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Economic analysis of energy use in groundwater irrigation of dry areas: a case study in Syria

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Abstract

This study analyzed the relationship between the fuel-subsidy policy and groundwater-use expansion at macro level and water allocation to different crops at micro level in Syria. Energy uses for major crops were calculated, and a logistic equation fitted to model groundwater, well drilling, and total-irrigated area trends for the period 1986–1999. Energy costs and water use were modeled using input factor cost function to determine the farmers' response to subsidized energy, using well-monitoring data and formal crop budget survey data, and to analyze water allocation to different crops. Different fuel-cost scenarios were simulated to show the likely effects on crops gross margins and cropping patterns.

The study concluded that farmers responded to the agricultural policy of subsidized inputs and supported-prices by expanding cotton, wheat, maize and beat root areas. The research results also showed that the expansion was associated with a high intensity of well drilling and an expansion in groundwater-irrigated areas.

This paper analyses the energy costs of groundwater irrigation in five villages in four stability zones in the northeast of Aleppo province in Syria. Although low fuel prices led to expansion in irrigated areas and a rapid increase in cereal production, farmers in all villages

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tended to over-irrigate and allocated water to high-consuming crops. However, farmers reduced the area allocated to high-consuming crops when water became scarce because costs became prohibitive. The simulation results show that high water-consuming crops do not constitute optimal water allocation decision in water-scarce areas.
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Keywords: Groundwater; Energy cost; Gross margin; Simulation models

1. Introduction

The relationship between energy use and groundwater depletion has not been examined in water-scarce regions. Syria's agricultural policy employed many instruments such as input subsidies, low interest-rate loans and price support, to achieve food self-sufficiency. Fuel as a production input is heavily subsidized. Further, lower interest rates were provided to farmers for well drilling, although there was a shift in policies during the late 1990s toward drilling restrictions. Consequently, cereal production increased from two to four million tons during the period 1990–1995 [1].

These facilities and other supporting policies were geared towards expanding cereal production to narrow the gap between food supply and demand, and to increase foreign exchange earnings through increased cotton production. As a result, there was intensification of well drilling throughout the Syrian basins, and cotton and wheat areas rapidly increased. The annual average wheat production was 1.6, 3.4 and 4.6 million tons during 1980, the 1990s, and 2000–2003, respectively. This reflects the positive side of the policy.

Oil and natural gas have been the major sources of energy in Syria, although the country's crude-oil reserves are small and production has been minor by Arab and international standards. Oil accounts for 55–60% of Syria's total export earnings and more than one-third of its gross domestic product (GDP). Starting in the mid-1980s and into the 1990s, oil production increased dramatically, peaking at 604,000 barrels per day (bbl/d) in 1996 [4]. Since then, however, Syria's oil output has fallen steadily, to an estimated average of 546,000 bbl/d for 1999, as older fields have reached maturity. Syria's natural-gas was discovered in conjunction with oil exploration operations in the northeast of the country. In 1984, gas reserves were estimated at 98.8×10^9 m^3 with associated gas reserves of 33.3×10^6 m^3. The sectoral share of energy consumption comprises transportation (44.6%), industry (38.0%) and residential use (17.4%). During the 1990s, the natural-gas share in energy production increased to 24.3% [4].

Energy use in irrigated agriculture is heavily dependent on diesel fuel, since most pumps used for irrigation are powered by diesel engines. A negligible fraction of irrigation pumps is operated by electricity. Thus, diesel-fuel prices have a crucial effect on the efficiency of water application and area allocation to different crops.

Groundwater is estimated to constitute more than 50% of the total volume of irrigation water used in Syria [2,3]. The objective of this study was to analyze energy use

in groundwater irrigation for different crops, and evaluate the impact of changes in relative energy-prices on water allocation to different crops. The study investigated the driving forces behind the high intensity of groundwater use. Sensitivity analysis was also used to simulate the likely effect of different energy-cost scenarios on irrigated-crop areas in different zones. Crop-water allocation alternatives are discussed and policy recommendations proposed.

2. Materials and methods

Located in the western part of the Mediterranean basin, Syria has a surface area of 185,180 km^2. In 1997, the cultivated area was 55,212 km^2. Approximately 21% of the cultivated land is irrigated, 60% with groundwater and 40% with surface water [5]. Although Syria's annual per capita water availability is less than 1000 m^3, 90% of Syria's current water withdrawal is used for irrigation [6].

