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Wheat production in Saudi Arabia between feasibility and efficiency

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Abstract

The cultivation of wheat in Saudi Arabia has been claimed to be resource depletable. Huge amounts of high quality inputs, especially water, seeds, and nitrogen fertilizers, have been applied to the sandy Saudi soils to increase productivity. However, the economic feasibility of wheat production has been totally neglected, mainly for political reasons. Classical production functions analysis has not yielded significant conclusions regarding the use of inputs. A 3-year experiment on an educational farm with a soil type representative of the agricultural soil in Saudi Arabia, yielded some interesting results concerning the use of inputs. The findings were obtained through the stochastic dominance efficiency criterion which assessed the efficient levels of seeds, water, and nitrogen fertilizers in wheat cultivation when production risk was considered.

1. Introduction

The cultivation of wheat is considered controversial in the Kingdom of Saudi Arabia. The controversy arises from it being a 'strategic' crop that can provide food security, but which can only be grown at relatively high cost. The severity of the problem stems from the scarcity of resources, in general, and water in particular. In the Kingdom, as in most other Middle East countries, water is the scarcest natural resource. Exhaustible groundwater resources and costly desalinated sea water are the main sources utilized in the Kingdom for all uses, i.e. agricultural, domestic, municipal, and industrial. Recently, treated sewage water has been used for some agricultural purposes.

The Kingdom has experienced an agricultural 'revolution' in the past two decades. The objective of the revolution was to achieve food security for Saudi citizens. The decision-making entities concerned with wheat cultivation were faced with the question of economic feasibility and political dignity. Apparently, the political side dominated. The reason was that the consequences of not locally producing wheat may cause high social costs in the form of not achieving food security. Accordingly, the Saudi government adopted some quick and effective strategies towards wheat production, some of which are: distribution of lands free of charge to wheat producers; provision of grants, subsidies, and free-interest loans; and the adoption of modern production techniques regarding water use and production practices. More importantly, the government has created some marketing channels for wheat producers and also assists them by purchasing their production at prices in excess of current world prices.

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The objective of wheat self-sufficiency was achieved in 1984 with a surplus that was exported, in most cases free, to less wealthy Arabian and Islamic neighbors in the form of grants. However, the cost of producing the wheat was far higher than in other parts of the world. The reasons for this lie in the importation of most production means and the enlargement of the required investments, especially those needed for water use. Nevertheless, a low productivity of 1.5–4 tons ha^{-1} was achieved despite the government's efforts (globally this value is 5 tons ha^{-1}). More seriously, groundwater resources are believed to be depleted due to the expansion in wheat production. After the 1991 Gulf War, the Saudi government was obliged to review its agricultural policies. Subsidization and loaning policies adopted in the past were hampered. The question of the economic feasibility of wheat production was revived. For numerous political and economic reasons, the government could not completely reverse its strategy concerning wheat production. However, the question remains: if we must continue to grow wheat, can we at least grow it efficiently?

Table 1 shows some economic studies that have dealt with this issue, mostly assuming perfect knowledge. Wheat production costs were examined through analytical economic studies (Al-Attar and Al-Dossary, 1975; Ministry of Agriculture and Water, 1977; Al-Dossary, 1980). The average percentage costs for seeds, irrigation, and fertilizer were reported to be 5.2%, 16.8%, and 13%, respectively, but factors affecting wheat yield were not indicated. The Saudi Arabian Agricultural Bank (1981) and Al-Nashwan (1988) studied the relationship between the amount of wheat yield and some related factors utilizing correlation and regression analyses. The former study indicated there is a positive relationship between the amount of yield on the one hand, and total cultivated area, total fixed costs, and the amount of inputs used on the other. Al-Nashwans' estimates of production functions showed that the most important factors affecting yield are cultivated area and machinery; labor was shown to have a negative effect. Other authors discussed deferent issues related to wheat production and marketing policy in the Kingdom. Ismaile and Mansour (1988) indicated that the Saudi government was almost obliged to support a policy of growing wheat locally, for a number of reasons. Some of these are:

1. the global deficit in the supply of wheat, which cannot match population increases;
2. instability in world wheat production due to climate variability;
3. the concentration of wheat production in three countries;
4. the weak share of wheat in international trade (wheat does not exceed 14% of total world production);
5. high and unpredictable fluctuations in world wheat prices.

