FIELD-SCALE EVALUATION OF A SYSTEM FOR MANURE EXPORT THROUGH TURFGRASS SOD

A Thesis

by

IN HO CHOI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2005

Major Subject: Biological and Agricultural Engineering

FIELD-SCALE EVALUATION OF A SYSTEM FOR MANURE EXPORT THROUGH TURFGRASS SOD

A Thesis

by

IN HO CHOI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Clyde L. Munster
Committee Members,	Donald M. Vietor
	Binayak P. Mohanty
Head of Department,	Gerald L. Riskowski

August 2005

Major Subject: Biological and Agricultural Engineering

ABSTRACT

Field-Scale Evaluation of a System for Manure Export through Turfgrass Sod.

(August 2005)

In Ho Choi, B.En., Yeungnam University

Chair of Advisory Committee: Dr. Clyde L. Munster

A total maximum daily load (TMDL) assessment in the Upper North Bosque River (UNBR) has mandated reductions of soluble reactive phosphorus (SRP). The large concentrations of dairies in the UNBR watershed have been identified as a source of the SRP. Agricultural best management practices (BMPs) can be used to reduce in-stream loads of manure nutrients from confined dairy feeding operations (CAFOs). A new BMP utilizes turfgrass sod to export composted dairy manure nutrients out of the impaired watershed in a sustainable manner. Previous plot-scale experiments have showed that 46 to 77% of applied phosphorus (P) and 36 to 47% of applied nitrogen (N) were removed in a single sod harvest. Two, 1.4 ha turfgrass fields were instrumented to measure runoff flow and sediment and nutrient transport. One turfgrass field was topdressed with composted dairy manure and fertilizer N and the other with fertilizer N only. A total of 3.5% of the applied manure P and 3.1% of applied manure N were lost in the surface runoff over a 1.5 year period. The runoff data from the experimental fields were used to calibrate and validate Soil and Water Assessment Tool (SWAT) model simulations of flow, sediment, organic, and mineral nutrients. The Nash-Sutcliffe model fit statistic was greater than 0.6 for flow, sediment, and nutrients during the calibration period and greater than 0.3 during the validation period. Research results indicated that turfgrass sod can be used to export composted dairy manure out of impaired watersheds to improve water and soil quality.

ACKNOWLEDGEMENTS

I would like to acknowledge the guidance and support of Clyde Munster, Donald Vietor, and Binayak Mohanty as the members of my graduate committee for the completion of this project and thesis.

I am grateful to Richard White, Tony Provin, Brandon McDonald, and Nels Hansen for their help on my research. Special thanks to my colleagues, Chad Richards and George Stewart, who provided their assistance for field monitoring and modeling.

I would like to give a very special thanks to my family and friends for their encouragement and support that made my studies possible. I am also appreciative of the friendship and assistance of our research group: Jason Afinowicz, Jeremy Hanzlik, Philip Taucer, Shane Porter, and Yuli Suhurnato.

This research was supported by the Texas Advanced Technology Program (Project 000517-0073-2001), the USDA-CSREES (Project 2001-51130-11459), the Department of Interior USGS (Project 01HQGR0209) and the Texas Water Resources Institute.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

TABLE Page

CHAPTER I

INTRODUCTION

Recently, CAFOs have been identified as a source of nutrient pollutants in rural watersheds (Saleh et al., 2000). The upper North Bosque River (UNBR) watershed of north central Texas covers app[1]roximately 93,250 ha and has at least 94 dairies with approximately 35,000 dairy cows (Saleh et al., 2000). Continued manure applications to the land near dairy farms have resulted in soils with high level of nutrients. These excess nutrients have the potential to be transported to the UNBR through storm water runoff or to be leached into the groundwater. McFarland and Hauck (1999) showed that nitrogen (N) and phosphorus (P) concentrations in streams and reservoirs were directly related to the density of dairies on the portion of watersheds draining into sampled stream segments. Their observations indicate land application of dairy manure is a potential nonpoint source (NPS) of N and P in adjacent streams.

Due to elevated soluble reactive P in segments of the UNBR, the surrounding watershed was classified as impaired in 1998 (Section 303(d) of the Clean Water Act). The Texas Commission on Environmental Quality (TCEQ), formerly the Texas Natural Resource Conservation Commission (TNRCC), performed a total maximum daily load (TMDL) assessment of the UNBR and called for a 50% reduction in the average annual concentration and total annual loading of soluble reactive phosphorus (SRP). A TMDL

This thesis follows the style and format of the *Transactions of the American Society of Agricultural Engineers*.

specifies the maximum contaminate levels that a water body can receive without adversely affecting intended stream uses (TNRCC, 2001).

The U.S. Environmental Protection Agency (EPA) currently subsidizes the transportation of manure from dairies in the UNBR watershed to composting facilities. Manure composting and subsequent export to other watersheds decreases manure application to land near dairies and the potential for NPS losses of P in the watershed (TCEQ, 2003). The Texas Department of Transportation (TxDOT), the largest governmental consumer of the compost, has also been subsidized by the State to transport composted dairy manure out of the UNBR watershed for highway construction projects. These subsidy programs have provided economic incentives for the development of a composting infrastructure in the UNBR watershed region. These composting facilities provide a source of organic matter and nutrients for turfgrass sod production in the UNBR watershed (Vietor et al., 2002).

Previous plot-scale experiments that utilized manure to grow turfgrass sod showed that 46 to 77% of applied P and 36 to 47% of applied N were removed in a single sod harvest (Vietor et al., 2002). The P and N removal in clippings and in the plant components of the sod were limited according to the rates of manure application. Similarly, the mass of P and N removed in the sod increased with increasing manure application rates. The use of composed manure has many benefits over fresh manure, including decreased odors, reduced volatilization losses of NH_3-N and diminished counts of pathogenic microorganisms (Vietor et al., 2002). In addition, field-scale sod production research in which P rates of 75 kg/ha were applied as composted manure resulted in loss of only 3.8% of applied P in stormwater runoff during establishment of turfgrass sod (Choi et al., 2003). Moreover, preliminary results indicate that the use of composted manure in sod production may result in less runoff than from the sod field without compost (Choi et al., 2003). Both the plot- and field-scale experiments support the use of composted manure as a feasible environmental choice for turfgrass sod production.

Another benefit of turfgrass sod is that it is a high value commodity, which is transplanted to sports fields, golf courses, and home lawns (Munster et al., 2004). Turfgrass produced with composted manure on an impaired rural watershed could be sold and imported into developing suburban areas such as Dallas/Fort Worth (DFW) metroplex in a sustainable manner. Vietor et al. (2004) demonstrated that turfgrass sod transplanted from fields produced with manure established faster than sprigged plots top-dressed with composted manure. In addition, runoff losses of manure P from transplanted manure-grown sod were much less than those from sprigged plots topdressed with conventional fertilizer during turfgrass establishment. Moreover, the relatively short hauling distance from turfgrass sod fields near the composting facilities in the UNBR watershed to the DFW metroplex offers an economic advantage for producing and exporting sod out of this impaired watershed. The current EPA subsidy to move manure out of the UNBR watershed will run out soon (Vietor et al., 2002). Therefore, turfgrass sod can be used as a sustainable best management practice (BMP) for exporting manure nutrients out of the UNBR and other impaired watersheds.

The long-term goal of this research project is to improve water quality and achieve in-stream P reductions as mandated by the TMDL assessment of the UNBR watershed.

The P reductions would be achieved by using turfgrass sod topdressed with composted dairy manure to move manure P out of the watershed.

This research focused on the following objectives in order to obtain the goal mentioned above:

1. Estimate the potential for nutrient losses from turfgrass production fields topdressed with composted dairy manure under typical turfgrass sod management practices.
2. Calibrate and validate the Soil and Water Assessment Tool (SWAT) to simulate runoff flow and sediment and nutrient transport from the paired sod production fields under natural meteorological conditions and typical turf maintenance practices.
3. Evaluate the existing Soil Water Assessment Tool (SWAT) model algorithms that simulate nutrient transport from composted manure applied to turfgrass production fields.

Research results are addressed in the following chapter.

CHAPTER II

MATERIALS AND METHODS

Experimental Design

Two 1.4-ha turfgrass production research fields were established on a Ships clay soil with a 1% slope at the Texas A&M University research farm near College Station, Texas (Figure 1). Clay berms 0.3 m high were installed to separate the site into North and South fields and to contain surface runoff. A groundwater monitoring well located near the center of the two fields was used to monitor groundwater quality (Figure 1). The monitoring well consisted of a 51-mm diameter polyvinyl chloride (PVC) well casing with a 150 mm long screen located at a depth of 11.3 m. The groundwater beneath the field was typically at a depth of 10 m.

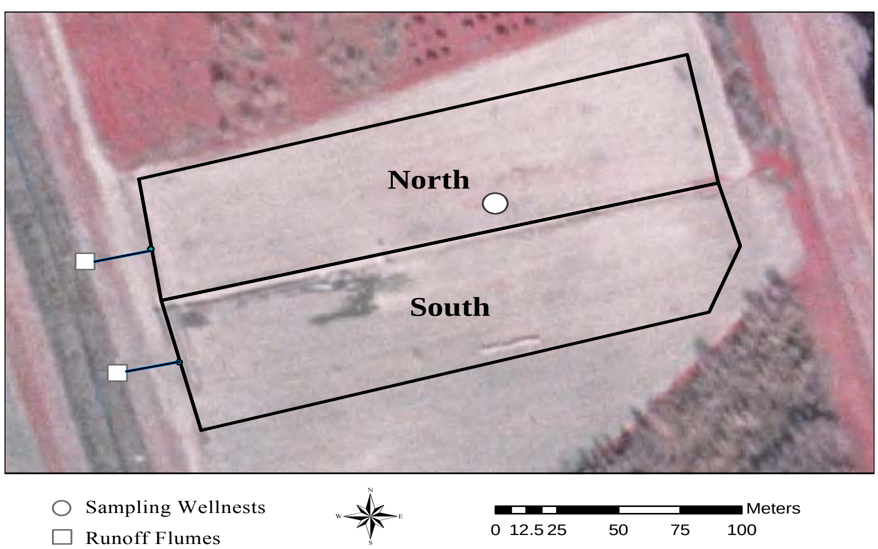


Figure 1. The two, 1.4 ha, turfgrass production research fields located at the Texas A&M University research farm in College Station, Texas, with a shallow groundwater well and surface runoff flumes also shown.

After the turfgrass was planted in June 2002, each field was managed the same except for the composted dairy manure application on the North field. Ammonium sulfate (21-0-0), the primary N source, was applied to both fields at equal rates during the growing season. The P rates of the applied manure were split between two applications in September 2002 and November 2002 for the first sod crop and the third application in June 2003 for the second sod crop. In 2002, composted dairy manure applied to the North field provided a P rate of 75.0 kg ha^{-1} with and an N rate of 130.4 kg ha^{-1}. In 2003, composted dairy manure supplied 127.0 kg P ha^{-1} and 353.2 kg N ha^{-1} to the North field (Table 1). Total N applied to both North and South fields as inorganic fertilizer was 388.0 kg N ha^{-1} prior to the first sod harvest (May 2003) and 395 kg N ha^{-1} during production of the second sod crop.

Tifway bermudagrass (*Cynodon dactylon* (L.) Pers. X C. *transvaalensis* Burtt-Davey), an adapted, high-value species, was plugged after tillage and firming of the soil surface of each field. A hose reel with a rotating Nelson Big-Gun sprinkler was used for irrigation. Irrigation water was supplied by an irrigation well centered between the fields. Equal mowing, irrigation, and pest control treatments were applied as necessary to maintain the bermudagrass in the two fields.

Table 1. The dates and application rates of composted dairy manure applied to the North field and nitrogen applied to both the North and South fields.

Manure Application[1]		
Date	P (Kg/ha)	N (kg/ha)
09-27-2002	25.8	31.8
11-13-2002	18.6	37.2
11-15-2002	19.3	39.1
11-25-2002	11.3	22.3
06-20-2003	63.5	176.6
06-23-2003	63.5	176.6

Inorganic Nitrogen Applications[2]			
Date	N (kg/ha)	Date	N (kg/ha)
07-08-2002	67.3	06-18-2003	84.1
07-23-2002	67.3	07-15-2003	67.3
08-13-2002	102	08-25-2003	108.7
09-18-2002	67.3	09-26-2003	67.3
04-02-2003	84.1	04-01-2004	67.3

[1] North field only
[2] North and South fields

Sampling and Analysis

The fields were instrumented to monitor surface runoff and groundwater quality. Runoff was collected in PVC gutters and routed through 0.3-m H flumes at the west end of each field for measurements and sampling. The surface runoff from each field was sampled and quantified for each rainfall event. A bubbler flow meter was used to monitor flow rates and an automated water sampler was programmed to sample the runoff in each H-flume. An electronic tipping bucket rain gauge located on-site was used to record daily rainfall. The surface runoff flow rate was measured at 5-minute intervals and the automated samplers were programmed to collect composite runoff samples from the H-flume of each field. Four, 250 ml samples were combined in one sample bottle at

10-minute intervals. The runoff samples were filtered through a 1-µm glass fiber filter and the particulate and dissolved portions were analyzed by the Texas A&M University Soil and Forage Testing Laboratory. The glass filter disk with sediment was digested to determine concentrations of total particulate phosphorus (PP) and total Kjeldahl nitrogen (TKN) (Parkinson and Allen, 1975). Concentrations of total dissolved P (DP) in the filtrate and total P (TP) in digests were determined using inductively coupled plasma-optical emission spectroscopy (ICP-OES). Colorometric (Dorich and Nelson, 1983; Isaac and Jones, 1970) and cadmium reduction methods (Dorich and Nelson. 1984) were used to measure TKN in digests and ammonium-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N) of filtrate in an auto analyzer.

Soil was sampled from the turfgrass fields on a grid of six rows and two columns. Samples were collected to a 90-cm depth at each grid point or sampled to 5-cm depth and composited across grid points on a field. Composite samples were taken with a hand probe (2.5-cm diameter) and a hydraulic probe was used to obtain cores (3.8-cm diameter) to 90 cm. The 90-cm cores were divided into depths of 0 to 5, 5 to 15, 15 to 30, 30 to 60, and 60 to 90 cm. Soil from each field was sampled and analyzed before the initial application of the composed dairy manure, during production of each sod crop, and after the second sod harvest. Extractable P and NO_3-N of the soil samples were analyzed at the Texas A&M University Soil and Forage Testing Laboratory. An acidified ammonium-acetate - ethylenediaminetetraacetic acid (NH_4OAc-EDTA) extractant was used to determine plant-available P (Hons et al., 1990). Soil NO_3-N was extracted and analyzed through a modified version of Dorich and Nelson (1984).