Syria has five agroecological stability zones, which differ in terms of rainfall levels. Table 1 shows the main rainfall characteristics of the zones [7]. In this study, five villages in four stability zones (Table 2) were selected and six farmers in each of the five villages were chosen as participant farmers for well-monitoring and water-allocation recording. Participant farmers' water use and well pumping was monitored for winter and summer seasons in the years 1999 and 2000 to measure water application for different crops. In addition, 50 farmers from Bershaya village in zone 2 were randomly selected and included in the crop budget and water-use surveys. Participant farmers recorded the number of pumping hours required for one irrigation applied to one hectare of each crop and the number of irrigations applied to each crop during the growing season. Water use for each crop was measured in cubic metres per hectare. The farm-gate diesel price was calculated in Syrian Pounds (SYP [1]). Diesel, labor and maintenance constituted the main irrigation-cost component. However, fuel comprises the major part of the irrigation cost and therefore the labor cost was assumed to be identical for all crops and across villages. Official prices of wheat and cotton were used in the analysis. Production level was based on the survey data compiled through interviews with participant farmers. The irrigation cost for each crop varied between farmers and villages. These variations were attributed to differences in depths and the condition of the water table. Observation during visits to the research sites showed that well-water yield tended to decrease with the increased duration of pumping.

Although rainfall variation would be expected to influence the cost of energy, the years 1999 and 2000 were dry and the rainfall condition was almost identical in all zones.

Aggregated data on surface and groundwater-irrigated areas were compiled from the Ministry of Agriculture and Agrarian Reform statistical yearbooks.

[1] 1 USD is equivalent to around 50 Syrian Pound at the market rate.

Table 1
Rainfall characteristics of the zones in Syria

Zone	Average annual rainfall (mm)	Probability of annual rainfall being less than the threshold (%)
1	>300	33
2	>250	33
3	>250	50
4	>200	50
5	<200	–

Table 2
Long term annual precipitation and potential evapotranspiration for villages in the study areas

Village	Zone	Elevation (m)	Average precipitation (mm/yr)	Average potential evapotranspiration (mm/yr)
Fafin	1	416	349	1500
Barshaya	2	461	309	1493
Baggat and Rabia'a	3	362	264	1544
Hobs and Harbakieh	4	416	237	1576
Seyaleh	4	390	225	1571

Compiled by the hydrology group of the research project.

The supply function of water was calculated by considering water as a commodity. A production function for water is

$$Y = f(x_i), \tag{1}$$

where x_i represents the inputs required to capture and transport the water. The variable costs associated with water abstraction and transportation were determined using the water unit-price multiplied by the quantity used, which is a function of the quantity of water captured and the factor prices [8].

$$\mathrm{VFC} = f(y, r_i) \tag{2}$$

From the variable factor cost (VFC) function, the marginal irrigation cost (MIC) is calculated by taking the first derivative with respect to (y)

$$\mathrm{MIC} = \frac{\mathrm{dVFC}}{\mathrm{d}y} = f(y, r_i) \tag{3}$$

MIC is the change in variable cost for one unit change in water supplied. The supply function for water would be represented by the marginal cost curve for any quantity above the minimum average variable cost. Water supply can also be seen as the cost per unit or marginal factor cost. By attaching cost to each unit of water, the producer in his efforts to equate the value marginal product with marginal factor cost, has an incentive to reduce the quantity of water demanded. Supply of water from an aquifer is, therefore, a function of the cost of pumping and distributing the water over fields. Lynn et al. [9] (1984) examined the water supply process from groundwater pumping by farmers. They found that the supply curve of effective water is positively sloped even when the marginal cost is constant.

The total cost of groundwater irrigation TIC (SYP/ha year) was calculated as follows:

$$\mathrm{TIC} = n_{\mathrm{i}} \times C_{\mathrm{pi}}, \tag{4}$$

where n_{i} is the number of irrigations and C_{pi} is the cost of one irrigation (SYP/ha - year) and it can be calculated as

$$C_{\mathrm{pi}} = n_{\mathrm{h}} \times V_{\mathrm{d}} \times P_{\mathrm{d}}, \tag{5}$$

in which n_{h} is the number of irrigation hours (h), V_{d} is the amount of diesel used (L/ha h) and P_{d} is the price of diesel (SYP/L).

