Value of Soil Test Information for Crop Production

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Abstract

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This study was conducted to determine the value of independent and joint nitrogen and phosphorus soil tests. Generalized stochastic dominance was used to estimate the value of information. Combined information from both the nitrogen and phosphorus tests was substantially more valuable than the knowledge of only one of the tests.

Value of Soil Test Information for Crop Production

Farmers may use soil tests to determine the fertility level of soils. They may test for a single nutrient or they may obtain a more comprehensive analysis to determine the levels of several nutrients as well as pH. They may elect to obtain samples from near the surface (0 to 6 inches) or they may obtain samples from the subsoil (6 to 24 inches). If soil test results are available, applications of fertilizer may be adjusted to reflect plant needs to achieve a target yield. Alternatively, farmers may elect to not test soil and apply a level of fertilizer based upon prior experience of farming the field.

When immobile nutrients such as phosphorus are applied to the soil they are expected to either be used by the crop or remain in the tilled soil zone. However, nitrogen is mobile in the soil profile. A test of the tilled surface layer of soil would not identify the presence of nitrogen in the subsoil that would be available for plant use. Further, the von Liebig hypothesis of nonsubstitution between nutrients suggests that the value of the knowledge of both nitrogen and phosphorus levels would exceed the value of the sum of the tests considered independently. The objective of the research reported in this paper is to determine the value of independent and joint nitrogen and phosphorus soil test information for wheat production.

The Value of Information

Several methods for estimating the value of information have been proposed. Bosch and Eidman used a stochastic dominance (Meyer) approach to value information. An alternative approach to estimate the value of information is based on obtaining the posterior probability distributions to find the optimal or Bayes strategy and the expected returns associated with that strategy. Then, those returns are compared with expected returns obtained using the prior, or no-data, probabilities (Eidman et al.; Baquet et al.).

The generalized stochastic dominance approach is used in this study. However, distributions of returns generated for different soil nutrient states are obtained using a conditional probability approach. Then, the returns simulated using a conventional fertilization scheme are compared with those based on the soil test information. The value of the information is derived from the comparison of the return distributions with and without soil test information until one distribution no longer dominates the other.

Response Functions and Fertilizer Recommendations

Several assumptions were imposed to enable estimation of net return distributions for winter wheat. The first set of assumptions relates the soil nutrient status and yields in terms of Bray's mobility concept (Bray). This concept is used to make fertilizer recommendations for a target yield based upon soil tests (Johnson et al.). According to the mobility concept, nitrogen is a mobile nutrient. Nitrogen rates are estimated as the difference between the amount that is taken up by plants and the amount of the nutrient in the soil layer occupied by the crop's roots. For immobile nutrients including phosphorus, sufficiency levels are used to determine fertilizer recommendations. Given the knowledge provided by soil testing, fertilizer recommendations for both nitrogen and phosphorus can be made for a specified target yield.

A second set of assumptions is made to enable estimation of conventional fertilizer strategies, based on knowledge other than soil test information. Two types of fertilizer strategies are plausible. One option is to posit a strategy based on average fertilizer application rates used by Oklahoma winter wheat producers. The second option is a “safety” rate that guarantees a sufficient (but not necessarily efficient) level of nutrients. For example, Zhang et al. report that many farmers in the region arbitrarily apply 100 pounds of nitrogen and 46 pounds of phosphorus per acre to fields seeded to winter wheat. For the present study, rates that maximize expected net returns from a uniform application of fertilizers are used.

Third, wheat response to nitrogen is assumed to be appropriately represented by a linear response plateau (LRP) model. This type of response may be expressed as:

$$y = min\ (f(X_i), y_m) + u$$

where y is crop yield, $f(X_i)$ is a function that determines yield, X_i is a yield limiting nutrient, y_m is a maximum yield that can be achieved eliminating deficiency of X_i, and u is an error term. Based upon this crop response model application of excessive amounts of fertilizers will not result in yields different from y_m.

The response to phosphorus is expressed in terms of sufficiency levels, which represent the availability of the nutrient in the soil. Calibrated potential reduction of yields due to phosphorus deficiency is presented in Table 1. This effect can be expressed as

$$y(X_N, X_P) = s(X_P)y(X_N)$$

where s is a phosphorus sufficiency level.

Generating Return Distributions

The model used to generate net returns to fertilization is similar to that described by Perrin:

$$\Pi = p_w y(X_S, X_F, \theta) - p_F X_F$$

where Π is net returns, p_w is the price of wheat, y is yield expressed as a function of X_s nutrient content in soil, applied fertilizers X_F, p_F is a fertilizer price, and θ is a weather state. Returns were calculated for fixed output and input prices of $3.25 per bushel, $0.17 per pound, and $0.27 per pound, for wheat, nitrogen, and phosphorus, respectively (Zhang et al.).

