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Abstract

The management practices farmers choose have significant effect on agricultural pollution. The authors analyze the adoption of alternative combinations of conservation practices and their impacts on fertilizer use, corn yield, and soil erosion in the Central Nebraska Basin, using a polychotomous-choice selectivity model. The results suggest that soil N testing and corn-legume rotation complement each other, but that the interaction between conservation tillage and rotation is more complicated.

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Abstract

Which management practices farmers adopt has a significant effect on agricultural pollution. Research has analyzed factors influencing adoption of a single management practice. But often adoption decisions about many practices are made simultaneously, which suggests use of a polychotomous-choice model to analyze decisions. We apply such a model to the choice of alternative management practices on cropland in the Central Nebraska Basin and control for self-selection and the interaction among alternative practices. We use the results of the choice model to estimate the economic and environmental effects of adopting alternative combinations of management practices. Our results suggest that crop rotation and soil N testing are complementary practices, perhaps because soil N testing enables farmers to properly credit the N fixed by legume crops. As a result, farmers who adopted both rotation and soil N testing achieved greater profits from corn production while decreasing N fertilizer use than farmers who only adopted one of the practices. Also, farmers who adopted both conservation tillage and crop rotation reduced their average soil erosion rates, but not their N fertilizer rate, as compared with farmers who adopted only one of the practices. Our findings demonstrate the importance of conducting joint analysis of alternative farm management practices.

Key Words: conservation tillage, rotation, soil N testing, corn yield, fertilizer use, soil erosion, the polychotomous-choice selectivity model.

THE CHOICE OF TILLAGE, ROTATION, AND SOIL TESTING PRACTICES: ECONOMIC AND ENVIRONMENTAL IMPLICATIONS

Adoption of certain management practices, such as soil testing and conservation tillage, is believed to be an effective way to reduce nonpoint-source pollution from agriculture. In order to design policies that encourage adoption of these practices, we must analyze adoption decisions and their economic and environmental implications. Many studies have examined factors affecting adoption of specific management practices, such as conservation tillage (Ervin and Ervin; Korsching et al.; Napier et al.; William, Llewelyn, Barnaby; Helms, Bailey, and Glover), irrigation technologies (Caswell and Zilberman, 1985, 1986) and soil N testing (Fuglie and Bosch). In analyzing these specific management practices, these studies either ignored other crop management practices or treated them as given. This is permissible when other crop management decisions are made exogenously. But when other decisions are made in conjunction with the adoption decision considered, this approach may under- or over-estimate the influences of various factors on the adoption decision, as in the case of directly applying the least square method to a structural equation. In this case, a joint analysis of these management decisions is necessary. Furthermore, a joint analysis may still be needed to determine the total effect of simultaneous adoption, even when other management decisions are made exogeneously, because the total effect of adopting several conservation practices simultaneously does not necessarily equal the sum of the effects of adopting each practice separately.

In addition to these adoption studies, the economic and environmental effects of adoption decisions have also been analyzed (e.g., Logan et al.; Fuglie and Bosch). The effects of adoption are often determined by comparing relevant variables across fields that employ different practices. This approach may be appropriate for controlled experiments, but not for empirical analysis, because of self-selection. Self-selection occurs when a practice is likely to be adopted by those who find it most useful. For example, suppose soil N testing is most useful to farmers who use more nitrogen. A direct comparison of the N application rates of adopters with those of nonadopters will underestimate the effect of soil N testing in reducing nitrogen applications. When self-selection exists, the effect of a management practice cannot be directly estimated by simply including a dummy variable into the regression. Instrumental-variable techniques are the procedure to be used (Maddala, pp. 260-1).

An analysis that includes all crop management decisions is desirable not only because crop management decisions are often made jointly, but also because it is necessary to evaluate the effects of alternative combinations of crop management practices. For example, suppose farmers who adopt crop rotation are also more likely to adopt conservation tillage. If crop rotation is not considered, simply comparing soil erosion levels across fields that adopt different tillage systems will underestimate the effect of conservation tillage in reducing soil erosion if crop rotation increases soil erosion. Similarly, if farmers who rotate their crops are less likely to adopt soil N testing, simply comparing nitrogen application rates of adopters with those of nonadopters will underestimate the effects of soil N testing in reducing nitrogen use.

In this paper, we model farmers' adoption of conservation tillage, rotation, and soil N testing for the central Nebraska corn area. We then assess the impacts of various combinations of these practices on fertilizer use, corn yield, and soil erosion. The comprehensive Area Study data collected by the U.S. Department of Agriculture are used to conduct the empirical analysis. The database includes detailed information on crop management practices and land characteristics for each field in the sample, as well as socioeconomic characteristics of the farm and operators. Thus, it allows a joint analysis of farmers' management decisions. We use a polychotomous-choice selectivity model (Lee) to control for sample selection bias. This model has been used by Hay to examine the specialty choice and specialty income for physicians, but we found no other application of this technique. One-choice selectivity models have been applied to various economic issues. For example, Cooper and Keim and Fuglie and Bosch applied it to the adoption of farm management practices. Lee and Trost applied it to the problem of housing demand, with choice of owning or renting. Willis and Rosen applied the model to the problem of education and self-selection. But these are switching regression models that can only be used to analyze dichotomous decisions. Our polychotomous-choice selectivity model has at least two advantages over models of specific management practices. First, it can be used to evaluate alternative combinations of management practices, as well as individual practices. Second, it accounts for both self-selection and the interaction between alternative practices. As such, it should provide more accurate estimates of the effects of individual conservation practices.

The Model

Presentation of the polychotomous-choice selectivity model is tailored to our empirical problem. First, farmers' choices of crop management plans (i.e., alternative combinations of tillage, rotation, and nutrient management practices) are modeled. Then the effects of each management plan on fertilizer use and crop yields are estimated, according to plan choice.

The Choice of Crop Management Plans

Suppose a farmer can choose from N possible crop management plans. Let u_s^* be the farmer's expected utility from choosing plan s:

$$u_s^* = Z'\beta_s + \varepsilon_s, \tag{1}$$

where Z is a set of physical and socioeconomic characteristics of the farm and operator (e.g., soil types, farm size, the operator's education and farming experience), and ε_s is a residual that captures errors in the perception and optimization by the farmer. The farmer's utility from choosing an alternative plan is not observable but the choice of plan is. Let I be a polychotomous index that denotes the farmer's choice of plan.

$$I = s \text{ if and only if } u_s^* = \max(u_1^*, \ldots, u_N^*). \tag{2}$$

It has been shown (Maddala, p. 60) that, if the residuals ε_s are independently distributed with the extreme value distribution, then the choice of crop management plans can be represented by a multinominal logit model:

$$P_s \equiv \Pr(I = s) = \frac{\exp(Z'\beta_s)}{\sum_{i=1}^{N} \exp(Z'\beta_i)}, \quad s = 1, \ldots, N. \tag{3}$$

The multinominal logit model has been widely used in economic applications, including the study of the choice of transportation modes, occupations, asset portfolios, and the number of automobiles demanded. Caswell and Zilberman (1985) use the model to examine the choice of irrigation technologies in California. The main limitation of the multinominal logit model is the assumption of independence of irrelevant alternatives. This assumption asserts that the relative choice probabilities for any two alternatives are independent of the other available choices. This is a convenient property with regards to estimation, but it is an unappealing restriction to place on farmer behavior.