The general logistic model is used to model the trends of groundwater-irrigated areas, drilled wells and total irrigated areas: it is represented by the following equation [10,11]:

$$Y = A + C/(1 + T\mathrm{e}^{-B(X-M)})^{1/T}, \tag{6}$$

where Y is the total irrigated area, A a lower asymptote indicating the initial irrigated area, C a parameter controls the upper asymptote which indicates the level where the growth is saturated, T a shape parameter which controls the maximum growth near the upper or lower asymptote, B the rate of growth, M the time at which maximum growth occurs and X the time in years.

Water supply and cost functions were determined. The marginal cost was derived from the functional relationship. Sensitivity analysis was applied to determine the response of farmers to different fuel costs [12].

3. Groundwater use intensity: trend analysis

Irrigated agriculture has proliferated in Syria since the 1950s. From 1966 to 1999, the irrigated area increased from 0.4×10^6 to 1.2×10^6 ha. Total cultivated area also increased from 2.03×10^6 to 4.50×10^6 ha during the same period. The rapid increase started during the 1980s and 1990s. Trends for groundwater irrigated, total irrigated, and drilled wells area are depicted in Fig. 1, illustrating the rapid growth that occurred during the last 20 years.

Up to 1994, this expansion in irrigated land was mainly in groundwater-irrigated areas. It was also associated with similar high expansion in well drilling as shown in the figure.

Though the expansion is an economic phenomenon based on a policy option and farmer-level decisions, it is linked to the natural-resource base. To what extent the existing resource base can uphold this option remains an unanswered question.

The logistic model, which is based on aggregated country data for several years [5], shows that the rapid growth followed by saturation indicates the limited capacity of aquifers in all basins in the country. The likely subsequent decline of the irrigated area and decline of the growth of well drilling would be a negative impact crop production and a consequent out-migration which both have an adverse effect on the policy objective of food self-sufficiency.

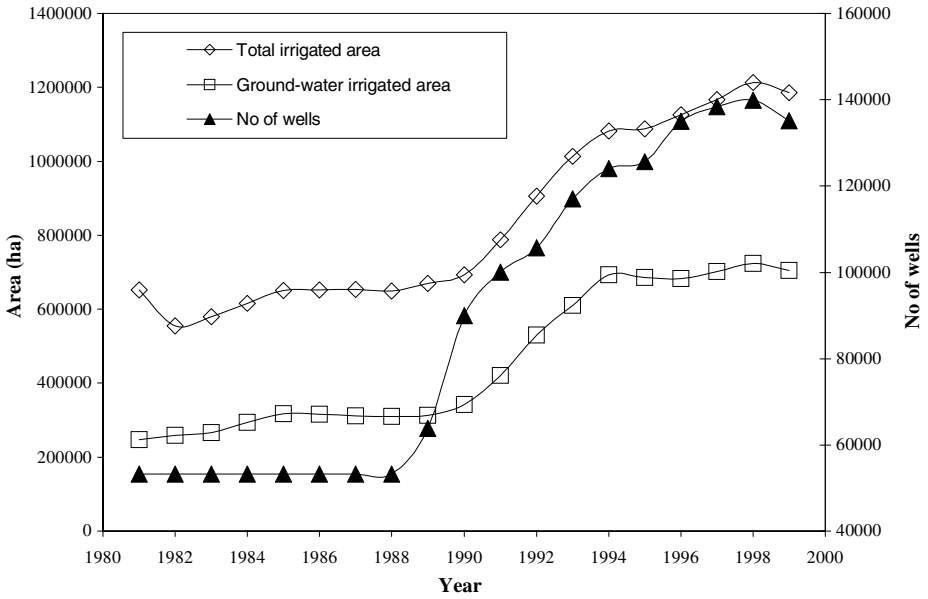


Fig. 1. Total irrigated and groundwater irrigated areas and number of wells during the 1980s and 1990s in Syria.

4. The driving forces

Expansion in surface-irrigated areas has officially been considered the basis of economic growth [6]. Growth in irrigated areas during 1986–1998 reflects the government's economic-policy objectives [13]. Policy makers opted to expand irrigated areas as a strategy for food self-sufficiency for the increasing population. Major policy objectives during the same period included: the achievement of self-sufficiency on major food crops, particularly cereals; increased agricultural production to expand rural employment; raising foreign-exchange earnings; and providing raw materials to domestic industries as part of the overall strategy of economic development. Government devoted 60–70% of the agricultural budget to irrigation projects [13] as well as providing subsidies for well drilling in form of low-interest loans. Irrigation with surface water from public irrigation projects was supported by charging relatively low fees and subsidized diesel. Irrigation fees charged for the Euphrates projects, for example, comprise only 50% of the real cost. Groundwater abstraction has also been supported through highly-subsidized fuel.