SWAT Model

The SWAT hydrological model was developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) (Arnold et al., 1998). It is a physically based simulation model that operates on a daily time step. It was developed to estimate the impact of management practices on water, sediment and agricultural chemical yields in watersheds (Santhi et al., 2001). This model has been integrated into EPA's modeling program, Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). In this study, the SWAT2000 model was interfaced with ArcView 3.2 to compare simulated with measured runoff volumes and nutrient losses on the scale of the two turfgrass production fields. The SWAT model utilized Geographic Information Systems (GIS) databases at a resolution of 0.3 m for topography, land use, soil type and weather data in the model simulations. Weather data from a National Climatic Data Center (NCDC) weather station at College Station (411889) was used to input daily maximum and minimum air temperature data in the SWAT model. In addition, daily rainfall data from the on-site rain gauge was used for model simulations. Relative humidity, wind speed, solar radiation, and other meteorological data were simulated by the SWAT weather generator.

Evaluation of SWAT Model

Two statistical methods, coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) (Nash and Sutcliffe, 1970), were used for model evaluation. The R^2 value describes the degree of linear relationship between model simulations and observations, with ranging from 0.0 to 1.0. R^2 is oversensitive to extreme values (outliers) (Legates et al., 1997) and is insensitive to additive and proportional differences between observed and simulated values (Willmott, 1984). Due to these limitations, higher vale of R^2 can be evaluated even when the simulated data differ considerably from the observed values (Legates et al., 1999). Therefore, E_{NS} which ranges from minus infinity to 1.0 was used to supplement in R^2 interpretation. An E_{NS} equal to 1.0 represents a perfect fit of the 1:1 line between the observed and simulated values. The values less than or very close to zero for the R^2 and E_{NS} indicates that the model prediction is considered to be unacceptable or poor while values of one indicate the model prediction with a perfect fit. However, clear standards are not specified to assess the goodness of fit of a hydrologic model using the statistical measures such as R^2 and E_{NS} (Santhi et al., 2001). In general, if $R^2 > 0.6$ and $E_{NS} > 0.5$, model prediction is considered to be acceptable or satisfactory (Ramanarayanan et al., 1997).

Model Calibration and Validation

Surface runoff water quality data collected from the experimental fields were used to calibrate and validate the SWAT model. Observations from October 2002 through May 2003 were used for calibration of simulations on a daily basis. Model parameters and input variables were continuously modified during the calibration phase until the R^2 of the regression relationship between simulated and observed flow values were $R^2 > 0.6$ and the E_{NS} was > 0.5. The same criteria were applied to the calibrations for sediment and nutrient loads transported in surface runoff. Sediment and nutrient simulations were calibrated after the flow calibration. For flow calibration, all runoff curve numbers (CN2) were decreased by 8 %. Other flow related input parameters such as threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) and soil evaporation compensation factor (ESCO) were adjusted from SWAT initial values in order to match the simulated and observed flows (Table 2).

Surface and soil parameters and variables were similarly adjusted. The cover or management factor (C factor) of the Universal Soil Loss Equation (USLE) was adjusted to better represent turfgrass production for calibration of sediment transport. The C factor values were changed to 0.009 for the north field and 0.002 for the south field. Initial concentrations of organic N, organic P and mineral P in the soil layer (SOL_ORGN, SOL_ORGP and SOL_MINP) were available from the soil test in June 2002. However, these values were modified to satisfy the calibration criteria for this study. The initial values were continuously adjusted from those Santhi et al. (2001) suggested for manure land application sites (SOL_MINP: 5000 ppm, SOL_ORGP: 700 ppm and SOL_MINP: 250). Parameters changed during calibration are shown in Table 2.

After calibration, the model input parameters and variables were not changed during the validation process. The R^2 and E_{NS} statistics were used to evaluate relationships between simulated and observed values of flow and sediment and nutrient transport during a validation period from August 2003 through April 2004.

Table 2. SWAT model parameters and variables adjusted during model calibration for flow, sediment and nutrient transport.

Variable Name	Model Process	Description[2]	Value
CN2	Flow	Curve number	-8%[1]
GWQWN	Flow	Return flow threshold depth	5000
ESCO	Flow	Soil evaporation compensation factor	0.6
C FACTOR	Sediment	Cover or management factor	North : 0.009
			South : 0.002
SOL_ORGN	Organic N	Initial soil organic N concentration	7000 ppm
SOL_ORGP	Organic P	Initial soil organic P concentration	300 ppm
NPERCO	Mineral N	Nitrogen percolation coefficient	100%[1]
SOL_MINP	Mineral P	Initial soil mineral P concentration	200 ppm
PHOSKD	Mineral P	Phosphorus soil partitioning coefficient	-100%[1]
PPERCO	Mineral P	Phosphorus percolation coefficient	10

[1] Percent changes from the default SWAT model values.
[2] Detailed descriptions are available in the Soil and Water Assessment Tool User's Manual (SWAT, 2000).

Results and Discussion

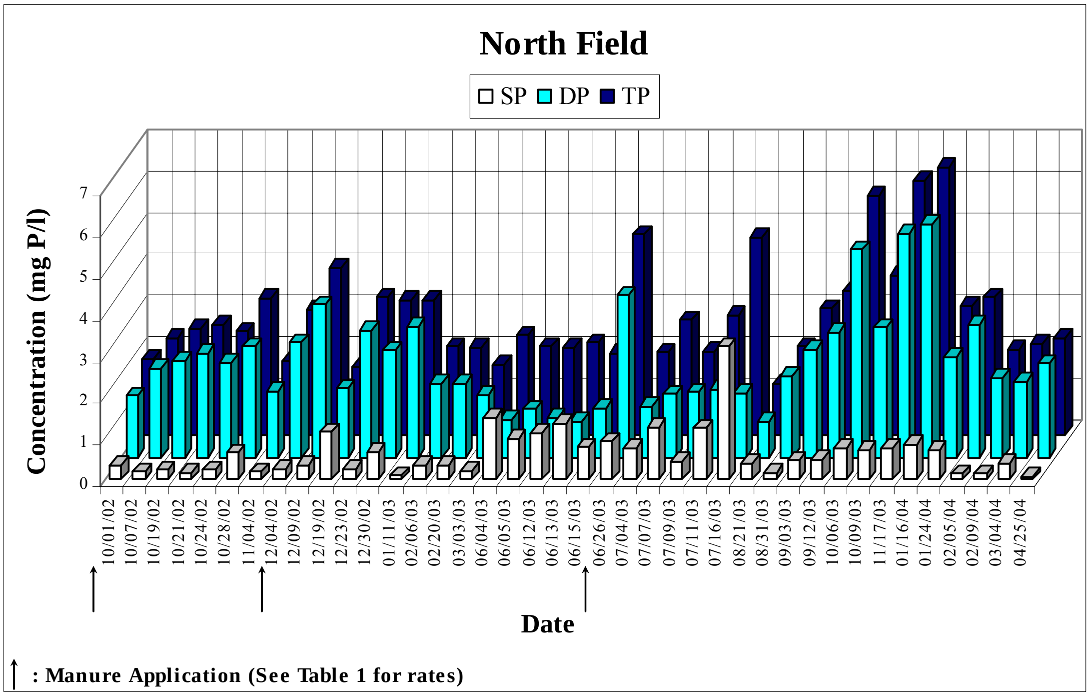
Field Monitoring: Surface Runoff

Total rainfall depth was 1432.8 mm over 42 runoff events during the monitoring period from September 2002 to April 2004. Total runoff from the South field (548.4 mm) was 13% greater than from the North field (487.2 mm), which received the composted manure. The average runoff to rainfall ratio was 30% for the South field and 26% for the North field.

Field Monitoring: Phosphorus in Runoff

Samples from 40 surface runoff events during production of two sod crops indicated the mass of total P lost in runoff was 14.1 kg P/ha for the North field and 7.1 kg P/ha for the South field. The South field was used as a control to compute the mass loss of P in runoff attributed to the manure P applied on the North field. Initial soil test P concentrations averaged 127 mg P/kg in both fields. The applications of composted manure on the North field for two sod crops increased the mass loss of total of total P 7.1 kg/ha (sediment P plus dissolved P) over that of the South field (7.1 kg P/ha) or control.

Similar to mass loss differences between fields, the average dissolved phosphorus (DP) concentration (2.4 mg/l) for 40 surface runoff events of the North field was 2.4 times greater than that of the South field (1.0 mg/l). The average dissolved phosphorus (DP) concentration was calculated as the quotient of total DP loss divided by the total runoff volume from all 40 runoff events. The DP concentrations in runoff from the North field increased compared to the South field during runoff events soon after a manure application on June 23, 2003 (Figure 2). Similarly, DP concentrations in runoff from the North field after October 6, 2003 were higher than the South field (Figure 2). In addition, the higher DP concentrations for North compared to South fields after October 6, 2003 contributed to greater mass losses of P from the North field (Figure 3).



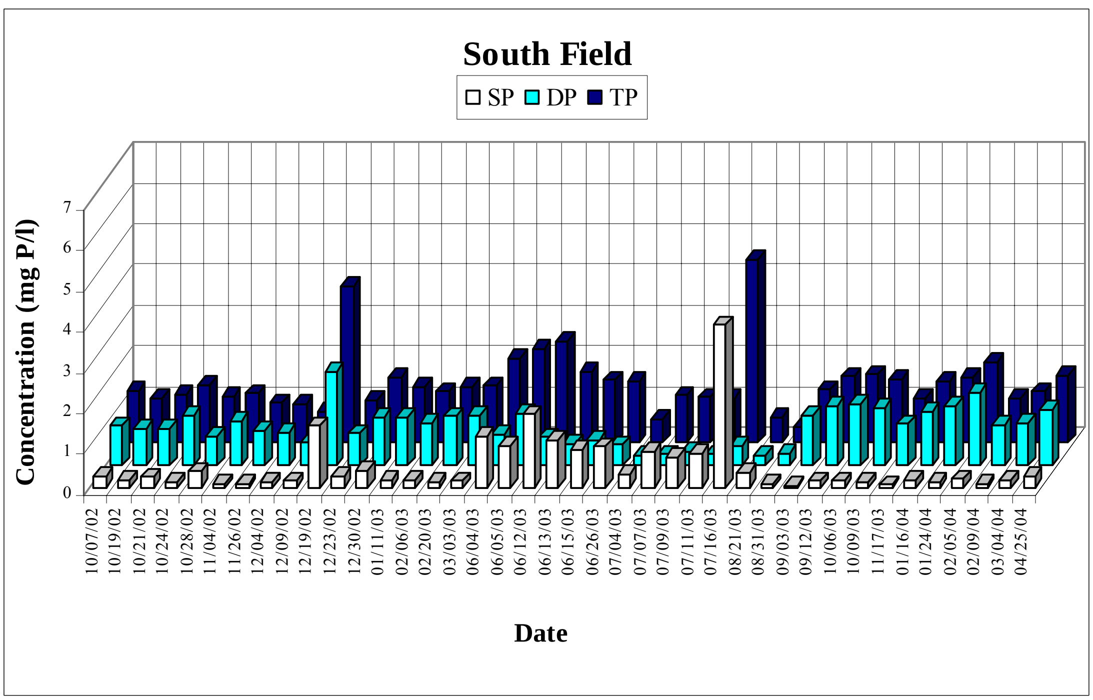
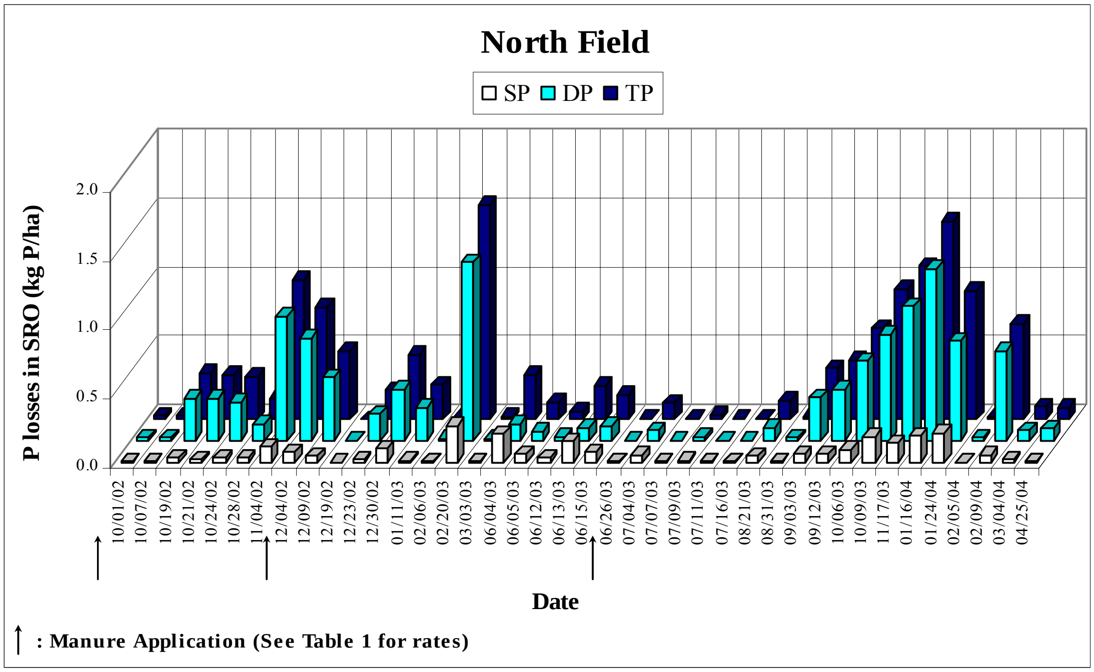


Figure 2. Mean dissolved P (DP), sediment P (SP) and total P (TP) concentrations in each surface runoff (SRO) event for the North and South fields.



