## Author(s)

| First Name | Middle Name | Surname | Role | Email |
|---|---|---|---|---|
| Prasanna | H | Gowda | ASAE Member | pgowda@cprl.ars.usda.gov |

## Affiliation

| Organization | Address | Country |
|---|---|---|
| CPRL-USDA-ARS | P.O. Drawer 10,<br>Bushland, TX 79012 | USA |

## Author(s)

| First Name | Middle Name | Surname | Role | Email |
|---|---|---|---|---|
| David | J | Mulla | ASAE Member | mulla003@umn.edu |

## Affiliation

| Organization | Address | Country |
|---|---|---|
| Department of Soil, Water, and Climate<br>University of Minnesota | 1991 Upper Buford Circle<br>St. Paul, MN 55108 | USA |

## Publication Information

| Pub ID | Pub Date |
|---|---|
| 051042 | 2005 ASAE Annual Meeting Paper |

The Society for engineering
in agricultural, food, and
biological systems

*An ASAE Meeting Presentation*
*Paper Number: 051042*

# Environmental Benefits of Precision Farming – A Modeling Case Study

**Prasanna H. Gowda, Agricultural Engineer**

CPRL-USDA-ARS, P.O. Drawer 10, Bushland, TX 79012, pgowda@cprl.ars.usda.gov

**David J. Mulla, Professor & W.E. Larson Chair**

Department of Soil, Water, and Climate, Univ. of Minnesota, mulla003@umn.edu

**Written for presentation at the**
**2005 ASAE Annual International Meeting**
**Sponsored by ASAE**
**Tampa Convention Center**
**Tampa, Florida**
**17 - 20 July 2005**

***Abstract*.** In this study, we evaluated the environmental impacts of spatially variable versus uniform phosphorus fertilizer application rates on a 32-ha commercial corn field in Blue Earth County of southern Minnesota. In 1998, the phosphorus rates (0-39 kg/ha) were variably applied in accordance with measured surface soil pH and soil Bray P levels across 50 x 50 grid spacing. Surface runoff and tile drain leaching losses of sediment and phosphorus were measured using automated sampling systems. The Agricultural Drainage and Pesticide Transport (ADAPT) model was calibrated to measured water fluxes, and losses of sediment and phosphorus to surface waters. There was good agreement between measured and modeled water fluxes, sediment, and phosphorus losses. Using the calibrated model, a sensitivity analysis was conducted for both uniform and variable rate phosphorus application strategies using a 50-yr climatic record. Phosphorus losses for the variable strategy were significantly lower than losses for a uniform strategy.

**Keywords:** site-specific management, water quality modeling

---

## Introduction

The Minnesota River Basin contributes large amounts of sediment and phosphorus from agricultural lands, often exceeding US EPA's water quality standards, adversely affecting water quality at both local and regional levels. For example, sediment loading from the Minnesota River Basin is filling in Lake Pepin, a part of the Upper Mississippi River System (UMRS), at a rate which will lead to the disappearance of Lake Pepin in about 300 years (Engstrom and Almendinger, 1998). High sediment losses are attributed to erosion on intensive row cropped lands and stream bank erosion in the Minnesota River Basin. Roughly 26% of the total suspended sediment load and 33% of all the phosphorus entering the UMRS from the Minnesota River are contributed by the Lower Minnesota River watershed located near the mouth of the Minnesota River (Mulla and Mallawatantri, 1997). High P losses are primarily due to excessive soil P levels as a result of long term P fertilizer and manure applications and high soil erosion rates (Randall et al., 1997), although about one fourth of the phosphorus loads are from wastewater treatment plant discharges. Not surprisingly, in 2004, Minnesota Legislature passed a law to ban phosphorus in lawn fertilizer.

Precision agriculture is an approach that allows the rate of phosphorus fertilizer to a field to be varied in response to spatial pattern of soil P levels and soil pH. It is hypothesized that this approach maintains crop productivity (Larson et al., 1997) while reducing the environmental impacts of fertilizers and increases farm profitability (Clay et al., 1999). This hypothesis has not been fully tested.