Farmers interviewed during the study indicated that they did not consider energy costs as a production constraint. Drilling machinery is run by diesel, which is subsidized, thus encouraging farmers to search for more water by drilling new wells. This affects the efficiency of energy use and the natural resource use. Because of low pumping costs, farmers have limited incentives to irrigate more efficiently, and this results in low productivity.

Table 3
Major production input subsidy based on 1999 exchange rate in Syria

Commodity	Local prices (SYP)	World market prices (US$)	Border prices (SYP)	Input price subsidy (SYP)
Diesel fuel (L)	6.1	0.23	11.54	5.44
N fertilizer (kg)	8.3	0.18	9.00	0.70
P fertilizer (kg)	8.3	0.23	10.72	2.42

Border prices = Exchange rate × (Int. FOB Prices + Transport).
1 USD is equivalent to around 50 Syrian Pound at the market rate.

The fuel subsidy is estimated to be 80% of the purchase prices (Table 3). Diesel prices do not fluctuate with the prices of international petroleum products and, therefore, in certain periods the subsidy reaches as high as 130% as a result of higher international prices.

Farmers registered in the state agricultural-plan have access to low-interest loans and input purchase credits of 5% compared with the official interest rate of 9%. This is in contrast with the annual interest rate which ranges from 25% to 40%, charged by local moneylenders in the informal financial sector [14]. Direct input subsidies cover farm inputs such as diesel, seeds, farm equipment, fertilizers and bags.

5. High water-consuming crops and energy-cost trends

The cotton area expanded from 93,815 to 14,6301 ha during the period 1990–1999 [5]. Fig. 2 shows the estimated total energy expenditure on cotton irrigation during

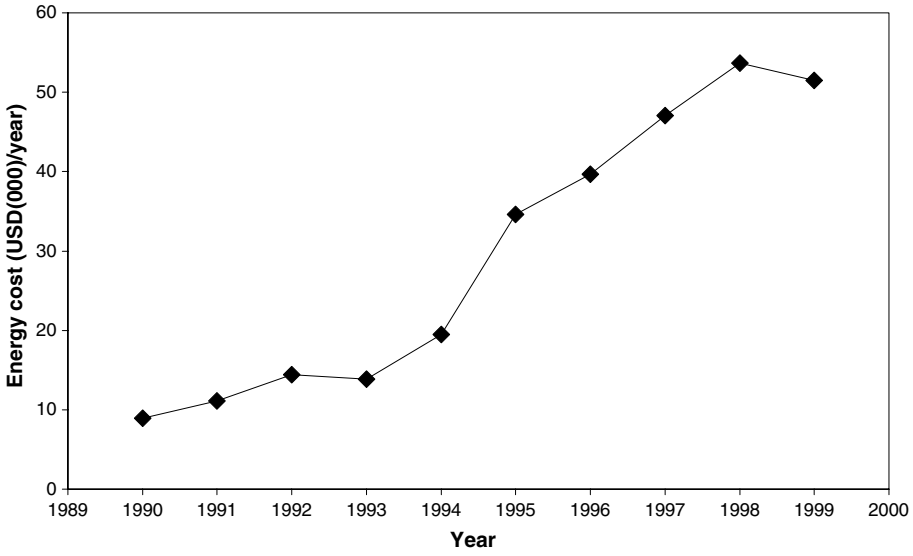


Fig. 2. Energy cost for cotton irrigation in Syria for the period 1990–1999.

this period. The increase in energy costs is due to the rapid increase in groundwater-irrigated areas and to increases in prices. However, the estimated costs of irrigation published in the official statistical yearbook differ significantly from the present study for groundwater-irrigated crops. This is due to the fact that our cost estimate is based on groundwater irrigation only, while the official estimate covers both surface and groundwater irrigation: surface irrigation is also highly subsidized. The figure shows that costs increased rapidly during the 1990s, followed by a slowdown. The slowdown reflects the decline in the cotton area due to groundwater scarcity and the consequent increase in the cost of pumping. Recently, there has been a shift in policy aimed at reducing groundwater use by forbidding the cultivation of summer crops in the steppe areas, well licensing, conversion to new irrigation methods, installation of well-water flow meters and credit guarantees for new irrigation techniques [1]. The question that may be raised is: to what extent will these policy shifts be implemented?