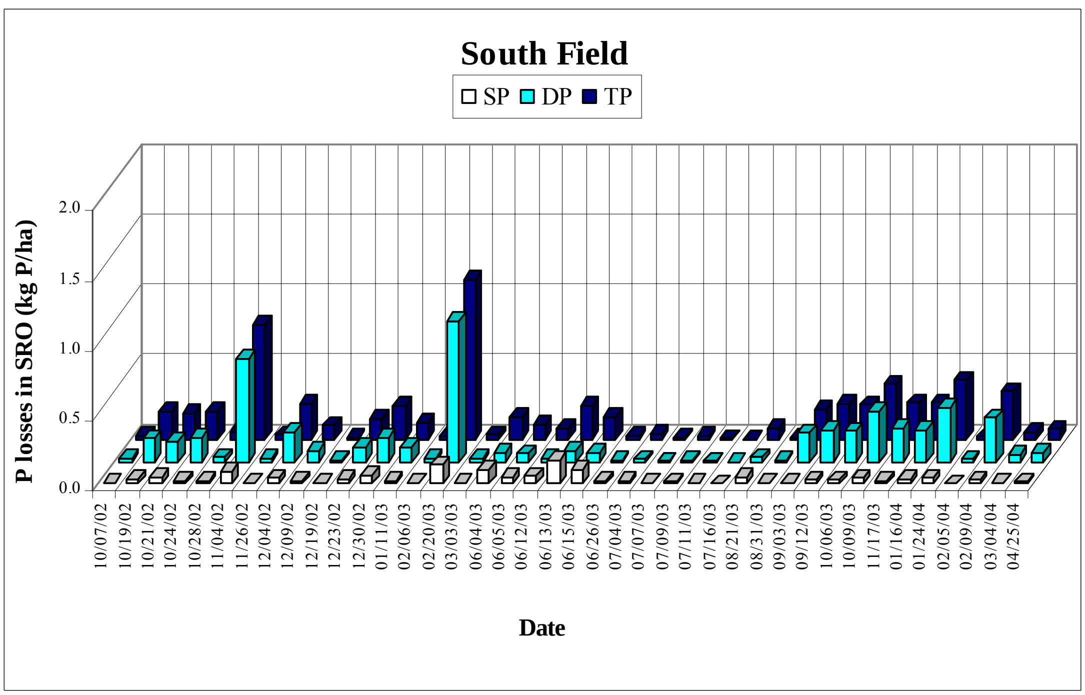


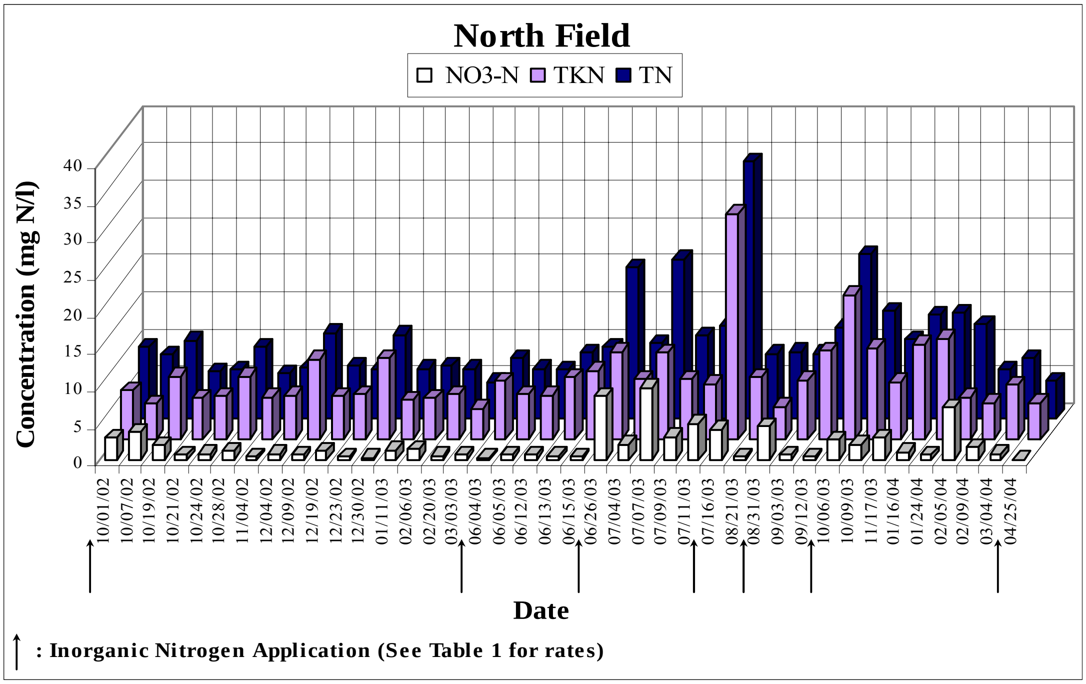
Figure 3. Dissolved P (DP), sediment P (SP) and total P (TP) losses in each surface runoff (SRO) event for the North and South fields.

Relatively high Sediment P (SP) concentrations in runoff from both North and South fields on July 16, 2003 were attributed to small runoff volumes. Conversely, mass losses of P in runoff were minimal for both fields on July 16, 2003 (Figure 3). Similarly, small runoff volumes contributed to high P concentrations, but minimal mass loss of P in runoff from the South field on December 19, 2002 (Figure 3).

Field Monitoring: Nitrogen in Runoff

The total mass of N lost in surface runoff during the 40 surface runoff events was 43.8 kg/ha for the North field and 30.4 kg/ha for the South field. Total mass losses of TKN from the North field (39.0 kg/ha), which includes dissolved TKN and sediment TKN, was nearly 1.5 times greater than that from the South field (25.9 kg/ha). The total mass of dissolved NO_3-N loss in surface runoff from the North field (4.8 kg/ha) was similar to the amount lost from the South field (4.5 kg/ha). Total N losses in the surface runoff from the South field (the control field) were subtracted from the N losses from the North field to calculate the mass of manure N lost in runoff. The calculated value indicated 14.9 kg /ha of manure N was lost in runoff from the North field, which was 3.1% of the total N applied as composted manure.

The average TKN concentration (8.0 mg/l) for 40 surface runoff events from the North field was 1.7 times greater than from the South field (4.7 mg/l). However, the average NO_3-N concentration (1.0 mg/l) for those same events had only 20% difference for the North compared to the South field (0.8 mg/l). In general, the average TKN concentrations were relatively low, but tended to be higher than the average dissolved NO_3-N concentrations in surface runoff from the North and South fields (Figure 4).



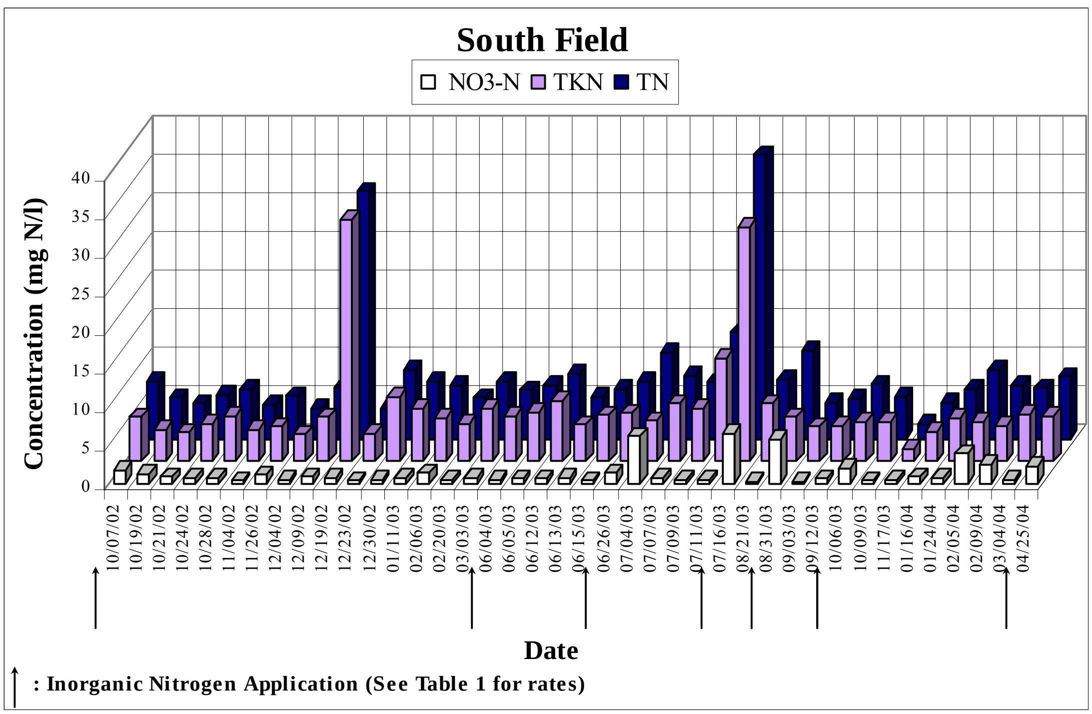
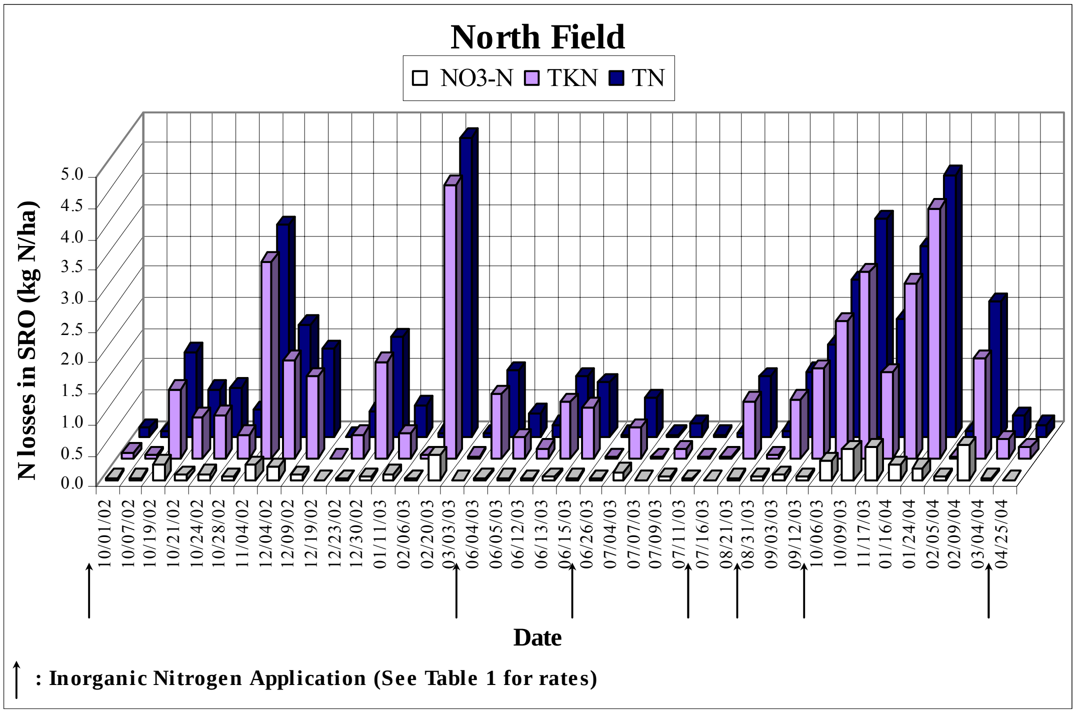


Figure 4. Mean dissolved NO_3-N, TKN and total N concentrations in each surface runoff (SRO) event for the North and South fields.



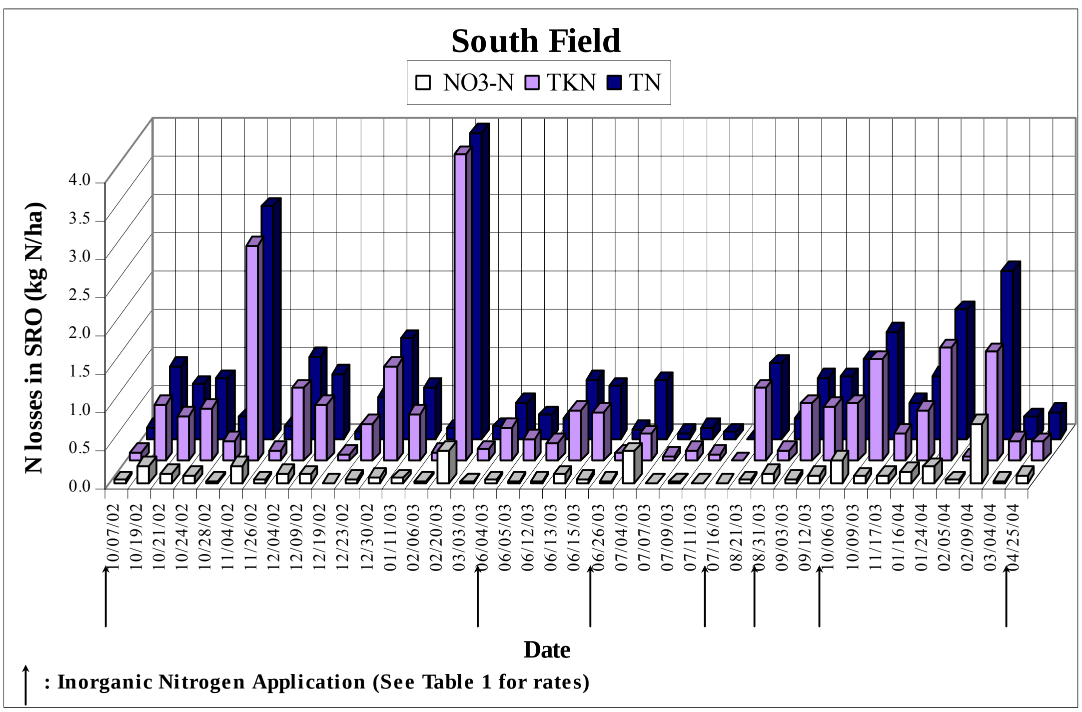


Figure 5. Dissolved NO_3-N, TKN and total N losses in each surface runoff (SRO) event for North and South fields.

Therefore, more manure N was lost in the form of TKN rather than as NO_3-N in runoff from the North field. For the North field, the TKN concentrations in the runoff were typically twice the concentrations observed for the South field after October 6, 2003. The concentration differences contributed to significantly higher N losses from the North field than from the South field (Figure 5). Again, the differences between fields were attributed to manure sources of N. In the North field, high TKN concentrations on June 26, July 7 and July 16, 2003 (see Figure 4) were due to very small runoff volumes, which resulted in low mass loss of TKN (Figure 5). In the South field, very small runoff volumes contributed to high TKN concentrations but small TKN losses in runoff on December 19, 2002 and July 16, 2003 (Figure 4). Large runoff volumes caused the large mass of TKN from both fields on November 4, 2002 and February 20, 2003 (Figure 5).

