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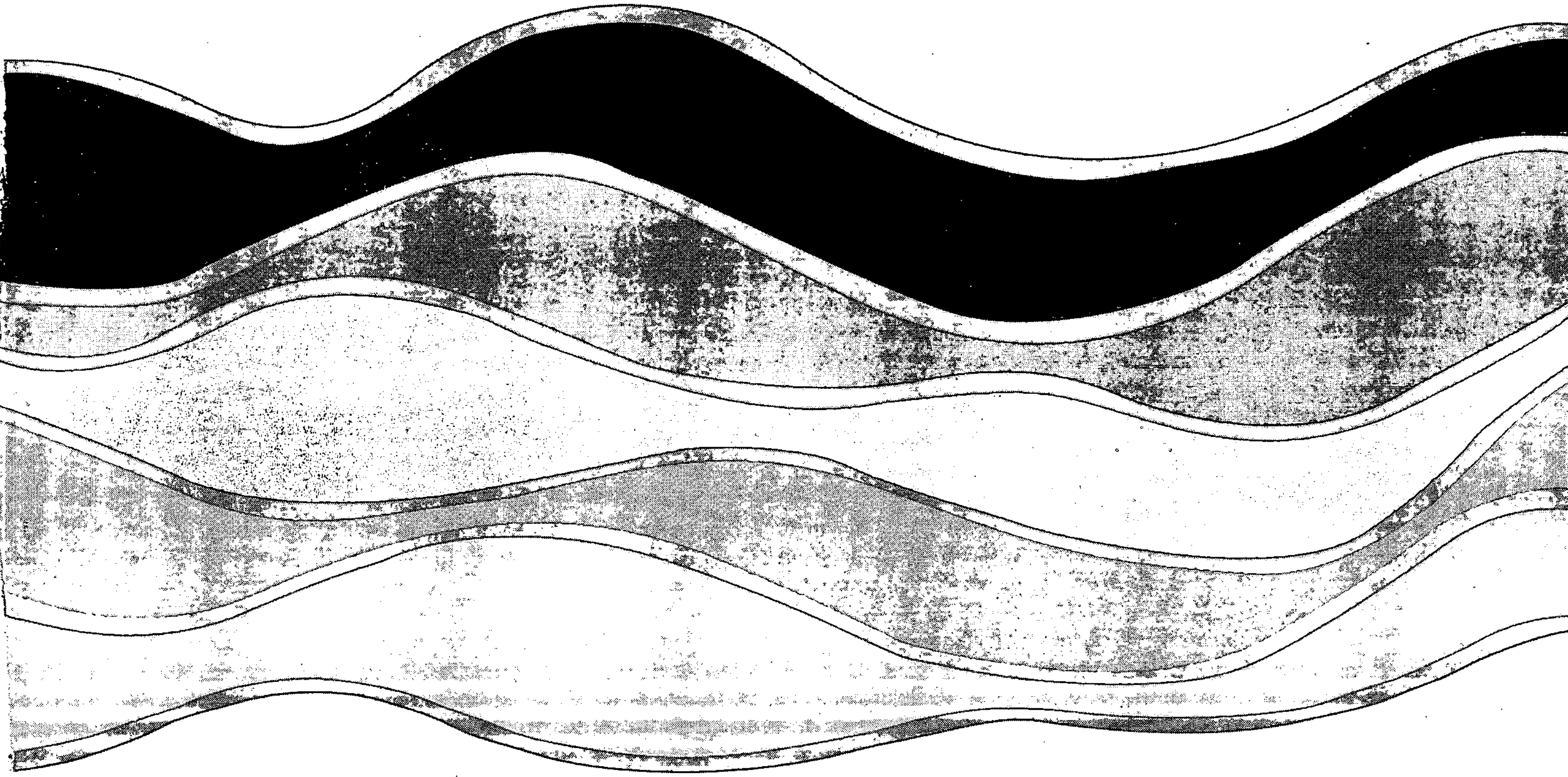

MODELLING AND TESTING OF THE EFFECT OF COMBINED TILLAGE, CROPPING AND WATER MANAGEMENT PRACTICES ON NITRATE LEACHING IN CLAY SOIL

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Modelling and Testing of the Effect of Combined Tillage, Cropping and Water Management Practices on Nitrate Leaching in Clay Soil

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MANAGEMENT PERSPECTIVE

The effect of combined tillage, cropping and water management treatment was investigated for nitrate leaching in a clay soil using field plots of factorial design.

The investigation was carried out by using the LEACHM model together with data collected from field plots of factorial design. The results of the investigation showed that the controlled drainage/subirrigation system would reduce nitrate leaching.

This report should be useful for on-farm management to abate nitrate pollution from agricultural land.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Les auteurs ont étudié, sur des parcelles au sol argileux, l'effet combiné du travail du sol, de la culture et de la gestion de l'eau sur le lessivage du nitrate, en appliquant un plan d'expérience factoriel.

La recherche reposait sur l'utilisation du modèle LEACHM et sur l'obtention de données recueillies dans des parcelles suivant un plan d'expérience factoriel. Ces travaux montrent que le drainage contrôlé et l'irrigation souterraine réduiraient le lessivage du nitrate.

Cet article peut aider à la gestion sur place de terres agricoles en vue de lutter contre la pollution par le nitrate.

