# Predicting subsoil nitrate content from surface measurements[1]

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## ABSTRACT

Preplant soil profile nitrate ($NO_3$-N) tests are effective for predicting corn (Zea mays L.) response to applied N. The difficulty of obtaining profile soil samples is one of the main obstacles to more extensive use of preplant tests. One approach to overcoming this barrier is to develop and use models to predict subsoil $NO_3$-N contents from surface soil $NO_3$-N measurements. Data from 2295 routine field samples submitted to the University of Wisconsin Soil and Plant Analysis Laboratory from 1989 through 1991 and 208 samples from a separate study in 1990 and 1991 were used to correlate surface soil and subsoil $NO_3$-N contents. Six linear regression models that included factors for soil texture, previous crop, geographical location, and legume and manure N-credits were evaluated. Models were developed to predict 2nd and 3rd ft $NO_3$-N contents from surface soil measurements. During three climatically different years, distribution of $NO_3$-N within 3 ft soil profiles was similar, but total profile $NO_3$-N content varied significantly. Models developed to predict 3rd ft $NO_3$-N following corn and soybeans (Glycine max L.) are reliable and are suitable for routine use with the preplant test. Prediction of 2nd and 3rd ft $NO_3$-N contents from 1st ft measurements is probably not reliable enough to allow use of a 1 ft sampling depth for the preplant test, unless a greater margin of error in N recommendations is tolerated or the concept of a minimum N application at most preplant $NO_3$-N test values is implemented. A 2 ft sampling depth for the preplant test and use of models to predict 3rd ft $NO_3$-N content is feasible and should promote more widespread use of this test.

## INTRODUCTION

During the 1980's, many states in the humid regions of the USA initiated work to evaluate soil nitrate tests as a method of improving N-fertilizer recommendations for corn. Some states have adopted the pre-sidedress soil nitrate test (PSNT) (Magdoff et al., 1984; Magdoff, 1991), while other states are using a preplant soil profile nitrate test (preplant test) (Bundy and Malone, 1988; Bundy et al., 1990). The PSNT provides an index of N availability by measuring the release of $NO_3$-N from organic matter plus any residual $NO_3$-N in the surface soil. The

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PSNT requires only a 1 ft deep sample, which is a major advantage of the test. The preplant test, on the other hand, is a measurement of residual $NO_3$-N in the soil profile. The deep profile samples are needed for the preplant test, because soil $NO_3$-N is very mobile and corn can extract $NO_3$-N from depths to 4.5 ft (Herron et al., 1968). In fact, most Western and Plains states suggest a 2 to 6 ft sampling depth (Hergert, 1987).

The convenience of sampling in the PSNT has lead researchers to evaluate shallower sampling depths for the preplant test. The relationship between the $NO_3$-N content in a surface soil layer and the $NO_3$-N content of the entire soil profile has been examined in numerous studies. While significant correlations have been found, the procedure of correlating two values that contain part of the same information will usually exaggerate the degree of correlation. A more appropriate approach is to correlate the $NO_3$-N content in a surface layer with the $NO_3$-N in a lower layer. However, the potential for large annual variations in profile distribution is a major concern with use of models based on this correlation. The percentage of total profile $NO_3$-N in each layer can be affected by annual precipitation, N fertilizer use history, soil characteristics, and previous crop (Herron et al., 1968; Olsen et al., 1970; Jolley and Pierre 1977). High correlations between the profile $NO_3$-N and the surface $NO_3$-N contents have been found in individual experiments with similar soils and climatic conditions. However, the correlation is often reduced when data is combined across several years, soils, and other variables.

Despite these relatively low correlations between surface $NO_3$-N and subsoil $NO_3$-N contents, work to evaluate use of shallower sampling depths for the preplant test is justified, since the greater ease of sampling would increase on-farm preplant test use. The potential advantages of shallower sampling must be weighed against the risk of less reliable N recommendations based on these samples. The objective of this study was to evaluate the reliability of using shallower sampling depths in the preplant test.

## MATERIALS AND METHODS

Two independent statewide databases were collected in Wisconsin to develop models for predicting subsoil $NO_3$-N contents from surface measurements. In 1990 and 1991 county extension agents, water resource agents and Nutrient and Pest Management program staff collected 2 or 3 ft profile preplant test and PSNT samples in 1-ft increments from 0.25-acre unfertilized farmer-managed corn plots. The 134 randomly selected plots in 1990 and 74 in 1991 represented much of the corn growing region of Wisconsin. Data from these plots is identified as the Wisconsin farms data base. Site management histories including soil type and texture, previous crop, manure and legume N credits, primary tillage practices and April through June precipitation records were collected. Soil samples were either dried or frozen following standard handling practices and shipped to the University of Wisconsin Soil and Plant Analysis Laboratory (SPAL) in Madison, WI. The samples were dried, ground and analyzed for $NO_3$-N using the phenoldisulphonic acid procedure (Schulte et al., 1987).

