SEARCHING FOR A SUITABLE FUNCTIONAL FORM IN WHEAT YIELD RESPONSE TO FERTILIZATION

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ÖZET: Doğu Anadolu'nun doğu geçit bölgesinde buğday verimi-gübre ilişkisini değerlendirmek amacıyla farklı matematiksel maddeler değerlendirilmiştir. Sonuçlar hiçbir modelin diğerine üstünlüğü olmadığını, ancak kuadratik formun agronomik görüş açısından ve ekonomik değerlendirme bakımından uygun olduğu ortaya çıkmıştır. Belli girdi-çıktı fiyat oranlarında tavsiye edilecek miktarlarda fazla bir değişme olmamıştır. Bölge agro-ekolojik karakterleri göze alındığında çiftçilere biraz fazla gübre kullanımı önerilebilir. Çiftçi verilerini değerlendirmede diğer değişmeleri de içine alan genel bir model araştırıcı ve politika üreticiler için daha fazla bilgi verebilir.

SUMMARY: *Various functional forms are used to evaluate wheat yield response to fertilizer application in Easter Margin of Central Anatolia (EMCA). Results indicate that any single model is superior, however, quadratic form seems to fit the data better and has some agronomic rational and economic easiness to interpret. Given the input - output price ratios, recommended application rates do not vary much. Farmers can be advised to use slightly more fertilizer than their current practices taking into account the agro-ecological characteristics of the region. A more general model including other variables to evaluate farmers data would yield more information for researchers and policy-makers.*

INTRODUCTION

Although agriculture has received less attention in recent years, it still is an important sector in Turkish economy. There is not any developed country in the world that is not developed in agriculture. Turkey should therefore, put more emphasis on agricultural sector if it wants to be a developed country.

In recent years, agricultural support policies have changed and are less beneficial to farmers. Transfers to agriculture have declined, and the costs of inputs have increased two to three fold. Especially fertilizer, which itself may increase yield 10 % to 50 %, (ACIL, 1980), became a very expensive input. That has had a negative impact on farmer incomes, and the continuity of food supply is threatened. Owing to increases in input prices, farmers have to pay more attention to optimize input use. The aim of this research is, therefore, to recommend to farmers optimum fertilizer application rate to achiev maximum economic yield within the context of current practices.

Productivity in wheat farming depends on a variety of factors such as soil, climate, seed quality and type, irrigation, fertilizer use. The objective of this study is to compare and evaluate some functional forms to identify the economic optimum rates of fertilizer.

Crop response analysis is an important area of research for appropriate fertilizer recommendations which have generally been developed using production functions, and input-output relationships have been estimated by conducting fertilizer experiments in the field (NELSON ET AL. 1985). "Directly or indirectly, decisions concerning optimal rates of fertilization involve fitting some type of model to yield data collected when several rates of fertilizer are applied" (CERRATO and BLACKMARE, 1990). Obviously, fertilizer recommendation should be derived using the most appropriate model. Agronomist and agricultural economists have spent more than a century in search of such a model (PARIS, 1992). Data obtained from farmers have not been usually used for fertilizer recommendations. Models fit the experimental data better. However, goodness of fit to farmers' data is not as good, and researchers are to recommend also optimal fertilizer use based on farmers data.

Von Liebig enunciated a conjecture about crop response implying a very particular family of response models (PARIS, 1992). Von Liebig formulated "the low of minimum" around 1850 (GUZEL, 1985). Since then several different response models have been algebraically formulated and used to identify economic optimum rate of fertilization.

Numerous researchers have compared response functions and noted that these models often disagree when indentifying these rates of fertilization. Among those who have used different response models are Abraham and Rao, Anderson and Nelson, Barreto and Westerman, Nelson et al, Blackmer and Meisinger (CERRATO and BLACKMER, 1990, JAURAGUI and SAIN, 1992). Some response studies are summarized here.

ABRAHAM and RAO (1966) compared several functional forms and concluded, based on the results as well as the goodness of fit, test of hypothesis about model parameters favor the quadratic polinomial function.