## Objective

The objective of this research was to evaluate predicted long-term edge-of-field phosphorus losses on a commercial corn field to variable rate fertilizer application. The ADAPT (Agricultural Drainage and Pesticide Transport) model was used to predict phosphorus. These losses were compared with simulated losses of phosphorus from the same field receiving uniform fertilizer application rates.

## Methods and Materials

A commercial corn field (800 x 400 m) in Blue Earth County of southern Minnesota was selected for this study (Fig. 1). Phosphorus fertilizer application rate was varied from 0 to 39 kg/ha. Application rates were determined based on information about the spatial variability in soil P (Bray P) levels and surface pH. Typical phosphorus fertilizer application rates in the region are about 40 kg/ha for corn in corn-soybean rotation.

Topography at the site was surveyed using a geodimeter (Geotronics 126). The site has rolling topography (maximum 6% slope), with two depressional areas where water collects. Each of these depressional areas had tile drains to remove water from the subsurface and/or surface. These tile drains were equipped with automatic water quality samplers (ISCO 3700) and area velocity sensors to measure water flow and losses of sediment, and phosphorus.

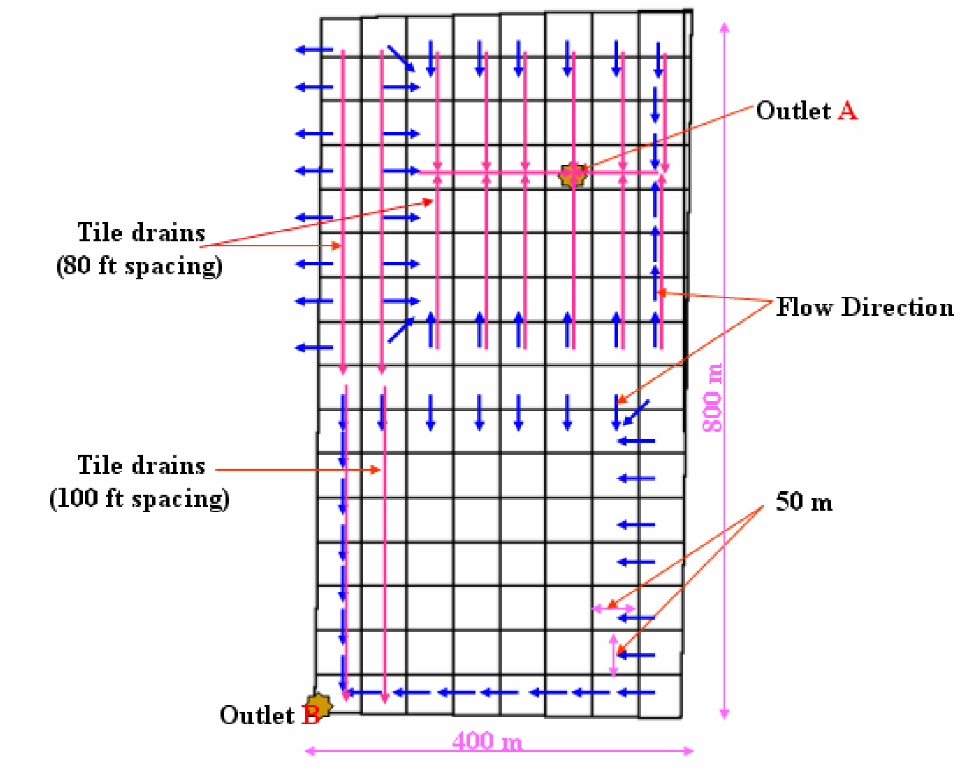

Figure 1. Location of subsurface tile lines and drainage characteristics.

The soil map used in this study to derive soil information was developed by digitizing the Blue Earth County Soil Survey map. Soils are typical of the region, and are primarily fine textured, poorly drained series with high organic matter content (up to 10%). Soil series included Lester, Shorewood, Cordova, Waldorf, Lura, and Blue Earth and their characteristics are reported in Tables 1 and 2.