A larger database was compiled from the results of routine preplant test samples analyzed by SPAL in 1989, 1990 and 1991. These samples were collected by independent consultants, agronomists, extension agents, and farmers and used to make N fertilizer rate decisions. Soil name and texture, field location, legume and manure N credit information and previous crop were provided for most fields. Most fields were sampled to 3 ft in 1-ft increments and were on medium or heavy textured soils where the previous crop was corn.

For both databases, fields containing 200 lb or more $NO_3$-N per acre-ft were deleted prior to regression because these fields are outside the desired predictive range of the models to be developed. According to Wisconsin N recommendations, fields with more than 200 lb $NO_3$-N/acre in a 3 ft profile would receive no N fertilizer. Previous crop, legume and manure N credits, and geographical location were used as factors in each of the models evaluated. Since the preplant test is not recommended on sandy soils in Wisconsin, only data from medium and heavy textured mineral soils were used in this study. Significant differences in predictive models were not found for sites north and south of the 2300 growing degree day ($50^oF$ base) accumulation line, used in making corn N-fertilizer recommendations in Wisconsin (Kelling et al., 1991).

Nitrate-N contents of selected surface layers were correlated with $NO_3$-N in deeper layers instead of correlating the $NO_3$-N content in a surface layer to the entire profile. Various linear and non-linear relationships among 1st, 2nd, and 3rd ft soil $NO_3$-N contents were evaluated using the SAS REG procedure, and studentized residuals were calculated for each observation (SAS Institute, Inc., 1982). All observations with a studentized residual greater than 3 or less than -3 were identified as outliers and deleted prior to recalculation of regressions. Deleting outliers did not significantly change any of the regression equations presented. Agreement between the predicted and actual measured soil $NO_3$-N contents (lb/acre) was stressed more than the correlations alone. If models from two years are dissimilar, but vary by only 5 or 10 pounds $NO_3$-N per acre in their prediction, they may still have good practical predictive value.

## RESULTS AND DISCUSSION

Wisconsin's preplant soil profile nitrate test currently suggests a 3 ft sample depth. In this study, six linear regression models were evaluated to predict the $NO_3$-N content in the 2nd and 3rd ft of the profile based on the $NO_3$-N contents of surface layers. Several polynomial models examined did not adequately describe these relationships. The models used to describe the relationships between $NO_3$-N in various soil depths for both the SPAL and Wisconsin farms databases are shown in Table 1.

Table 1. Linear regression models evaluated in this study to predict 2nd and 3rd ft soil $NO_3$-N.

| Equation 1/ | r² values 2/ 1989 | 1990 | 1991 | All |
|---|---|---|---|---|
| 1. $N2 = b_o + N1*X$ | 0.38 | 0.48 | 0.61 | 0.58 |
| 2. $N2+N3 = b_o + N1*X$ | 0.27 | 0.34 | -- | -- |
| 3. $N3 = b_o + (N1+N2)*X$ | 0.50 | 0.50 | 0.48 | 0.51 |
| 4. $N3 = b_o + N1*X_1 + N2*X_2$ | 0.70 | 0.62 | 0.59 | 0.64 |
| 5. $N3 = b_o + N2*X$ | 0.73 | 0.70 | 0.67 | 0.71 |
| 6. $N3 = b_o + N1*X$ | 0.14 | 0.21 | -- | -- |