6. Relationship between crop prices, diesel fuel cost and water use

In Syria, in almost all zones, farmers supplement rainfall with groundwater, applying several irrigations to the crop during critical periods. In summer, crops are fully irrigated. The irrigation cost for farmers in rainfall zones depends on the aquifer water-capacity, depth of the water table, the distance between the well and the field, and the crop type.

The cost of irrigation is the major component of the variable cost in water-scarce areas (Table 4). Fig. 3 shows the variation of total groundwater-irrigation costs (total factor cost), TIC in SYP/ha year, with the amount of water used V_w in m^3/ha - year. As can be seen from the figure, the data points exhibit a significant scatter. An equation was fitted to the data points for TIC (SYP/ha year) with $R^2 = 0.53$

$$\mathrm{TIC} = 10138 + 0.5025V_w + 10^{-4}V_w^2 \tag{7}$$

Groundwater marginal irrigation cost MIC (SYP/m^3) can be computed from TIC as

$$\mathrm{MIC} = \frac{\mathrm{dTIC}}{\mathrm{d}V_w} = 0.5025 + 2 \times 10^{-4}V_w \tag{8}$$

Although the standard errors of the estimate were high (2.2 and 0.000118) for the linear and quadratic estimates, respectively, the model is justified in that the cost of using additional water would increase the average and marginal cost. When fitting the cubic function, the model shows a high fit and the parameters are highly significant. However, this is not justifiable since the marginal cost cannot be a decreasing function of an increasing total cost. Average irrigation cost AIC (SYP/m^3) was calculated from the TIC as

$$\mathrm{AIC} = \mathrm{TIC}/V_w \tag{9}$$

An equation for average irrigation cost (SYP/m^3) can be obtained from Eq. (7) as

$$\mathrm{AIC} = 0.5025 + 10138V_w^{-1} + 10^{-4}V_w \tag{10}$$

Table 4
Annual average values for water cost, crop price and well depth, and marginal cost per cubic metre for different crops across the village in the stability zones 1–4

Crop	Zone	Water quantity (m^3/ha)	Total cost (SYP/ha)	Marginal cost (SYP/m^3)	Average cost (SYP/m^3)	Well depth (m)	Crop price (SYP/kg)	Gross margin (SYP/ha)	Gross margin (SYP/m^3)
Cotton	1	16,800	42,000	3.41	2.50	50	29	42,168	2.51
	2	14,300	37,800	2.91	2.64	63	29	35,607	2.49
	3	14,400	37,000	2.93	2.57	96	29	29,232	2.03
	4	10,400	44,000	2.13	4.23	51	29	17,368	1.67
	4	87,00	47,000	1.79	5.40	62	29	10,875	1.25
Wheat	1	3800	9000	0.81	2.37	50	11.1	17,214	4.53
	2	5400	10,000	1.13	1.85	63	11.2	10,368	1.92
	3	5100	12,200	1.07	2.39	96	10.6	1530	0.30
	4	8300	15,000	1.71	1.81	51	10.3	5395	0.65
	4	5100	13,750	1.07	2.70	62	11	12,750	2.50
Faba beans	1	3600	16,215	0.77	4.50	50	21	14,508	4.03
	2	3600	10,200	0.77	2.83	63	21	55,368	15.38
Cucumber	1	6400	12,000	1.33	1.88	50	6	70,336	10.99
	2	6400	8400	1.33	1.31	63	5	59,392	9.28
Beans	1	6400	10,925	1.33	1.71	50	10	41,792	6.53
	2	6600	10,800	1.37	1.64	63	10	28,710	4.35
Tomato	1	7000	10,000	1.45	1.43	50	5	23,170	3.31
	2	7600	11,250	1.57	1.48	63	5	92,872	12.22
Potato	1	3800	15,000	0.81	3.95	50	5.5	43,852	11.54
	2	3200	21,000	0.69	6.56	63	5.5	34,368	10.74
Onions	1	5300	18,000	1.11	3.40	50	5	16,271	3.07
	2	2000	16,000	0.45	8.00	63	5	29,260	14.63
Garlic	1	4900	22,500	1.03	4.59	50	10	26,803	5.47
	2	4900	19,250	1.03	3.93	63	10	29,253	5.97