Relationship of Soil Test P and Runoff Phosphorus

Previous plot-scale experiments indicated that runoff losses of total dissolved P summed over runoff events during turf establishment were linearly related to soil test P (Vietor et al., 2004). Analysis of soil samples from the North field indicated increases of soil test P occurred after surface applications of composted manure. A total of seven composite samples of surface soil (0-5 cm depth) were collected from each the North and South fields during production of two sod crops (Table 3). The first composite sampling on 9/13/02 was prior to the initial surface application of manure. The composite samples collected from the surface layer on 11/12/02 preceded the second manure application. Initially, the average soil-test P concentration in the 0 to 5-cm depth of the South field (115.9 mg/l) was slightly lower than in the North field (138.0 mg/l).

After the last soil test on 10/08/03 prior to the second sod harvest, the soil-test P concentration of North field (237.0 mg/l) was 2 times greater than in the South field (115.0 mg/l). The P concentration in the 0 to 5-cm depth of the South field was unchanged throughout the experiment. The manure applications increased average soil-test P concentrations in the 0 to 5-cm depth of the North field from 138 to 258 mg/l (Table 3). The P concentrations in runoff were compared with soil-test P concentrations for runoff events close to soil sampling dates (Fig. 6 and 7). In the North field, dissolved P (DP) and total P (TP) concentrations in the runoff increased linearly with increasing soil-test P concentrations (Figure 6). In contrast, sediment P (SP) concentrations in runoff did not change as soil-test P increased. In the South field, runoff concentrations of DP, SP and TP remained relatively constant in among runoff events consistent with relatively constant P concentrations in composite soil samples (Figure 7).

Table 3. Relationship between soil-test P in 0 to 5-cm depth and average P concentrations in runoff (dissolved P), sediment (sediment P) and combined dissolved and sediment P (total P) in seven surface runoff events in the North and South field.

North Field						
Soil Test Date	**Avg. Soil P (mg/l)**	**Standard Deviation (n*)**	**Runoff Date**	**Avg. dissolved P in Runoff (mg/l)**	**Avg. sediment P in Runoff (mg/l)**	**Avg. total P in Runoff (mg/l)**
9/13/02	138.0	22.0 (12)	9/8/02	1.05	0.21	1.26
10/17/02	158.0	0.0 (1)	10/7/02	2.15	0.19	2.34
11/12/02	156.0	0.0 (1)	11/4/02	1.59	0.19	1.78
1/10/03	184.5	6.4 (2)	1/11/03	3.17	0.10	3.27
7/7/03	185.3	29.5 (12)	7/7/03	1.53	1.25	2.78
9/16/03	257.8	66.0 (6)	9/12/03	3.02	0.48	3.50
10/8/03	237.0	28.3 (2)	10/9/03	3.14	0.73	3.87
South Field						
Soil Test Date	**Avg. Soil P (mg/l)**	**Standard Deviation (n*)**	**Runoff Date**	**Avg. dissolved P in Runoff (mg/l)**	**Avg. sediment P in Runoff (mg/l)**	**Avg. total P in Runoff (mg/l)**
9/13/02	115.9	14.4 (12)	9/8/02	0.83	0.20	1.03
10/17/02	117.0	0.0 (1)	10/7/02	0.97	0.30	1.27
11/12/02	111.0	0.0 (1)	11/4/02	1.09	0.13	1.22
1/10/03	118.0	4.24 (2)	1/11/03	1.18	0.20	1.38
7/7/03	113.6	13.33 (12)	7/7/03	0.27	0.90	1.17
9/16/03	115.7	9.81 (6)	9/12/03	1.45	0.18	1.63
10/8/03	115.5	14.14 (2)	10/9/03	1.41	0.16	1.57

* The number of soil samples for each soil P test

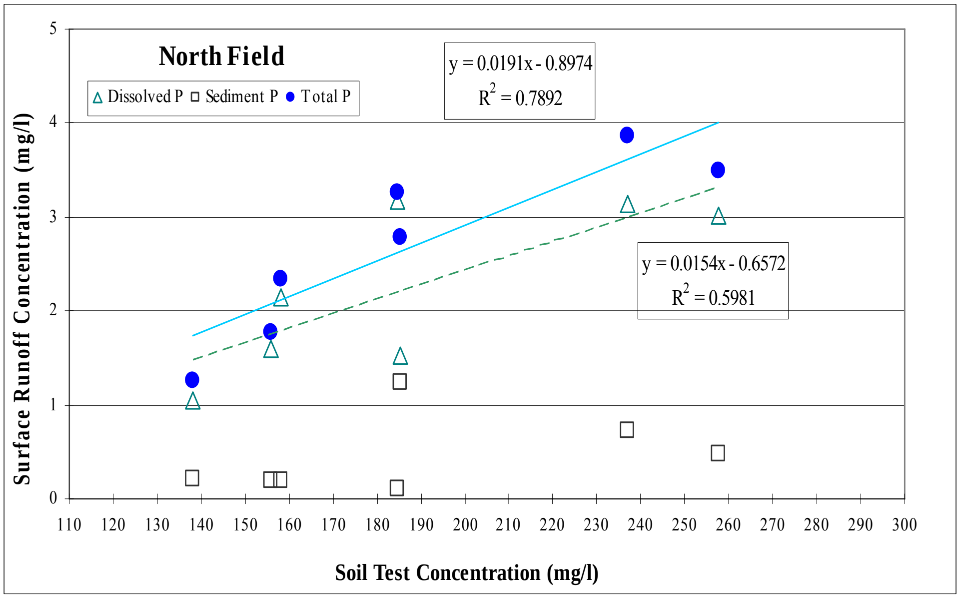


Figure 6. Relationship between soil-test P concentration in 0 to 5-cm depth and average P concentrations in runoff (dissolved P), sediment (sediment P) and combined dissolved and sediment P (total P) in seven surface runoff events in the North field.

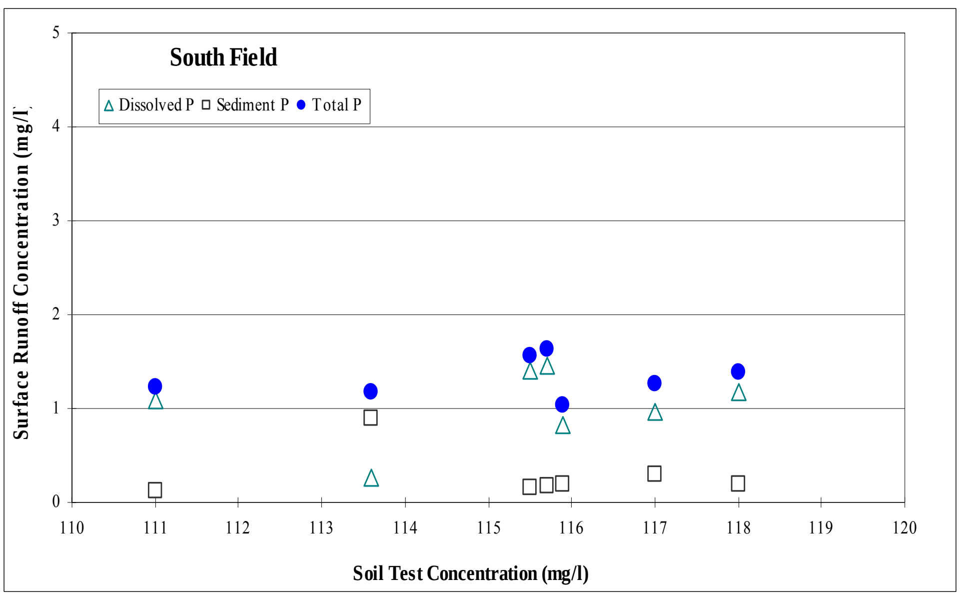


Figure 7. Relationship between soil-test P concentration in 0 to 5-cm depth and average P concentrations in runoff (dissolved P), sediment (sediment P) and combined dissolved and sediment P (total P) in seven surface runoff events in for South field.

Field Monitoring: Groundwater

A standard EPA well purging method (USEPA, 1986) and 3.8-cm diameter plastic bailer were used to sample groundwater and monitor N and P concentrations at the well location shown in Figure 1. Groundwater flowed from west to east under the research site. Prior to N and manure applications at the turfgrass sod research fields, the groundwater contained relatively low P (0.1 mg P/l) and relatively high NO_3-N concentrations (9.2 mg TN/l). The NO_3-N concentrations in the groundwater at the field site tended to be high and cyclic through the year. The NO_3-N concentrations were relatively low in the winter and early spring prior to planting and peaked during fall after the growing season.

Subsurface transport of NO_3-N and total P in groundwater could have affected concentrations in well samples. The turfgrass fields were on a Ships clay soil (very fine mixed active thermic Chromic Hapludert). The capacity for shrinking and swelling of the Ships soil is high, which leads to cracking and development of preferential flow paths during dry periods (Lin at al., 1995). In contrast, the hydraulic conductivity of the Ships soil at field capacity is very slow. Frequent irrigation on the turf fields maintained high soil water content, prevented cracking and rapid water flow through soil, and could have limited NO_3-N transport to well sampling depths at the research site (Hay, 2003).

An evaluation of NO_3-N transport through the root zone (3-m depth) in SWAT model simulations indicated maximum NO_3-N concentrations in groundwater were 0.07 mg/l. A simulated average NO_3-N concentration in groundwater equal to 0.02 mg/l .In addition, leaching loss of NO_3-N was predicted during three or four months of the fall and winter period only (Figure 8).

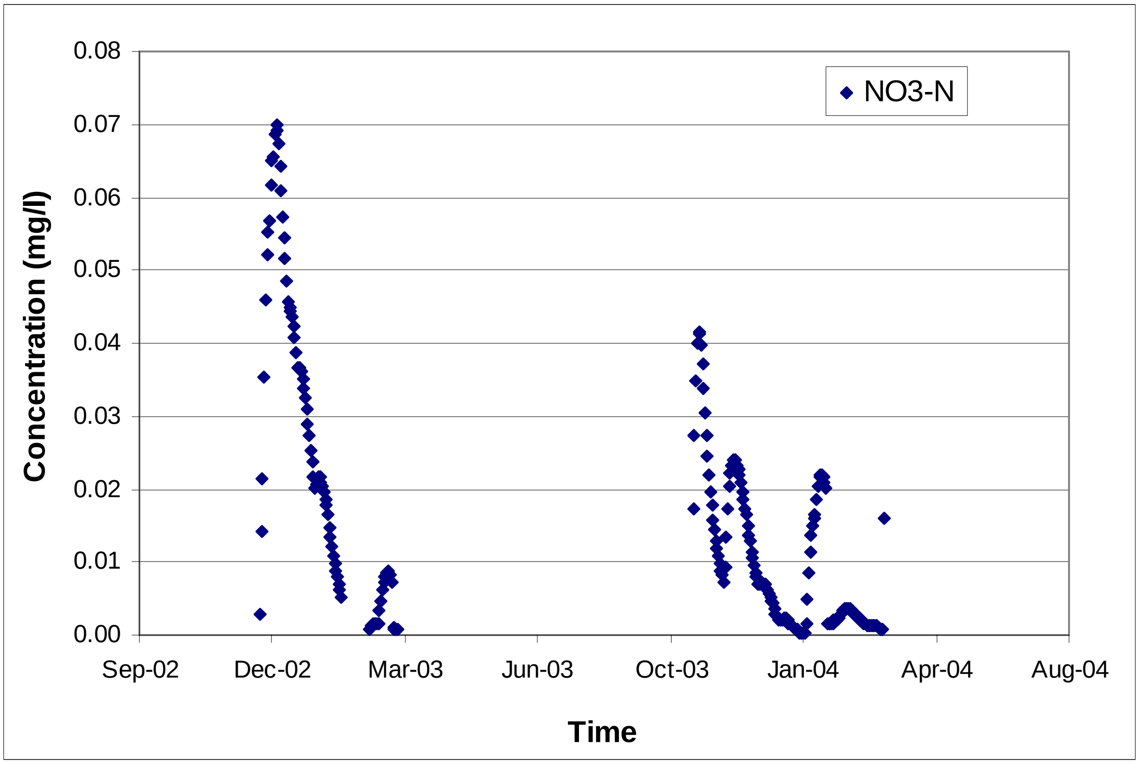


Figure 8. Simulated nitrate N concentrations leached through the soil profile (3-m depth) during the SWAT model simulations.

Model Calibration

The SWAT simulations of daily surface runoff closely matched observed values during model calibration. The R^2 values for regressions between observed and predicted water flow volumes were greater than 0.95 and E_{NS} values were greater than 0.85 (Table 4). Simulated daily surface runoff was over-predicted only slightly. Similar to calibrations for flow, regression analysis of simulated versus observed sediment loss in surface runoff for North and South fields yielded an $R^2 \geq 0.85$ (Table 4). The E_{NS} statistic for predictions of sediment loss from both the North and South fields was above 0.82, which indicated close agreement between observed and simulated sediment transport during the calibration period. The model tended to over-estimate total sediment loads in the North field and under-estimate losses from the South field during the calibration period.

Close agreement between observed and simulated values was similarly observed during calibration of SWAT simulations of organic N and P losses in surface runoff. The R^2 value was greater than 0.81 and the E_{NS} value was greater than 0.66 (Table 4). Total simulated loadings of organic N (North: 13.86 kg/ha, South: 11.40 kg/ha) and P (North: 0.78 kg/ha, South: 0.60kg/ha) in runoff from the North and South fields were within 7% of total observed organic N (North: 13.59 kg/ha, South: 12.04 kg/ha) and P (North: 0.72 kg/ha, South: 0.56 kg/ha) loadings.

The SWAT calibration indicated the model effectively predicted the temporal patterns of observed and simulated losses of mineral N and P in surface runoff from the two sod fields. The R^2 and E_{NS} statistics indicated the simulated mineral N and P in the runoff from the North and South fields matched observed values closely (Table 4). The simulated values for total mass of mineral N (1.83 kg/ha) in runoff from the North field and total mass loss of both mineral N (1.72 kg/ha) and P (2.94 kg/ha) from the South field were comparable to the observed values (North: 1.73 mineral N kg/ha, South: 1.68 mineral N kg/ha and 2.92 mineral P kg/ha). Yet, the model slightly under-predicted the total mineral P loads (Simulated: 4.41 kg/ha, Observed: 5.28 kg/ha) in runoff from the North field (-16%).