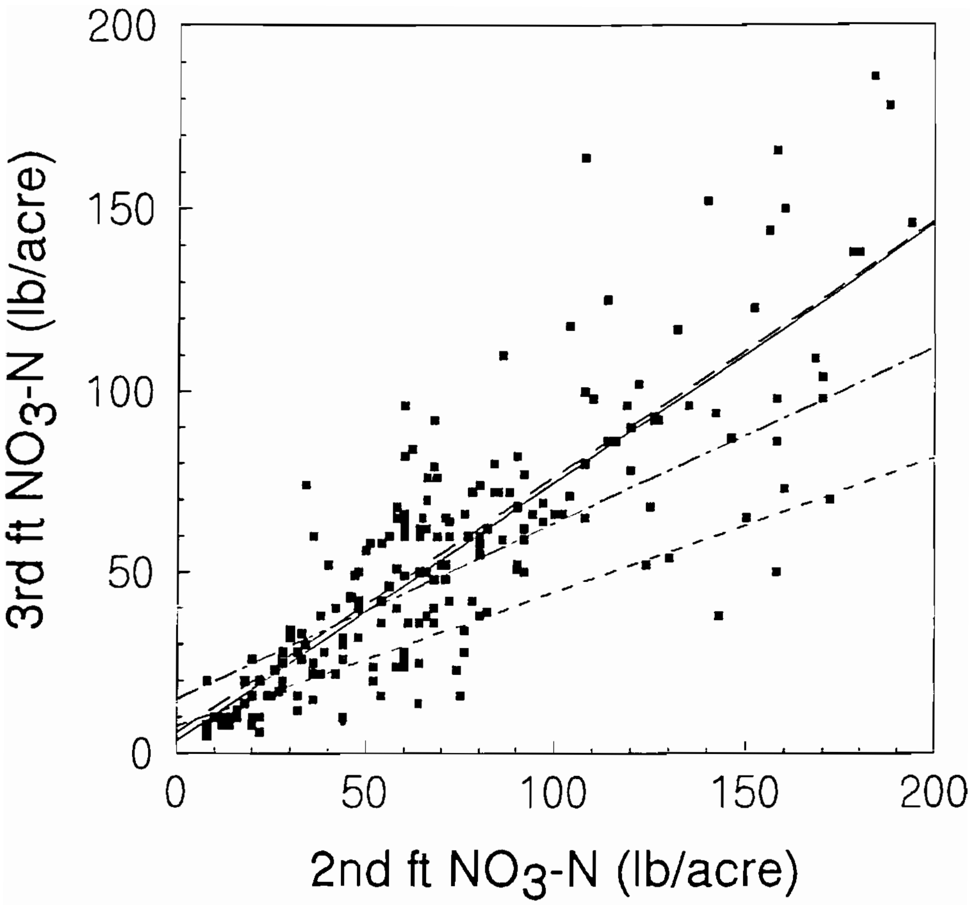
1/ N1, N2 and N3 = $NO_3$-N content of the 1st,2nd and 3rd ft of soil respectively; $b_o$ = intercept; X, $X_1$, and $X_2$ are various slopes.

2/ $r^2$ values are for data collected by the Soil and Plant Analysis Laboratory only.

The preferred models to predict 2nd and 3rd ft $NO_3$-N from measured $NO_3$-N values are equations 1 and 5, respectively. Equation 4 gave higher $r^2$'s for predicting 3rd ft $NO_3$-N content following some crops in 1989 and 1990, but the slope for N1 was not significant in 1991, so the more robust equation 5 was used.

Results from this work indicate that predicting 2nd and 3rd ft $NO_3$-N contents from a 1 ft sampling depth for the preplant test is not reliable. Although the $r^2$ for the relationship between 1st ft and 2nd ft $NO_3$-N is 0.58 for the combined data, the relationship between 1st ft $NO_3$-N and 3rd ft $NO_3$-N content is very poor (Table 1). If a 1 ft sampling depth is used to predict total $NO_3$-N in a 3 ft profile, a minimum N application at most $NO_3$-N values would likely be needed to prevent crop N deficiences when profile $NO_3$-N content is overestimated. Alternatively, 2nd ft $NO_3$-N could be predicted from 1st ft $NO_3$-N (equation 1, Table 1) without considering $NO_3$-N in the 3rd ft. A minimum N application may also be needed with this approach. However, using a 2 ft sampling depth and a predictive model to estimate 3rd ft $NO_3$-N may be the most suitable alternative to the 3 ft sampling depth. This paper will focus on the practicality of a 2 ft sample used to predict 3rd ft $NO_3$-N content.