However, we believe that there are two reasons for the Saudi Arabian agricultural policy of supporting the wheat price and subsidizing its input factors. The first is to achieve income distribution equity between urban and rural areas, and the second is to encourage the adaptation of new technology to the agriculture

Table 1
Studies which have addressed the productivity and cost of wheat production in the Kingdom of Saudi Arabia

Source	Yield	Cost percentage			Main factors affecting yield
	(ton ha^{-1})	Seeds	Irrigation	Fertilizer	
Al-Attar and Al-Dossary, 1975	NA	5.0	18.0	9.0	Not indicated
Ministry of Agriculture and Water, 1977	2.5	4.0	16.0	21.0	Not indicated
Al-Dossary, 1980					
(a)	1.9	NA	NA	10.3	Not indicated
(b)	2.3	NA	NA	10.3	Not indicated
The Saudi Arabian Agricultural Bank, 1981	3.75	NA	NA	NA	Cultivated area, total fixed costs, and the amount of inputs used
Al-Nashwan, 1988	3.82	6.7	16.4	14.0	Cultivated area and machinery

(a) and (b) are the Al-Aflaj and Wadi Al-Dawasser regions, respectively.

sector. In an investigation of wheat subsidies, Al-Qunaibet (1994) claimed that wheat alone received three types of subsidy: (i) food (the subsidization of wheat flour imports since 1973); (ii) input (subsidization of fertilizers and agricultural machinery, both of which were subsidized by as much as 50%); (iii) output (price support).

To summarize, no significant conclusions have been reached concerning the relative importance of the factors of production affecting wheat yields, even though all the studies mentioned above were conducted in the same Central Region. However, almost all the studies show that wheat production is neither efficient nor characterized by high productivity.

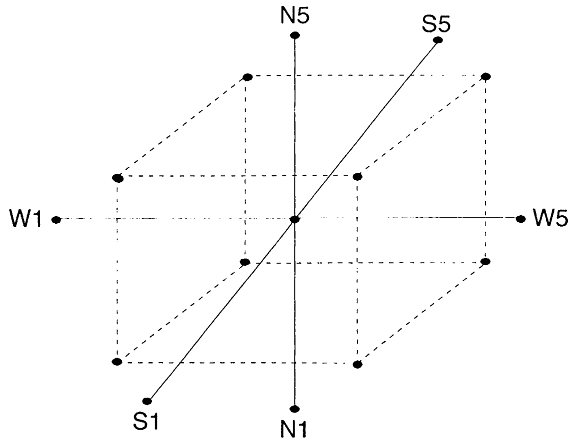

Fig. 1. Central composite design treatment of seeds, nitrogen and water level for estimating wheat grain production function.

2. Objective

The objective of this study was to assess the optimal levels of three factors of production: seeds, water, and nitrogen fertilizers. The latter was of special interest, as it showed a rather unusual relationship with yield (more nitrogen fertilizer was associated with low yield). Utilizing production function estimation, the efficient use of inputs was realized through marginal analysis. The impact of these inputs on wheat yield and profitability was determined by means of the stochastic dominance efficiency criterion under the assumption of production uncertainty.