Table 4. Calibration results for daily SWAT model simulations of the North and South fields for the period October 2002 to May 2003.

	North Field		South Field	
Variable (units)	R^2	[1]E_{NS}	R^2	[1]E_{NS}
Flow Volume (mm)	0.95	0.85	0.95	0.93
Sediment (t/ha)	0.86	0.82	0.85	0.82
Organic N (kg/ha)	0.87	0.86	0.90	0.90
Organic P (kg/ha)	0.83	0.83	0.81	0.66
Mineral N (kg/ha)	0.69	0.69	0.77	0.76
Mineral P (kg/ha)	0.89	0.89	0.93	0.93

[1] Nash-Suttcliffe simulation efficiency.

Model Validation

The prediction statistics (R^2 and E_{NS}) indicated SWAT simulations of surface runoff and nutrient transport did not match observed values as closely as was achieved during the calibration period (Table 5). Although a strong regression relationship was observed between simulated and observed daily surface runoff on both fields (R^2 =0.87), the E_{NS} statistic for flow was less than 0.5 on the North field.

The statistical analyses indicated SWAT adequately simulated sediment transport for the North (R^2= 0.72 and E_{NS}= 0.59) and South (R^2= 0.76 and E_{NS}= 0.63) fields during the validation period (Table 5). Unlike the calibration period, the model over-predicted total sediment transport for the South field and under-predicted sediment loads for the North field.

The validation experiment indicated variation of SWAT simulations of flow volume, sediment, and mineral N and P accounted for 72% or more ($R^2 \geq 0.72$) of variation in field observations of the respective variables on the North and South fields

(Table 5). The R^2 values for organic N and P were reduced for the North field compared to those of other variables during the validation experiment. Yet, the R^2 values for organic N and P were ≥ 80 on the South field. Manure application on the North field could have increased variance of observed runoff losses of organic N and P compared to the South field, which could explain the reduced R^2 values.

The E_{NS} values less than 0.5 indicated unsatisfactory agreement between simulated and observed values for the respective variables during model validation (Table 5). Most notable were E_{NS} values ≤ 0.4 for organic P and mineral N on the South field, which received no manure. In contrast, E_{NS} values ≥ 0.71 were observed for mineral P in both the North and South fields. Mineral or dissolved P is of particular interest in current efforts to quantify and manage TMDL for P forms in river segments near high densities of CAFOs on the Upper North Bosque River watershed in Texas. The E_{NS} values for mineral P suggest the parameter and variable adjustments during calibration were sufficient to enable SWAT predictions of mineral P loss during sod production with and without application of composted manure. Yet, the E_{NS} near 0.5 for other simulated variable on the North field indicate further calibration may be necessary to use SWAT simulations at the scale of fields or hydrologic units for predictions of flow volume and transport of organic N and P forms and mineral N (Table 3).

Table 5. Validation results for daily SWAT model simulations of the North and South fields for the period August 2003 to April 2004.

	North Field		South Field	
Variable (units)	R^2	[1]E_{NS}	R^2	[1]E_{NS}
Flow Volume (mm)	0.87	0.47	0.87	0.69
Sediment (t/ha)	0.72	0.59	0.76	0.63
Organic N (kg/ha)	0.61	0.52	0.80	0.72
Organic P (kg/ha)	0.57	0.56	0.82	0.40
Mineral N (kg/ha)	0.87	0.52	0.81	0.34
Mineral P (kg/ha)	0.73	0.71	0.82	0.75

[1] Nash-Suttcliffe simulation efficiency.

CHAPTER III

SUMMARY AND CONCLUSION

Runoff monitoring at the paired turfgrass sod production fields illustrated the advantages of using composted manure for sod production. Manure application reduced surface runoff from the North field compared to that from the South field without manure. Reduced runoff volume could decrease nutrient mass losses through stormwater runoff. Yet, manure application increased mass loss of total P and N in runoff from the North compared to the South field during production of two sod crops. The increases in mass loss of nutrients attributed to manure on the North field were 7.1 kg P/ha (3.5% of applied manure P) and 14.9 kg N/ha (3.1% of applied manure N).

At the manure rates used on 1% slope of a clay soil, the mass loss of manure nutrients in surface runoff were small compared to amounts applied in manure during turfgrass sod production. The quotient of P mass losses in runoff divided by applied manure P was only 3.5 % during the monitoring periods after manure application on the North field even though soil test P levels increased. Application of composted manure is a viable environmental option for sod production. Since turfgrass sod is a high value agricultural commodity, it could be an economically sustainable means of using and exporting manure nutrients from impaired watersheds.

The SWAT model was successfully applied to the small-scale sod production fields in this study. Daily simulations of runoff flow and sediment and nutrient loads in runoff were compared with observed values for North and South production fields. Measured data for the calibration and validation periods came from on-site gauging stations. Calibration of the SWAT model yielded that simulated values for runoff flow and for transport of sediment and organic and mineral nutrients were similar to daily observations. The validation experiment for a subsequent set of runoff events indicated the model simulation continued to predict mass losses of mineral P similar to observed values on both fields. Yet, model adjustments may be needed to improve simulations of flow, organic P, and mineral N for sod production fields with or without composted manure applications. The calibration and validation experiments on the scale of the paired fields indicate nutrient-release algorithms in the SWAT model governing transport of N and P in surface runoff are acceptable for evaluations of manure application and management during turfgrass sod production.

REFERENCES

Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams. 1998. Large area hydrologic modeling and assessment Part I: Model development. *J. Amer. Water Res. Assoc.* 34(1):73-89.

Choi, I., C. L. Munster, D. M. Vietor, R. H. White, C. E. Richards, G. A. Stewart, and B. McDonald. 2003. Use of turfgrass sod to transport manure phosphorus out of impaired watersheds. In *Proc. Total Maximum Daily Load Environmental Regulations II Conf.*, 518-526. St. Joseph, MI: ASAE.

Dorich, R. A., and D. W. Nelson. 1983. Direct colorometric measurement of ammonium in potassium chloride extracts of soil. *Soil Sci. Soc. Am. J.* 47:833-836.

Dorich, R. A., and D. W. Nelson. 1984. Evaluation of manual cadmium reduction methods for determination of nitrate in potassium chloride extracts of soils. *Soil Sci. Soc. Am. J.* 48:72-75.

Hay, F. J. 2003. Phosphorus and nitrogen leaching losses during turf establishment. MS thesis. College Station, TX: Texas A&M University, Department of Soil and Crop Sciences.

Hons, F. M., L. A. Larson-Vollmer, and M. A. Locke. 1990. NH_4OAc-EDTA-Extractable phosphorus as a soil test procedure. *Soil Sci.* 149:249-256.

Isaac, R. A., and J. B. Jones, Jr. 1970. Auto analysis for the analysis of soil and plant tissue extracts. In *Advances in Automated Analysis.* 57-64. Tarrytown, NY: Techicon Corp.

Legates, D. R., and R. E. Davis. 1997. The continuing search for an anthropogenic climate change signal: Limitations of correlation-based approaches. *Geophys. Res. Lett.* 24:2319-2322.

Legates, D. R., and G. J. McCabe Jr. 1999. Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation. *Water Res. Research.* 35(1):233-241.

Lin, H. S., and K. J. McInnes. 1995. Water flow in a clay soil beneath a tension infiltrometer. *Soil Sci.* 159:375-382.

McFarland, A., and L. Hauck. 1999. Relating agricultural land uses to in-stream stormwater quality. *J. Environ. Qual*. 28(3): 836-844.

Munster, C. L., J. E. Hanzlik, D. M. Vietor, R. H. White, and A. McFarland. 2004. Assessment of manure phosphorus export through turfgrass sod production in Erath County, Texas. *J. Environ. Manage.* 73(2):111-116.

Nash, J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models-Part I-A discussion of principles. *J. Hydrology*. 10:282-290.

Parkinson, J. A., and S. E. Allen. 1975. A wet oxidation procedure for determination of nitrogen and mineral nutrients in biological material. *Commun. Soil Sci. Plant Anal.* 6:1–11.

Ramanarayanan, T. S., J. R. Williams, W. A. Dugas, L. M. Hauck, and A. M. S. McFarland. 1997. Using APEX to identify alternative practices for animal waste management: Part II. Model application. ASAE Paper 97-2209. St. Joseph, MI: ASAE.

Saleh, A., J. G. Arnold, P. W. Gassman, L. M. Hauck, W. D. Rosenthal, J. R. Williams, and A. M. S. McFarland. 2000. Application of SWAT for the Upper North Bosque River Watershed. *Trans. ASAE*. 43(5): 1077-1087.

Santhi, C., J. G. Arnold, J. R. Williams, W. A. Dugas, R. Srinivasan, and L. M. Hauck. 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. *J. AWRA.* 37(5): 1170-1188.

SWAT 2000. *Soil and Water Assessment Tool User's Manual*. Version 2000. Temple, TX: Blackland Research Center, Texas Agricultural Experiment Station.

TCEQ. 2003. Composted Manure Incentive Project. Austin, TX: Texas Commission on Environmental Quality. Available at: http://www.tnrcc.state.tx.us/water/quality/nps/compost/index.html. Accessed 10 February 2004.

TNRCC. 2001. Two Total Maximum Daily Loads for Phosphorous in the North Bosque River. Austin, TX: Texas Natural Resource Conservation Commission. Available at: http://www.tnrcc.state.tx.us/admin/topdoc. Accessed 10 July 2003.

U.S. Environmental Protection Agency. 1986. RCRA Ground-Water Monitoring Technical Enforcement Guidance Document; OSWER-9950.1, U.S. Government Printing Office, Washington, D.C.

Vietor, D. M., E. N. Griffith, R. H. White, T. L. Provin, J.P. Muir, and J.C. Read. 2002. Export of manure P and N through turfgrass sod. *J. Environ. Qual*. 31:1731-1738.

Vietor, D. M., T. L. Provin, R. H. White, and C. L. Munster. 2004. Runoff losses of phosphorus and nitrogen imported in sod or composted manure for turf establishment. *J. Environ. Qual*. 33: 358-366.

Willmott, C. J. 1984. On the evaluation of model performance in physical geography. In *Spatial Statistics and Models*, 443-460. G. L. Gaile, and C. J. Willmott, ed. Norwell, MA.: D. Reidel Publishing.

APPENDIX

Table A 1. Comparison of surface runoff volumes in the North and South turfgrass sod production fields from September 2002 to April 2004.

Date	Rainfall (mm)	Runoff North (mm)	Runoff South (mm)	Difference South-North (mm)	North Ratio : Runoff / Rainfall (%)	South Ratio : Runoff / Rainfall (%)
09/08/02	31.8	6.9	10.6	3.7	21.8	33.5
10/01/02	15.0	1.4	2.4	1.0	9.5	15.9
10/07/02	22.1	1.1	2.0	0.9	4.8	8.8
10/19/02	46.0	13.2	17.8	4.7	28.7	38.8
10/21/02	34.3	12.3	15.5	3.2	35.8	45.1
10/24/02	30.7	12.3	13.8	1.6	39.9	45.0
10/28/02	14.7	4.5	4.4	-0.1	30.7	29.8
11/04/02	110.2	56.8	67.6	10.9	51.5	61.4
11/26/02	16.5	0.5	3.2	2.7	2.8	19.1
12/04/02	56.6	27.0	26.9	-0.1	47.7	47.5
12/09/02	25.4	12.4	12.8	0.4	48.8	50.5
12/19/02	9.4	0.1	0.3	0.2	0.6	2.8
12/23/02	23.6	6.3	13.6	7.3	26.8	57.6
12/30/02	25.7	14.4	14.7	0.3	56.3	57.3
01/11/03	23.4	7.7	8.9	1.2	33.0	37.9
02/06/03	14.2	0.9	2.0	1.1	6.3	13.9
02/20/03	140.2	72.9	83.3	10.4	52.0	59.4
03/03/03	12.5	1.0	2.2	1.2	8.0	17.8
06/04/03	31.0	13.3	7.6	-5.7	42.9	24.5
06/05/03	19.1	5.8	4.5	-1.3	30.3	23.6
06/12/03	16.3	2.8	3.1	0.2	17.5	18.8
06/13/03	36.1	11.0	13.9	2.9	30.5	38.6
06/15/03	25.7	9.0	10.6	1.6	35.1	41.3
06/26/03	12.4	0.2	1.6	1.5	1.3	13.2
07/04/03	18.3	6.1	6.8	0.7	33.3	37.0
07/07/03	7.6	0.1	0.8	0.7	1.5	10.9
07/09/03	11.2	1.8	2.0	0.1	16.5	17.5
07/11/03	10.4	0.3	0.7	0.4	2.9	6.3
07/16/03	4.6	0.1	0.0	-0.1	2.7	0.2
08/21/03	43.7	11.2	12.7	1.6	25.6	29.1
08/31/03	23.4	1.1	2.3	1.2	4.6	9.9
09/03/03	40.1	12.1	16.6	4.4	30.2	41.3
09/12/03	56.9	12.3	15.7	3.4	21.6	27.6
10/06/03	53.6	11.5	14.7	3.2	21.4	27.4
10/09/03	55.1	24.5	25.5	1.0	44.4	46.2
11/17/03	61.2	18.1	23.4	5.3	29.5	38.2
01/16/04	55.4	22.2	17.2	-5.0	40.1	31.1
01/24/04	63.8	29.9	26.0	-3.9	46.9	40.8
02/05/04	9.1	0.7	0.9	0.2	7.9	9.8
02/09/04	83.6	33.5	31.2	-2.3	40.1	37.4
03/04/04	21.3	4.2	4.4	0.2	19.7	20.7
04/25/04	20.8	3.8	4.4	0.6	18.3	21.0
Total	1432.8	487.2	548.4	61.2	25.5 (avg.)	29.9 (avg.)

Table A 2. Dissolved P (DP), sediment P (SP) and total P (TP) losses in each surface runoff (SRO) event of the North and South turfgrass sod production fields from October 2002 to April 2004.