Since net returns are a function of random variables, X_S, X_F, and θ, Π can be expressed as a multivariate random variable, $\Pi(y(X_S, X_F, \theta))$. X_F is a discrete random variable, which may either be a fixed value under uniform (without soil test) application, or varies depending upon the results of a soil test. Therefore, sets of returns with and without soil test information, $\Pi(y(X_S, X_F(k), \theta))$ were generated, where $X_F(k)$ is either a fertilizer rate based upon a soil test, or a fixed rate used traditionally by farmers who do not use soil testing. Average nitrogen and phosphorus fertilization rates used by Oklahoma wheat producers in 1996 of 52 pounds per acre of N and 32 pounds per acre of P_2O_5 were used (Economic Research Service).

To capture yield variability due to states of nature, the θ factor, distributions for yields lower than 10, 20, 30, 40 and 50 bushels per acre were estimated using Oklahoma county level data for 1993-1997. These data are presented in Table 2.

To simplify calculations, it was assumed that expected yield is a random variable subject to a production function and variability due to states of nature. It was also assumed that the occurrence of yield within the yield ranges does not depend upon the level of nutrients, which implies independence between states of nature and the nutrient levels. A LRP functional form is assumed to represent wheat grain yield response to nitrogen with a 50 bushel per acre maximum yield (Westerman). It can be expressed as

$$y(X_N, \overline{X}_P) = \begin{cases} 0.5X_N, & y < 50\text{bu/acre} \\ 50 & \end{cases}$$

where X_N is the amount of nitrogen in pounds per acre available to the crop given 100 percent sufficiency in phosphorus. When phosphorus is deficient, it becomes first limiting and expected wheat grain yield is decreased (Johnson et al.).

Soil test data were obtained from an extension service sponsored soil-testing program. A total of 3,079 surface (0 to 6 inches) and 2,957 subsurface (6 to 24 inches) soil test observations from a single season for a single crop were available (Zhang et al.). These data were used to generate the distributions reported in Table 3. The distributions are clearly skewed. Fitting a continuous distribution function, such as a gamma function (Babcock et al.) would complicate calculations without assurance that it would reflect the real distribution of nutrients. Therefore, for simplicity, it was assumed that nutrients were uniformly distributed within a given range. It was assumed that number of soil samples was sufficiently representative to make an inference about soil nutrient status. The range intervals correspond to those used to provide fertilizer recommendations (Johnson et al.).

Estimation of Returns

Examples used to teach farm management often are based upon a known strictly concave twice differentiable crop response function and a set of expected prices. A deterministic returns function may be optimized to find precise fertilization levels. In practice, agronomists provide fertilizer recommendations based upon an expected or target yield independent of expected prices. Fertilizer is recommended to supplement what is available in the soil to provide the amount of nutrients that the crop will need to achieve the target yield. For the present study, rather than optimizing the levels of nitrogen and phosphorus fertilizers, returns were calculated based on three fertilization levels to achieve targeted yields of 30, 40 and 50 bushels per acre.

The expected returns using the fertilizer scheme based on the soil test can be expressed in the following equations:

$$\Pi_{jk} = \sum_{i=1}^{s} \left\{ p_w y_{ik}(X_k, F_k) - p_F F_k - C_j \right\} P(\theta = \theta_i)$$

where Π_{jk} is a return obtained from the *k*th range of soil nutrients and *j*th target yield level, p_w and p_F are the prices for wheat and fertilizer, respectively, y_{ik} is a yield achieved given a weather state *i*, and the level of nutrients in soil X_k, F_k is a recommended fertilizer rate given a soil test, C_j is a value of information for each target level, and $P(\theta=\theta_i)$ is a probability of observing the *i*th state of nature.

Returns for each target yield level are determined by:

$$\Pi_j = \sum_{k=1}^{n} \Pi_{kj} P(X = X_k)$$

The returns with uniform fertilizer application are determined by:

$$\Pi_u = \sum_{k}^{n} \left[\sum_{i=1}^{s} \left\{ p_w y_{ik}(X_k, \overline{F}) - p_F \overline{F} \right\} P(\theta = \theta_i) \right] P(X = X_k)$$

The difference between Π_u and Π_{jk} is that a fixed rate of fertilizer is assumed for the *k*th nutrient level, and no cost for obtaining soil test information is accessed.

Results and Discussion

To estimate the value of separate nitrogen and phosphorus soil tests, 100 returns were simulated for each strategy. The distributions obtained with the soil test information dominate the uniform application. To analyze the nitrogen and phosphorus joint probability distribution, 1000 returns on fertilizers were simulated. The C_j values were maximized up to the point when the distributions with soil test no longer dominate the distribution with uniform application. These values are referred to as the values of soil test information and are presented in Table 4.

The value of soil test information is positive in most cases. It was $3.82 per acre for the topsoil nitrogen test for the 30 bushels per acre target yield strategy. Having the information on the nitrate content in the topsoil and subsoil increased the value of the information to $22 per acre. The value of the soil test information is relatively lower for greater target yields. For relatively high target yields, such large quantities of fertilizers are required that soil reserves do not make a substantial difference.

Average applications of fertilizer may not reflect optimal application rates that maximize returns given the existing distribution of nutrients in soil. The estimated optimal uniform application rates for N and P_2O_5 are 50 and 40 pounds per acre, respectively. These estimated rates are close to the average rates, which suggests that Oklahoma wheat producers have been using reasonable fertilization strategies. The information values obtained with optimal rates are lower than those with average rates. It was reflected in a more than $5 per acre decrease in returns on soil P test and about $1 per acre for N.