An alternative to the multinominal logit model is the multinominal probit model, in which the residuals ε_s in the utility functions are assumed to have a multivariate normal distribution. However, a multinominal probit model with more than two choices cannot be estimated efficiently with the existing econometric techniques (Greene 1993, pp. 662-63). A second alternative is the nested logit model, which can be derived from the assumption that the residuals ε_s in the utility functions have a generalized extreme-value distribution (Maddala, p. 70). Although this model is computationally tractable, it requires specification of a nesting structure or sequence of decisions on the choice of management practices. A third alternative to the multinominal logit model is the multivariate probit model (Greene 1993, p. 660), in which a utility function is assumed for each management practice rather than each management plan: $Y_j^* = Z'\xi_j + e_j$, where $j = 1, \ldots, M$ denotes individual conservation practices (e.g., conservation tillage, rotation, and soil N testing), and Y_j^* is the utility from choosing conservation practice j. The farmer will adopt all conservation practices if and only if $e_j > -Z'\xi_j$ for $j = 1, \ldots, M$. To establish linkages between the adoption of alternative conservation practices, these M equations are assumed to be seemingly unrelated. Because estimation of this model requires evaluating multiple integrals, the existing econometric techniques do not allow accurate evaluation of more than two choices (Greene 1993, pp. 662-63). Because of the difficulties with potential alternative procedures, we use a multinominal logit model to represent the choice of alternative crop management plans.

It is often convenient to normalize the multinominal logit model in (3). Note that the probability ratios can be written as

$$\text{(4)} \qquad \frac{P_s}{P_N} = \exp(Z'\beta_s - Z'\beta_N) = \exp(Z'\gamma_s), \quad s = 1, \ldots, N-1$$

where $\gamma_s = \beta_s - \beta_N$. Add these N-1 equations together and note that the sum of the N probabilities equals one

(5) $$\frac{1-P_N}{P_N} = \sum_{s=1}^{N-1} \exp(Z'\gamma_s).$$

Solve for

(6) $$P_N = \frac{1}{1+\sum_{i=1}^{N-1} \exp(Z'\gamma_i)}.$$

Substituting (6) into (4),

(7) $$P_s = \frac{\exp(Z'\gamma_s)}{1+\sum_{i=1}^{N-1} \exp(Z'\gamma_i)}, \quad s = 1, \ldots N-1.$$

Equations (6) and (7) represent the normalized multinominal logit model.

The coefficients in a multinominal logit model are difficult to interpret. The marginal effects of explanatory variables on the choice of alternative management strategies are (Greene 1991, p. 478):

(8) $$h_s \equiv \frac{\partial P_s}{\partial Z} = P_s\left(\gamma_s - \sum_{i=1}^{N-1} P_i \gamma_i\right).$$

The sign and magnitude of these marginal effects have no direct relationship with any specific coefficient. They depend on the sign and magnitude of many coefficients. Thus, it is important to determine the statistical significance of these effects. The asymptotic covariance matrix of h_s (Greene 1991, p. 478) is

(9) $$Var(h_s) = \sum_k \sum_m U_{sk} Cov(\hat{\gamma}_k, \hat{\gamma}'_m) U_{sm},$$

where $U_{sk} = P_s[\delta(s=k) - P_k]E + [\delta(s=k) - 2P_k]h_s Z'$, $\delta(s=k) = 1$ if $s = k$, 0 otherwise, and E is the identity matrix.

It is also interesting to determine the effects of various factors on the choice of a specific management practice. Suppose a practice is used in management plan 1 to N_1. The probability that a farmer adopts this conservation practice is

(10) $$P^c \equiv \sum_{s=1}^{N_1} P_s.$$

The marginal effects of explanatory variables on the P^c can be obtained by differentiating (10) with respect to the explanatory variables and substituting (8) into the result:

(11) $$\frac{\partial P^c}{\partial Z} = \sum_{s=1}^{N_1} P_s\left(\gamma_s - \sum_{t=1}^{N-1} P_t\gamma_t\right) = \sum_{s=1}^{N_1} P_s\gamma_s - P^c\sum_{t=1}^{N-1} P_t\gamma_t.$$

Estimating the Effects of Management Decisions

Farmers' management decisions will affect input demand and output supply. To evaluate these effects, the relationship between a decision variable Y and a vector of exogenous variables X is specified for each management plan:

(12) $$Y_s = X'\eta_s + v_s, \quad s = 1, \ldots, N,$$

where $E(v_s|X, Z) = 0$. Y_s is observed if and only if management plan s is used. Because of the sample selection, Ordinary Least Square estimates of the model coefficients in (12) will be biased. Lee shows that

(13) $$E(v_s|I = s) = -\rho_s\sigma_s\frac{\phi(\Phi^{-1}(P_s))}{P_s},$$

where $\sigma_s = \text{var}(v_s)$, ρ_s is the correlation coefficient between v_s and a transformation of ε_s, $\phi(\cdot)$ is the p.d.f. of the standard normal distribution, and $\Phi^{-1}(\cdot)$ is the inverse of the standard normal distribution function. Thus, the problem of estimating equation (12) can be viewed as correction of the specification error caused by an omitted variable.

Lee suggested a two-stage method for estimating equation (12). In the first stage, the normalized multinominal logit model in (6) and (7) is estimated. The estimated model is then used to predict

(14) $$\hat{P}_s = \frac{\exp(Z'\hat{\gamma}_s)}{1 + \sum_{t=1}^{N-1}\exp(Z'\hat{\gamma}_t)},$$

which is then used to calculate $\hat{\lambda}_s \equiv \phi(\Phi^{-1}(\hat{P}_s))/\hat{P}_s$, $s = 1, \ldots, N$. In the second stage, these variables are added to (12) and these equations are estimated by OLS:

(15)
$$Y_s = X'\eta_s - \theta_s\hat{\lambda}_s + e_s, \quad s = 1,\ldots,N,$$

where $E(e_s) = 0$. A test for selectivity bias is a test for $\theta_s = 0, s = 1,\ldots,N$. If the null hypothesis of $\sigma_s = 0$ is rejected, then there is self-selection in choosing management plan s, and OLS estimates of the equations in (12) will be biased.