North Field			
Date	DP in SRO (kg/ha)	SP in SRO (kg/ha)	TP in SRO (kg/ha)
10/01/02	0.021	0.005	0.026
10/07/02	0.023	0.002	0.025
10/19/02	0.308	0.031	0.339
10/21/02	0.309	0.019	0.328
10/24/02	0.279	0.028	0.307
10/28/02	0.121	0.029	0.150
11/04/02	0.902	0.110	1.012
12/04/02	0.746	0.070	0.816
12/09/02	0.456	0.043	0.499
12/19/02	0.001	0.001	0.002
12/23/02	0.195	0.016	0.211
12/30/02	0.373	0.096	0.469
01/11/03	0.244	0.008	0.252
02/06/03	0.016	0.003	0.019
02/20/03	1.292	0.260	1.552
03/03/03	0.015	0.002	0.017
06/04/03	0.121	0.200	0.321
06/05/03	0.067	0.056	0.124
06/12/03	0.027	0.032	0.060
06/13/03	0.097	0.148	0.245
06/15/03	0.107	0.070	0.178
06/26/03	0.006	0.002	0.008
07/04/03	0.075	0.047	0.122
07/07/03	0.002	0.001	0.003
07/09/03	0.029	0.008	0.037
07/11/03	0.005	0.004	0.009
07/16/03	0.002	0.004	0.006
08/21/03	0.096	0.044	0.140
08/31/03	0.021	0.002	0.023
09/03/03	0.315	0.056	0.371
09/12/03	0.371	0.059	0.429
10/06/03	0.575	0.086	0.661
10/09/03	0.769	0.178	0.947
11/17/03	0.974	0.135	1.109
01/16/04	1.248	0.187	1.435
01/24/04	0.723	0.212	0.935
02/05/04	0.023	0.001	0.024
02/09/04	0.646	0.049	0.695
03/04/04	0.077	0.016	0.093
04/25/04	0.086	0.003	0.089
Sum	11.762	2.323	14.085

Table A 2 Continued

South Field			
Date	DP in SRO (kg/ha)	SP in SRO (kg/ha)	TP in SRO (kg/ha)
10/07/02	0.019	0.006	0.025
10/19/02	0.164	0.035	0.199
10/21/02	0.141	0.043	0.184
10/24/02	0.173	0.024	0.197
10/28/02	0.032	0.018	0.050
11/04/02	0.736	0.085	0.821
11/26/02	0.027	0.004	0.031
12/04/02	0.216	0.040	0.256
12/09/02	0.076	0.023	0.099
12/19/02	0.006	0.004	0.010
12/23/02	0.107	0.038	0.145
12/30/02	0.176	0.063	0.239
01/11/03	0.105	0.018	0.123
02/06/03	0.021	0.004	0.025
02/20/03	1.008	0.137	1.145
03/03/03	0.027	0.004	0.031
06/04/03	0.059	0.098	0.157
06/05/03	0.058	0.046	0.104
06/12/03	0.021	0.056	0.077
06/13/03	0.076	0.167	0.243
06/15/03	0.065	0.099	0.164
06/26/03	0.008	0.017	0.025
07/04/03	0.016	0.023	0.040
07/07/03	0.002	0.007	0.010
07/09/03	0.007	0.015	0.022
07/11/03	0.002	0.006	0.007
07/16/03	0.000	0.000	0.000
08/21/03	0.032	0.049	0.081
08/31/03	0.007	0.002	0.009
09/03/03	0.206	0.011	0.217
09/12/03	0.228	0.028	0.256
10/06/03	0.220	0.027	0.247
10/09/03	0.358	0.040	0.398
11/17/03	0.239	0.021	0.260
01/16/04	0.227	0.034	0.261
01/24/04	0.384	0.040	0.424
02/05/04	0.016	0.002	0.018
02/09/04	0.314	0.029	0.343
03/04/04	0.047	0.009	0.056
04/25/04	0.060	0.013	0.073
Sum	5.687	1.386	7.072

Table A 3. Total P (TP) losses in each surface runoff (SRO) event from manure fertilizer in the North field by subtracting the TP losses in the South field from the TP losses in the North field.

Date	North Field TP in SRO (kg/ha)	South Field TP in SRO (kg/ha)	Manure Losses TP in SRO (kg/ha)
10/01/02	0.026	N.S.[1]	-
10/07/02	0.025	0.025	0.000
10/19/02	0.339	0.199	0.140
10/21/02	0.328	0.184	0.144
10/24/02	0.307	0.197	0.110
10/28/02	0.150	0.050	0.100
11/04/02	1.012	0.821	0.191
11/26/02	N.S.[1]	0.031	-
12/04/02	0.816	0.256	0.560
12/09/02	0.499	0.099	0.400
12/19/02	0.002	0.010	0.000
12/23/02	0.211	0.145	0.066
12/30/02	0.469	0.239	0.230
01/11/03	0.252	0.123	0.129
02/06/03	0.019	0.025	0.000
02/20/03	1.552	1.145	0.407
03/03/03	0.017	0.031	0.000
06/04/03	0.321	0.157	0.164
06/05/03	0.124	0.104	0.019
06/12/03	0.060	0.077	0.000
06/13/03	0.245	0.243	0.002
06/15/03	0.178	0.164	0.014
06/26/03	0.008	0.025	0.000
07/04/03	0.122	0.040	0.082
07/07/03	0.003	0.010	0.000
07/09/03	0.037	0.022	0.015
07/11/03	0.009	0.007	0.001
07/16/03	0.006	0.000	0.005
08/21/03	0.140	0.081	0.059
08/31/03	0.023	0.009	0.014
09/03/03	0.371	0.217	0.154
09/12/03	0.429	0.256	0.173
10/06/03	0.661	0.247	0.414
10/09/03	0.947	0.398	0.549
11/17/03	1.109	0.260	0.849
01/16/04	1.435	0.261	1.174
01/24/04	0.935	0.424	0.511
02/05/04	0.024	0.018	0.006
02/09/04	0.695	0.343	0.352
03/04/04	0.093	0.056	0.037
04/25/04	0.089	0.073	0.016
SUM	14.085	7.072	7.087

Table A 4. Mean dissolved P (DP), sediment P (SP) and total P (TP) concentrations in each surface runoff (SRO) event of the North and South turfgrass sod production fields from October 2002 to April 2004.

North Field			
Date	DP Concenetration (mg P/l)	SP Concenetration (mg P/l)	TP Concenetration (mg P/l)
10/01/02	1.479	0.352	1.831
10/07/02	2.150	0.187	2.336
10/19/02	2.337	0.235	2.572
10/21/02	2.514	0.155	2.669
10/24/02	2.274	0.228	2.502
10/28/02	2.677	0.642	3.319
11/04/02	1.588	0.194	1.782
12/04/02	2.763	0.259	3.022
12/09/02	3.680	0.347	4.027
12/19/02	1.667	1.157	1.667
12/23/02	3.081	0.253	3.333
12/30/02	2.585	0.665	3.250
01/11/03	3.165	0.104	3.268
02/06/03	1.798	0.337	2.135
02/20/03	1.772	0.357	2.129
03/03/03	1.515	0.202	1.717
06/04/03	0.912	1.502	2.413
06/05/03	1.161	0.978	2.140
06/12/03	0.968	1.138	2.106
06/13/03	0.881	1.344	2.225
06/15/03	1.192	0.780	1.972
06/26/03	3.914	0.925	4.840
07/04/03	1.224	0.772	1.996
07/07/03	1.532	1.254	2.786
07/09/03	1.574	0.442	2.016
07/11/03	1.647	1.239	2.887
07/16/03	1.547	3.218	4.765
08/21/03	0.856	0.395	1.251
08/31/03	1.980	0.152	2.132
09/03/03	2.596	0.465	3.061
09/12/03	3.015	0.476	3.492
10/06/03	5.014	0.751	5.766
10/09/03	3.141	0.727	3.868
11/17/03	5.388	0.747	6.135
01/16/04	5.622	0.842	6.464
01/24/04	2.417	0.709	3.126
02/05/04	3.194	0.139	3.333
02/09/04	1.927	0.146	2.073
03/04/04	1.829	0.380	2.209
04/25/04	2.257	0.079	2.336
Total SRO Events	2.414	0.477	2.891

Table A 4 Continued

South Field			
Date	DP Concenetration (mg P/l)	SP Concenetration (mg P/l)	TP Concenetration (mg P/l)
10/07/02	0.974	0.308	1.282
10/19/02	0.919	0.196	1.115
10/21/02	0.911	0.278	1.189
10/24/02	1.250	0.173	1.423
10/28/02	0.729	0.410	1.139
11/04/02	1.088	0.126	1.214
11/26/02	0.857	0.127	0.984
12/04/02	0.804	0.149	0.952
12/09/02	0.592	0.179	0.772
12/19/02	2.308	1.538	3.846
12/23/02	0.787	0.279	1.066
12/30/02	1.197	0.429	1.626
01/11/03	1.185	0.203	1.388
02/06/03	1.061	0.202	1.263
02/20/03	1.211	0.165	1.375
03/03/03	1.222	0.181	1.403
06/04/03	0.779	1.288	2.067
06/05/03	1.284	1.031	2.316
06/12/03	0.696	1.820	2.516
06/13/03	0.545	1.199	1.744
06/15/03	0.613	0.934	1.547
06/26/03	0.508	1.020	1.527
07/04/03	0.244	0.340	0.584
07/07/03	0.273	0.899	1.173
07/09/03	0.348	0.772	1.121
07/11/03	0.273	0.842	1.115
07/16/03	0.504	4.007	4.511
08/21/03	0.250	0.386	0.635
08/31/03	0.295	0.105	0.400
09/03/03	1.241	0.069	1.310
09/12/03	1.454	0.179	1.633
10/06/03	1.500	0.184	1.684
10/09/03	1.406	0.156	1.563
11/17/03	1.023	0.090	1.113
01/16/04	1.317	0.197	1.515
01/24/04	1.475	0.154	1.629
02/05/04	1.778	0.222	2.000
02/09/04	1.005	0.093	1.098
03/04/04	1.063	0.204	1.267
04/25/04	1.373	0.297	1.670
Total SRO Events	1.037	0.253	1.290

Table A 5. Dissolved TKN, Dissolved NO3-N, sediment TKN, Total TKN and total N losses in surface runoff (SRO) of the North and South turfgrass sod production fields from October 2002 to April 2004.

North Field					
Date	Dissolved TKN in SRO (kg/ha)	Dissolved NO3-N in SRO (kg/ha)	Sediment TKN in SRO (kg/ha)	TKN in SRO (kg/ha)	Total N in SRO (kg/ha)
10/01/02	0.077	0.043	0.016	0.093	0.136
10/07/02	0.043	0.040	0.008	0.051	0.091
10/19/02	0.556	0.255	0.561	1.117	1.371
10/21/02	0.608	0.090	0.067	0.675	0.765
10/24/02	0.538	0.099	0.165	0.702	0.801
10/28/02	0.236	0.051	0.144	0.380	0.432
11/04/02	2.494	0.238	0.687	3.181	3.419
12/04/02	1.336	0.219	0.255	1.591	1.810
12/09/02	1.154	0.086	0.173	1.327	1.413
12/19/02	0.002	0.001	0.001	0.003	0.004
12/23/02	0.323	0.028	0.060	0.383	0.412
12/30/02	0.891	0.047	0.673	1.563	1.611
01/11/03	0.385	0.103	0.021	0.406	0.509
02/06/03	0.036	0.013	0.013	0.049	0.062
02/20/03	3.353	0.411	1.070	4.423	4.834
03/03/03	0.031	0.007	0.010	0.040	0.047
06/04/03	0.399	0.037	0.632	1.031	1.067
06/05/03	0.173	0.035	0.171	0.345	0.380
06/12/03	0.079	0.018	0.087	0.166	0.184
06/13/03	0.438	0.059	0.470	0.908	0.967
06/15/03	0.577	0.034	0.253	0.831	0.865
06/26/03	0.015	0.014	0.004	0.019	0.033
07/04/03	0.345	0.129	0.142	0.487	0.616
07/07/03	0.008	0.011	0.005	0.013	0.024
07/09/03	0.118	0.057	0.029	0.147	0.204
07/11/03	0.012	0.015	0.010	0.022	0.037
07/16/03	0.022	0.005	0.015	0.037	0.043
08/21/03	0.731	0.040	0.189	0.920	0.960
08/31/03	0.040	0.048	0.007	0.047	0.095
09/03/03	0.715	0.091	0.241	0.957	1.047
09/12/03	1.086	0.048	0.365	1.451	1.499
10/06/03	1.678	0.312	0.537	2.214	2.526
10/09/03	2.338	0.503	0.668	3.006	3.509
11/17/03	0.829	0.531	0.553	1.382	1.912
01/16/04	1.918	0.242	0.912	2.830	3.072
01/24/04	2.766	0.194	1.271	4.037	4.230
02/05/04	0.037	0.051	0.004	0.040	0.091
02/09/04	1.430	0.563	0.184	1.614	2.176
03/04/04	0.217	0.032	0.090	0.307	0.339
04/25/04	0.175	0.003	0.010	0.185	0.188
Sum	28.209	4.801	10.771	38.980	43.781

Table A 5 Continued

South Field					
Date	Dissolved TKN in SRO (kg/ha)	Dissolved NO3-N in SRO (kg/ha)	Sediment TKN in SRO (kg/ha)	TKN in SRO (kg/ha)	Total N in SRO (kg/ha)
10/07/02	0.085	0.034	0.026	0.111	0.146
10/19/02	0.583	0.219	0.156	0.738	0.957
10/21/02	0.442	0.128	0.140	0.581	0.710
10/24/02	0.556	0.103	0.128	0.684	0.787
10/28/02	0.176	0.032	0.079	0.256	0.288
11/04/02	2.485	0.224	0.326	2.811	3.034
11/26/02	0.115	0.036	0.027	0.142	0.178
12/04/02	0.794	0.132	0.153	0.947	1.079
12/09/02	0.644	0.116	0.092	0.736	0.852
12/19/02	0.062	0.002	0.019	0.081	0.084
12/23/02	0.375	0.056	0.120	0.495	0.552
12/30/02	0.986	0.072	0.254	1.240	1.312
01/11/03	0.541	0.063	0.064	0.605	0.668
02/06/03	0.095	0.027	0.016	0.111	0.138
02/20/03	3.405	0.423	0.677	4.082	4.505
03/03/03	0.134	0.017	0.016	0.150	0.167
06/04/03	0.190	0.042	0.251	0.440	0.482
06/05/03	0.162	0.027	0.122	0.285	0.312
06/12/03	0.097	0.018	0.144	0.241	0.259
06/13/03	0.313	0.112	0.349	0.662	0.774
06/15/03	0.389	0.044	0.250	0.639	0.683
06/26/03	0.058	0.022	0.044	0.102	0.124
07/04/03	0.289	0.412	0.065	0.354	0.766
07/07/03	0.042	0.006	0.020	0.062	0.068
07/09/03	0.094	0.010	0.041	0.134	0.144
07/11/03	0.073	0.003	0.015	0.088	0.091
07/16/03	0.002	0.001	0.001	0.003	0.003
08/21/03	0.760	0.035	0.190	0.950	0.985
08/31/03	0.122	0.131	0.012	0.134	0.266
09/03/03	0.668	0.045	0.085	0.753	0.798
09/12/03	0.561	0.101	0.155	0.716	0.816
10/06/03	0.607	0.293	0.142	0.749	1.042
10/09/03	1.101	0.084	0.220	1.321	1.405
11/17/03	0.260	0.107	0.105	0.365	0.472
01/16/04	0.531	0.155	0.137	0.669	0.824
01/24/04	1.330	0.211	0.149	1.479	1.690
02/05/04	0.040	0.035	0.006	0.046	0.081
02/09/04	1.309	0.773	0.116	1.425	2.198
03/04/04	0.222	0.024	0.047	0.268	0.292
04/25/04	0.186	0.101	0.069	0.255	0.356
Sum	20.880	4.477	5.030	25.910	30.386

Table A 6. Total N (TN) losses in surface runoff (SRO) from composted manure in the North field by subtracting the TN losses in the South field from the to TN losses in the North field.