When the information from both tests was taken into account the information values were much greater. For the combined N-P soil test the values were about $24 for the 30 bushels per acre target yield and as high as $76 for the 50 bushels per acre target. The synergism of combined information reflects its importance when the high production goals are set. The difference between the average and optimal rates was not greater than $2.

Conclusions

The results show that the subsoil nitrogen test in combination with the topsoil nitrogen test is substantially more valuable than having only the topsoil test. The estimated value of the phosphorus test ranged from $8 to $14 per acre depending upon the crop price and target yield. As hypothesized, combined information from both the nitrogen and phosphorus tests was substantially more valuable than the sum of the values of the tests when considered independently.

For the purposes of this study, the value of soil testing was estimated under the assumptions that soil test sampling accurately represented the state of nutrients in the soil and that the results of the test would be used for only a single growing season. Variable rate and site specific technologies provide farmers with the opportunity to fine tune fertilizer application. However, the optimal grid size and frequency of soil testing remain to be determined.

The values of soil test information in Oklahoma winter wheat production were calculated using the generalized stochastic dominance approach. The cumulative distributions of returns for various production strategies were estimated using conditional probabilities of yields given a state of nature and the distribution of nutrients in soils. The information values varied with the type of soil test and the strategy of production. The riskiest production action had negative values for the soil nitrate test. However, the returns on the combined N-P soil test were the highest in the 50 bushels per acre strategy and the value of soil test information was $75-$94 per acre depending on the output price.

The analysis used in this paper has several shortcomings. The distributions of soil nutrients were presented as discrete with uniform distribution of nutrients within each interval. With additional information, the distributions could be transformed into continuous functions. Working with state average data simplified the analysis, but may have resulted in inaccuracy of estimates. However, the estimated results are close to those observed in practice.

Expected monetary outcomes were used in this study instead of utility values. It seems to be impossible to make an inference about the broad range of wheat producers in Oklahoma. Instead, three different strategies were evaluated which may refer to the risk preferences of the producers.

Variable rate technologies (VRT) for fertilizer application have received considerable attention in recent years (Raun et al.). A major concern is the cost effectiveness of utilization of such technologies. Estimates of the value of soil test information may help in determining the cost limits for introduction of VRT into agricultural production.

Table 1. Phosphorus sufficiency levels and fertilizer requirements (P_2O_5 lbs. /acre) for small grains

P Soil Test Index	Percent Sufficiency	Fertilizer Requirement
0	25	80
10	45	60
20	80	40
40	90	20
65	100	0

Note: Adapted from Johnson et al.

Table 2. Distribution of winter wheat yields in Oklahoma with county level data, 1993-97.

Yield Range bu./acre	Median bu./acre	Frequency	Occurrence θ	Cumulative
Less than 15	10	21	0.055	0.055
16 –25	20	165	0.434	0.489
26 – 35	30	145	0.382	0.871
36 – 45	40	45	0.118	0.989
More than 45	50	4	0.011	1.000

Source: Oklahoma Agricultural Statistics, various issues

Table 3. Joint Probability Table for N-P Distribution in Soil.

		Soil Nitrogen, 0 - 6" soil layer (lb/acre)					
		5	**15**	**30**	**50**	**70**	**90**
		$P(N = N_j)$					
Soil P Index	**Probability (Soil $P = P_i$)**	0.13	0.21	0.38	0.17	0.06	0.05
5	0.01	0.0013	0.0021	0.0038	0.0017	0.0006	0.0005
15	0.03	0.0039	0.0063	0.0114	0.0051	0.0018	0.0015
35	0.16	0.0208	0.0336	0.0608	0.0272	0.0096	0.0080
57.5	0.32	0.0416	0.0672	0.1216	0.0544	0.0192	0.0160
87.5	0.34	0.0442	0.0714	0.1292	0.0578	0.0204	0.0170
110	0.14	0.0182	0.0294	0.0532	0.0238	0.0084	0.0070

Note: Adapted from Zhang et al.

Table 4. Value of Soil Test Information in Winter Wheat Production.

	Average rates			Optimal rates		
	Target yields (bu./acre)					
Soil test	**30**	**40**	**50**	**30**	**40**	**50**
	Wheat price - $3.25/bu.					
N (0 - 6 inches)	3.82	2.33	(1.18)	3.82	2.33	(1.18)
N (0 - 24 inches)	22.59	6.57	4.34	22.02	6.00	3.77
P (0 - 6 inches)	11.30			8.03		
Combined N - P	24.69	49.81	76.44	23.80	48.93	75.55
	Wheat price - $3.50/bu.					
N (0 - 6 inches)	3.88	2.40	(1.12)	3.88	2.40	(1.12)
N (0 - 24 inches)	23.73	6.57	4.36	23.16	6.01	3.79
P (0 - 6 inches)	14.34			8.48		
Combined N - P	26.06	53.36	82.28	25.01	52.31	81.23
	Wheat price - $4.00/bu.					
Combined N - P	28.80	60.44	93.97	27.43	59.07	92.60

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