SANCHEZ et al (1981) compared alternative equations derived from field experiments, and suggested, that the response model does not really make much difference. TRONSTAD and TAYLOR (1989) evaluated 15 functional forms, examining the error structure and could not assert that any single functional form was superior.

Most widely used functional forms are quadratic square root, Cobb-Douglas, transcendental, translog, semilog and exponantial functional forms (HEADY, 1981, HEADY and DILLON, 1961, HEADY et al, 1961, JAURAGUI and SAIN, 1992, PARIS, 1992, CARRETO and BLACKMER, 1990, JOHNSON, JR. et al 1987, BEATTIE and TAYLOR, 1987).

The quadratic function is preferred because it is easily generalized to models with more then on nutrient and it allows for easy interpration of linear, curvilinecr, and interaction effects (JOHNSON, JR. et al 1987, JAURAGUI and SAIN, 1992).

Quadratic functional form has been used in numerous studies to examine the yield response to fertilizer use (SEFA, 1981, DIGDIGOGLU, 1982, BABUR, 983, ALEMDAR, 1988, AVCI et al 1988, CARRETO and BLACKMER, 1990, BATIONA et al, 1991, GRIFFIN and HESTERMAN, 1991, MUKHOPADHYAY et al, 1991, OZEL and BICER, 1992, ICARDA, 1992, DARA et al, 1992, PARIS, 1992, OZKAYA and OZDEMIR, 1992, AGARWAL et al, 1993, JERALD et al, 1993, REEVES et al, 1993, CAMPBELL et al, 1993, AYISI et al, 1993, EKER, 1992, BAYANER and UZUNLY, 1993, AVCI et al, 1993, AVCIN et al, 1993).

Input-output relations have also been examined in a number of studies using Cobb-Douglas production function (ULUG, 1973, ZORAL, 1973, TONGISI, 1977, ACIL and REHBER, 1978, REHBER, 1978, SARIMESELI, 1981, ARIKAN, 987, OZCELIK, 1989, VURAL et al, 1993).

MATERIALS AND METHODS

Virtually all previous studies of this type have relied on field experimental data. These data fit the model well. However, farmers conditions are not the same as experimental conditions which could be controlled by the researchers and except for the climate excluding irrigation, resources are not limited. Results obtained in such condition are different than that of farmers conditions. Therefore it is worth to evaluate data obtained from the farmers. The data used was obtained from the farmers through a formal interview. Farmers were asked the wheat production technique in Eastern Margin of Central Anatolia (EMCA). A total of 207 farmers were interview of these, 94 farmers used phosphorus and nitrogen. Previous studies have generally used quadratic functional form to evaluate yield response to fertilizer application. This functional form in most cases fits the data best. However yield data obtained from the farmers do not exhibit a smooth response to fertilizer. Therefore, it is important to test different functional forms.

An ideal functional form is flexible enough to capture all the information conveyed by the data set. However, the quality of the data must also be considered. As COLWELL (1978) observed, poor data should not deter researchers from using "the best computing procedures available," but poor data cannot support strong arguments about whether one or another functional from is best (JAUREGUI and SAIN, 1992).

There are alternatives to the more or less arbitrary choice of a polynomial function to represent the response to fertilization, including the very flexible Box-Cox transformation. Owing to the computer programming limitations, this flexible Box-Cox transformation was not used.

In this study, data were analyzed using different functional forms in three steps (1), wheat yield response to nitrogen fertilization, (2) wheat yield response to phosphorus fertilization, and (3) wheat yield response to nitrogen and phosphorus fertilization. Primary analysis of the data yielded consistantly lower R^2. In order to improve R^2, area sown to wheat, weed chemical application, sowing data, sowing method, and tractor ownership were all included in the models estimated. R^2 was improved only when area sown to wheat (A) and weed chemical application (WCA) were added to the models. Therefore, following functional forms were formulated to be used in the analysis:

For nitrogen use;