Table 1. Input variables and their values representing the agricultural system and its initial conditions.

| **Input variable** | **Value** |
|---|---|
| Runoff Curve Number | 78 |
| Evaporation Constant (mm $d^{-0.5}$) | 4.0 |
| Effective Rooting Depth (cm) | 90 |
| Surface Sealing Threshold (cm) | 4.5 |
| Surface Storage Depth (cm) | 0.3 |
| Depth of Impermeable Layer (m) | 4.57 |
| Initial Depth of Water Table (m) | 1.25 |
| Hydraulic Conductivity of Soil Layer (cm $h^{-1}$) | 2.54 |
| Hydraulic Conductivity of Impeding Layer (cm $h^{-1}$) | 0.001 |

Table 2. Layer-specific soil input.

| Soil Series | Soil Texture | Horizon | Thickness (cm) | Porosity | Wilting Point | Organic Matter | Clay | Silt |
|---|---|---|---|---|---|---|---|---|
| | | | | ----(cm/cm)---- | | -----------(%)---------- | | |
| Blue Earth | Mucky Silt Loam | 1 | 25 | 0.61 | 0.37 | 9.34 | 25 | 66 |
| | | 2 | 127 | 0.70 | 0.42 | 9.34 | 28 | 65 |
| | | 3 | 305 | 0.47 | 0.27 | 0.17 | 25 | 43 |
| Lester | Loam | 1 | 23 | 0.45 | 0.13 | 3.90 | 21 | 37 |
| | | 2 | 69 | 0.40 | 0.17 | 1.04 | 30 | 37 |
| | | 3 | 366 | 0.38 | 0.14 | 0.39 | 25 | 37 |
| Cordova | Clay Loam | 1 | 36 | 0.51 | 0.19 | 5.50 | 29 | 37 |
| | | 2 | 53 | 0.45 | 0.22 | 2.05 | 32 | 49 |
| | | 3 | 368 | 0.40 | 0.16 | 0.68 | 24 | 37 |
| Lura | Silt Clay | 1 | 91 | 0.62 | 0.37 | 7.67 | 53 | 45 |
| | | 2 | 91 | 0.62 | 0.37 | 0.35 | 44 | 49 |
| | | 3 | 274 | 0.52 | 0.31 | 0.35 | 44 | 49 |
| Waldorf | Silt Clay Loam | 1 | 51 | 0.61 | 0.37 | 6.84 | 38 | 55 |
| | | 2 | 64 | 0.53 | 0.32 | 0.68 | 48 | 47 |
| | | 3 | 343 | 0.50 | 0.30 | 0.25 | 35 | 49 |
| Shorewood | Silt Clay Loam | 1 | 28 | 0.54 | 0.24 | 5.28 | 35 | 48 |
| | | 2 | 71 | 0.50 | 0.32 | 1.21 | 46 | 49 |
| | | 3 | 358 | 0.42 | 0.27 | 0.43 | 40 | 31 |
| Shorewood | Silt Clay Loam (Silty Substratum) | 1 | 28 | 0.54 | 0.24 | 6.56 | 35 | 48 |
| | | 2 | 71 | 0.50 | 0.32 | 2.17 | 46 | 49 |
| | | 3 | 358 | 0.52 | 0.27 | 0.77 | 40 | 31 |

Soil P levels, and surface pH values were determined after sampling surface soils (0-15 cm) in the field at 234 locations along 9 transects separated by 45 m spacing at intervals of 30 m within each transect. The remaining soil input such as soil-water release curve, vertical hydraulic conductivity and soil porosity were derived from the Map Unit Use File (MUUF; Baumer et al., 1994), a NRCS soil data base.