3. The experiment

The experiment was conducted three times from the fall of 1990 to 1992. The location of the experiment was King Saud University's farm at Derab. Teams of scientists from all disciplines of the College of Agriculture were involved. A Central Composite Design (CCD) for the three factors (seeding rate, irrigation level, and nitrogen fertilizer level) was made (Fig. 1). The three main levels for each factor (1, 3 and 5) were applied at the central level (3). A 2^3 factorial design of the second and fourth levels for each factor (2 and 4) was used for the other treatments. Thus, when any of the three inputs under consideration takes any of the three values (1, 3, 5), the other two inputs must take level 3, while the rest of the points take 2^3, where 2 stands for the two levels (2, 4) and 3 stands for the three inputs. It was expected that wheat grain production will attain its maximum level at the central point (3, 3, 3) according to the properties of this design.

Three blocks (replicates) were available. Each was divided into 15 plots, each of which was 4 m × 5 m in size, with 20 cm between rows. Treatment levels for each factor are presented in Appendix A. The seeding rate ranged from 60 to 200 kg with a central point of 130 kg ha^{-1}. Nitrogen fertilizer application ranged from 0 to 300 kg ha^{-1} with a central point at 150 kg ha^{-1}. Irrigation ranged from 400 to 1200 mm with a central point at 800 mm.

Seeds were applied once a year. Nitrogen fertilizer was added in the form of urea (42%), four times per year (15, 36, 57, and 78 days after planting; wheat needs a growing season of not less than 100 days). The planting date for the 3 years was on or after 22 November. The zero fertilizer level was chosen to reflect residual soil nutrients from preceding plantings. This practice exactly matches what the Saudi farmer does with nitrogen fertilizer, i.e. treatment levels were planned to cover a sufficient range of this input.

In estimating the yield–water relationship, the quantities of water applied at each irrigation were aggregated to the specified planned water treatment level. That is, rainfall that exceeded a specific quantity during the growing season was included (wheat

Table 2
Irrigation scheduling for water–wheat relationship

Irrigation treatment	No. of irrigations	Irrigation timing	Total quantity of water applied (mm)
W1	8	Every 2 weeks	400
W2	11	Every 10 days	660
W3	16	Every 10 days for the first three irrigations and weekly thereafter	800
W4	21	Weekly for the first nine irrigations and every 5 days thereafter	960
W5	24	Every 5 days	1200

needs annual rainfall of 381–1016 mm). Table 2 shows the timing and quantities of irrigation water applied.

4. Production function formulation

The functional relationship between inputs and an output is estimated by means of regression analysis (Hexem and Heady, 1978; Heady and Shashanka, 1984; Beattie and Taylor, 1985). Multiple regression analysis was performed and four functional forms were estimated. The estimation of the four functional forms (quadratic, orthogonal quadratic, square root, and 1.5 power) was done separately for each of the 3 years of the experiment. The reason for this was to evaluate the efficiency of the field work from 1990 to 1992, and to explain the impact of nitrogen fertilizer on yield each year. Nitrogen fertilizer received special attention because it was found that, in general, greater yield was obtained with less nitrogen fertilizer. Two dependent variables were considered: wheat grain yield (*GW*) and biological yield (*BY*), i.e. grain and straw. Regression analysis was applied to wheat grain yield in all 3 years of the experiment, to increase the data input. The linear parts of both quadratic and orthogonal quadratic forms were expected to be positive, and the quadratic part to be negative. According to the CCD, wheat grain production will attain its maximum level at the central point (130 kg ha^{-1} seeding rate, 150 kg ha^{-1} nitrogen fertilizer level, 800 mm ha^{-1} irrigation water level). Table 3 shows the results of the estimated functions for *GW* and *BY*.

5. Results of the production functions

The results of the quadratic functional form were the same as the orthogonal quadratic for the curvilinear and interaction parts; however, the linear part was significant for the orthogonal quadratic functional form. The coefficient of determination (R^2) was slightly higher (in the first and third years) for the square root functional form than for the other forms, but with no significant changes for factor inputs or their sign. The one-half power functional form lacked the significant of the linear part as the quadratic functional form; therefore, the orthogonal quadratic functional form results were considered.