ABSTRACT

Nitrate nitrogen from agricultural application has been identified as one of the nonpoint sources of pollution of surface and subsurface water. Numerous modelling and field investigations on occurrences of nitrate leaching have been well addressed. In contrast, on-farm schemes to control nitrate leaching from agricultural land are still lacking. In this study, a remedial experiment, using plot scale, to test the effect of combined tillage, cropping, and water management practices on nitrate leaching in clay soil was conducted. The arrangement of the experiment on plots comprised conventional tillage (MP) or conservation tillage (SS), with an intercrop (IC) or without intercrop (MC), under controlled drainage-subirrigation (CDS) or free drainage (FD) practices, in replication for a total of sixteen plots, on a 4 × 2 factorial design (i.e. MP, SS, IC and MC with a CDS system and MP, SS, IC and MC with a FD). A LEACHM model was used to examine the experimental data monitored at the plots. The mean differences between model predicted and measured values were used to determine the goodness of fit. When the mean difference between model predicted and measured values approaches zero, good match was obtained. The mean difference can be positive or negative. The average values of mean differences between model predicted and measured values corresponding to the combined management treatments of MP+IC, SS+IC, SS+MC, and MP+MC, with CDS system, respectively, were -0.618, -1.671, -1.357 and 0.333 mg/L. The average values of mean differences between model predicted and measured data, corresponding to MP+IC, SS+IC, MP+MC, and SS+MC, with FD system, respectively, were 7.475, 9.216, 12.677, 10.704 mg/L. The LEACHM model performed better prediction for nitrate leaching on plots under CDS system than on plots under FD. Both the LEACHM model predicted scenarios and field sampled data showed that CDS reduced nitrate leaching. Model calibration by using one full year of field data is acceptable, but for predictions based on shorter calibration records (part of the field season) produced unsatisfactory results.

RÉSUMÉ

L'azote des nitrates d'origine agricole est l'une des sources diffuses de pollution de l'eau superficielle ou souterraine. De nombreux travaux de modélisation et de nombreuses enquêtes sur le terrain portant sur le lessivage du nitrate ont donné des résultats intéressants. Cependant, les plans appliqués sur place de lutte contre le lessivage du nitrate sur les terres agricoles, sont inadéquats. Dans cette étude, une expérience à l'échelle de la parcelle avec des mesures correctives a permis de tester l'effet combiné du travail du sol, de la culture et de la gestion de l'eau sur le lessivage du nitrate dans les sols argileux. Les paramètres étaient le travail classique du sol (MP), ou le travail de conservation du sol (SS), avec culture intercalaire (IC) ou sans (MC), dans des conditions de drainage contrôlé et d'irrigation souterraine (CDS) ou de drainage non contrôlé (FD), toutes conditions répétées, pour un total de seize parcelles selon un plan d'expérience 4X2 (c.-à-d. MP, SS, IC et MC avec un système CDS, et MP, SS, IC et MC avec un FD). Un modèle LEACHM a été appliqué à l'examen des données d'expérience recueillies sur les parcelles. Les écarts moyens entre les prévisions du modèle et les mesures ont servi à déterminer le degré d'ajustement. Un écart moyen proche de zéro correspond à un bon ajustement. L'écart moyen peut être positif ou négatif. La valeur moyenne des écarts correspondant aux traitements combinés de MP+IC, de SS+IC, de SS+MC et de MP+MC, avec le système CDS, était de -0,618, -1,671, -1,357 et 0,333mg/L, respectivement. Celle correspondant aux traitements MP+IC, SS+IC, MP+MC et SS+MC, avec le système FD, était de 7,475, 9,216, 12,677 et 10,704mg/L, respectivement. Le modèle LEACHM a mieux prévu le lessivage du nitrate sur les parcelles soumises au régime CDS. Les prévisions du LEACHM autant que les résultats expérimentaux ont indiqué que le régime CDS réduit le lessivage du nitrate. L'étalonnage du modèle LEACHM au moyen de données sur le terrain portant sur une année complète est acceptable, mais il est insatisfaisant lorsqu'on emploie des relevés plus courts (correspondant à une partie de la campagne agricole seulement) pour le calcul de prévisions.

Introduction

Nitrate nitrogen is an essential nutrient for plants. Nitrate nitrogen promotes above-ground growth and produces the rich green color in leaves resulting from the production of chlorophyll. Much of this nutrient comes from reserves in the soil, but most soils do not have enough to meet the need of the crop during the growing season. Thus, the use of fertilizers or manure has become a standard crop production in agriculture practice.

Excess nitrate nitrogen in soil from fertilizer, livestock manure, or legume can make ground water unsafe to drink since the conversion of NO_3^- to NO_2^- can result in blood disorder (methaemoglobinemia), especially for infants, the elderly and young animals (Haynes, et al., 1986; Sittig, 1991).

The study of nitrate nitrogen pollution to lakes, rivers and groundwater from agricultural sources has been well documented (Porter, 1975; International Joint Commission, 1978, Coote et al., 1982; Great Lakes Water Quality Board, 1987; Jones and Schwab, 1992; Polglase, et al., 1995). The control scheme to abate nitrate nitrogen pollution from the agricultural areas is relatively lagging. To this end, a field plot experiment on control of nitrate losses was established to serve for data collection. The purpose of the experiment was to test the effect of combined tillage, cropping and water management practices on nitrate leaching.

Field data provide basic information for interpretation of experimental results of nitrate leaching. Field data are limited by its inflexibility as compared to mathematical modelling. In mathematical modelling, the values of the process parameters are adjustable for input to the model, for example, the parameters of molecular diffusion coefficient and the hydraulics conductivity. But both together may provide an in depth understanding of the on-farm control processes of nitrate leaching.

In this report, the LEACHM model (Hutson and Wagenet, 1989, 1992) together with data monitored in field plots were used to evaluate the effect of nitrate leaching, under a scheme of combined tillage, cropping and water management practices. The objective of this study was to identify which combination of the management practices would result in reducing nitrate leaching.

Materials and Methods

Experimental Design

The experimental design was a combination of management practices including conventional tillage, conservation tillage, mono-cropping, inter-cropping, free drainage and controlled drainage-subirrigation.

