (NIB). The model expressed in the equations given in Table 4 combined both irrigation methods. All input variables were significant or highly significant. Observed and predicted mean values of WUE_i and NIB for the treatments were quite similar (Table 4). The average application levels, in percent of full supplemental irrigation (234 mm) were 92% (S), 82% (F), 60% (D) for Trial A and 112% (S), 124% (F) and 141% (L) for Trial B. Separate regression equations indicated optimum productivity and profitability at about 80% FSI (Figure 5) for both methods under the trial conditions. However, there are technical limitations for applying so little with basin irrigation, i.e. insufficient land leveling. Two factors must be considered to put these results into the right perspective: The deficit treatment was applied too late in one site during the crucial jointing/booting stage (Trial A) and the soil EC was low before the trial due to intensive early local rain (Trial B). Therefore, the response to deficit irrigation and leaching should be better under other circumstances.

Table 4 Comparison of observed and simulated average values of WUE_i and NIB from the treatments

Irrigation method	Treatment	No. of observations	WUE_i (kg/mm/ha)		NIB (SP/mm/ha)	
			observed	simulated	observed	simulated
Sprinkler	***F***	8	5.83	5.82	20.49	25.73
	D	8	4.33	4.44	-10.63	-10.52
	S	8	6.54	6.58	46.55	41.53
Basin	***F***	8	13.21	13.23	131.18	125.94
	L	8	10.03	10.01	100.91	89.69
	S	8	14.03	13.99	136.71	141.73

$$WUE_i = 14.67 + 7.41Su - 1.37D - 3.21L + 0.763S - 1.452EC_i; \overline{R}^2 = 81\%$$

$$NIB = 114.4 + 100.2Su - 36.3D - 25.1L + 15.8S - 14.5EC_i; \overline{R}^2 = 88\%$$

Where: *Su* (surface irrigation), *D*, *L*, *S* = 1 when applied and 0 otherwise; EC=6.1

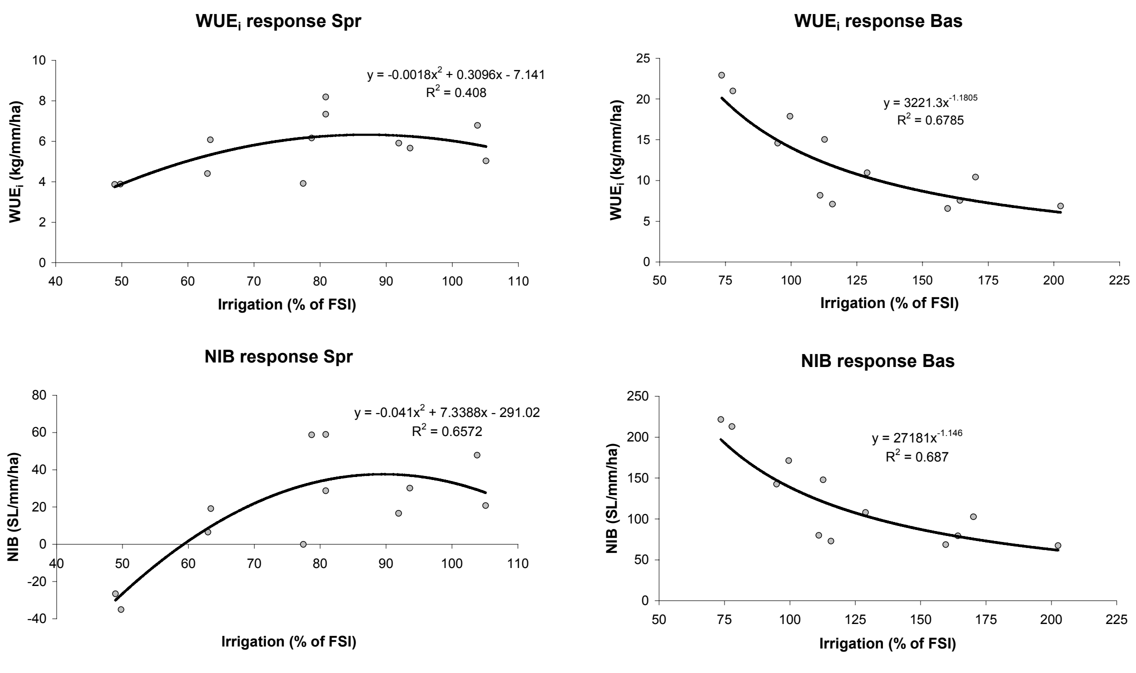

Figure 5 WUE_i and NIB response to irrigation

4.4 Implications for irrigation practice

With average pump discharge (15 m^3/hr), farmers can irrigate 2 hectares, if the evaporative demand at jointing/booting stage (4.5 mm) is considered as the decisive design criterion. For six irrigation hours per day this corresponds to 80% of FSI in a mean rainfall year (Table 5). The farmers can respond to drought in low rainfall years by increasing the number of irrigation hours per day or by additional irrigations in spring. Foliar application of saline water during sensitive crops stages (i.e. seedling, flowering and early grain filling) should be avoided or minimized. Operation costs of irrigation (incl. the opportunity cost of labor) are significant and can be reduced with fuel-economic pumps that have a good discharge. However, too high discharge (> 25 m^3/hr) is difficult to control using basin irrigation. Leaching with saline water on the well-drained soils is beneficial, but should not exceed about 50% of full supplemental irrigation, not to become uneconomical and wasteful. More frequent irrigations at less sensitive development stages and rotation of irrigated fields are also recommended to cope better with salinity.

Table 5 Exemplary wheat irrigation practices in Khanasser Valley (for FSI = 234 mm)

Irrigation Method		**Unit**	**Sprinkler**		**Surface**	
EC_w		**dS/m**	**< 8**	**> 8**	**< 8**	**> 8**
System capacity	Sprinklers	pcs	20		-	
	Discharge	m^3/hr	15			
	Design ET_c	mm/d	4.5	6	4.5	6
	Application	mm/ha	54	72	72	90
	Irrigation time	hr/d	6	8	8	8
		days/ha	6	6	6	7.5
	Irrigated area	donum*/d	1 2/3	1 2/3	1 2/3	1 1/3
		ha	2	2	2	1.6
Irrigations	Seedling growth	mm/ha	36	36	36	36
	Stem elongation	mm/ha	36	36	54	72
	Booting	mm/ha	54	72	72	90
	Milk ripe stage	mm/ha	54	-	72	72
	Total	mm/ha	180	144	234	270
		% of FSI	77	62	100	115

*1 donum = 0.1 hectare

5 Conclusions and Recommendations

Under the conditions of the trial season, which included a long drought period in spring, full supplemental irrigation was more productive and profitable than deficit irrigation (40% deficit) in Trial A and leaching (40%) in Trial B. The farmer treatment was at an intermediate level. With proper irrigation management, basin irrigation can be more productive and profitable than sprinkler irrigation in a dry Mediterranean climate, especially if the water is saline. Further observations are needed to arrive at best practice guidelines for Khanasser valley and similar agro-ecological regions. Specifically the effect of salinity on yield response under various application levels must be further investigated for both sprinkler and surface irrigation. This could be achieved by monitoring soil moisture and irrigations at various salinities in more farmer fields during several years, covering a range of rainfall conditions. An optimization model for wheat irrigation in agricultural productivity zone 4 of Syria and similar winter-rainfall areas of WANA (West Asia and North Africa) would help increase farm income and food production with less water.

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