Date	North Field TN in SRO (kg/ha)	South Field TN in SRO (kg/ha)	Manure Losses TN in SRO (kg/ha)
10/01/02	0.136	N.S.[1]	-
10/07/02	0.091	0.146	0.000
10/19/02	1.371	0.957	0.414
10/21/02	0.765	0.710	0.056
10/24/02	0.801	0.787	0.014
10/28/02	0.432	0.288	0.144
11/04/02	3.419	3.034	0.385
11/26/02	N.S.[1]	0.178	-
12/04/02	1.810	1.079	0.731
12/09/02	1.413	0.852	0.561
12/19/02	0.004	0.084	0.000
12/23/02	0.412	0.552	0.000
12/30/02	1.611	1.312	0.299
01/11/03	0.509	0.668	0.000
02/06/03	0.062	0.138	0.000
02/20/03	4.834	4.505	0.329
03/03/03	0.047	0.167	0.000
06/04/03	1.067	0.482	0.585
06/05/03	0.380	0.312	0.068
06/12/03	0.184	0.259	0.000
06/13/03	0.967	0.774	0.193
06/15/03	0.865	0.683	0.181
06/26/03	0.033	0.124	0.000
07/04/03	0.616	0.766	0.000
07/07/03	0.024	0.068	0.000
07/09/03	0.204	0.144	0.060
07/11/03	0.037	0.091	0.000
07/16/03	0.043	0.003	0.039
08/21/03	0.960	0.985	0.000
08/31/03	0.095	0.266	0.000
09/03/03	1.047	0.798	0.250
09/12/03	1.499	0.816	0.682
10/06/03	2.526	1.042	1.484
10/09/03	3.509	1.405	2.104
11/17/03	1.912	0.472	1.440
01/16/04	3.072	0.824	2.248
01/24/04	4.230	1.690	2.540
02/05/04	0.091	0.081	0.010
02/09/04	2.176	2.198	0.000
03/04/04	0.339	0.292	0.047
04/25/04	0.188	0.356	0.000
SUM	43.781	30.386	14.865

Table A 7. Mean dissolved TKN, Dissolved NO3-N, sediment TKN, Total TKN and total N concentrations in surface runoff (SRO) of the North and South turfgrass sod production fields from October 2002 to April 2004.

North Field					
Date	Dissolved TKN Concentration (mg /l)	Dissolved NO3-N Concentration (mg /l)	Sediment TKN Concentration (mg /l)	TKN Concentration (mg /l)	Total N Concentration (mg /l)
10/01/02	5.400	3.030	1.148	6.549	9.579
10/07/02	4.015	3.762	0.720	4.735	8.496
10/19/02	4.217	1.932	4.255	8.472	10.404
10/21/02	4.946	0.734	0.548	5.494	6.228
10/24/02	4.383	0.803	1.341	5.724	6.527
10/28/02	5.223	1.136	3.190	8.414	9.550
11/04/02	4.391	0.419	1.210	5.602	6.021
12/04/02	4.946	0.812	0.945	5.891	6.703
12/09/02	9.312	0.695	1.397	10.709	11.404
12/19/02	3.701	1.157	2.082	5.783	6.940
12/23/02	5.107	0.449	0.945	6.052	6.501
12/30/02	6.174	0.327	4.661	10.835	11.162
01/11/03	4.995	1.332	0.270	5.265	6.598
02/06/03	4.078	1.481	1.458	5.536	7.018
02/20/03	4.599	0.564	1.468	6.068	6.631
03/03/03	3.091	0.701	0.974	4.066	4.767
06/04/03	3.000	0.275	4.753	7.753	8.028
06/05/03	3.001	0.613	2.970	5.970	6.583
06/12/03	2.795	0.624	3.053	5.848	6.472
06/13/03	3.987	0.537	4.272	8.259	8.796
06/15/03	6.405	0.379	2.808	9.213	9.592
06/26/03	9.015	8.589	2.680	11.696	20.285
07/04/03	5.658	2.116	2.329	7.987	10.102
07/07/03	6.995	9.739	4.604	11.599	21.338
07/09/03	6.440	3.111	1.555	7.995	11.106
07/11/03	3.976	4.919	3.470	7.446	12.365
07/16/03	17.983	4.131	12.313	30.295	34.426
08/21/03	6.545	0.359	1.696	8.241	8.600
08/31/03	3.742	4.496	0.633	4.375	8.871
09/03/03	5.901	0.747	1.990	7.891	8.638
09/12/03	8.831	0.390	2.969	11.800	12.189
10/06/03	14.633	2.719	4.681	19.314	22.033
10/09/03	9.551	2.055	2.728	12.279	14.334
11/17/03	4.587	2.935	3.056	7.644	10.579
01/16/04	8.640	1.089	4.108	12.748	13.837
01/24/04	9.246	0.647	4.247	13.493	14.140
02/05/04	5.083	7.042	0.500	5.583	12.625
02/09/04	4.266	1.679	0.548	4.814	6.493
03/04/04	5.154	0.770	2.138	7.292	8.062
04/25/04	4.591	0.071	0.260	4.851	4.922
Total SRO Events	5.790	0.985	2.211	8.000	8.986

Table A 7 Continued

South Field					
Date	Dissolved TKN Concentration (mg /l)	Dissolved NO3-N Concentration (mg /l)	Sediment TKN Concentration (mg /l)	TKN Concentration (mg /l)	Total N Concentration (mg /l)
10/07/02	4.368	1.750	1.346	5.714	7.464
10/19/02	3.266	1.226	0.872	4.138	5.363
10/21/02	2.855	0.828	0.904	3.759	4.587
10/24/02	4.015	0.745	0.926	4.941	5.686
10/28/02	4.016	0.730	1.805	5.822	6.551
11/04/02	3.674	0.330	0.482	4.155	4.486
11/26/02	3.645	1.150	0.864	4.510	5.659
12/04/02	2.953	0.490	0.571	3.523	4.013
12/09/02	5.017	0.906	0.720	5.737	6.644
12/19/02	23.998	0.804	7.339	31.337	32.141
12/23/02	2.755	0.415	0.885	3.641	4.055
12/30/02	6.707	0.493	1.725	8.432	8.925
01/11/03	6.104	0.707	0.726	6.830	7.538
02/06/03	4.801	1.372	0.791	5.592	6.964
02/20/03	4.090	0.508	0.813	4.903	5.411
03/03/03	6.066	0.756	0.740	6.806	7.562
06/04/03	2.501	0.553	3.310	5.811	6.364
06/05/03	3.613	0.603	2.719	6.332	6.935
06/12/03	3.163	0.597	4.687	7.850	8.447
06/13/03	2.251	0.805	2.507	4.758	5.563
06/15/03	3.666	0.419	2.360	6.026	6.445
06/26/03	3.526	1.352	2.692	6.218	7.570
07/04/03	4.259	6.081	0.961	5.221	11.302
07/07/03	5.031	0.736	2.449	7.480	8.216
07/09/03	4.777	0.485	2.077	6.854	7.339
07/11/03	11.056	0.471	2.312	13.368	13.839
07/16/03	18.430	6.505	11.925	30.355	36.859
08/21/03	5.974	0.278	1.491	7.465	7.744
08/31/03	5.268	5.679	0.527	5.795	11.474
09/03/03	4.032	0.269	0.515	4.546	4.815
09/12/03	3.573	0.640	0.987	4.560	5.200
10/06/03	4.135	1.998	0.966	5.100	7.098
10/09/03	4.321	0.329	0.865	5.186	5.515
11/17/03	1.113	0.458	0.449	1.562	2.020
01/16/04	3.084	0.898	0.797	3.881	4.779
01/24/04	5.109	0.811	0.573	5.682	6.493
02/05/04	4.400	3.922	0.667	5.067	8.989
02/09/04	4.191	2.476	0.373	4.563	7.039
03/04/04	5.011	0.545	1.057	6.068	6.613
04/25/04	4.263	2.320	1.570	5.833	8.153
Total SRO Events	3.807	0.816	0.917	4.725	5.609

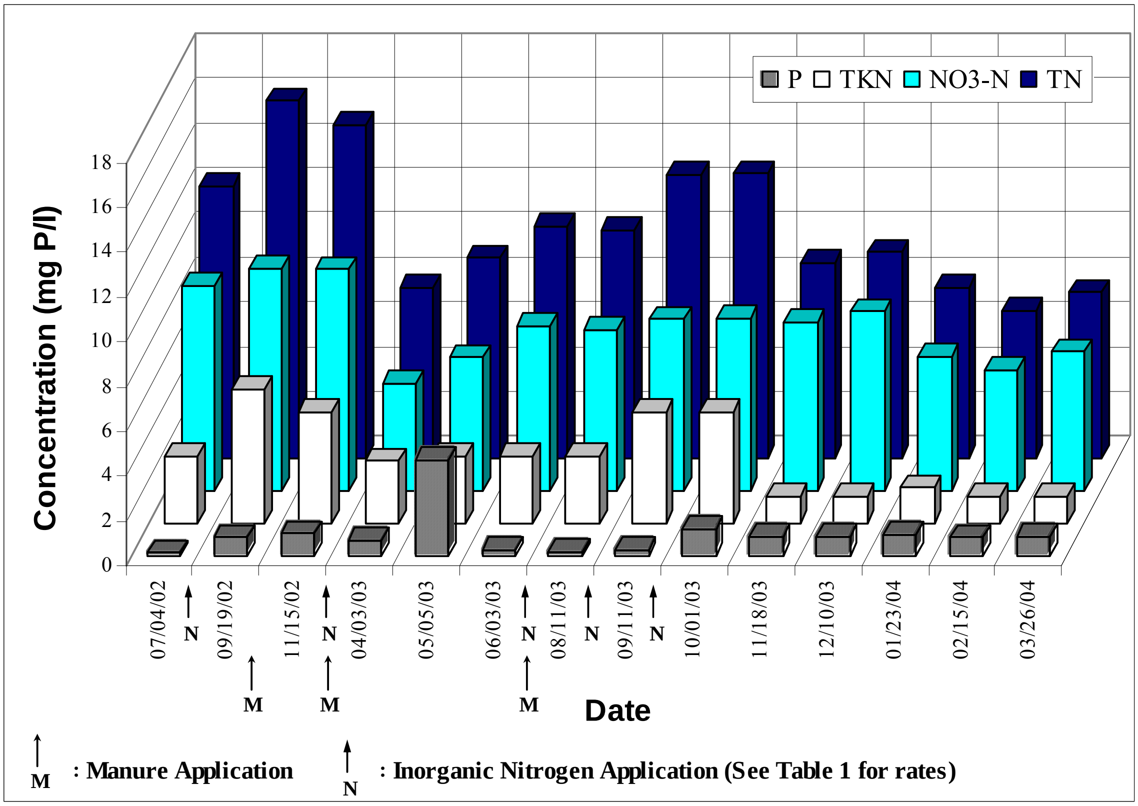


Figure A 1. The P and N (TKN, NO_3-N and TN) concentrations in the groundwater sampled at the monitoring well at the research site.

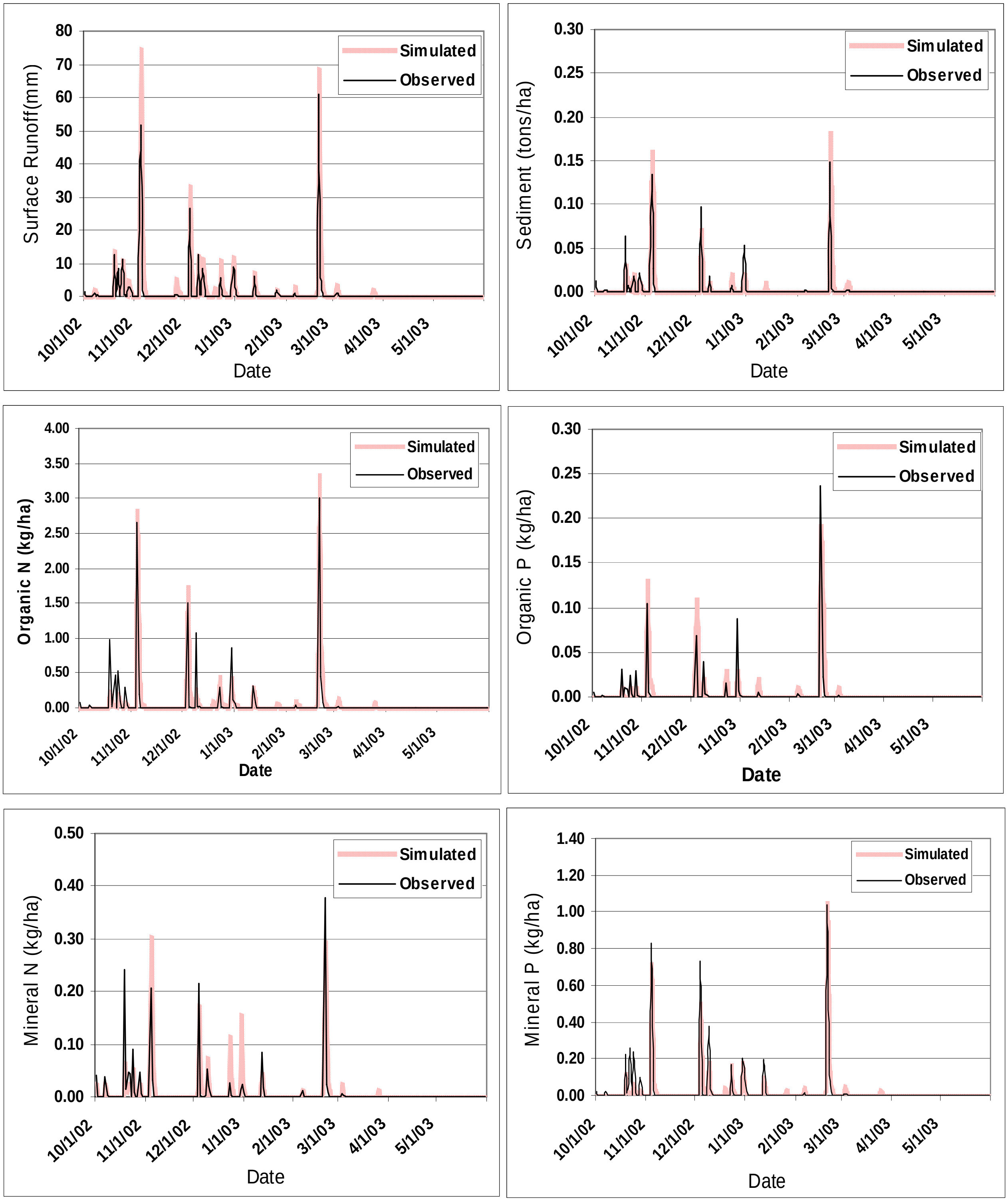


Figure A 2. SWAT model simulations of daily surface runoff, sediment and nutrient transport compared with observed values in the North field during the calibration period from October 2002 to May 2003.