The experimental field plot is located in south western Ontario, at Eugene F. Whelan Experimental Farm (Agriculture and Agri-Food Canada, Woodslee, Ontario). The field plot configuration has been reported elsewhere (Tan et al., 1993; Drury et al., 1996). Its description is briefly repeated here for convenience. The layout of the field plot design (Figure 1) consists of sixteen plots each 15 m wide by 67 m long with an area of 0.1068 ha (including berm). Each plot, isolated by a 4 mil plastic barrier from the surface to a depth of 1.2 m, contains two 104 mm diameter tile drains, arranged in parallel, 60 cm from the surface at 7.5 m spacing. The slope of the subsurface drain is 0.08%. The arrangements of the experiment on plots comprise tillage type, controlled drainage-subirrigation and type of crop, in replication for a total of sixteen plots (Figure 1).

Management Treatments, Planting, Fertilizer and Herbicide Applications

The experiment was initiated in the spring of 1991 on a Brookston clay soil. The combined treatments were mouldboard plowed tillage with monocrop (MP+MC), mouldboard plowed tillage with annual ryegrass intercropped (MP+IC), soil saver (chisel plowed) tillage with monocrop (SS + MC) and soil saver tillage with annual ryegrass intercrop (SS + IC). The water management practices were free drainage (FD) and controlled drainage-subirrigation (CDS). Thus, there were four crop-tillage management treatments and two water management treatments in a factorial design.

The corn (*Zea* mays L., Pioneer 3573) was seeded at a rate of 65,000 seeds per hectare in rows with a Kinze 4 row planter. The width between seed rows was 75 cm. Fertilizer (8-32-16) was banded beside the seed at a rate of 132 kg/ha. Annual ryegrass intercropped was seeded within corn rows at 14 kg/ha with a Brillion seeder. Side dressing of urea (46-0-0) was applied with a brush applicator of custom design at the six-leaf stage.

The rate of urea side dressing in 1992 to 1994 was based on the average NO_3^- test of soil samples collected on the day of planting.

Atrazine (6-chloro-*N*-ethyl-*N′*-(1-methylethyl)-1,3,5-triazine-2,4-diamine), metolachlor (2-chloro-*N*-(2-ethyl-6-methyl-phenyl)-*N*-(2-methoxy-1-methylethyl) acetamide), and metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one) were banded over the corn row immediately after planting to control weed.

The year, date, rate of fertilizer application and rate of urea side dressing are presented below:

Year	date	Fertilizer (8-32-16) (kg N/ha)	Urea side dressing (46-0-0) (kg N/ha)
1991	June 13 (seeding)	10.56	
	July 04		115.00
1992	May 14 (seeding)	10.56	
	June 29		141.22
1993	May 17 (seeding)	10.56	
	June 16		189.50
1994	May 13 (seeding)	10.56	
	June 21-22		170.70

Water Sampling and Flow Measurement of Surface Runoff and Tile Drainage Water

Water samples from surface runoff and from tile drainage were collected automatically with 32 autosamplers (CALYPSO 2000S), Buhler Gmbh & CO.) stationed in the instrumentation building. The autosampler was activated by the water meter sensor mentioned earlier, based on a predetermined setting of flow volume. The setting of flow volume to activate an autosampler to collect a sample ranged from 500 to 3000 L depending on the time of year.

Volumes of surface runoff and tile drainage water from the sixteen plots were measured in the instrumentation building (Figure 1) equipped with 32 sumps. Surface runoff and the tile drainage water from the individual plots flow into the respective sumps. Each sump is equipped with a float sensor to activate the sump to pump through a meter gauge into an outlet drain when there are surface runoff and tile drainage water flows into the sump. A multichannel datalogger was used to monitor and store the water meter signals. The data stored in the datalogger were converted into flow volumes using a computer.

Measurements of Soil Properties

Soil samples collected at 25, 45, 80 and 120 cm depths from each plot were analyzed for field capacity, permanent wilting point, and particle size distribution. Soil moistures at depths 20, 40, 60, 80 and 100 cm were measured during the growing season using soil moisture probe or Time Domain Reflectometry (TDR). Soil temperatures at depths 5, 10, 25, 40 and 60 cm were monitored year round using a soil temperature probe. Hydraulic conductivity was measured using an auger hole method and averaged over 0 - 120 cm depth. The soil organic carbon was laboratory determined from soil samples collected at 0 -15 cm depth, using Carbon Determinator. Soil samples at 20 cm depth increments to 100 cm were taken in spring and fall, analyzed for NH_4^+ -N and NO_3^- - N, and soil samples were taken from 0 - 30, 30 - 60 cm depths at 0, 3, 7, and 42 days after N application, and analyzed for NH_4^+ -N and NO_3^- -N. The concentrations of NH_4^+ -N and NO_3^- -N were determined using a TRAACS 800 autoanalyzer.

The dominant soil series, described as Brookston clay loam, is a poorly drained soil.

Analysis of Water Samples for Nitrate Concentration

Water samples were stored in glass bottles at 4 °C prior to analysis for concentrations of nitrate. Surface runoff and tile drainage samples filtered through a 0.45 µm filter (Gelman GN-6, Gelman Sciences, MI) were analyzed on a TRAACS 800 autoanalyzer (Bran + Leubbe, Buffalo Grove, IL) for nitrate using the cadmium reduction method (Tel and Heseltine, 1990, Drury, et al., 1996).

Flow weighted nitrate concentrations were calculated from the sum of nitrate loss divided by the sum of the nitrate loss over the study period from 1 Nov. 1991 through 31 Oct. 1994 divided by the sum of the total flow volume.