Linear : $Y = a + bN + cA + dWCA$
Quadratic ; $Y = a + bN + cN^2 + dA + eWCA$
Cubic : $Y = a + bN + cN^2 + dN^3 + eA + fWCA$
Squareroot : $Y = a + bN + cN^{0.5} + dA + eWCA$
Hiperbol ; $Y = a + b(1/N) + cA + dWCA$

Semilog ; $e^Y = e^{(a + cA + dWCA)} N^b$.
$Y = a + b\ln N + cA + dWCA$ (without quadratic term)
$e^Y = e^{(a + dA + eWCA)} N^b (N^2)^c$.
$Y = a + b\ln N + c(\ln N)^2 + dA + eWCA$ (with quadratic term)

Exponantial ; $Y = e^{(a + bN + cA + dWCA)}$.
$\ln Y = a + bN + cA + dWCA$ (without quardatic term)
$Y = e^{(a + bN + cN2 + dA + eWCA)}$.
$\ln Y = a + bN + cN^2 + dA + eWCA$ (with quadratic term)

Transcendental ; $Y = aN^b e^{(cN + dA + eWCA)}$
$\ln Y = \ln a + b\ln N + cN + dA + eWCA$

Translog : $Y = aN^b e^{cA + eWCA}$.
$\ln Y = \ln a + b\ln N + cA + dWCA$ (without quadratic term)
$Y = aN^b e^{(c\ln N + dA + eWCA)}$
$\ln Y = \ln a + b\ln N + c(\ln N)^2 + dA + eWCA$ (with quadratic term)

for phosphorus use;

Linear : $Y = a + bP + cA + dWCA$
Quadratic ; $Y = a + bP + cP^2 + dA + eWCA$
Cubic ; $Y = a + bP + cP^2 + dP^3 + eA + fWCA$
Squareroot : $Y = a + bP + cP^{0.5} + dA + eWCA$
Hiperbol ; $Y = a + b(1/P) + cA + dWCA$

Semilog ; $e^Y = e^{(a + cA + dWCA)} P^b$.
$Y = a + b\ln P + cA + dWCA$ (without quadratic term)
$e^Y = e^{(a + dA + eWCA)} P^b (P^2)^c$.
$Y = a + b\ln P + c(nP)^2 + dA + eWCA$ (wit quadratic term)

Exponantial ; $Y = e^{(a + bP + cA + dWCA)}$.
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Transcendental : $Y = aP^b e^{(cP + dA + eWCA)}$
$\ln Y = \ln a + b\ln P + cP + dA + eWCA$

Translog : $Y = aP^b e^{cA + dWCA}$.
$\ln Y = \ln a + b\ln P + cA + dWCA$ (without quadratic term)
$Y = aP^b e^{(c\ln P + dA + eWCA)}$
$\ln Y = \ln a + b\ln P + c(\ln P)^2 + dA + eWCA$ (with quadratic term)

For nitrogen and phosphorus use:

Linear : $Y = a + bN + cP + dNP + eA + WCA$
Quadratic : $Y = a + bN + cN^2 + dP + eP^2 + fNP + gA + WCA$
Cubic : $Y = a + bN + cN^2 + dN^3 + eP + fP^2 + gP^3 + hA + WCA$
Squareroot: $Y = a + bN + cN^{0.5} + dP + eP^{0.5} + f(NP)^{0.5} + gA + WCA$
Hiperbol : $Y = a + b(1/N) + c(1/P) + dA + WCA$

Semilog (without quadratic term):
$e^Y = e^{(a + eA + WCA)} N^b P^c NP^d$.
$Y = a + b\ln N + c\ln P + d\ln N\ln P + eA + WCA$

Semilog (with quadratic term):
$e^Y = e^{(a + gA + WCA)} N^b (N^2)^c P^d (P^2)^e (NP)^f$
$Y = a + b\ln N + c(\ln N)^2 + d\ln P + e(\ln P)^2 + f\ln NP + gA + WCA$

Exponantial (without quadratic term):
$Y = e^{(a + bN + cP + dNP + eA + WCA)}$.
$\ln Y = a + bN + cP + dNP + eA + WCA$