Factors for previous crop were significantly different at the 0.001 probability level as calculated by F-tests for the models containing the previous crop factors and the overall model without these factors. Figure 1 shows the relationship between 2nd and 3rd ft $NO_3$-N content for the SPAL data set in 1989. A separate regression line was developed for the previous crop factors of corn, soybeans, and alfalfa. Models developed for individual previous crops using 1990 and 1991 data produced results similar to those shown in Figure 1. The models to predict 3rd ft $NO_3$-N following corn and soybeans seem reliable given the number of observations and the $r^2$ values shown in Table 5. Separate factors




| | | | | |
|---|---|---|---|---|
| —— | All previous crops | Y=3.6+0.711x | n=200 | $r^2$=0.73 |
| — - | Previous crop corn | Y=5.9+0.703x | n=145 | $r^2$=0.74 |
| —· | Previous crop soybeans | Y=15.0+0.485x | n=5 | $r^2$=0.79 |
| - - | Previous crop alfalfa | Y=7.5+0.369x | n=21 | $r^2$=0.33 |

Fig. 1. Effect of previous crop on the relationship between 2nd and 3rd ft $NO_3$-N contents, 1989.

for vegetable crops and other crops were eliminated, due to an insufficient number of observations to develop reliable models.

All the models were evaluated using factors for legume and manure credits. However; almost all fields that had both legume and manure N-credits were previously cropped to alfalfa, fields that had only legume credits were previously cropped to soybeans and fields with no N-credits were almost all previously cropped to corn. Therefore the models developed using factors for N credits were almost identical to those models with factors for previous crop and did not contribute additional information. When a variable for manure-N credit was added to models containing separate factors for previous crops, the partial slope for the manure variable was not significant in any model and the variable for manure N-credit was therefore eliminated.

To evaluate year to year differences in predicted 3rd ft $NO_3$-N values due to annual variation in profile $NO_3$-N distribution, 2nd ft $NO_3$-N values at 20 lb/acre increments were inserted into the predictive models for each year. Table 2 shows the predicted values for 3rd ft $NO_3$-N contents for corn following corn for 3 years in the SPAL data sets. The close agreement of predicted values from year to year suggests that the annual variation in profile $NO_3$-N distribution was small. Good agreement among years was also found for 2nd ft $NO_3$-N predicted from 1st ft $NO_3$-N values and following crops other than corn. The feasibility of using regression models to predict subsoil $NO_3$-N content from surface soil measurements is further illustrated by the data in Table 3 which shows values for 2nd ft $NO_3$-N predicted from 1st ft $NO_3$-N using models developed from the independent SPAL and Wisconsin farms databases. Predicted values for each of the two years (1990-1991) are in close agreement between the two databases.

Table 2. Predicted value for 3rd ft $NO_3$-N calculated from measured 2nd ft $NO_3$-N values following corn.

| 2nd ft $NO_3$-N | Predicted value for 3rd ft $NO_3$-N 1989 | 1990 | 1991 | Combined |
|---|---|---|---|---|
| | ---------- lb/acre ---------- | | | |
| 20 | 20 | 24 | 23 | 24 |
| 40 | 34 | 38 | 41 | 39 |
| 60 | 48 | 52 | 59 | 53 |
| 80 | 62 | 66 | 76 | 67 |
| $r^2$ | 0.74 | 0.66 | 0.67 | 0.70 |
| n | 145 | 552 | 552 | 1248 |

Table 3. Predicted 2nd ft $NO_3$-N values from 1st ft measurements using independent databases.

| 1st ft $NO_3$-N | Predicted value for 2nd ft $NO_3$-N 1990A 1/ | 1990B | 1991A | 1991B |
|---|---|---|---|---|
| | | lb/acre | | |
| 20 | 37 | 33 | 24 | 25 |
| 40 | 45 | 41 | 32 | 31 |
| 60 | 69 | 66 | 54 | 50 |
| 80 | 85 | 82 | 68 | 63 |
| $r^2$ | 0.44 | 0.53 | 0.62 | 0.73 |
| n | 599 | 77 | 575 | 52 |

1/ A = SPAL database; B = Wisconsin farms database.

To further evaluate the fit of each model, the 2nd and 3rd ft predicted values were compared with the measured values. Table 4 shows the fit of the predictive models and Table 5 shows the regression equations used to calculate this fit. The average deviation of 3rd ft. predicted $NO_3$-N values from measured values is 13 lb $NO_3$-N/acre for all years following corn. Sixty percent of the values are within a 10 lb/acre margin of error, 82% are within a 20 lb/acre margin and 96% are within 40 lb/acre. The application of an additional 20 or 40 lb N/acre to the recommended rate when 3rd ft $NO_3$-N is predicted in the preplant test should minimize occurrence of corn N deficiencies where models are used to estimate 3rd ft $NO_3$-N. The economic and environmental costs of such applications must be weighed against the advantages of more widespread use of the preplant test. The agreement between actual and predicted values (lb $NO_3$-N/acre) when the previous crop was alfalfa or soybeans was better than for corn even though the $r^2$ values were not as high. This may be due to lower mean soil $NO_3$-N levels following legume crops in most years (see Table 6).