The LEACHM Model

Model Capacity

LEACHM model (Leaching Estimation And Chemistry Model) is a process-based model developed by Hutson and Wagenet (1989; 1992) that describes the water and solute movement, transformation, plant uptake and chemical reactions in unsaturated soils to a maximum depth of two metres. The model applies numerical solution techniques to the Richard's water flow equation (Hutson, 1983) and the convection dispersion equation (CDE) using finite difference methods. The LEACHM contains four modules:

(i) LEACH-W simulates only the water regime,
(ii) LEACH-N simulates nitrogen transport and transformation,
(iii) LEACH-P simulates the pesticide displacement and degradation, and
(iv) LEACH-C simulates the transient movement of inorganic ions.

The following inputs are common to all of the four modules.

- Soil properties and initial conditions for each soil segment:
  water content or water potential,
  hydrological constants for calculating retentivity and hydraulic conductivity or particle size distribution, and
  appropriate chemical contents and soil chemical properties for each version.
- Soil surface boundary conditions of :
  irrigation and rainfall amounts and rates of application,
  mean temperatures and diurnal amplitudes (weekly means), if a temperature simulation is required, and
  potential evaporation (weekly totals).
- Crop details (control variable will bypass if no crops are present):
  time of planting,
  root and crop maturity and harvest,
  root and cover growth parameters, and
  soil and plant water potential limits for water extraction by plants.
- Other constants used in determining lower boundary conditions, time steps, dispersion and diffusion coefficients, chemical reactions and transformation and output details. Some of

these constants rarely require alteration, and they are listed in the data files to define their value for the user and provide the option for change.

Model Limitations

There are limitations in LEACHM model. The model is not applicable to the following conditions:

- profiles with unequal depth increments,
- prediction of runoff water quantity and quality,
- simulating plant responses to soil or environmental changes,
- prediction of crop yields,
- transport of immiscible fluids,
- solute distributions and transport in 2 and 3 dimensional flux patterns,
- runoff water effects on management practices and nitrate leaching are not simulated by the model, and
- the model does not take into account macropore effects.

Model Input and Initial Values

In order to apply LEACHM model, the soil profile was divided into three horizontal segments of equal depths: 0-0.2, 0.2-0.4, 0.4-0.6 m. Since the available data were measured at the soil surface and 0.6 m drain depth only, intermediate data were either interpolated or approximated from the measured data. These data include water table depths, nitrate-N (NO_3^-N) concentrations, soil properties, and hydrologic parameters. As far as possible, the data measured in December 1991 were used as initial values for January 1992 and those measured in December 1992 for January 1993. The water table depths, surface soil temperature, and evaporation data were summarized to fit the weekly input format.

The initial NO_3^--N soil profile concentrations expressed in mg/kg dry soil were calculated from the drain water concentrations according to the equation (1):

$$[NO_3 - N]_s = \frac{[NO_3 - N]_w}{\frac{\rho}{wc}} \quad (1)$$

where

$[NO_3^- \text{-}N]_w$ = NO_3^--N concentration in mg/L water,

$[NO_3^- \text{-}N]_s$ = NO_3^--N concentration in mg/kg dry soil,

ρ = Bulk density of the soil layer, g/cm^3, and

wc = Volumetric water content, cm^3/cm^3.

This procedure assumes that the NO_3^--N concentration in the soil profile is equal to that in the drain water. This assumption may not always be true, but it gives good estimates in situations where measured data are not available.

Model Calibration and Prediction

The calibration and prediction were carried out in two sequences. The first sequence was that the data for 1992 were used to calibrate the model and do sensitivity analysis of model's key parameters. Available observed data between January and December 1992 were used in the calibration processes. The second sequence was that the datasets of 1993-1994 were used for validation of the calibrated parameters of the model. It has been suggested that it is a generally acceptable procedure (Donigian, 1983) to calibrate simulation models using one year's data and then apply the calibrated parameters to subsequent periods.

Results and Discussion

Calibration of Parameters

The calibration process was used to obtain initial values for model parameters that would give estimated NO_3^--N concentrations closest to the observed values in the drain flow. The main parameters were the transformation rate constants for urea hydrolysis, ammonia nitrification, and the denitrification processes. Also, included in the calibration were the molecular diffusion coefficient (D_o), which accounts for the movement of solute in response to aqueous concentration gradients, and the dispersivity (λ), which describes the effects of the soil porosity on the overall solute transport. Since saturated hydraulic conductivity and soil bulk density are the major parameters used by LEACHM to distinguish between tillage practices, these parameters were included in the calibration process. Incidentally the field measurements did not provide conductivity values for each soil layer which would enable direct distinctions of MP effects and the SS practices. The saturated conductivity (K_s) and soil bulk density measured in 1991for field plots are listed in Table 1. The MP practice exerts greater disturbance to the soil than the SS which results in greater porosity in the tilled layer. This results in higher hydraulic conductivity for soil under MP treatment (Table 1).

Table 1. Saturated hydraulic conductivity (K_s) and soil bulk density for field plots (1991)

Duplicate Plots No.		1&13	2&14	3&15	4&16	5&9	6&12	7&10	8&11
Management practices		MP-IC CDS	MP-IC FD	SS-IC CDS	SS-IC FD	MP-MC FD	SS-MC FD	SS-MC CDS	MP-MC CDS
K_s (mm/day)		58.0	30.5	36.5	24.5	52.5	26.0	65.0	93.5
Bulk density (g/cm^3)	0-25 cm	1.18	1.18	1.22	1.22	1.18	1.22	1.22	1.18
	25-60 cm	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46

Sensitivity Tests for Selected Parameters in LEACHM Model

Parameters are necessary components in a process model because they play the role of accuracy in matching between the output values of the model and the actual measured values. The matching of output values of the model to the actual measured values is achieved by means of adjusting the model parameters and then comparing the output values of the model to the measured values. In this study, the parameters of molecular diffusion coefficient, dispersivity, hydraulic conductivity, soil bulk density and urea hydrolysis in LEACHM model are considered to be the key parameters in influencing model output. Such parameters in LEACHM model were selected together with observed data from plots 1 & 13 under MP-IC-CDS and plots 2 & 14 under MP-IC-FD management practices, for sensitivity tests. The initial values contained in plots 1 & 13 and 2 & 14 are presented in Table 2a and Table 2b.