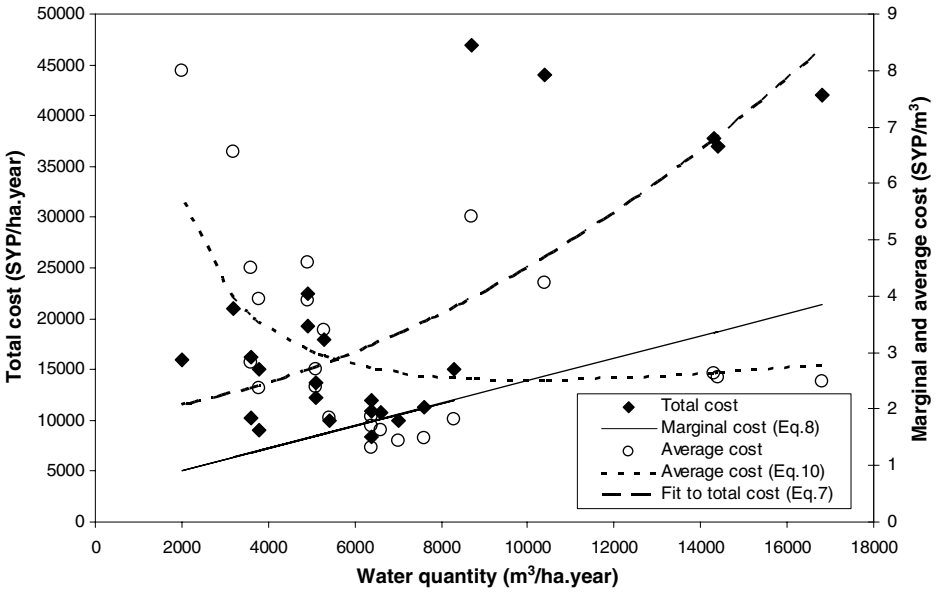


Fig. 3. Average and marginal costs of irrigation water for different crops across the villages in zones 1–4 in Syria.

Fig. 3 shows the relationship between total, marginal and average irrigation costs. The model is backed by economic theory. The marginal irrigation cost pulls the average irrigation cost downward when the marginal is below the average cost, and conversely pulls it upward when it is higher than the average cost. Microeconomic theory dictates that farmers whose marginal irrigation cost is lower than the output value (gross margins) (SYP/m^3) would still expand irrigation by allocating areas to high water-consuming crops. However, high water-consuming crops are responsible for the quadratic shape of the total cost curve. This model shows that farmers growing cotton incur high irrigation-costs, hence their profitability is determined by fuel subsidy and price support. Relatively higher fuel costs would result in the abandonment of cotton cultivation due to higher marginal and average costs.

The fuel cost can be a policy instrument to control water depletion and inefficient use of energy. Since fuel is highly subsidized, farmers in depleted aquifers will continue growing cotton and other high water-consuming crops. The marginal cost for high water-consuming crops such as cotton was estimated at 3.2 SYP/m^3 while it was less than 2 SYP/m^3 for other crops such as vegetables and wheat. Vegetables can be more profitable since the marginal cost of irrigation would be lower than output prices; however, price volatility and seasonal fluctuations make vegetable production risky.

Table 4 demonstrates that the marginal cost of irrigation for high water-consuming crops is relatively high compared with other crops. Furthermore, the table shows that the marginal cost of water is associated with high crop-prices. Hence, high crop-prices operate as an incentive for allocating water to high-consuming crops. The

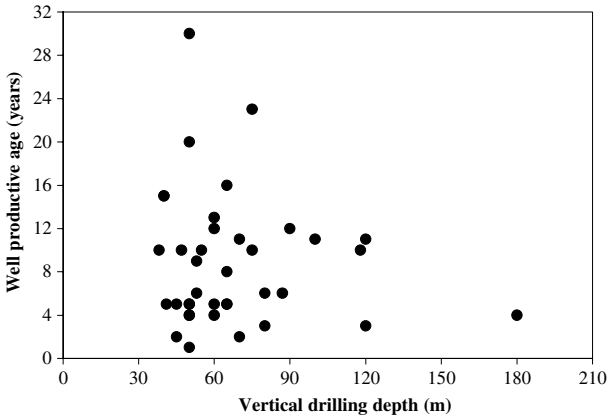


Fig. 4. The relationship between well depth and productive age of wells in the research site villages.

gross margin per cubic metre was computed as the difference between gross production value and the variable cost of each farming activity divided by the cost of irrigation.