The results of the production functions estimation where the dependent variable was wheat grain (*GW*) can be summarized as follows.

1. The results of the second year were found to be, in general, better than those of either the first or the third (which yielded the worst results).
2. Water gave good results for the orthogonal quadratic form in the second year, where water was highly significant. Although it was not significant, the curvilinear part W^2 correctly possessed a negative sign, i.e. increasing water levels result in diminishing increasing yield rate.
3. For the first year, the orthogonal quadratic form showed a significant N followed by W, whereas the N^2 part had a significant wrong sign (as nitrogen increases yield does not attain maximum level). However, the W^2 part possessed the right sign.
4. In the third year, nitrogen fertilizer N was the only significant input for the estimated orthogonal quadratic form with wrong signs for both linear and quadratic parts.

The results of the production functions estimation where the dependent variable was the biological yield (*BY*) are as follows.

1. For the first year, the orthogonal quadratic form showed that N was significant with a wrong sign for the quadratic part, whereas W^2 was insignificant.
2. For the second year, W possessed the right sign and was significant, while the quadratic part was

Table 3

Estimates of orthogonal quadratic response function of grain wheat (*GW*) and biological yield (*BY*) related to seeding rate (S), nitrogen level (N), and irrigation water (W)

	Constant	Seeds (S)	Nitrogen (N)	Water (W)	S^2	N^2	W^2	S×N	S×W	N×W	R^2	*F*
Grain wheat yield												
1990	5723.3	−5.639	4.144	1.168	−0.022	0.033	−0.001	0.052	−0.019	−0.003	0.400	2.81
		(0.058) *	(0.004) * *	(0.070) *	(0.800)	(0.093) *	(0.594)	(0.225)	(0.437)	(0.802)		(0.012) * *
1991	4266.9	8.637	−2.535	5.237	−0.036	−0.004	−0.005	0.042	−0.031	0.007	0.573	5.22
		(0.35) * *	(0.177)	(0.000) * * *	(0.812)	(0.909)	(0.276)	(0.472)	(0.376)	(0.677)		(0.000) * * *
1992	5555.6	3.702	−7.018	1.766	0.083	0.013	−0.001	0.020	−0.027	−0.002	0.191	0.92
		(0.566)	(0.024) * *	(0.211)	(0.735)	(0.812)	(0.870)	(0.830)	(0.630)	(0.945)		(0.521)
Biological yield												
1990	14301.6	−2.068	9.185	3.426	0.256	0.136	0.009	0.085	−0.054	0.011	0.329	2.07
		(0.795)	(0.017) * *	(0.053) *	(0.298)	(0.014) * *	(0.269)	(0.468)	(0.433)	(0.736)		(0.058) *
1991	11168.2	15.956	−5.779	11.525	−0.059	0.017	−0.001	0.197	0.028	0.045	0.657	7.47
		(0.035) * *	(0.097) *	(0.000) * * *	(0.834)	(0.783)	(0.867)	(0.073) *	(0.661)	(0.138)		(0.000) * * *
1992	13582.8	16.903	−0.674	3.221	−0.138	0.042	−0.004	0.081	0.002	0.001	0.125	0.56
		(0.156)	(0.902)	(0.211)	(0.760)	(0.666)	(0.797)	(0.636)	(0.980)	(0.986)		(0.823)

Grain wheat, wheat biological yield, seeding rate and nitrogen level are in kg ha^{-1}; water quantity is in mm.
Figures in parentheses are *P*-values for the corresponding coefficients.

insignificant. For the first time, seeds (S) was significant.

Application of regression analysis to a data set including all 3 years of the experiment did not improve the results. Only water showed significant results for the linear part. Although the curvilinear part W^2 was not significant, it correctly possessed a negative sign. The coefficient of determination (R^2) was very low (0.132). However, omitting non-significant variables (backwarding) did not change the significance of the others, and it ended only with water variable parts. The regression coefficients did not change remarkably from the full model to the reduced one, owing to the orthogonality of the CCD.