Initial tests indicated that the model did not respond to effects of varying calibration parameters in the winter period. The urea hydrolysis constant was varied between 0.1/day and 0.4/day, nitrification constant between 0.1/day and 0.3/day, and denitrification between 0.1/day and 10/day. After urea side dressing application on the 29th June 1992, a hydrolysis value of 0.4 /day increased NO_3^- - N concentrations in drainage water and by the December it was 10 times more than the observed. When the nitrification was increased to 0.3/day, the simulated NO_3^- - N concentrations increased 7 times between June and December. Values of denitrification above 0.1/day had no noticeable effects on simulated concentrations in the free drainage treatments. This is probably due to the drier soil conditions that exist under free drainage. After several trials, values of 0.36, 0.1, 0.1/day were chosen for urea hydrolysis, nitrification, and denitrification processes, respectively. The model predictions showed no increase in urea hydrolysis for all runs following the application of urea, but a gradual increase in the predicted output between July and December. This may suggest that the model assumes the hydrolysis of urea is continuing. Increasing the hydrolysis rate, however, tended to increase the deviation of the predicted NO_3^- - N leaching from the observed one.

The sensitivity of the model to molecular diffusion coefficient was tested using D_o values of 60, 120, and 150 mm^2/day. Using these values, no significant differences were observed in the simulated leaching. Since it is rare to encounter D_o values of 150 mm^2/day in the field (Van Der Ploeg, et al., 1995; Schulin et al., 1987), higher values were not tried. The model was not sensitive to dispersivity (λ) values between 10 and 80 mm, the range in which the model underestimated leaching, but a λ value of 120 mm increased the nitrate leaching by almost 10 times, resulting in better predictions.

Increasing the soil bulk density between 1.0 and 1.30 g/cm^3 tended to decrease leaching after fertilizer application on 14 May, 1992, but its effects were not noticeable in the winter period. Increasing the saturated hydraulic conductivity between 10 and 100 mm/day resulted in about 50% reductions in leaching in the winter, but in the summer a K_s value of 100 mm/day resulted in as high as 10 times increase in leaching. These observations underscore the need to have measured data for these parameters, especially in cases where tillage practices are important.

Other parameters found to be important in LEACHM performance include precipitation rates, water table depths, and evaporation rates. Precipitation rates in the range of 100 mm/day, representing precipitation duration of 2 to 4 hours, gave better leaching estimates. LEACHM assumes that no evaporation occurs during precipitation. It was also not possible to differentiate between snowmelt and actual rainfall from the available dataset.

Under free drainage conditions, the model predictions showed no increase in urea hydrolysis after urea application in June 29, 1992. The model predictions tended to deviate more from the observed data starting in June toward the end of the simulation period in December.

Parameter Values for Model Prediction of Scenarios

The values of the parameters for prediction of scenarios are listed in Table 3. These values were chosen after the calibration runs of the model. They gave the best estimates for nitrate leaching for 1992 period. The simulated results and observed values, using 1992 data, are plotted in Figures 2 and 3.

Table 3. Key parameters selected from LEACHM for calibration and simulation

Parameter definition	symbol, unit	value
Crop management		
Plant uptake	kg/ha	102/167[1]
N fertilizer application rate	kg-N/ha	10.56
Urea application rate	kg-N/ha	141.22/189.5/170.7[2]
Rate constants		
Denitrification	day^{-1}	0.1
Half saturation (at 50%)	mg/L	10
Urea hydrolysis	day^{-1}	0.36
Nitrification	day^{-1}	0.1
Soil		
Soil layer thickness	m	0.2
Molecular diffusion	mm^2/day	120
Dispersivity	mm	120
Aev value in Campbell's equation	kPa	-0.1
Value of b in Campbell's equation	--	3.0/3.5/4.0[3]
Soil Temperature response Q_{10} factor	--	3
Soil moisture response		
Saturation activity	--	0.6

[1] corn/annual ryegrass uptake, respectively.
[2] rates for 1992/1993/1994, respectively.
[3] soil layers: 0-0.2/0.2-0.4/0.4-0.6 (m).
Aev = air enter value (Hutson and Case, 1987).
Q_{10} factor = soil temperature response to a 10 ° C change of optimal temperature.

Prediction of Nitrate Leaching Scenarios

The results of simulation of the nitrate leaching by LEACHM, using the parameters listed in Table 3 together with the observed data for the 1993 and 1994 periods are plotted in Figures 4 and 5. The results indicated that the model performed well under CDS conditions, but under free drainage conditions (FD) the model overestimated NO_3^--N leaching. The deviation becomes more pronounced with time, especially after N application and progresses in the summer months throughout the fall, winter and spring to the following summer of 1994 (Figure 5). This overestimation may be caused by the inability of the model to distinguish between snowmelt and rain or subirrigation. In such a situation the model may predict larger flows through the soil resulting in increased NO_3^--N transport to the drains. It is possible that the model simulated drier soil profile conditions which inhibit denitrification, and subsequently lead to higher N amounts in the soil available for leaching. Khakural and Robert (1993) performed tests on LEACHM-N and found satisfactory results on the total leaching of NO_3^--N from the soil profile. However, Jemison et al. (1994) found that LEACHM-N performed well when the rate constants were calibrated for each year, a requirement that would be time consuming.

Under CDS conditions, there were no differences in model performance between MP and SS tillage systems with IC, but the model overestimated leaching between February and August 1994 under MP-MC treatments. Overall the model is not sensitive to immediate leaching following fertilizer applications after 17 May, 1993 (Figure 4), the date when fertilizer was applied. In Figure 4, the model predicted nitrate concentration was lower than the observed one. The model output indicated that the SS tillage system would reduce nitrate leaching. This is expected because the MP tillage system induces greater conductivity that enhances leaching.