Table 4 indicates that the average cost for cotton was relatively high in a situation where the quantity of water abstracted was low. Thus, the aquifer is depleted when the number of hours required to abstract the same volume of water is increased, which in turn increases the average cost per unit (m^3).

The energy required for water abstraction increases with the depth of the well. Groundwater literature postulates a positive correlation between depth and cost of water abstracted. Most wells in the studied villages were shallow, with considerable variations in depth.

These research findings contradict the conventional perception by farmers that in order to increase well productivity and the number of productive years, it was necessary to deepen the wells (Fig. 4). In a shallow aquifer, this does not necessarily hold. During the visits, it was noticed that farmers attempted to deepen their wells with the expectation that well-water yield would increase. In most cases the wells run reasonably well for one season, but failed to provide sufficient water for irrigating winter or summer crops in the following season. In most cases, deepening was not successful in increasing the productive life of the well. Hence, the return on these additional investments was negative. Further, energy consumption would increase as depth increased. Similar findings were reported by Engelhardt [15] in India, where high-yielding wells did not necessarily indicate potential increase in the water yield through further drilling.

7. Fuel cost and profitability for different crops: scenario analysis

The gross margins per hectare of nine crops, including cotton, summer vegetables: cucumber, onion, potato and tomato; winter field crops: wheat and faba bean; and

winter vegetables: garlic were compared (Table 4). Three summer vegetables namely, potato, cucumber, and beans gave the highest gross margins per hectare, respectively. The second highest gross margins were generated by cotton, garlic and tomatoes, respectively. The least profitable crops were onions, faba beans and wheat, respectively.

Cotton generated a higher income than wheat in all villages. However, cotton gross margins declined with decreasing groundwater. Farmers in all villages who operated wells with relatively abundant water grew cotton, while those who grew cotton under water-scarce conditions incurred losses. For example, in 1998/99, farmers abandoned crops due to insufficient water and dried-up wells in villages in zone 4. Farmers who cultivated cotton with unreliable water either abandoned the crop completely or received low gross margins. For example, the gross margin of cotton was negative or at breakeven level in villages in zone 4. A farmer in one of the villages in the zone failed to provide sufficient water to his cotton crop during July 2000 and incurred a net loss of 50,000 SYP/ha.

A crop-budget survey shows that irrigation costs form a substantial portion of the total variable costs, ranging from 52–60% for cotton, 34–51% for wheat, 35% for faba beans, and 20% for vegetables across the villages in four stability zones. Fuel costs were the main component of the irrigation variable cost. Changes in irrigation costs, as a result of changes in fuel costs, would have varying effects on the profitability of different crops and, subsequently, on crop-water allocation. In order to determine the effects of fuel costs on the profitability of irrigated crops, four scenarios were used: 25%, 50%, 75% and 100% higher fuel cost than the present. These scenarios were used because fuel is highly subsidized and they reflected a possible reduction or elimination of these subsidies. Other variable costs and government procurement prices were held constant and surface irrigation was assumed in the analysis.

The effects of higher fuel costs on the profitability of different crops in the selected villages are shown in Table 5. The decline of the gross margins per hectare was highest in the high water-consuming crops such as cotton, wheat, faba beans, and onions. The decline was also higher in the villages in zones 3 and 4. For instance, for a 25% higher fuel-cost scenario, cotton gross margins per hectare decreased by 26%, 28%, 38% and 94% in the villages in zones 1–4, respectively. Similarly, wheat gross margins decreased by 22%, 14%, 34%, and 118%, in the villages in zones 1 through 4 in the same order. The gross margins per hectare of faba beans decreased by 39% in Fafin (zone 1) and 17% in Barshaya (zone 2) under 25% higher fuel-cost scenario. The profitability of cucumbers and beans dropped by only 2–5% in Fafin and Barshaya villages.