The results of the production functions estimation were, in general, not reliable except those for the water input. This may be due to the insignificance of the curvilinear component (even for water). This led to the marginal analysis being abandoned and another criterion, which takes into account the stochastic nature of wheat yield, being taken into consideration.

6. The stochastic dominance model

The second-degree stochastic dominance model assumes that farmers prefer more to less and that they are risk averse. The technique relies on comparing the areas under the cumulative distribution functions (CDFs) for the gross margin of the different choices available to the decision makers. For instance, action T_1 (applying treatment level 1) dominates action T_2 (applying treatment level 2) if the area under the CDF of T_1 never exceeds that under the CDF of T_2, with the area under the first to be less than that under the second for some values (for more rigorous discussion of the stochastic dominance approach see Anderson et al., 1980; Boehlje and Eidman, 1984).

Grain wheat yield (GW) was assumed to be the farmer's ultimate goal. However, wheat straw was also considered. Grains plus straw was called the biological yield (BY). The plot size was about 4 m × 5 m, of which an area of 2 m × 2 m was selected at random to measure the biological yield. Wheat grains were then threshed from the sampled biological yield. Table 4 shows the estimated grain yield corresponding to different treatments. Owing to the large variation in experimental outcomes (wheat grain yield), it is assumed that these outcomes can simulate yield under different conditions, i.e. those conditions not under the farmer's control. These can be divided into three categories; unfavorable, normal, and favorable. Beside location, weather is one of these conditions. Rainfall is one of the factors determining the weather condition. About 90 mm of

Table 4
Estimated wheat grain yield (tons ha^{-1})

Treatment	Replicate								
	1	2	3	4	5	6	7	8	9
1	0.967	2.984	4.448	5.140	5.185	5.412	5.415	5.498	5.556
2	2.965	3.309	4.371	4.551	5.068	5.353	5.533	5.873	7.268
3	1.431	1.757	2.546	4.348	5.518	5.808	6.294	6.341	6.410
4	1.325	3.261	3.447	3.783	5.053	5.225	6.474	7.929	8.288
5	4.811	5.622	5.653	5.772	5.978	6.013	6.487	7.187	8.235
6	3.801	4.597	4.867	4.918	5.313	5.804	5.983	6.348	7.615
7	2.593	2.968	4.659	5.483	5.834	6.942	6.948	7.763	7.889
8	4.792	5.215	5.250	5.653	5.673	6.073	6.335	7.409	7.698
9	2.494	3.781	4.212	4.585	5.512	5.533	5.573	6.685	6.734
10	4.105	4.221	4.569	4.998	5.177	5.907	6.301	6.533	6.938
11	4.290	4.390	4.463	4.480	6.178	6.179	6.744	7.080	11.628
12	2.003	2.592	3.408	5.088	5.139	5.643	5.908	6.696	6.921
13	1.737	2.015	2.188	3.245	4.573	4.584	5.177	5.329	6.210
14	4.878	4.890	5.132	5.169	5.505	5.711	5.759	6.268	7.153
15	3.317	4.383	4.933	5.056	5.085	5.336	5.801	6.274	6.643
Probability	0.007	0.033	0.107	0.216	0.274	0.216	0.107	0.033	0.007

rainfall is expected during the wheat-growing season, which can be distributed favorably over the season, or unfavorably at the end of the season. Temperature is also an important determinant of the weather condition. Each condition or 'state of nature' can be divided into three categories according to the degree of the weather effect to match the experiment replicates. The first three columns (replicates 1, 2, and 3) represent yield when weather is unfavorable, the second three replicates represent yield when weather conditions are normal, whilst the last three columns stand for wheat yield when weather conditions were favorable. According to the local agronomist, the normal distribution can be used to assign the subjective probabilities of the state of nature; therefore, the range of the standard normal variable is divided around zero with equal space to form nine intervals. If we put the probabilities of the two extreme state of nature categories to be equal to 0.007 for each, then seven intervals can be formed between -2.45 and 2.45 of the standard normal distribution range. The three replicates for each year and the estimated yields were arranged in ascending order to correspond to the states of nature (weather conditions) in the stochastic dominance analysis. The probabilities at the end of the table were assigned from the standard normal distribution by spacing intervals from -2.45 to 2.45 with 0.7 of standardized unit.