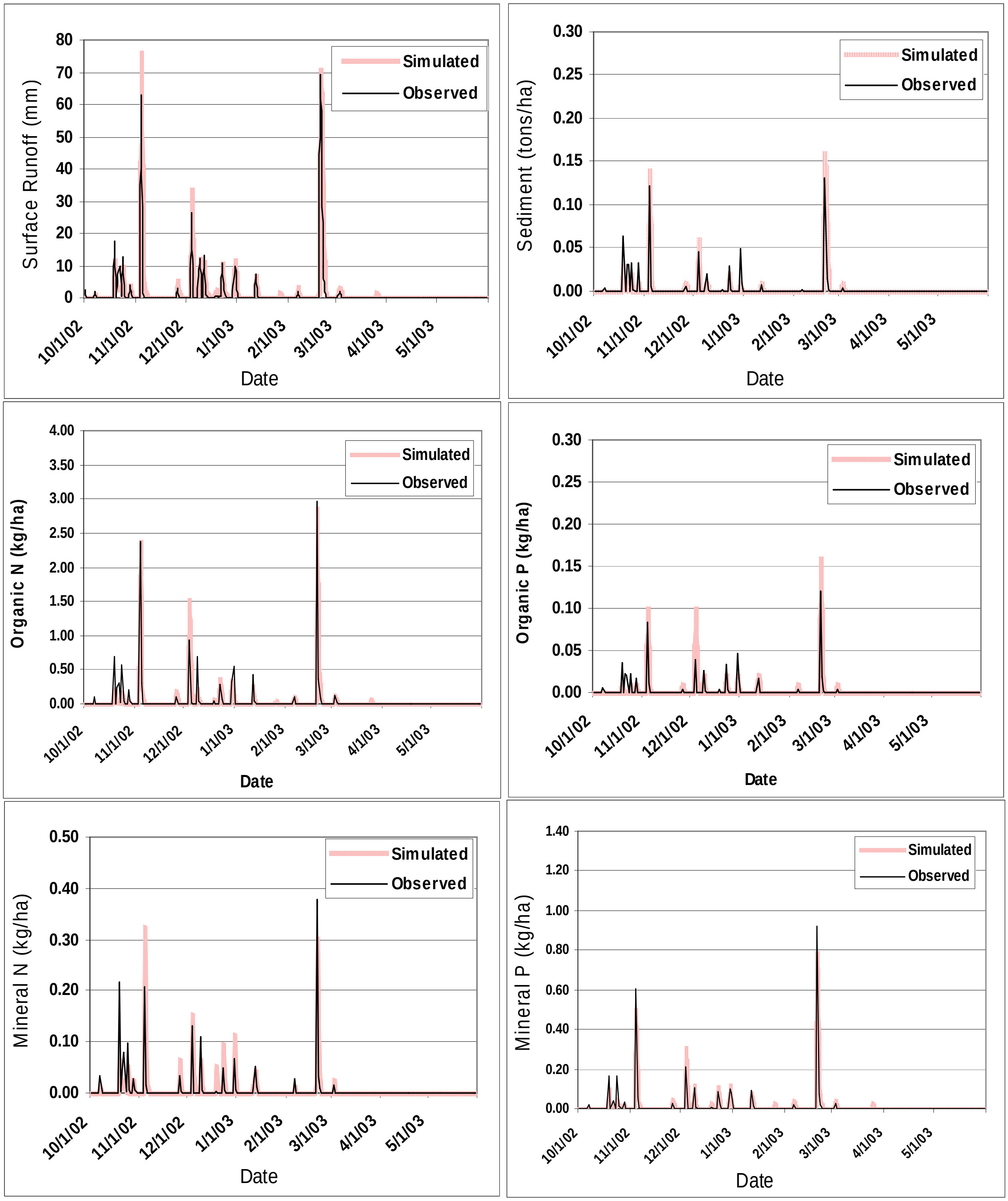


Figure A 3. SWAT model simulations of daily surface runoff, sediment and nutrient transport compared with observed values in the South field during the calibration period from October 2002 to May 2003.

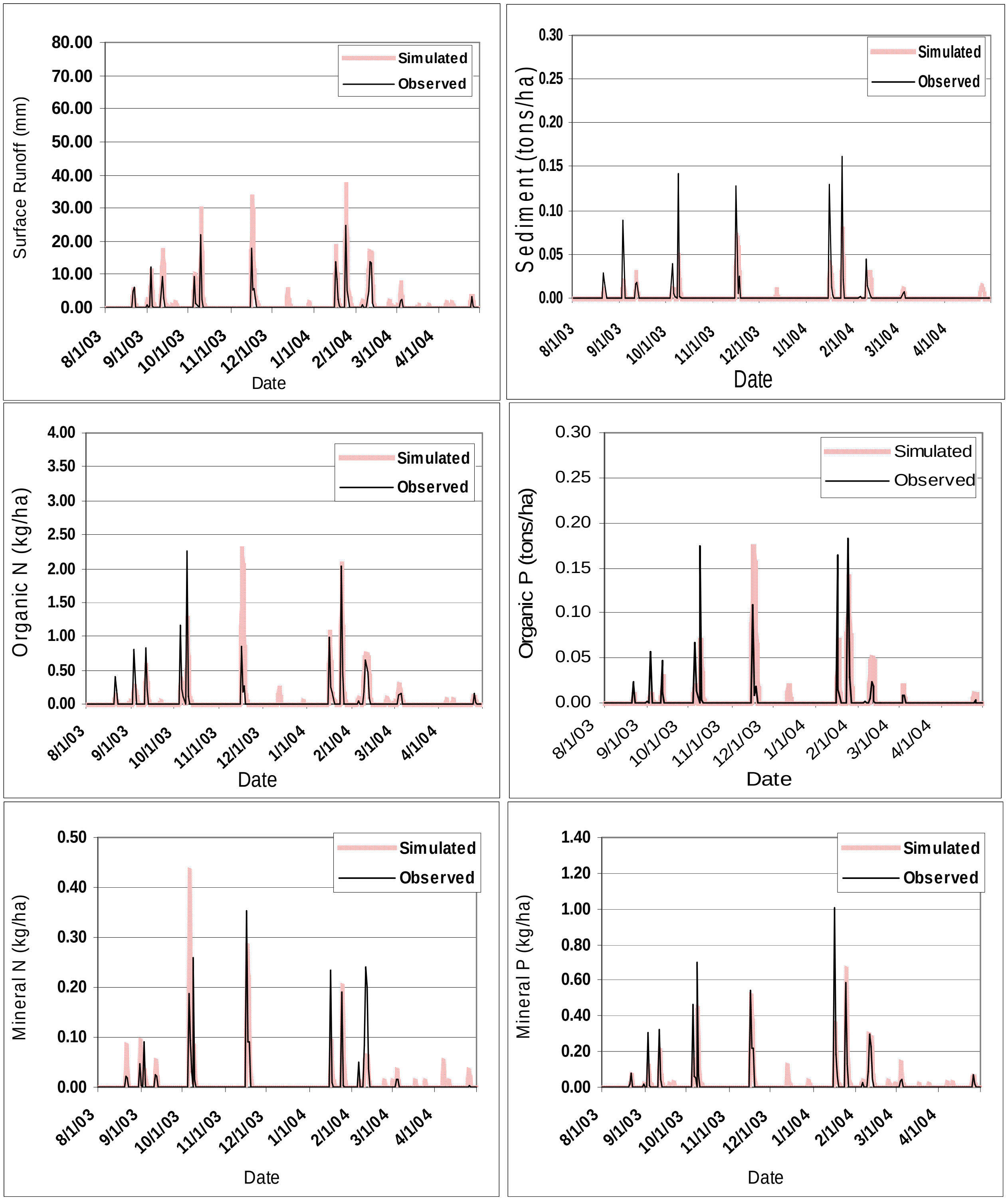


Figure A 4. SWAT model simulations of daily surface runoff, sediment and nutrient transport compared with observed values in the North field during the validation period from August 2003 to April 2004.

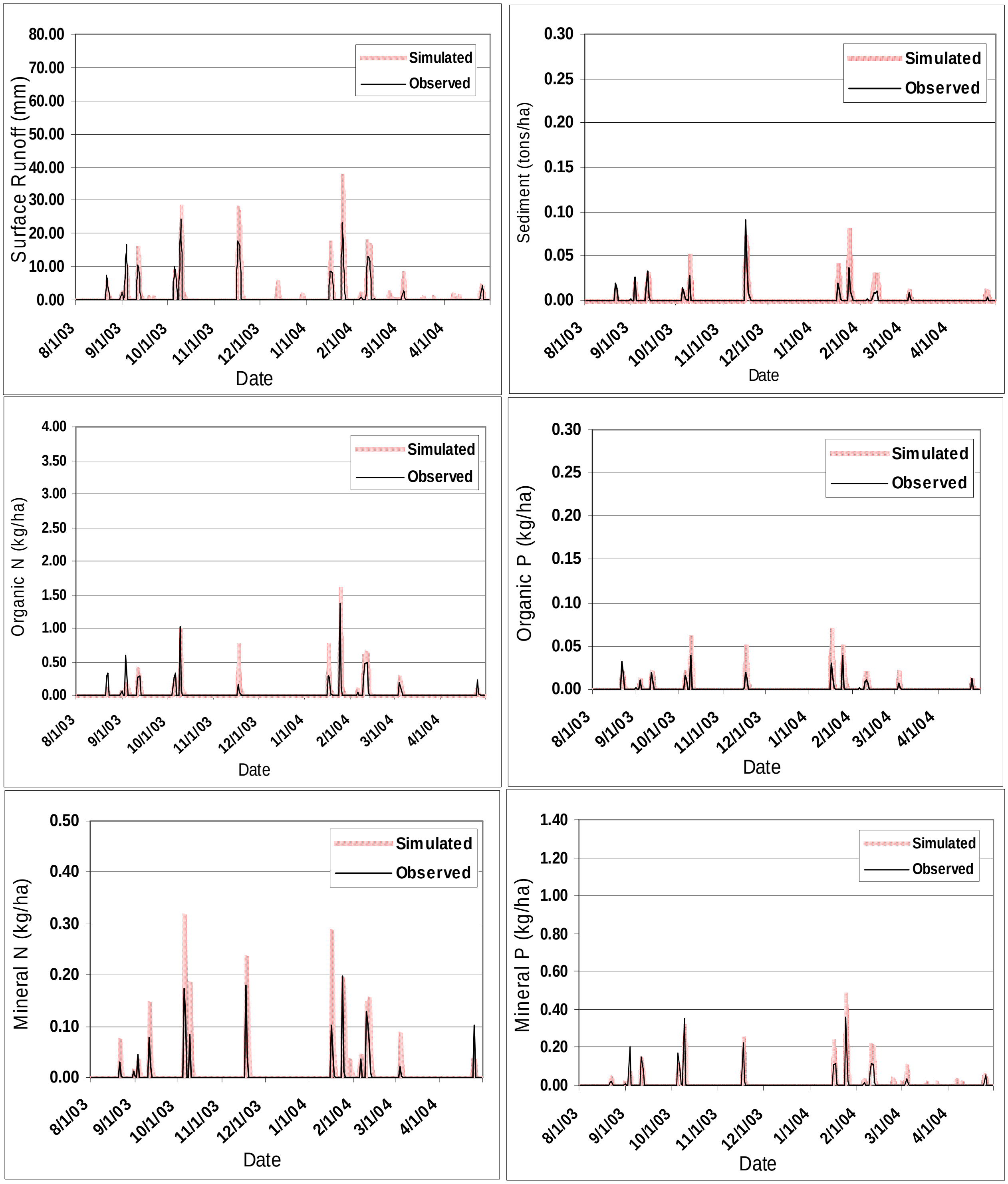


Figure A 5. SWAT model simulations of daily surface runoff, sediment and nutrient transport compared with observed values in the South field during the validation period from August 2003 to April 2004.

VITA

In Ho Choi

Permanent Address
116-3, Daehyun1-dong Buk-gu
Daegu, 702-041, Republic of Korea

Education

M.S. in Biological and Agricultural Engineering, August 2005
Texas A&M University, College Station, TX

B.En. in Environmental Engineering, August 2000
Yeungnam University, Kyungsan, Republic of Korea

Professional Experience

Graduate Teaching Assistant, Biological and Agricultural Engineering Department
Texas A&M University, College Station, TX, 2004-2005

Graduate Research Assistant, Biological and Agricultural Engineering Department
Texas A&M University, College Station, TX, 2002-2004

Civil Engineer, Duckyung Construction Co., LTD
Kyungsan, Republic of Korea, 2000-2001