This two-stage procedure gives unbiased estimates of η_s and θ_s, but not their variances. OLS estimates of variances of these parameters are biased because the disturbance terms e_s in (15) are heteroscedastic and correlated across observations. The appropriate asymptotic covariance matrix of η_s and θ_s (Greene 1991, p. 620) are

(16)
$$C_s = (V_s'V_s)^{-1}\left[\sigma_s^2 V_s'(E - \rho_s^2\Delta_s)V_s + \theta_s V_s'G_s\Sigma G_s'V_s\right](V_s'V_s)^{-1}.$$

where V_s is the matrix of regressors used in (15) including λ_s. Δ_s is a diagonal matrix with $\hat{\delta}_{si} = [\hat{\lambda}_{si}^2 + \Phi^{-1}(P_{si})\hat{\lambda}_{si}]$ on the diagonal of the i^{th} row, Σ is the asymptotic covariance matrix of the estimated logit parameters $\gamma = (\gamma_1,\ldots,\gamma_{N-1})$, G_s is the matrix of derivatives of the $(\hat{\lambda}_{s1},\ldots,\hat{\lambda}_{sN_s})'$ with respect to $\gamma = (\gamma_1,\ldots,\gamma_{N-1})$, and the σ_s^2 and ρ_s can be consistently estimated by

(17)
$$\hat{\sigma}_s^2 = \frac{e_s'e_s}{N_s} + \hat{\theta}_s^2\left[\frac{1}{N_s}\sum_{i=1}^{N_s}\hat{\delta}_{si}\right],$$

(18)
$$\hat{\rho}_s = \frac{\hat{\theta}_s}{\hat{\sigma}_s}.$$

The marginal effect of a variable that appears in both X and Z on Y in the observed sample consists of two parts:

(19)
$$\frac{\partial E[Y_s | I = s]}{\partial x_i} = \eta_{si} - \theta_s\frac{\partial\hat{\lambda}_s}{\partial x_i}.$$

The first part is the direct effect of changes in x_i on the mean of Y_s. The second part is the effect of changes in x_i on the probability of adopting plan s. For example, suppose farmer education reduces N applications and increases the probability of adopting soil N testing and that soil N testing reduces N applications. The marginal effect of farm education on N applications has two parts: one due to its influence in increasing the probability of adopting soil N testing and the other due to education's effect on N application rates within the group. As such, the coefficient on education in regression overstates its marginal effect on N applications for the adopter of soil N testing and understates it for the nonadopter.

This model can also be used to estimate the effects of adopting management plans. Suppose at least one practice is used in management plans 1 to $N-1$, and no conservation practice is used in plan N. Consider a farmer with characteristics (X_j, Z_j) who has adopted management plan s, where $s < N$. Then the expected value of Y for this farmer is

$$E(Y_s|I=s) = X_j'\eta_s - \theta_s\hat{\lambda}_s. \tag{20}$$

The last term in (20) reflects self-selection; that is, the farmer who has adopted management plan s may behave differently from a randomly selected farmer with the same characteristics. If the farmer had not adopted any conservation practice ($I = N$), the expected value of Y for this farmer would have been

$$E(Y_N|I=s) = X_j'\eta_N - \theta_N\hat{\lambda}_s. \tag{21}$$

Thus, the expected change in Y due to the adoption of management plan s is

$$E(Y_s|I=s) - E(Y_N|I=s) = X_j'(\eta_s - \eta_N) + (\theta_N - \theta_s)\hat{\lambda}_s. \tag{22}$$

The first term in the right-hand side of (22) is the expected change in Y that would result from adopting management plan s on a randomly selected farm with (X_j, Z_j). The second term accounts for self-selection. The expected change in Y due to adoption of management plan s in the region equals the weighted average of (22) over all farms that have adopted the plan, with weights determined by field size.

Data

The Area Study data collected by the U.S. Department of Agriculture (USDA) for the Central Nebraska Basins were used to conduct the empirical analysis. The data were collected for three years, from 1989 to 1991, and covered approximately 30,000 square miles, of which 45 percent was cropland and 50 percent was rangeland. This area includes the watersheds of the Platte River and its tributaries between the confluence of the North and South Platte Rivers in western Nebraska and downstream to the Missouri River at the eastern boundary of Nebraska.

The Area Study data include detailed information on both production activities and environmental characteristics for 1,433 sample points. Personal interviews with farm operators were conducted by the National Agricultural Statistical Service (NASS) to collect information on agricultural practices in the fields and socioeconomic characteristics of the farms where the sample points fell. The sample points were chosen to correspond with National Resource Inventory (NRI) sample points. Each point was assigned a weight corresponding to the area the point represents. The National Resources Conservation Service (NRCS) conducts an NRI every five years, collecting soil, water, and other natural resource data for nearly a million sample points nationwide. Thus, the use of NRI points establishes a link between production activities as measured by the Area Studies data and associated resource settings as measured by the NRI data. Of the 4,299 observations (1,433 sample sites observed for three years), 1,149 were collected on corn fields. These 1,149 observations were used in the present analysis.

The management practices considered in this study include conservation tillage, corn-legume rotation, and soil N testing. Conservation tillage was not divided into no-till and reduced till categories because no-till was used on only 3.7 percent of corn acreage in the study area. Corn was regarded as being rotated with a legume crop if both corn and a legume crop were grown in the field in the 1989-91 period. Conservation tillage, rotation, and soil N testing constitutes eight possible combinations or plans. Table 1 shows the percentages of corn acreage that were cultivated under these plans.

Table 2 shows the interdependence of alternative conservation practices. Clearly, soil N testing was more frequently adopted for continuous corn, while conservation tillage and corn-legume rotation were more frequently adopted together. The adoption of conservation tillage and soil N testing seems negatively correlated, but the relationship is weak.

Definitions and summary statistics of variables used in this analysis are given in Table 3. All variables were weighted by field size in calculating these statistics. Thus, they are representative of the study area. Conservation tillage was used on 57.5 percent of corn acreage in the 1989-91 period. Corn was rotated with a legume crop on 39.3 percent of corn areas. Soil N tests were conducted on 50.9% of corn acreage. Of these three choice variables, conservation tillage and soil N testing vary by both field and year, while rotation varies only by field. The impacts of management practices on corn yield and N and P application rates were evaluated.