Gross margins were defined as the total value of wheat grain, at a price of S.R. 2000 ton^{-1} (US$1 = S.R. 3.75) minus the variable costs of production under consideration. Seeds and nitrogen fertilizer prices were estimated at S.R. 1800 and S.R. 1700 ton^{-1}, respectively. Irrigation water was priced at S.R. 0.25 m^{-3} (as priced by the government). Table 5 shows the means and variances of the estimated gross margins and wheat grain yields corresponding to different treatments. The mean gross margins in the table were calculated according to

$$E(y) = \sum_i y_i P_i$$

where y_i is the gross margin at the ith state of nature

$$y_i = GW \times GW\,\text{price} - (\text{S}/1000) \times \text{S price} - (\text{N}/1000) \times \text{N price} - (\text{W} \times 100) \times \text{W price}$$

Table 5
Means and variances of gross margins and wheat grain yields

Treatment		Gross margin		Wheat grain yield	
No.	Code	Mean ('000 S.R. ha^{-1})	Variance	Mean (tons ha^{-1})	Variance
1	S2 N2 W2	8.310	1.412	5.081	0.353
2	S4 N2 W2	7.923	1.310	4.962	0.328
3	S2 N4 W2	7.971	6.555	4.974	1.639
4	S4 N4 W2	7.530	5.383	4.828	1.346
5	S2 N2 W4	9.391	0.583	5.997	0.146
6	S4 N2 W4	7.996	1.027	5.374	0.257
7	S2 N4 W4	9.177	4.222	5.952	1.055
8	S4 N4 W4	8.785	0.865	5.831	0.216
9	S1 N3 W3	8.092	1.825	5.153	0.456
10	S5 N3 W3	8.274	1.522	5.369	0.380
11	S3 N1 W3	9.134	4.373	5.684	1.093
12	S3 N5 W3	7.740	3.289	5.092	0.822
13	S3 N3 W1	6.721	4.175	4.030	1.044
14	S3 N3 W5	7.613	0.432	5.476	0.108
15	S3 N3 W3	8.077	0.631	5.208	0.158

where GW is expressed in ton ha^{-1}; GW, S and N prices in S.R. ton^{-1}; W price in S.R. m^{-3}; S and N in kg ha^{-1}; and W in mm ha^{-1}. P_i represented the assigned probability corresponding to the ith state of nature.

For example, the mean gross margin of 8.310 000 S.R. per ha in the first row (S2 N2 W2; corresponding to input levels seeds S2, nitrogen fertilizer N2, and water level W2) was obtained by multiplying the yield given in Table 4 by the selling price of wheat and then subtracting the costs of seeds, nitrogen fertilizer, and water. The outcome is then multiplied by the probability and summed horizontally.

The means of GW were obtained from a similar equation except that no multiplication was made by prices of inputs and/or output and that no subtractions were made. That is, the figures were obtained by multiplying the estimated grain yields (tons ha^{-1}) of Table 4 by the probabilities associated with them and then summing horizontally, as in the following equation

$$E(x) = \sum_i x_i P_i$$

where x_i is GW (ton ha^{-1}) at the ith state of nature, and P_i is the assigned probability corresponding to the ith state of nature.