Legumes such as soybeans or alfalfa are effective scavengers of residual profile $NO_3$-N. This scavenging ability and the fact that little or no N is applied for these crops should result in very low $NO_3$-N contents in the profile following these legumes. Table 6 shows the effects of previous crop on soil $NO_3$-N content for the SPAL data set. The average 3 ft profile $NO_3$-N content for the legumes was significantly different from that the average for corn only in 1989. This suggests that soil $NO_3$-N tests could be used to measure profile $NO_3$-N following legume crops, but these tests do not reflect the N release from decomposition of legume residues. Preplant $NO_3$-N tests probably reflect most of the N released from soybean residues, but adequate accounting for the N contributions from a previous alfalfa crop requires use of an additional N credit. Therefore, preplant tests are not adequate for determining crop N requirements following alfalfa.

Table 4. Deviation of predicted values from measured values for various models. 1/

| Predicted depth increment 2/ | Previous Crop | $r^2$ | n | Ave Dev. | -- % sites within -- +/-10 | +/-20 | +/-40 |
|---|---|---|---|---|---|---|---|
| | | | | lb/acre | -------lb/acre------ | | |
| 2nd ft | All | 0.55 | 2277 | 17 | 46 | 72 | 91 |
| 3rd ft | All | 0.70 | 1922 | 12 | 59 | 82 | 96 |
| 2nd ft | Corn | 0.56 | 1433 | 18 | 42 | 69 | 92 |
| 3rd ft | Corn | 0.70 | 1227 | 13 | 60 | 82 | 96 |
| 2nd ft | S.bean | 0.57 | 134 | 12 | 61 | 81 | 96 |
| 3rd ft | S.bean | 0.52 | 129 | 10 | 66 | 86 | 99 |
| 2nd ft | Alfalfa | 0.34 | 127 | 11 | 63 | 85 | 100 |
| 3rd ft | Alfalfa | 0.53 | 111 | 7 | 78 | 94 | 100 |

1/ Models developed by combining all data from 1989 to 1991 for both SPAL and Wisconsin farms databases.

2/ 2nd ft $NO_3$-N was predicted from 1st ft $NO_3$-N content using model 1 from Table 1. 3rd ft $NO_3$-N was predicted from 2nd ft $NO_3$-N content using model 5 from Table 1.

Table 5. Relationships between 2nd ft and 3rd ft soil $NO_3$-N for various previous crops, 1989-1991.

| Previous Crop | Regression Equation 1/ | n | $r^2$ |
|---|---|---|---|
| Corn | Y = 10.1 + 0.715 | 1248 | 0.70** |
| Soybeans | Y = 13.1 + 0.595x | 130 | 0.52** |
| All Crops | Y = 9.1 + 0.709x | 1942 | 0.71** |

** Significant at the 0.01 level.

1/ Y = 3rd ft $NO_3$-N content (lb/acre);
x = 2nd ft $NO_3$-N content (lb/acre).

Table 6. Effect of previous crop on mean 3 ft profile $NO_3$ content. 1/

| Previous Crop | Year 1989 | 1990 | 1991 |
|---|---|---|---|
| Corn | 208 a 2/ | 197 a | 123 a |
| Soybeans | 208 a | 136 b | 114 a |
| Alfalfa | 120 a | 106 b | 101 a |
| LSD | 170.6 | 56.6 | 33.7 |
| n | 210 | 783 | 688 |

1/ SPAL database only.

2/ Treatments with same letter are not significantly different.

## CONCLUSIONS

Use of models to predict 3rd ft profile $NO_3$-N content from $NO_3$-N measurements on soil samples taken to a 2-ft depth seems promising and should promote expansion of $NO_3$-N test use. A model based on 1248 observations over three growing seasons ($r^2 = 0.70$) predicted 3rd ft $NO_3$-N within 20 lb/acre of measured values 82% of the time. Prediction of 2nd ft $NO_3$-N from 1st ft $NO_3$-N content has potential ($r^2 = 0.58$), but would increase the risk of inaccurate N recommendations relative to use of the 2-ft sampling depth.

Agreement between the predictive models from each of the three years suggests that the yearly variation in profile $NO_3$-N distribution is quite small. Data from additional growing seasons is needed to confirm the reliability of the predictive models.

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