Under FD conditions, the model predicted highest nitrate leaching in MP-MC treatment, and no notable differences between MP-IC, SS-IC and SS-MC. In all treatments, the model overestimated the NO_3^--N leaching, with greater deviations occurring after September 1993. A further calibration, using consecutive multi-year data may be required for the model to perform better in each case.

Mean Differences between Model Prediction and Field Observation

There are several methods that can be used for evaluating the fit between the model predicted and the field measured values. These methods are tests of means and variances, analysis of variances, mean differences between model predicted and measured values, and goodness of fit (Donigian, 1983; Harrison, 1990; Loague and Green, 1991; Power, 1993). In this study, the method of mean differences between model predicted and measured values, equation (2) was used.

$$M = \frac{\sum_{i=1}^{i=n} (O_i - P_i)}{n} \qquad (2)$$

where M (mg/L) is the mean differences between the model predicted and the field observed values, n is the number of observations, and O_i and P_i are individual observed and predicted values (mg/L) respectively. According to equation (2), values of M can be positive or negative. Thus when the value of M (mg/L) approaches zero, good match between model predicted and observed values was obtained.

The results of calculation of M (mg/L) for the model predicted and observed nitrate concentrations under a combined tillage, cropping and water management, using equation (2) for the study years of 1992 to1994 are presented in Table 3. In addition, an overall average of the M (mg/L) nitrate concentrations was calculated for each study year of the eight duplicated plots, regardless of the various combination of treatments applied on the duplicated plots. The overall average of M (mg/L) for nitrate concentrations for the years of 1992, 1993 and 1994, respectively, was 1.261, 1.282 and 11.241 mg/L. These values are shown in the rightmost column of Table 3. Furthermore, an average of the three years (1992, 1993 and 1994) of M (mg/L) for nitrate concentrations was calculated for each of the eight duplicated plots. The three-years average of M (mg/L) for nitrate concentrations for the duplicated plots of 1&13, 2&14, 3&15, 4&16, 5&9, 6&12, 7&10, and 8&11, respectively, was -0.618, the 7.475, -1.671, 9.216, 12.677, 10.704, -1.357 and 0.332 mg/L. These values are shown in the bottom row of Table 3. A comparison of the overall average of the M (mg/L) for nitrate concentrations between 1992 and 1993, for the simulation periods from January to December (Table 3), showed no significant difference (1.2%). However, by comparing the overall average of M (mg/L) for nitrate concentrations between 1994 and 1992 or 1993, the M (mg/L) of nitrate concentrations in 1994 was significantly larger than the M (mg/L) of nitrate concentrations of both years of 1992 and 1993. This was interpreted as that model was underestimating the nitrate concentrations of 1994. The simulation period for 1994 was from January to August. This may suggest that the modelling of NO_3^--N leaching in an agricultural area, using a dataset covering only a partial period of the year (January to August) would produce inaccurate results because the model assumed that there was no nitrate loss from the field for the rest of months from September to December. Higher nitrate leaching during the noncropped period both in surface runoff and in tile drainage was observed (Drury et al., 1996). In temperate regions, the cropping period usually occurs between May through October of the year. Thus the underestimation of nitrate leaching by the model appeared to be caused by the missing noncropped period (September to December) in the simulation.

Table 3 also showed that LEACHM model performed better prediction on plots under CDS treatments, that is all the values of mean differences between model predicted and measured nitrate concentrations under CDS are smaller than the values of mean differences between model predicted and measured nitrate concentrations under FD. The three-year averages of M (mg/L) of nitrate concentrations under CDS for MP-IC-CDS, SS-IC-CDS, SS-MC-CDS, and MP-MC-CDS, respectively, were, -0.618, -1.671, -1.357, and 0.332 mg/L (Table 3). Both the model predicted scenarios and the field measured nitrate concentrations showed that CDS decreased NO_3^--N leaching.

Table 3. Mean differences between the model predicted and observed nitrate concentrations (mg/L) under a combined tillage, cropping and water management practices.

Plots	1&13	2&14	3&15	4&16	5&9	6&12	7&10	8&11	Overall
Treatments	MP-IC-CDS	MP-IC-FD	SS-IC-CDS	SS-IC-FD	MP-MC-FD	SS-MC-FD	SS-MC-CDS	MP-MC-CDS	Average M (mg/L)
Jan-Dec 1992 M (mg/L)	-0.072	0.776	-3.675	1.685	9.033	5.843	-2.645	-0.854	1.261
Jan-Dec 1993 M (mg/L)	-2.207	3.087	-1.798	5.950	2.464	6.255	-2.033	-1.462	1.282
Jan-Aug 1994 M (mg/L)	0.426	18.561	0.461	20.014	26.534	20.015	0.608	3.312	11.241
3-year Mean	-0.618	7.475	-1.671	9.216	12.677	10.704	-1.357	0.332	

M (mg/L) = mean differences between model predicted and measured values.

Conclusions

The simulated results indicate that free drainage (FD) management systems would result in higher nitrate leaching where plots under controlled drainage and subirrigation (CDS) showed reduced nitrate leaching. The LEACHM model also performed better prediction for nitrate leaching on plots under CDS than on plots under FD. The field plots under CDS showed smaller values of mean differences between model predicted and measured values than the field plots under FD. The calibration process using a one year of data appeared to be acceptable. However, calibration with data representing only a part of the year did not produce satisfactory results. This implies that nitrate leaching is a matter of seasonal cycle.