Average N and P application rates for corn were 97 and 20 pounds per acre in the 1989-91 period. The average corn yield was 122 bushels per acre.

Independent variables include farm and operator characteristics and soil properties. Farm and operator characteristics include farmers' education, farming experience, farm size, ownership and size of the field, and whether a farmer purchased crop insurance and participated in corn programs. Several previous studies (Ervin and Ervin; Korsching et al.; Napier et al.) have found that farmers with more education and farming experience are more likely to adopt new technologies or practices. Fuglie and Bosch suggested that use of crop insurance should be expected to be positively correlated with adoption of technologies that reduce risk and negatively correlated with adoption of technologies that increase risk because having crop insurance is an indication of a high degree of risk aversion. Whether a farmer participates in the government corn program may also affect adoption of management practices because the Conservation Compliance provisions of the 1985 Food Security Act made eligibility for participating government programs conditional on adoption of an approved conservation plan.

A dummy variable was used to indicate whether a field was irrigated. In the study area, 63.4 percent of corn acreage was irrigated in the study area. Dummy variables were also included to indicate whether manure was applied in the field and whether N fertilizer was broadcast. Five physical variables were included to describe soil properties and topography in the sampled fields. Several other variables were also considered but not included in the final analysis. These included the age of farm operator, soil permeability, and year dummies.

The multinominal logit model of crop management plan was estimated by using the TSP's LOGIT procedure (Hall). The procedure estimates the marginal effects of independent variables on the choice of crop management strategies, but does not indicate statistical significance. The variances of these marginal effects were estimated separately by using the package's ANALYZ function.

Factors Affecting Adoption of Conservation Practices

Parameter estimates for the multinominal logit model of crop management decisions are presented in Table 4. The model correctly predicts the choice of combinations of conservation tillage, rotation, and soil N testing for 35 percent of the sample. And 62 percent of actual choices of combinations are predicted as the first or second choice. The choice of conservation tillage, rotation, and soil N testing is correctly predicted for 62, 71, and 68 percent of the sample.

The marginal effects of independent variables on the choice of conservation tillage, rotation, and soil N testing are shown in Table 5. The results show that adoption of conservation tillage was significantly affected by farmers' education level, participation in the corn program, and some field and soil characteristics. College education was positively correlated with adoption of conservation tillage. Similar results have been found in several previous studies (Ervin and Ervin; Korsching et al.; Napier et al.). Conservation tillage was also more frequently adopted by farmers who participated in the corn program, suggesting that conservation compliance increased adoption of conservation tillage during this period. Adoption rates for conservation tillage were lower on irrigated fields, perhaps because crop residue interferes with irrigation operations. Conservation tillage was also less frequently adopted on fields that were treated with manure. This may result from tillage operations that required injecting or incorporating manure. Finally, farmers used conservation tillage more frequently on sloping land, reflecting their desire to reduce soil losses on highly erodible land.

Crop rotation was adopted more frequently by farmers who had more farming experience, suggesting that experience increases a farmer's knowledge of the long-term benefits of crop rotation. Crop rotation was adopted less frequently on irrigated fields, indicating that irrigation reduces the payoff from crop rotation and increases the opportunity cost (costs of idling the irrigation system) of growing less water-intensive crops such as soybeans. Crop rotation was also less likely to be adopted by large farms and by farms that own the land. To the extent that crop rotation is one way to diversify the risk of total crop failure, this result suggests that large farms and farms who own the land are more able to afford farming risk.

Adoption of soil N testing was significantly affected by farmers' education, crop insurance, government commodity programs, and field and soil characteristics. As with conservation tillage, soil N testing was adopted more frequently by farmers with college education. Although farming experience was positively correlated with adoption of soil N testing, the correlation was not statistically significant. Crop insurance increases adoption of soil N testing. As Fuglie and Bosch point out, the purchase of crop insurance may be an indication of risk aversion. And risk-averse farmers are more likely to adopt risk-reducing technology such as soil N testing. Soil N testing was adopted more frequently on irrigated fields, reflecting large potential payoffs from soil N testing for irrigated fields because of high N application rates associated with irrigation. Large farms were also more likely to have soil N tested, presumably because these farms were able to spread the fixed costs of soil N testing across more acreage. Clay percentage, organic matter content, available water capacity, and land capability class were also statistically significant at the 1 percent level in some of the management plans. This demonstrates the importance of soil properties in the choice of cropping practices.

The Effects of Alternative Combinations of Management Practices

Equations for fertilizer N and P application rates, corn yield, and soil erosion rate were estimated for each crop management plan by including the λ variables from the multinominal logit model. The results are shown in Tables 6 through 9. There is strong evidence that self-selection occurred in the adoption of crop management plans. All coefficients of λ_s in the soil erosion equations are statistically significant at the 1 percent level, and so are the most coefficients of λ_s in the yield and N application rate equations. These results suggest that these crop management plans would not have the same effects on nonadopters, should they choose to adopt, as it would on adopters.

The coefficients of many variables in the regressions change signs and are somewhat difficult to interpret. However, the signs of coefficients on variables that have been the focus of past studies are consistent with previous findings. The coefficients on crop insurance are either negative or statistically indifferent from zero in the yield and N application rate equations. This suggests that farmers who purchased crop insurance had both lower N application rates and corn yields than they would have had if they had not purchased crop insurance. This finding is consistent with studies by Smith and Goodwin; Quiggin, Karagin, and Stanton; and Babcock and Hennessy who examined the effect of crop insurance on Midwest grain farmers. The coefficients on the corn program variable indicate that farmers who participated in the program used more nitrogen fertilizer and produced higher corn yields. This finding supports the argument that past commodity programs encouraged more intensive farming practices (Just and Antle). But it appears that the program did not increase soil erosion rates in the study area during the 1989-91 period. In fact, the coefficients of the corn program variable in the soil erosion equations are either negative or statistically indifferent from zero, indicating that the corn program might have actually reduced soil erosion. This reduction may be attributed to the conservation compliance that made eligibility for participating in government commodity programs conditional on farmers implementing their conservation compliance plans on highly erodible land. All coefficients on irrigation in the yield equation are statistically significant at the 1 percent level. Only one irrigation coefficient in the N application rate equation is negative, but this coefficient is statistically indifferent from zero. These results show that irrigation significantly increased corn yields and N application rates.