Table 6
Comparison among gross margins for different treatments using second-degree stochastic dominance

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.000														
2	−0.430	0.000													
3	−0.869	0.059	0.000												
4	−1.165	−0.726	−0.588	0.000											
5	1.081	1.459	1.364	1.865	0.000										
6	−0.388	0.073	0.014	0.776	−1.386	0.000									
7	0.013	−0.073	0.734	1.687	−0.209	−0.165	0.000								
8	0.209	0.862	0.762	1.328	−0.597	0.789	−0.360	0.000							
9	−0.298	0.178	0.104	0.669	−1.260	0.105	−0.245	−0.658	0.000						
10	−0.305	0.358	0.299	0.941	−1.062	0.285	−0.318	−0.460	0.180	0.000					
11	−0.281	1.152	0.983	1.558	−0.307	1.079	−0.098	0.290	0.066	0.630	0.000				
12	−0.687	−0.176	−0.243	0.322	−1.607	−0.249	−0.259	−1.005	−0.354	−0.534	−0.190	0.000			
13	−1.607	−1.192	−1.251	−0.447	−2.670	−1.265	−0.002	−2.064	−1.309	−1.550	−0.888	−1.016	0.000		
14	−0.708	−0.299	−0.358	0.592	−1.778	−0.372	0.170	−1.172	−0.412	−0.657	0.081	−0.123	0.893	0.000	
15	−0.311	0.165	0.105	0.854	−1.315	0.091	0.219	−0.640	0.018	−0.193	0.297	0.365	1.357	0.464	0.000

Table 7
Comparison among wheat grain yield for different treatments using second-degree stochastic dominance

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.000														
2	−0.156	0.000													
3	−0.412	0.017	0.000												
4	−0.465	−0.310	−0.230	0.000											
5	0.916	1.028	0.962	1.169	0.000										
6	0.105	0.409	0.392	0.655	−0.618	0.000									
7	0.033	−0.014	0.519	1.132	−0.042	−0.084	0.000								
8	0.750	0.869	0.813	1.024	−0.162	0.456	−0.108	0.000							
9	−0.108	0.194	0.165	0.376	−0.817	−0.215	−0.216	−0.647	0.000						
10	0.043	0.409	0.386	0.596	−0.597	0.000	−0.242	−0.427	0.215	0.000					
11	−0.071	0.691	0.602	0.832	−0.336	0.282	−0.294	−0.174	0.037	0.217	0.000				
12	−0.141	0.132	0.103	0.314	−0.879	−0.277	−0.150	−0.710	−0.062	−0.277	−0.057	0.000			
13	−1.055	−0.925	−0.266	−0.289	−1.966	−1.344	−1.922	−1.801	−1.123	−1.339	−0.606	−0.002	0.000		
14	0.170	0.515	0.497	0.787	0.000	0.106	0.062	−0.173	0.321	0.105	−0.177	0.383	1.446	0.000	
15	0.053	0.250	0.233	0.518	−0.789	−0.159	0.081	−0.623	0.069	−0.159	0.168	0.132	1.178	−0.265	0.000

The variances in the gross margins shown in Table 5 were calculated as follows

$$\text{var}(y) = \sigma_y^2 = E(y^2) - [E(y)]^2$$

and

$$E(y^2) = \sum_i y_i^2 P_i$$

The variances of the wheat grain yield were obtained in a similar manner.

7. Results of the stochastic dominance model

Tables 6 and 7 summarize the results of the stochastic dominance analysis. Table 6 shows comparisons among the gross margins of the different treatments. Note that treatment 15 is the one which represents the central point, i.e. the one expected to yield the highest yield and highest profitability. The figures in the table represent the differences in the areas under the CDFs of the vertical and horizontal treatments. Accordingly, a minus sign vertically implies that this treatment stochastically dominates the corresponding horizontal ones. A positive sign horizontally indicates that the horizontal treatment is better than the corresponding vertical one.