The analysis shows that cotton would not be profitable in the villages in zone 4 at 25% higher fuel cost and in another village in the same zone at 75% higher fuel cost. Wheat would not be profitable in villages in zone 4 at 75% higher fuel cost and at 50% higher fuel cost in another village in the same zone. Similarly, wheat would not be profitable in villages in zone 3 at 100% fuel cost increase and may only breakeven at 75% fuel cost increase. This shows that the removal of fuel subsidies could render wheat and cotton unprofitable in these water-scarce villages. With higher

Table 5
Crops gross margin changes under different fuel-price scenarios

Crop	Village	Zone	Gross margin per area unit (SYP/ha) under different scenarios				
			Current fuel cost	25% fuel cost-increase scenario	50% fuel cost-increase scenario	75% fuel cost-increase cenario	100% fuel cost-increase scenario
Cotton	Fafeen	1	42,251	33,501	24,751	16,001	7251
	Bershaya	2	35,596	27,896	20,196	12,496	4796
	Rubia and Bagat	3	29,256	21,256	13,256	5256	Neg.
	Hubs and Hurbakia	4	Neg.	Neg.	Neg.	Neg.	Neg.
	Sayala	4	17,318	8918	518	Neg.	Neg.
Wheat	Fafeen	1	10,845	8895	6945	4995	3045
	Bershaya	2	17,212	15,112	13,012	10,912	8812
	Rubia and Bagat	3	10,388	7738	5088	2438	Neg.
	Hubs and Hurbakia	4	1550	Neg.	Neg.	Neg.	Neg.
	Sayala	4	5435	2497	Neg.	Neg.	Neg.
Faba beans	Fafeen	1	12,771	9187	5603	2019	Neg.
	Bershaya	2	14,504	12,354	10,204	8054	5904
Cucumber	Fafeen	1	55,365	53,165	50,965	48,765	46,565
	Bershaya	2	70,307	68,907	67,507	66,107	64,707
Beans	Bershaya	2	59,374	57,505	55,636	53,768	51,899
	Fafin	1	41,775	39,750	37,725	35,700	33,675
Tomato	Fafin	1	28,680	26,743	24,805	22,868	20,930
	Bershaya	2	23,195	21,226	19,258	17,289	15,320
Potato	Fafin	1	92,860	90,110	87,360	84,610	81,860
	Bershaya	2	43,850	39,300	34,750	30,200	25,650
Onions	Fafin	1	34,361	31,161	27,961	24,761	21,561
	Bershaya	2	16,250	11,625	7000	2375	Neg.
Garlic	Fafin	1	29,261	27,461	25,661	23,861	22,061
	Bershaya	2	26,800	24,400	22,000	19,600	17,200

Neg = negative value.

energy costs, farmers in these villages would have to find alternatives to these traditional crops.

8. Conclusions

The high fuel share of the irrigation cost indicates that a reduction or removal of the diesel subsidy could have a considerable impact on the profitability of irrigated

crops and on farmers' allocation strategies. This study shows that although subsidized fuel has a significant positive impact on cereal production, it has also led to intensive groundwater use and aquifer depletion in water-scarce areas. The intensity of groundwater use has been associated with the expansion in areas of high water-consuming crops. Although the rate of drilling success was low, farmers in these water-scarce areas continue to invest in wells and well irrigation, and respond to policy signals like low fuel costs.

Scenarios of higher fuel-costs show that as water becomes more valuable, farmers may shift production to crops with higher water-productivity. The evidence shows that farmers in the study area shifted to short-season crops such as vegetables and reduced high-consuming crops as a result of the high cost of irrigation when water became scarce.

Fuel subsidies contributed to low water productivity (gross margin per cubic metre). This was evident in the case of cotton where high quantities of water produced a low gross margin per cubic metre. Further, the subsidy on fuel could have been channeled to different sustainable investment options having higher value added at the farm level.

This study shows that the expansion in total irrigated areas has reached a level where potential increase in well drilling will be minimal. The intensive increase in well drilling and the consequent slowdown occurred in a considerably shorter time than the policy planner would have expected.

Market-based fuel prices might have a positive impact on the efficiency of groundwater use, fuel consumption and cropping patterns in Syria. Further, introducing conserving irrigation methods may reduce over-irrigation and raise the productivity of water. However, it may not reduce water use.

Further, the absence of options forces farmers into low-productivity investments that are unprofitable in most cases. Eliminating subsidies will provide the farmers with the incentive to adopt activities with higher profits for both per unit energy and water productivity. Absence of interventions in price determination for both inputs and outputs in the agricultural sector will contribute to the sustainability of agricultural resources and increase farmers' incomes.

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