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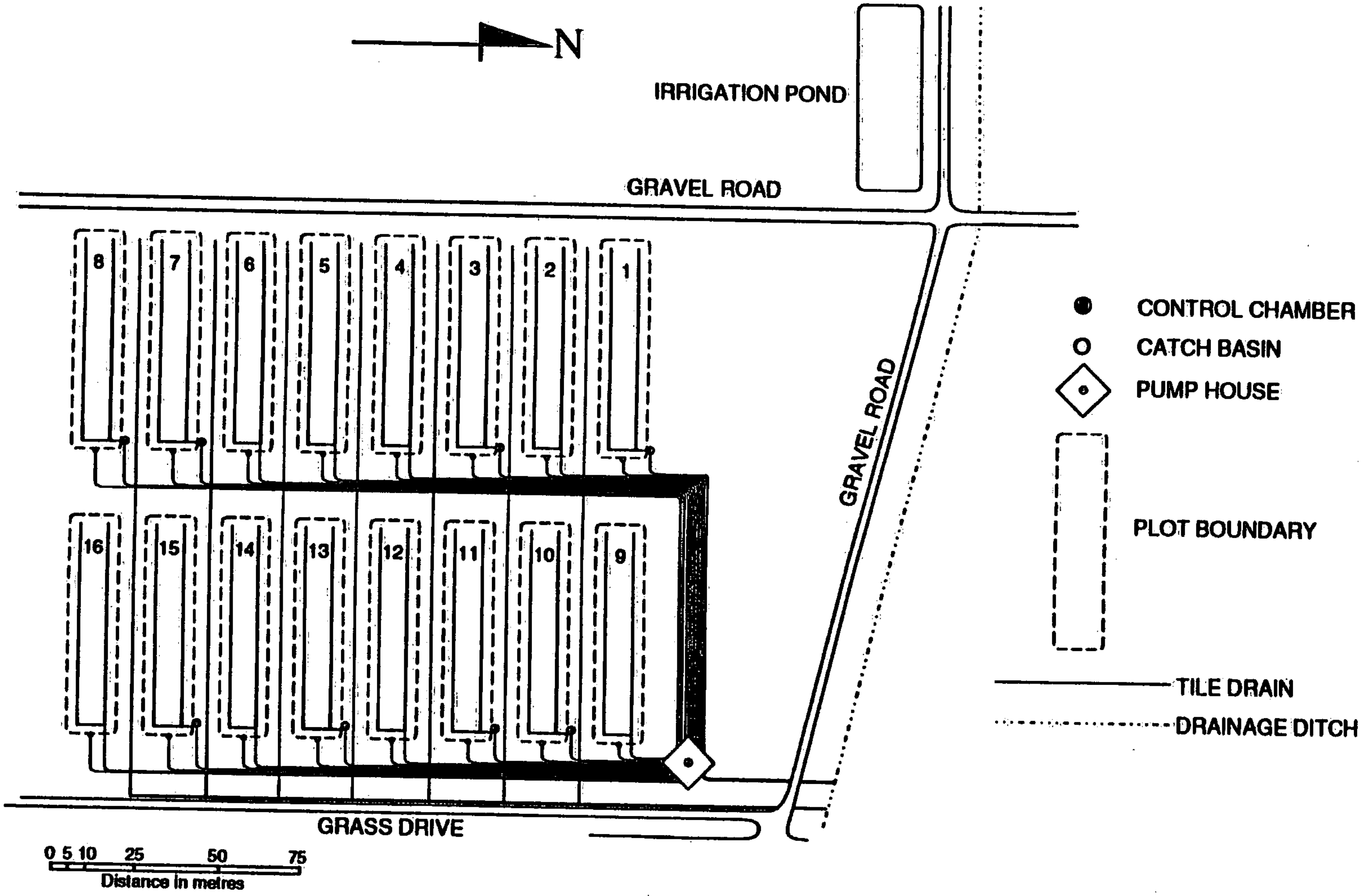
Figure 1. Experimental plot and drainage layout system.