The comparisons show that treatment 5 (S2 N2 W4) dominated all other treatments. Its corresponding expected value and variance are estimated at 9.391 and 0.583, respectively (Table 5). Treatments 1 (S2 N2 W2), 8 (S4 N4 W4), and 15 (S3 N3 W3) follow in efficiency. Treatments 1 and 8 dominated 11 other treatments, while treatment 15 dominated ten other treatments. Treatments 7 (S2 N4 W4), 10 (S5 N3 W3), and 11 (S3 N1 W3) each dominated nine other treatments. Treatment 13 (S3 N3 W1) did not dominate any other treatment, and was thus the least efficient of all treatments applied with the least expected value of 6.721 and the highest variance of 4.175. Treatments 4 (S4 N4 W2) and 12 (S3 N5 W3) dominated only one and three other treatments, respectively.

The following conclusions can be drawn from Table 6:

1. water is an important factor of production when used with low amounts of seeds and nitrogen fertilizer;
2. utilizing equal amounts of the three inputs could lead to efficient allocation of the three inputs;
3. the central point treatment, expected to yield the highest profits came in fourth place regarding efficiency;
4. over-utilization of the three factors of production, even water, results in inefficient use of the inputs.

Table 7 shows the results of the stochastic dominance model when we disregard profitability and concentrate only on the efficiency of input use considering only the wheat grain yield. The results did not change significantly. Treatment 5 (S2 N2 W4) was still the most efficient treatment, dominating 13 other treatments. Treatment 13 (S3 N3 W1) remained the least efficient treatment with no domination over any other treatment. However, the order of the most efficient treatments differed slightly. Treatment 8 (S4 N4 W4) was in second place, dominating 12 other treatments. This was followed by treatment 14 (S3 N3 W5) which dominated 11 other treatments (contrary to the case when considering gross margins). Treatment 14 possessed the lowest variance (0.108) of all the treatments. Treatments 6 (S4 N2 W4), 7 (S2 N4 W4), 11 (S3 N1 W3), and 15 (S3 N3 W3) followed in order of efficiency.

8. Conclusions

The application of marginal analysis through the estimation of non-stochastic production functions did not yield reliable or significant results regarding the use of inputs for wheat production in the Kingdom of Saudi Arabia. This matches the results of previous studies.

However, stochastic dominance analysis showed some interesting results. The main findings can be summarized as follows.

1. Treatment 5 (S2 N2 W4) is the most efficient treatment in terms of yield and profitability. This implies that applying relatively high amounts of water with low levels of seeds and nitrogen fertilizers is the most efficient choice.
2. The central point, represented by treatment 15 (S3 N3 W3) which was expected to be the most efficient, was ranked fourth in terms of profitabil-

ity and yield. Thus, applying moderate levels of the three inputs is neither very efficient nor very inefficient.

3. Treatment 14 (S3 N3 W5) was ranked third in efficiency when considering yield only but not profitability, mainly due to the over-use of irrigation water, which is a very scarce resource in the Kingdom.

Appendix A

Central composite design treatments for estimating wheat grain production function

Treatment	Seeding rate (kg ha^{-1})	Nitrogen level (kg ha^{-1})	Water amount (mm)	Treatment code
1	88.4	60.8	660	S2 N2 W2
2	171.6	60.8	660	S4 N2 W2
3	88.4	239.2	660	S2 N4 W2
4	171.6	239.2	660	S4 N4 W2
5	88.4	60.8	960	S2 N2 W4
6	171.6	60.8	960	S4 N2 W4
7	88.4	239.2	960	S2 N4 W4
8	171.6	239.2	960	S4 N4 W4
9	60.0	150.0	800	S1 N3 W3
10	200.0	150.0	800	S5 N3 W3
11	130.0	0.0	800	S3 N1 W3
12	130.0	300.0	800	S3 N5 W3
13	130.0	150.0	400	S3 N3 W1
14	130.0	150.0	1200	S3 N3 W5
15	130.0	150.0	800	S3 N3 W3

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