Exponantial (with quadratic term):
$Y = e^{(a + bN + cN2 + dP + eP2 + fNP + gA + WCA)}$.
$\ln Y = a + bN + cN^2 + dP + eP^2 + fNP + gA + WCA$

Transcendental (without interaction):
$Y = aN^b P^c e^{(dN + eP + WCA)}$.
$\ln Y = \ln a + b\ln N + c\ln P + dN + eP + fA + WCA$

Transcendental (with interaction):
$Y = aN^b P^c e^{(dN + eP + fNP + gA + WCA)}$.
$\ln Y = \ln a + b\ln N + c\ln P + dN + eP + fNP + gA + WCA$

Translog (without quadratic term):
$Y = aN^b P^c e^{(d\ln N\ln P + eA + WCA)}$.
$\ln Y = \ln a + b\ln N + c\ln P + d\ln N\ln P + eA + WCA$

Translog (with quadratic term):
$Y = aN^b P^c e^{(d(\ln N) + e(\ln P) + f\ln N\ln P + gA + WCA)}$.
$\ln Y = \ln a + b\ln N + c\ln P + d(\ln N)^2 + e(\ln P)^2 + f\ln N\ln P + gA + WCA$
Cobb-Douglas : $Y = aN^b P^c e^{dA + WCA}$.
$\ln Y = \ln a + b\ln N + c\ln P + dA + WCA$

where:

Y = Wheat Yield (kg/da),
a = Constant,
b, c, d, e, f, g, h = Estimated coefficients,
N = Nitrogen application rate (kg/da),
P = Phosphorus application rate (kg/da),
A = Area sown to wheat (da),

WCA = Weed chemical application,
WCA = 1, if weed chemical applied,
WCA = 0, otherwise.

Agricultural economists and agronomists have generally judged their empirical models only on the basis of coefficient of determination (R^2). Generally accepted that the higher the fit the better the model. This criterion was explicitly followed by numerous researchers. But what happens when all the models exhibit about the same R^2 (PARIS, 1992). Consequently, the coefficient of determination is not a relevant statistics for selecting a model (CERRATO and BLACKMER, 1990). These discussions were also supported by JAUREGUI and SAIN (1992), that models used in fertilizer response studies display positive and negative features and R^2 commonly used does not by itself provide sufficient support for selecting any one model over others, and therefore other criteria should be used for choosing the appropriate specification.

This study involves fitting each functional forms to data obtained from the farmers and comparing coefficient of determination, Sum of Squares Errors (SSE), Log of the Likehood Functional (LLF), and correlation coefficients between actual and predicted wheat yields (r_{YY}) (KMENTA, 1986, WHITE and BUI, 1988, OZCELIK, 1994).

RESULTS AND DISCUSSION

The importance of fertilizer use is well known by the majority of the farmers in the region, but they are unclear on appropriate rates and means of application (BAYANER et al, 1993). Fertilizer use differs from farmers to farmers, depending on their financial situation and farming ability. The most commomly used fertilizer types were Diammonium Phosphate (DAP) and Amonium Nitrate (AN). The average nitrogen use was 6.39 kg/da (= AN * 0.26 + DAP * 0.18), and phosphorus use 7.13 kg/da (= DAP * 0.46) in EMCA.

The estimates of the models given in methodology for wheat yield response to nitrogen (N), phosphorus (P) and nitrogen + phosphorus (N-P) were obtained by Ordinary Least Square (OLS) technique. The selection criteria for these models are given in Table 1, 2 and 3 for N, P and N-P models respectively. Criteria taken into acccount are R^2, F-value, Log of the Likelyhood Function (LLF) and the correlation coefficient between observed and predicted yield values (r_{YY}).

The coefficients of determination for models including nitrogen varied between 0.198 and 0.230 including phosphorus 0.189 and 0.209 and for the full models 0.119 and 0.246 All the R^2 values for the models are statistically significant at the level of 0.01. The data consistanly exhibited a lower R^2 because the data were obtained from the farmers with a low variation. Most of the farmers use about the same amount of fertilizer. This type of data generally exibite the second stage of the classical production function.