***ADAPT Model:*** The ADAPT model is a daily time step field-scale water table management simulation model that was developed by integrating GLEAMS (Groundwater Loading Effects of Agricultural Management Systems; Leonard et al., 1987), a root zone water quality model, with subsurface drainage algorithms from DRAINMOD (Skaggs, 1982), a subsurface drainage model. More detailed information about ADAPT can be found in Chung et al. (1992), Ward et al. (1993), and Desmond et al. (1996). Additional enhancements to the model include potential evapotranspiration estimation with the Doorenbos and Pruitt method (1977) as an alternative to the Ritchie method (1972). Runoff was estimated using the SCS curve number method (SCS, 1972, 1985) with daily curve number updates dependent on antecedent moisture conditions. Soil erosion was estimated using the Universal Soil Loss Equation (Foster et al., 1980). Edge of field sediment losses were estimated by multiplying predicted erosion rates by a sediment delivery ratio (the ratio of sediment transported beyond the edge of field to the predicted rate of erosion). The phosphorus cycle used in the ADAPT model includes routines for mineralization, immobilization, fertilization, animal waste application, and crop uptake. Phosphorus losses are simulated at daily time-step based on rates of sediment loss and soil concentrations of phosphorus, as well as rates of runoff and concentrations of soluble phosphorus (Knisel et al., 1993).

The ADAPT model was used here because of its ability to simulate water quality effects of all typical agricultural management practices (tillage, crop rotation, fertilizer management), including subsurface drainage contributions to agricultural runoff. The ability to accurately simulate tile drainage effects is especially important in the Midwest where nearly 30% of all crop land has been improved using subsurface tile drainage systems (Zucker and Brown, 1998), which can have a significant impact on the quantity and quality of runoff and drainage from agricultural watersheds. Recently, the ADAPT model was calibrated and validated for conditions in southern Minnesota using long-term monitoring data collected from an experimental plot with continuous corn (Davis et al., 2000). Also, a frost depth algorithm developed by Benoit and Mostaghimi (1985) was incorporated to enhance the model's capability to predict flow during spring and fall months (Dalzell, 2000).

For modeling purposes, the study area was subdivided into one hundred twenty eight 50 m x 50 m cells (Fig. 1), and an initial set of soil and slope input factors were assigned to each cell. The surface routing patterns for runoff and erosion from each cell were determined based on topographic slope and aspect. The subsurface routing patterns for tile drainage were determined using farmer supplied maps of tile drainage patterns.

***Model Calibration:*** The model was run to simulate one year for each cell, the surface and subsurface flows were routed to each of the two sample collection locations, and the predicted and measured water flows were compared. Adjustments of soil porosity, soil moisture retention, soil hydraulic conductivity, crop leaf area index, and initial depth to water table were made to improve the match between predicted and observed flows. Next, predicted and measured sediment and phosphorus losses were compared at the two measuring locations. Adjustments were made to the sediment delivery ratio from cells to improve this comparison.

The final model parameters from this process were then used with a 50 year climatic record from nearby Waseca, Minnesota to evaluate several herbicide management scenarios over a range of climatic conditions. The scenarios evaluated were 1) uniform P fertilizer application at rates of 20, 30 and 40 kg ha$^{-1}$and 2) a variable rate application of P fertilizer corresponding to the variable rates actually applied to the field during 1998.

## Results

Soil P levels averaged 14.8 ppm with a range from 5.7 to 27 ppm. Highest soil P levels were found in depressional areas of the field. Lowest soil P levels were found along eroded hill slopes of the field. Surface pH followed the same trend as soil P levels. Statistical comparison of observed and predicted daily flow, sediment and phosphorus losses indicated that the ADAPT model performance was satisfactory (Table 3). Performance of the ADAPT model was better for flow, sediment and P losses in the southern part of the field where the landscape is relatively steep.