To determine the actual effects of alternative management plans on fertilizer use, corn yield, and soil erosion rate, the input-output decisions of farmers who adopted management plans 1 to 7 are compared with what they would have been if the farmers had adopted the conventional plan (plan 8). The differences (Equation 22) are weighted by the field size and aggregated for each management plan. The results are shown in Table 10. For farmers who adopted plans 1 and 5, the average N and P application rates were significantly lower and the average corn yield was significantly higher than they would have been if the farmers had adopted the conventional plan. What these two management plans have in common is that both include the use of crop rotation and soil N testing. This finding may reflect that information from soil N testing enables farmers to properly credit the N fixed by the legume crops.

The use of management plans 2 and 6, which include crop rotation but not soil N testing, reduced N application rates but not corn yield. The reduction in N application rate under plan 2 was smaller than under plan 1, and the same comparison can be made for plans 5 and 6. This indicates that when soil N testing is not used with crop rotation, farmers may not be able to properly credit the N fixed by legume crops. As a result, some farmers may apply more nitrogen than needed to reach their targeted corn yield, while others may apply less. Although on average these farmers still use less nitrogen than they would under plan 8, the average yield will not be significantly affected.

Adoption of management plans 3 and 7 significantly increases both N application rate and corn yield. What these two plans have in common is that both include the use of soil N testing but not crop rotation. This result suggests that soil N testing may actually increase N applications on continuous corn. The increase in N application rates was profitable because the increase in marginal value of the product was greater than the cost of soil N testing and additional N use. The price of N fertilizer was \$0.15 to \$0.25 per pound. The cost of soil N testing was about \$0.60 per acre. Given that the corn price was above \$2 per bushel in the 1989-91 period, it was profitable to adopt these management practices.

For all management plans that include the use of soil N testing, the predicted change in average corn yield is 16 bushels per acre or more, while for all management plans that do not include the use of soil N testing, the predicted change in average corn yield is five bushels per acre or lower. The predicted changes in average P application rate are always negative. Compared with the conventional management plan, all management plans that include conservation tillage are predicted to reduce the soil erosion rate.

The effects of management plans on fertilizer use, corn yield, and the soil erosion rate were estimated for each sampled field. These effects vary from field to field, depending on soil properties and field and farm characteristics. A management plan may increase fertilizer use on one field but decrease fertilizer use on others. No management plan is predicted to increase or decrease fertilizer use or corn yield on all fields. This finding suggests that mandating the use of specific management practices may not be an efficient way to reduce nonpoint pollution.

Concluding Remarks

Substantial research has focused on adopting individual conservation practices and their economic and environmental implications. But many conservation practices are interdependent. In order to determine the effects of alternative combinations of conservation practices, it is necessary to conduct joint analysis of these conservation practices. In this paper, we analyze the adoption of alternative combinations of conservation practices and their impacts on fertilizer use, corn yield, and soil erosion in the Central Nebraska Basin. A polychotomous-choice selectivity model is used to account for self-selection in choosing alternative conservation practices and the interaction between them.

Our results suggest that soil N testing and corn-legume rotation complement each other. Soil N testing enables farmers to properly credit the N fixed by legume crops. And a corn-legume rotation increases the value of soil N testing. The interaction between conservation tillage and rotation is more complicated. Farmers who adopted both conservation tillage and rotation reduced soil erosion rates more than farmers who adopted only one of them; however, farmers who adopted only one of them still reduced their N application rates. The results of this study also show that total benefit from adopting two or more conservation practices simultaneously does not equal the sum of the benefits from adopting each management practice separately. This demonstrates the importance of conducting joint analysis of alternative management practices.

Table 1. Alternative Crop Management Plans Used in the Central Nebraska Basins

	Conservation tillage		Rotation with a legume		Soil N testing		Corn Acreage
Plan	Yes	No	Yes	No	Yes	No	%
1	X		X		X		9.45
2	X		X			X	16.85
3	X			X	X		16.90
4	X			X		X	14.33
5		X	X		X		4.97
6		X	X			X	7.66
7		X		X	X		17.53
8		X		X		X	12.31

Table 2. The Interdependence of Alternative Conservation Practices in the Central Nebraska Basin

	Percentage of sample fields adopted		
	Conservation tillage	Rotation with a legume	Soil N testing
Unconditional	53	34	55
Conditional on adoption of			
Conservation tillage	100	41	52
Rotation with a legume	63	100	40
Soil N testing	51	25	100

Table 3. Definition of Variables

Variables	Mean	Standard Deviation	Definition
Choice variables			
Conservation tillage	0.575	0.523	Conservation tillage adopted in field (1=yes, 0=no)
Rotation	0.393	0.504	Corn was rotated with a legume crop (1=yes, 0=no)
Soil N test	0.509	0.504	Soil N test was conducted (1=yes, 0=no)
Impact variables			
N application	97.185	61.087	Nitrogen application rate (pounds/acre)
P application	19.889	20.339	Phosphate application rate (pounds/acre)
Corn yield	121.769	39.832	Corn yield (bushels/acre)
Soil erosion	6.142	9.294	Average annual soil loss due to water and wind erosion (tons/acre)
Independent variables			
Farming experience	22.157	14.328	Number of years farmer has operated a farm/ranch
College education	0.436	0.512	Farm operator had some college education (1=yes, 0=no)
Crop insurance	0.662	0.494	Had crop insurance for crops grown in field (1=yes, 0=no)
Corn program	0.807	0.432	Participate in corn program (1=yes, 0=no)
Field irrigated	0.634	0.519	Field was irrigated (1=yes, 0=no)
Manure applied	0.114	0.319	Manure was applied in field (1=yes, 0=no)
N broadcast	0.290	0.505	Fertilizer N was broadcast (1=yes, 0=no)
Large farm	0.348	0.487	Gross annual sales greater or equal to $250,000 (1=yes, 0=no)
Own land	0.363	0.503	Field owned by farm operator
Field acreage	80.206	44.744	Number of acres in field
Next to a stream	0.25	0.465	Field is next to a stream
Clay percentage	21.38	9.347	Clay percentage in top layer of field (%)
Organic matter	2.473	1.122	Organic matter percentage in top layer of field (%)
Av. water capacity	0.189	0.062	Available water capacity
Bulk density	1.362	0.267	Bulk density
PH	6.656	0.905	Soil reaction (PH)
T factor	4.813	0.765	Soil loss tolerance factor (tons/acre)
Slope of field	3.324	4.335	Slope percentage of field (%)
Land capability class	2.56	1.496	Land capability class (1-8)

Table 4. Parameter Estimates for the Multinominal Logit Model of Crop Management Plans