SSE values are higher for transformed data for the models including nitrogen and phosphorus, indicating that models are not better, and LLF values are somewhat higher however, the differences are not important. r^{YY}, on the other hand, does not vary in a great detail.

The models including nitrogen phosphorus are statisticallly proven to be somewhat better or superior to those only including nitrogen or phosphorus in terms of SSE, LLF, and r^{YY} criteria. Users are suggested to include both fertilizer types in their analysis for farmer recommendations.

Results reported here indicate that no single model can be recommended over others for all situations, regardless of the selection criteria used. "The researchers can only hope that the best model has some agronomic rational, and produces estimates of economics optimum that are reasonably free of bias (PARIS, 1992).

For the purpose of calculating economcis application rates of fertilizer for recommondation in Eastern Margin of Central Anatolia, among the models estimated, quadratic model was selected. The results of the estimates are given in Tables 4, 5, and 6.

There are three major reasons for using the quadratic. The first, and perhaps most prominent reason is to capture turning points. Turning points occur when the effect of an additional unit of X causes a change in the direction of the effect of X on Y, i.e., Marginal Product (MP) of X is zero. The qiadratic form can easily be generalized to models with more than one nutrients, and it allows for easy interpretation of linear, curvilinear, and interaction effects.

Optimum fertilizer rates for the models were calculated, given the input-output price ratios (r/p) (Table 7). Maximum yield is optained by only applying 7.732 kg/d nitrogen or 10.041 kg/da phosphorus. When both fertilizers are applied, maximum yield is reached at 7.830 kg/da nitrogen and 9.190 kg/da phoshorus.

Optimum rates of nitrogen varied from 7.200 to 7.625 kg/da, and phosphorus from 8.101 to 9.653 kg/da when only using nitrogen or phosphorus. For the model including nitrogen + phosphorus, optimum nitrogen rates were between 7.72 and 7.81 kg/da, and phosphorus rates between 9.11 and 9.18 kg/da.

SUMMARY AND CONCLUSIONS

The objectives of this study were to investigate a suitable functional form in wheat yield response to fertilizer application and to recommend to farmers optimum fertilizer application rate within the context of current practices. Because of the nature of the data used, strong econometric evidence is unlikely that any of the functional forms investigated can be recommended over others. In addition, this type of data does not fit the models well, comparing with experimental data. Nevertheless, farmers' data should also be used to recommend fertilizer application rate.

Models of this sort should include not only fertilizer but also other variables such as, previous crops, soil nutrient content, available moisture, rainfall received and temperature during the growing period, irrigation if applied, sowing equipment, weed and pest chemicals etc.

Sush a general model would capture the changes in wheat yield that is of interest to both researchers and policy makers.

Results obtained are in favor of quadratic form, because it has some agronomic rational and economic easiness to interpret and seems to fit the data better. Recommended application rates did not change much, given the price ratios. As input prices increase, or output prices decline, input use reduces or vice versa. Depending on a number of factors, however, operating area is bounded with the second stage of the production function. Farmers in EMCA can be recommended to use more fertilizer than their current application rates with cautious, because the region is dry receiving around 300 mm rainfall a year.

Table 4. Wheat yield response to Nitrogen fertilization

Variables	Parameters	Standard Error
Intercept	9.4567	89.378
N	36.320	28.114
N^2	- 2.3487	2.1536
A	0.21573	0.064212**
WCA	18.848	13.857
Statistics		
R^2	0.221	
F	6.32	
N	94	

** Significant at the 0.01 level

Table 5. Wheat yield response to phosphorus fertilization

Variables	Parameters	Standard Error
Intercept	83.694	68.487
P	12.941	18.997
P^2	- 0.64440	1.2737
A	0.21002	0.064973**
WCA	17.744	14.343
Statistics		
R^2	0.205	
F	5.74	
N	94	

** Significant at the 0.01 level

Table 6. Wheat yield response to nitrogen and phosphorus fertilization

Variables	Parameters	Standard Error
Intercept	29.683	93.543
N	28.706	57.418
N^2	4.1716	8.3447
P	0.26332	38.196
P^2	4.3694	3.4172
NP	-10.229	9.0944
A	0.20885	0.06744**
WCA	16.553	93.543
Statistics		
R^2	0.237	
F	3.818	
N	34	