Table 3. ADAPT model performance criteria for calibration year (1998).

| Property | Observed Mean | Predicted Mean | $R^2$ | Slope | Intercept | RMSE |
|---|---|---|---|---|---|---|
| ---------------- Northern Monitoring Location ---------------- | | | | | | |
| Flow ($m^3$) | 154.8 | 157.2 | 0.63 | 0.65 | 52.49 | 121.2 |
| Sediment (kg) | 0.9 | 0.7 | 0.27 | 0.38 | 0.59 | 3.6 |
| Phosphorus (kg) | 0.01 | 0.01 | 0.37 | 0.50 | 0.001 | 0.01 |
| ---------------- Southern Monitoring Location ---------------- | | | | | | |
| Flow ($m^3$) | 72.9 | 71.2 | 0.73 | 0.58 | 31.77 | 140.0 |
| Sediment (kg) | 1.7 | 1.5 | 0.81 | 0.91 | 0.29 | 4.2 |
| Phosphorus (kg) | 0.02 | 0.02 | 0.57 | 0.67 | 0.001 | 0.04 |

Table 4. Predicted long-term mean annual P losses (kg/ha) and percent reduction using a 50-year ADAPT simulation.

| P Fertilizer Application Strategy | P Loss (kg/ha) | % Reduction[1] |
|---|---|---|
| ---------------- Northern Monitoring Location ---------------- | | |
| Uniform – 20 kg/ha | 0.49 | 10.9 |
| Uniform – 30 kg/ha | 0.52 | 5.4 |
| Uniform – 40 kg/ha | 0.55 | - |
| Variable Rate | 0.53 | 3.6 |
| ---------------- Southern Monitoring Location ---------------- | | |
| Uniform – 20 kg/ha | 0.63 | 13.7 |
| Uniform – 30 kg/ha | 0.68 | 6.8 |
| Uniform – 40 kg/ha | 0.73 | - |
| Variable Rate | 0.65 | 11.0 |

[1] – Percent reduction in P losses is based on P losses associated with typical uniform P fertilizer application rate of 40 kg/ha.

Table 4 presents the long-term mean annual phosphorus losses for both northern and southern parts of the field. The average rate of P fertilizer applied was 27.2 kg/ha with the variable application strategy versus a typical uniform application rate of 40 kg/ha in southern Minnesota, about 32 percent less than with the uniform strategy. The phosphorus losses for the uniform strategy averaged 0.49, 0.52 and 0.55 kg/ha in the northern portion and 0.63, 0.68 and 0.73 kg/ha in the southern portion of the field for application rates of 20, 30 and 40 kg/ha, respectively. The phosphorus losses for the variable application strategy averaged 0.53 kg/ha for the northern portion and 0.65 kg/ha for the southern portion of the field.

In the flat northern portion of the field, reductions in phosphorus losses associated with the variable application strategy are about 3.6% smaller than the losses with a typical uniform application strategy. In the steep southern portion of the field, the phosphorus losses with the variable application strategy are roughly 11% smaller than the losses with the typical uniform strategy.

## Conclusions

This is one of the few studies to provide comparisons between field-scale losses with a variable rate versus a uniform P fertilizer application rate using a long-term climatic record. Modeled phosphorus losses were roughly 1.4-3.2 percent of the amount applied. In the flat portion of the field, the phosphorus losses were 3.6 percent smaller with the variable application rate than with the uniform application strategy. In the steep portion of the field, losses were 11% smaller with the variable rate than the uniform rate strategy. These results indicate that the variable rate application strategy could produce measurable reductions in off-site phosphorus losses on similar fields in comparison to a uniform application rate strategy.

## References

Baumer, O., P. Kenyon, and J. Bettis. 1994. MUUF V2.13 User's Manual. Natural Resources Conservation Service, Computer file which accompanies the MUUF software.

Benoit, G. R., and S. Mostaghimi. 1985. Modeling frost depth under three tillage systems. Transactions of ASAE, 28(5):1499-1505.

Chung, S. O., A. D. Ward, and C. W. Schalk. 1992. Evaluation of the hydrologic component of the ADAPT water table management model. Transactions of ASAE, 35(2):571-579.