Variable	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7
Constant	-1.617	2.908**	-1.837	2.969**	-0.363	3.102**	0.556
	(1.402)	(1.369)	(1.162)	(1.196)	(1.757)	(1.323)	(1.127)
Farming experience	0.011	0.032*	0.014	0.001	0.013	0.013	0.008
	(0.012)	(0.011)	(0.011)	(0.011)	(0.016)	(0.012)	(0.011)
College education	1.058*	1.567*	1.602*	0.982*	1.268*	0.726**	0.950*
	(0.334)	(0.318)	(0.275)	(0.297)	(0.384)	(0.348)	(0.273)
Crop insurance	1.775*	0.843*	0.710*	0.188	0.406	0.329	1.261*
	(0.367)	(0.289)	(0.255)	(0.268)	(0.354)	(0.306)	(0.264)
Corn program	-2.039*	-1.672*	-0.696	-0.018	0.094	-0.954**	-2.373*
	(0.452)	(0.397)	(0.451)	(0.469)	(0.715)	(0.445)	(0.404)
Field irrigated	0.741	-0.498	1.413*	-0.243	1.755*	-0.790**	2.227*
	(0.396)	(0.343)	(0.380)	(0.344)	(0.693)	(0.375)	(0.422)
Manure applied	-1.534*	-0.834**	-0.789**	-1.963*	-0.104	-1.174**	-0.822*
	(0.506)	(0.387)	(0.331)	(0.493)	(0.431)	(0.495)	(0.324)
Large farm	0.102*	-0.160	0.778*	0.273	0.381	0.048	0.627**
	(0.339)	(0.315)	(0.269)	(0.296)	(0.373)	(0.340)	(0.266)
Own land	-1.442*	-0.895*	-0.155	-0.014	0.455	-0.345	-0.776*
	(0.355)	(0.295)	(0.254)	(0.270)	(0.363)	(0.313)	(0.261)
Field acreage	-0.003	-0.005	-0.001	0.002	0.001	0.005	0.005
	(0.004)	(0.004)	(0.003)	(0.004)	(0.005)	(0.004)	(0.003)
Next to a stream	0.782**	0.841*	0.556	0.830**	0.890**	1.037*	0.540
	(0.341)	(0.329)	(0.304)	(0.334)	(0.410)	(0.361)	(0.303)
Clay percentage	-0.087**	0.129*	-0.021	0.053	0.056	0.113*	0.012
	(0.040)	(0.031)	(0.032)	(0.033)	(0.043)	(0.032)	(0.031)
Organic matter	0.817*	-0.189	0.191	-0.138	-0.132	-0.028	0.222
	(0.180)	(0.169)	(0.161)	(0.183)	(0.228)	(0.183)	(0.162)
Av. water capacity	1.034	-23.964*	-4.119	-24.115*	-20.692*	-27.969*	-15.062*
	(6.693)	(6.304)	(5.384)	(5.675)	(7.487)	(6.126)	(5.278)
Slope of field	0.079	0.100	0.114*	0.080	0.033	-0.193**	0.046
	(0.060)	(0.059)	(0.055)	(0.058)	(0.089)	(0.077)	(0.058)
Land capab. class	0.199	-0.104	0.387*	0.132	-0.153	0.180	0.300*
	(0.176)	(0.181)	(0.147)	(0.163)	(0.237)	(0.177)	(0.147)

Pseudo R-square	0.49
Likelihood ratio test statistic	759
Correct predictions	
Management Plan (combinations of tillage, rotation, and soil N testing)	35%
Actual choice of plan was predicted as the 1st and 2nd choice by the model	62%
Conservation tillage adoption	58%
Rotation with a legume crop	71%
Soil N testing adoption	68%

Notes: Standard errors are in parentheses. * indicates statistical significance at the 1% level, and ** indicate statistical significance at the 5% level.

Table 5. Estimated Marginal Effects for the Adoption of Conservation Tillage, Rotation, and Soil N Tests

	Conservation Tillage		Rotation		Soil N Tests	
Variable	Mar. Effect	Std. Error	Mar. Effect	Std. Error	Mar. Effect	Std. Error
Farming experience	0.0016	0.0014	0.0025**	0.0013	0.0002	0.0015
College education	0.1608*	0.0365	0.0380	0.0344	0.1049*	0.0380
Crop insurance	0.0120	0.0355	0.0437	0.0336	0.1796*	0.0382
Corn program	0.1024**	0.0516	-0.0732	0.0457	-0.2271*	0.0578
Field irrigated	-0.1497*	0.0555	-0.2198*	0.0475	0.4966*	0.0579
Manure applied	-0.1501*	0.0539	-0.0173	0.0519	0.0455	0.0600
Large farm	0.0047	0.0361	-0.0970*	0.0342	0.1322*	0.0387
Own land	-0.0149	0.0354	-0.0800**	0.0344	-0.0606	0.0381
Field size	-0.0012*	0.0004	-0.0006	0.0004	0.0002	0.0005
Next to streams	0.0472	0.0396	0.0793**	0.0354	-0.0103	0.0418
Clay percentage	-0.0032	0.0041	0.0112*	0.0035	-0.0191*	0.0043
Organic matter	0.0077	0.0220	0.0012	0.0192	0.0872*	0.0233
Av. water capacity	0.3979	0.6702	-1.5714**	0.6473	2.2569*	0.7246
Slope of field	0.0258*	0.0075	0.0014	0.0065	0.0046	0.0075
Land capability class	0.0094	0.0197	-0.0439**	0.0189	0.0573*	0.0213

Notes: * indicates statistical significance at the 1% level, and ** indicates statistical significance at the 5% level.

Table 6. Parameter Estimates for the Equation of Fertilizer N Application Rates Under Alternative Management Plans