Table 7. Optimum fertilizer application rates (kg/da)

r/p	N use	N + P use P use	N + P use N	P
Technical opt.	7.732	10.041	9.190	7.830
0.5	7.625	9.653	9.180	7.810
1.0	7.520	9.265	9.160	7.790
1.5	7.413	8.877	9.140	7.760
2.0	7.306	8.489	9.120	7.740
2.5	7.200	8.101	9.110	7.720

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Table 1. Selection criteria for the functional relationships between wheat yield and nitrogen use

Models	R^2	F	SSE	LLF	r_{YY}
Linear	0.211	8.02	305 370	-513.422	0.459
Quadratic	0.221	6.32	301 340	-512.798	0.471
Cubic	0.230	5.25	298 070	-512.285	0.479
Squareroot	0.217	6.18	302 900	-513.040	0.466
Hiperbol	0.214	8.16	304 270	-513.252	0.462
Transcendental	0.198	5.51	$1.81x10^6$	-504.358	0.458
Translog/without quadratic term	0.198	7.41	$1.83x10^6$	-504.382	0.457
Translog/with quadratic term	0.198	5.50	$1.82x10^6$	-504.379	0.457
Semilog/without quadratic term	0.244	8.17	304 150	-513.233	0.463
Semilog/with quadratic term	0.215	6.09	303 840	-513.185	0.463
Exponantial/without quadratic term	0.196	7.31	$1.94x10^6$	-504.500	0.453
Exponantial/with quadratic term	0.202	5.62	$1.64x10^6$	-504.161	0.464

Table 2. Selection criteria for the functional relationships between wheat yield and phosphorus use

Model	R^2	F	SSE	LLF	r_{YY}
Linear	0.203	7.64	308 490	-513.899	0.450
Quadratic	0.205	5.74	307 610	-513.764	0.453
Cubic	0.209	4.66	306 060	-513.527	0.457
Squareroot	0.204	5.72	301 510	-513.801	0.452
Hiperbol	0.204	7.70	307 980	-513.821	0.452
Transcendental	0.192	5.29	2.18×10^6	-504.735	0.445
Translog/without quadratic term	0.191	7.09	2.23×10^6	-504.776	0.445
Translog/with quadratic term	0.192	5.28	2.20×10^6	-504.751	0.445
Semilog/without quadratic term	0.204	7.69	308 010	-513.826	0.452
Semilog/with quadratic term	0.204	5.72	307 920	-513.812	0.452
Exponantial/without quadratic term	0.189	7.00	2.87×10^6	-504.897	0.444
Exponantial/with quadratic term	0.193	5.33	2.10×10^6	-504.662	0.446

Table 3. Selection criteria for the functional relationships between wheat yield and nitrogen + phosphorus use

Model	R^2	F	SSE	LLF	r_{YY}
Linear	0.222	5.035	300910	-512.730	0.472
Quadratic	0.237	3.818	295240	-511.835	0.487
Cubic	0.246	3.040	291920	-311.304	0.496
Squareroot	0.235	3.767	296180	-511.986	0.484
Hiperbol	0.216	6.136	303340	-513.108	0.465
Transcendental/without Interaction term	0.199	3.594	1.79×10^6	-504.345	0.457
Transcendental/with Interaction term	0.212	3.304	1.21×10^6	-503.557	0.477
Translog/without quadratic term	0.199	4.363	1.29×10^6	-504.344	0.459
Translog/with quadratic term	0.211	3.287	1.24×10^6	-503.611	0.469
Semilog/without quadratic term	0.217	4.882	302960	-513.048	0.466
Semilog/with quadratic term	0.233	3.729	296880	-512.096	0.483
Exponantial/without quadratic term	0.204	4.512	1.52×10^6	-504.025	0.463
Exponantial/with quadratic term	0.209	3.254	1.31×10^6	-503.708	0.476