Clay, S. A., G. L. Lems, D. E. Clay, M. M. Ellsbury, and F. Forcella. 1999. In Proceedings of 4th International Conference on Precision Agriculture, Robert, P.C., W. E. Larson, and R. Rush (Eds.), Soil Science Society of America, WI 1996, pp 465-474.

Dalzell, B. J. 2000. Modeling and evaluation of nonpoint pollution in the Lower Minnesota River Basin. M.S. Thesis, Water Resources Program, University of Minnesota, St. Paul, MN. 281 p.

Davis, D. M., P. H. Gowda, D. J. Mulla, and G. W. Randall. 2000. Modeling nitrate nitrogen leaching in response to nitrogen fertilizer rate and tile drain depth or spacing for southern Minnesota, USA. Journal of Environmental Quality, 29:1568-1581.

Desmond, E. D., A. D. Ward, N. R. Fausey, and S. R. Workman. 1996. Comparison of daily water table depth prediction by four simulation models. Transactions of ASAE, 39(1):111-118.

Doorenbos, J. and W. O. Pruitt. 1977. Guidelines for predicting crop water requirements, 144. Irrigation and Drainage Paper 24. New York: FAO United Nations.

Engstrom, D. R. and J. E. Almendinger. 1998. Historical changes in sediment and phosphorus loading to the Upper Mississippi River: Mass-balance reconstruction from the sediments of Lake Pepin. Final research report prepared for the Metropolitan Council Environmental Services, St. Croix Watershed Research Station, Science Museum of Minnesota, Marine on St. Croix, MN.

Foster, G. R., L. J. Lane, J. D. Nowlin, J. M. Laflen, and R. A. Young. 1980. A model to estimate sediment yield from field-size areas: Development of model. In Knisel, W. G. (Ed.), CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems. U. S. Department of Agriculture, Science and Education Administration, Conservation Research Report No. 26. pp. 36-64.

Knisel, W. G., R. A. Leonard, and F. M. Davis. 1993. The GLEAMS model plant nutrient component, Part I: Model documentation. Department of Agricultural Engineering, Tifton, GA.

Larson, W. E., J. A. Lamb, B. R. Khakural, R. B. Ferguson, and G.W. Rehm. 1997. In The State of Site-Specific Management Agriculture; Pierce, F. J. and E. J. Sadler (Eds.), Soil Science Society of America, Madison, WI, pp337-367.

Leonard, R. A., W. G. Knisel, and D. A. Still. 1987. GLEAMS: Groundwater loading effects of agricultural management systems. Transactions of ASAE, 30(5):1403-1418.

Mulla, D. J. and A. P. Mallawatantri. 1997. Minnesota River Basin water quality overview. Minnesota Extension Service, F-7079-E, University of Minnesota, St. Paul, MN.

Randall, G., D. Mulla, G. Rehm, L. Busman, J. Lamb, and M. Schmitt. 1997. Phosphorus: Transport and availability in surface waters. Minnesota Extension Service, FO-6796-B, University of Minnesota, St. Paul, MN.

Randall, G. W., R. K. Iragavarapu, and S. D. Evans. 1997. Long-term P and K applications: I. Effect on soil test incline and decline rates and critical soil test levels. J. Prod. Agric. 10:565-571.

Ritchie, J. T., 1972. A model for predicting evaporation for a row crop with incomplete cover. Water Resources Research, 8(5):1204-1213.

Soil Conservation Service. 1972, 1985. Hydrology, Sect. 4, Soil Conservation Service National Engineering Handbook. U.S. Department of Agriculture, Washington, DC.

Skaggs, R. W. 1982. Field evaluation of a water management simulation model. Transactions of ASAE, 25(3):666-674.

Ward. A.D., E.Desmond, N.R. Fausey, T.J. Logan, and W.G. Logan. 1993. Development studies with the ADAPT water table management model. 15th international congress on irrigation and drainage, The Hague, The Netherlands.

Zucker, L.A., and L.C. Brown (eds.). 1998. Agricultural drainage - Water quality impacts and subsurface drainage studies in the Midwest. Bulletin 871, The Ohio State University, 40 p.