Variable	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8
Constant	715.5*	50.98	31.21	58.60	-273.8	-56.68	117.75*	66.30
	30.64	59.88	48.61	58.56	467.6	92.88	41.02	68.86
Farming experience	1.29	-0.49	-0.26	-0.27	5.63**	-0.05	0.08	-0.76
	0.80	0.29	0.26	0.32	2.40	0.54	0.31	0.53
College education	-27.45	-16.42	18.46	17.34	43.03	-65.02**	-13.07	0.27
	33.84	14.54	10.72	12.14	44.17	28.12	8.72	19.47
Large farm	52.10*	0.19	16.39**	-20.30	-38.84	10.47	-3.81	7.60
	17.70	10.82	6.97	10.29	37.76	15.51	7.48	11.58
Field acreage	1.58*	0.41*	-0.35*	-0.08	-0.06	0.79*	-0.24**	0.10
	0.45	0.16	0.08	0.14	0.73	0.18	0.09	0.12
Crop insurance	-164.5*	-0.99	2.36	-18.03	-1.73	-5.90	-33.98*	-35.48**
	33.41	15.34	8.78	11.54	48.56	22.78	8.55	17.91
Corn program	63.73	54.15*	91.67*	74.96*		30.45	-6.03	81.57*
	55.85	14.64	16.67	21.33		22.13	12.11	27.13
Field irrigated	13.66	73.06*	28.40	50.54*	42.22	-5.19	45.57**	24.06**
	21.59	15.00	16.01	12.52	143.1	20.63	17.82	12.50
Manure applied	103.4**	-2.16	46.02*	-72.32*	-35.87	-11.80	-44.80*	9.49
	44.18	17.15	12.93	19.52	44.95	24.31	11.79	20.71
N broadcast	17.90	39.28*	-0.17	26.04*	85.15*	46.44*	-5.39	-25.18**
	16.52	8.48	5.71	8.52	20.68	17.35	7.19	12.12
Clay percentage	14.49*	-3.72*	-1.71**	4.03*	-6.97	0.79	-1.79	1.87
	4.58	1.13	0.75	0.97	5.01	1.86	1.04	1.10
Organic matter	-68.39	9.83	-4.75	-15.01**	13.57	1.02	18.18*	-3.33
	6.21	6.10	3.79	7.56	31.45	3.02	5.90	7.64
Av. water capacity	-2001*	412.5	-19.09	-793.6*	-47.52	-161.6	93.32	-179.5
	536.1	270.0	160.6	214.3	607.9	414.6	167.6	265.1
Slope of field	0.86	-1.20	-1.24	0.41	-22.03	-5.13**	4.43**	2.85
	4.12	1.78	0.80	2.03	17.34	2.34	1.75	2.53
Land capab. class	-18.67	7.85	-6.11	-9.38	29.37	7.24	7.20	-27.69*
	14.35	7.24	3.68	5.53	28.11	7.41	6.00	7.51
$\hat{\lambda}_N$	-226.1*	-77.86*	45.76**	48.65**	133.3	55.41	-16.94**	42.56
	22.77	19.95	20.16	20.49	164.4	32.92	7.68	32.50
R-square	0.37	0.31	0.37	0.51	0.54	0.47	0.30	0.46

Notes: The number below each coefficient is its standard error. * indicates statistical significance at the 1% level. and ** indicate statistical significance at the 5% level.

Table 7. Parameter Estimates for the Equation of Fertilizer P Application Rates Under Alternative Management Plans

Variable	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8
Constant	157.4*	34.59	70.00*	33.13	-46.57	11.48	-4.69	37.00
	39.64	27.24	22.09	30.80	157.78	20.67	14.12	21.46
Farming experience	0.04	-0.05	-0.11	0.14	1.18	0.32**	-0.04	-0.11
	0.26	0.12	0.12	0.17	0.81	0.12	0.11	0.16
College education	9.91	8.01	-4.77	-5.44	31.80**	-20.18*	-10.03*	4.55
	10.80	6.18	5.01	6.66	14.89	6.58	2.95	6.09
Large farm	17.67*	11.29*	-10.25*	2.10	-6.18	31.65*	8.55*	-3.14
	6.01	4.21	3.15	5.46	12.68	3.85	2.56	3.67
Field acreage	0.09	0.09	0.10*	0.09	0.05	0.12*	-0.07**	-0.06
	0.13	0.06	0.03	0.07	0.25	0.04	0.03	0.04
Crop insurance	-20.62**	-4.26	-11.46*	2.72	-31.38	11.87**	7.15**	-7.05
	9.78	5.74	3.98	6.07	16.22	5.34	2.93	5.60
Corn program	26.09	5.33	0.96	-29.30*		-0.87	6.76	-18.53**
	16.37	5.96	8.54	11.13		5.28	4.09	8.54
Field irrigated	-14.82	-3.04	5.22	-6.81	53.52	15.07*	8.07	17.49*
	9.24	5.71	7.17	6.64	46.74	4.66	6.17	3.88
Manure applied	19.61	1.11	8.70	0.91	13.90	28.20*	-11.79*	4.17
	12.61	6.43	5.95	9.91	14.84	5.59	4.08	6.52
Clay percentage	-0.10	-0.84	-0.04	0.59	2.08	-1.59*	-0.24	-0.31
	1.41	0.43	0.34	0.50	1.62	0.50	0.36	0.35
Organic matter	-7.69*	7.62*	-0.29	-4.19	-13.81	2.56	3.50	9.36*
	2.63	2.35	1.71	3.79	10.60	1.34	2.05	2.39
Av. water capacity	-199.6	-73.52	-123.3	-5.15	-354.2	-37.08	10.53	-39.33
	172.6	116.8	73.26	116.5	203.0	98.82	57.93	83.56
Slope of field	3.04**	0.89	-0.60	-2.54	4.67	3.65*	0.65	2.39*
	1.45	0.73	0.37	1.12	5.46	0.63	0.61	0.79
Land capab. class	-5.97	-1.54	-0.20	1.21	-18.39**	0.42	1.06	-3.27
	4.18	2.87	1.65	2.91	8.52	1.73	2.08	2.37
$\hat{\lambda}_c$	-44.10*	-9.63	-12.19	10.27	42.46	-1.91	6.63*	-4.43
	12.04	7.97	9.16	10.78	55.49	8.29	2.20	10.21
R-square	0.22	0.21	0.24	0.23	0.58	0.85	0.20	0.41

Notes: The number below each coefficient is its standard error. * indicates statistical significance at the 1% level. and ** indicate statistical significance at the 5% level.

Table 8. Parameter Estimates for the Corn Yield Equations Under Alternative Management Plans

Variable	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8
Constant	220.2*	144.7*	9.10	9.70	-73.52	222.5	110.0*	121.7*
	2.55	35.38	25.87	23.89	56.38	137.40	14.63	35.77
Farming experience	0.67*	0.08	0.28	-0.59*	1.55*	-1.54	-0.11	-0.20
	0.20	0.16	0.14	0.10	0.32	0.78	0.11	0.27
College education	3.49	16.29**	23.66*	-19.92*	30.56*	54.65	-7.69**	9.21
	8.07	8.03	5.69	4.55	6.01	35.17	3.21	10.02
Large farm	24.36*	-0.38	18.34*	2.61	-25.14*	20.80	14.32*	11.99**
	4.60	5.77	3.77	3.27	5.17	10.87	2.77	5.98
Field acreage	0.51*	0.05	-0.04	0.09**	0.09	-0.21	-0.06	0.05
	0.11	0.08	0.04	0.04	0.09	0.28	0.03	0.06
Crop insurance	-21.56*	-11.17	2.22	5.12	-14.09**	-3.74	-6.92**	-11.68
	8.26	7.82	4.55	4.49	6.26	28.97	3.07	9.25
Corn program	26.80**	10.76	29.68*	36.33*		-1.89	10.64**	31.47**
	13.98	8.19	9.57	6.44		25.26	4.50	14.21
Field irrigated	63.20**	52.89*	57.98*	37.17*	72.06*	131.38*	57.62*	51.18*
	4.18	7.42	8.87	5.02	18.01	29.34	6.30	6.51
Manure applied	11.87	17.18**	-6.14	2.29	22.27*	-18.75	6.52	13.94
	11.18	9.13	7.07	8.04	5.94	33.23	4.07	10.67
N broadcast	2.50	1.13	7.07*	6.15*	-4.22**	-0.03	-3.12	-8.19
	4.25	3.74	2.50	1.45	1.76	20.84	2.02	4.83
Clay percentage	5.61*	-3.16*	-0.62	0.34	0.02	-2.45*	-1.19*	1.77*
	1.07	0.57	0.40	0.39	0.57	0.00	0.36	0.56
Organic matter	-21.49*	10.83*	-3.61	0.36	-7.76**	-0.95*	5.61*	10.70*
	1.59	3.01	2.11	3.09	3.77	0.00	2.03	3.83
Av. water capacity	-699.5*	45.18	98.08	9.55	3.37	1010**	27.03	-407.0*
	134.7	144.4	85.14	84.25	82.60	430.0	59.48	136.7
Slope of field	-1.36	-0.08	0.14	-0.75	-3.71**	12.48*	0.59	0.99
	1.00	0.96	0.46	0.70	1.86	0.00	0.59	1.24
Land capab. class	-5.96	0.27	-1.68	4.73**	0.39	1.85	-4.67**	-16.21*
	3.58	3.80	1.95	2.04	3.31	9.28	2.10	3.79
$\hat{\lambda}_s$	-56.44*	-30.84*	22.87**	26.26*	68.41*	-181.1*	0.74	-8.13
	6.16	10.98	10.73	7.91	20.44	15.98	3.84	16.88
R-square	0.83	0.59	0.49	0.81	0.86	0.87	0.55	0.71

Notes: The number below each coefficient is its standard error. * indicates statistical significance at the 1% level, and ** indicate statistical significance at the 5% level.

Table 9. Parameter Estimates for the Soil Erosion Equations Under Alternative Management Plans

Variable	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8
Constant	84.254*	93.777*	83.238*	-59.447	-83.947*	39.784	-20.050*	-13.285
	21.605	29.098	5.364	45.916	10.235	40.512	1.472	7.370
Farming experience	0.538*	-0.056**	0.020	-0.130	-0.580*	-0.247**	0.038*	0.103*
	0.047	0.026	0.027	0.087	0.046	0.116	0.003	0.035
College education	17.179*	-7.302*	-1.641	-8.597**	-3.492*	10.115	0.782*	5.119*
	3.047	0.602	1.248	3.895	0.857	6.139	0.003	1.031
Large farm	7.355*	2.734*	-5.089*	1.519*	-1.588**	4.700*	0.010*	1.695*
	0.953	0.952	0.975	2.945	0.685	1.089	0.003	0.370
Field acreage	0.079*	0.037	0.072*	0.021*	0.213*	-0.077**	0.029*	0.032*
	0.030	0.019	0.011	0.039	0.015	0.034	0.004	0.006
Crop insurance	-3.969	-0.076	0.244	-1.075	-6.788*	1.182	0.952*	4.412*
	2.150	1.514	1.321	4.032	0.887	4.739	0.003	1.261
Corn program	-8.533*	2.173	-6.592*	1.146		-8.912**	-2.945*	-8.549*
	4.116	1.183	0.003	5.891		4.136	0.003	1.767
Field irrigated	-4.708*	4.178*	-8.603*	-13.442*	21.707*	6.280	2.677*	0.646
	1.283	1.349	2.558	4.547	2.484	4.636	0.340	0.719
Manure applied	9.807*	-3.406	4.358**	-7.897	10.620*	5.015**	-1.354*	-6.834*
	3.459	1.804	1.714	7.311	1.270	2.207	0.070	1.097
Clay percentage	1.278*	-0.273	0.623*	0.866**	1.132*	-0.453*	-0.253*	0.002
	0.271	0.182	0.121	0.402	0.090	0.170	0.055	0.068
Organic matter	-7.864*	-1.504*	-0.403	-2.312	-7.112*	-1.270	0.298	0.415
	0.003	0.534	0.556	3.058	0.556	0.676	0.305	0.473
Av. water capacity	-485.8*	-111.2*	-152.5*	-169.7**	-109.1*	64.419	51.192*	7.516
	56.354	21.930	25.867	78.521	16.505	33.377	0.003	14.487
Slope of field	0.680	-0.187	0.578*	2.365*	2.628*	3.445*	2.000*	1.930*
	0.361	0.175	0.081	0.656	0.381	0.578	0.047	0.128
Land capab. class	0.031	0.261	-0.379	-0.321	-6.445*	-0.870	-0.175*	1.631*
	1.013	0.630	0.581	2.055	0.853	0.773	0.003	0.484
Bulk density	-39.183*	-50.723*	-15.209*	21.536	4.843	-18.462**	-8.134*	-0.023
	6.882	13.555	2.380	16.720	2.800	16.582	1.851	3.371
PH	13.486*	4.562*	-0.421	2.155	10.893*	7.111	1.949*	3.281*
	2.116	1.406	0.937	4.235	0.739	3.009	0.303	0.559
T factor	-1.703**		-0.889		-5.569*	-2.437	0.559**	0.302
	0.748		0.727		1.004	1.598	0.240	0.218
λ_s	-15.807*	-12.341*	-15.941*	31.436*	21.012*	-22.825*	4.070*	-11.478*
	1.960	1.446	3.019	7.386	3.198	1.806	0.003	2.263
R-square	0.85	0.56	0.59	0.92	0.99	0.95	0.81	0.83

Notes: The number below each coefficient is its standard error. * indicates statistical significance at the 1% level, and ** indicate statistical significance at the 5% level.

Table 10. Estimated Changes in Average N and P Application Rates, Corn Yield, and Soil Erosion Rate From Adoption of Alternative Management Plans in the Central Nebraska Basin

Management Plan	N Application (lb/acre)	P Application (lb/acre)	Corn Yield (bu/acre)	Soil Erosion (tons/acre/yr)
1	-28	-5	16	-1.26
2	-9	-11	-5	-9.23
3	10	-3	17	-7.59
4	-25	-2	3	-2.21
5	-45	-5	16	4.35
6	-27	-6	2	2.65
7	50	-7	28	-10.26

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