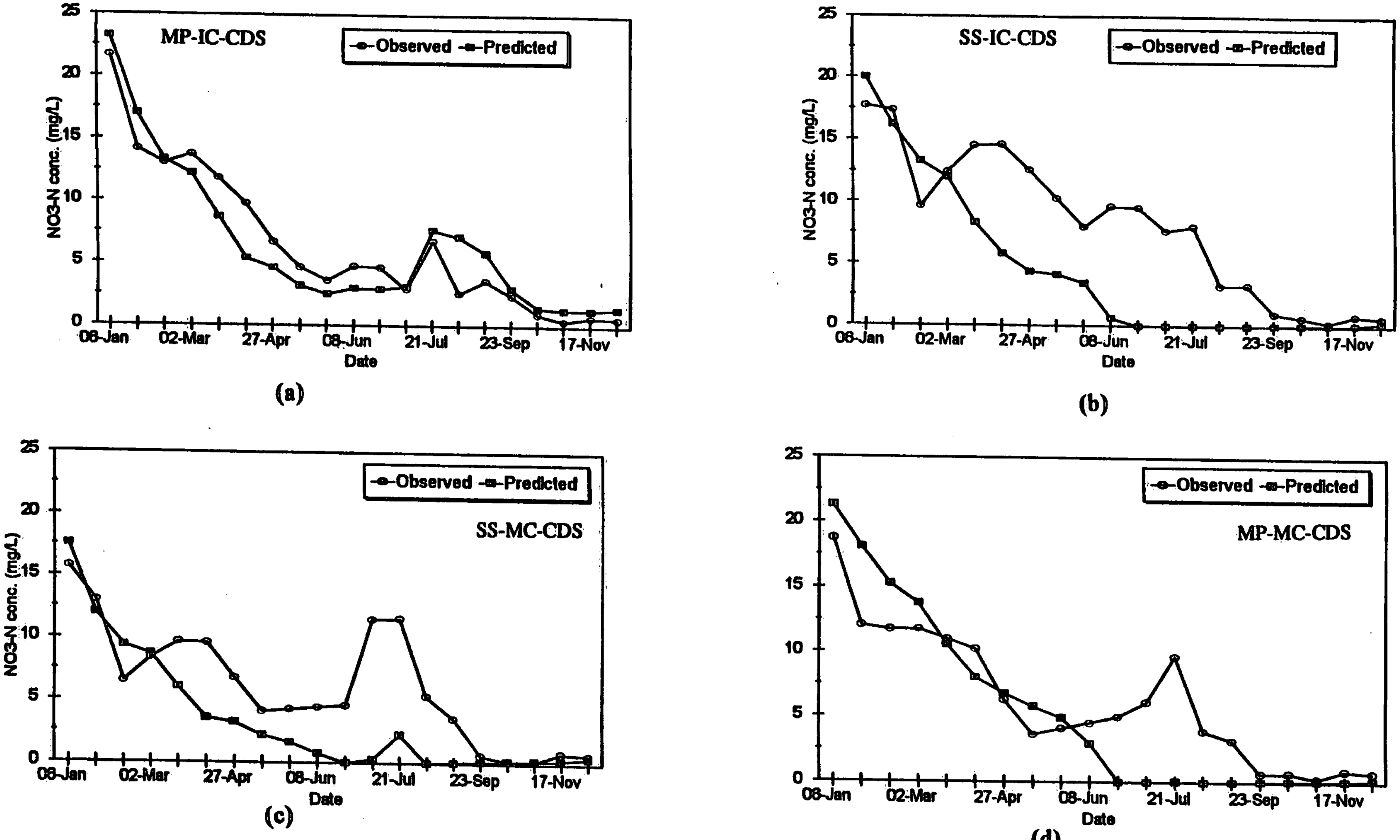


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Figure 2. Nitrate concentrations in drain water under controlled water table and subirrigation conditions. Study period 1992.

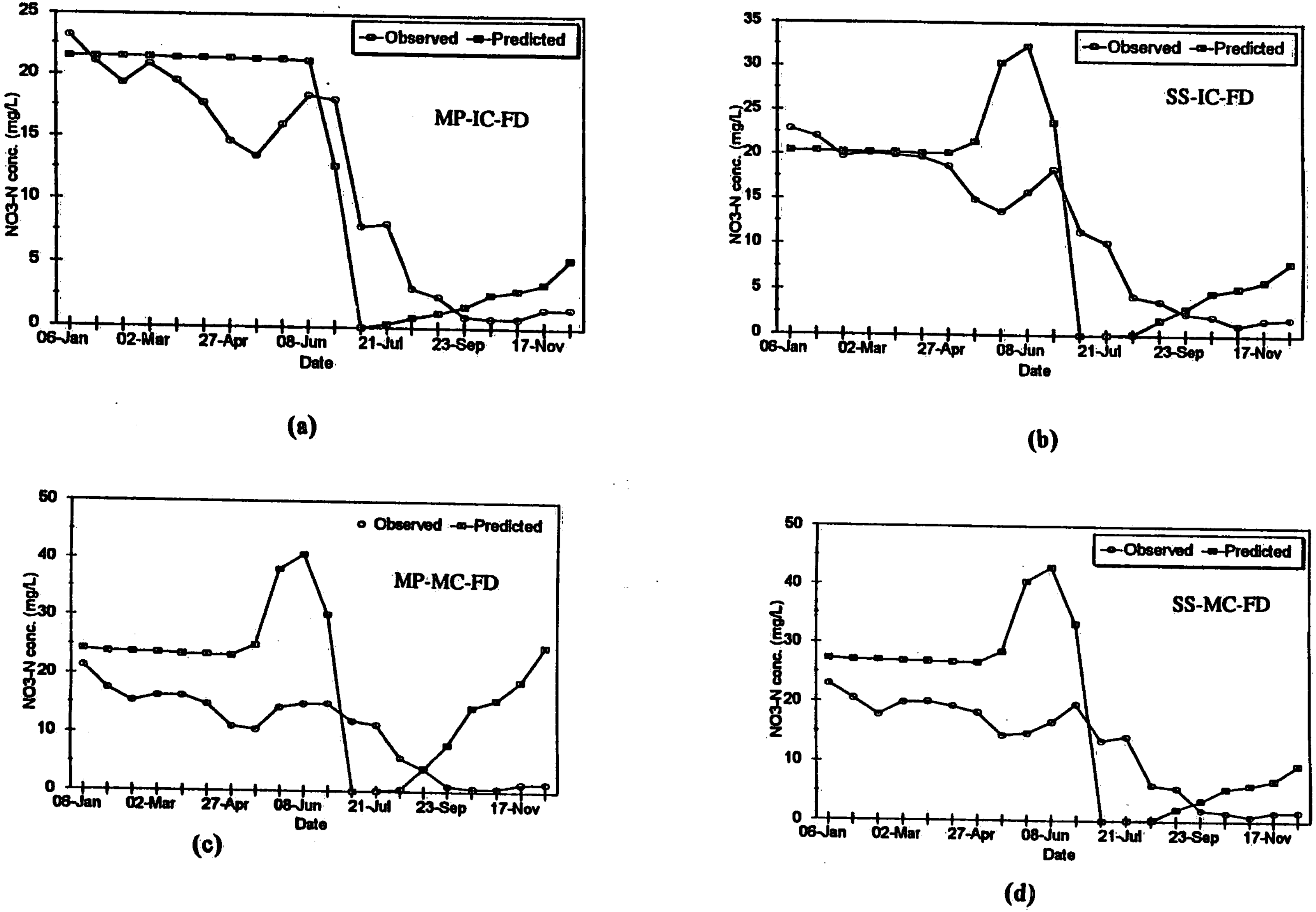

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Figure 3. Nitrate concentrations in drain water under free drainage conditions. Study period 1992.

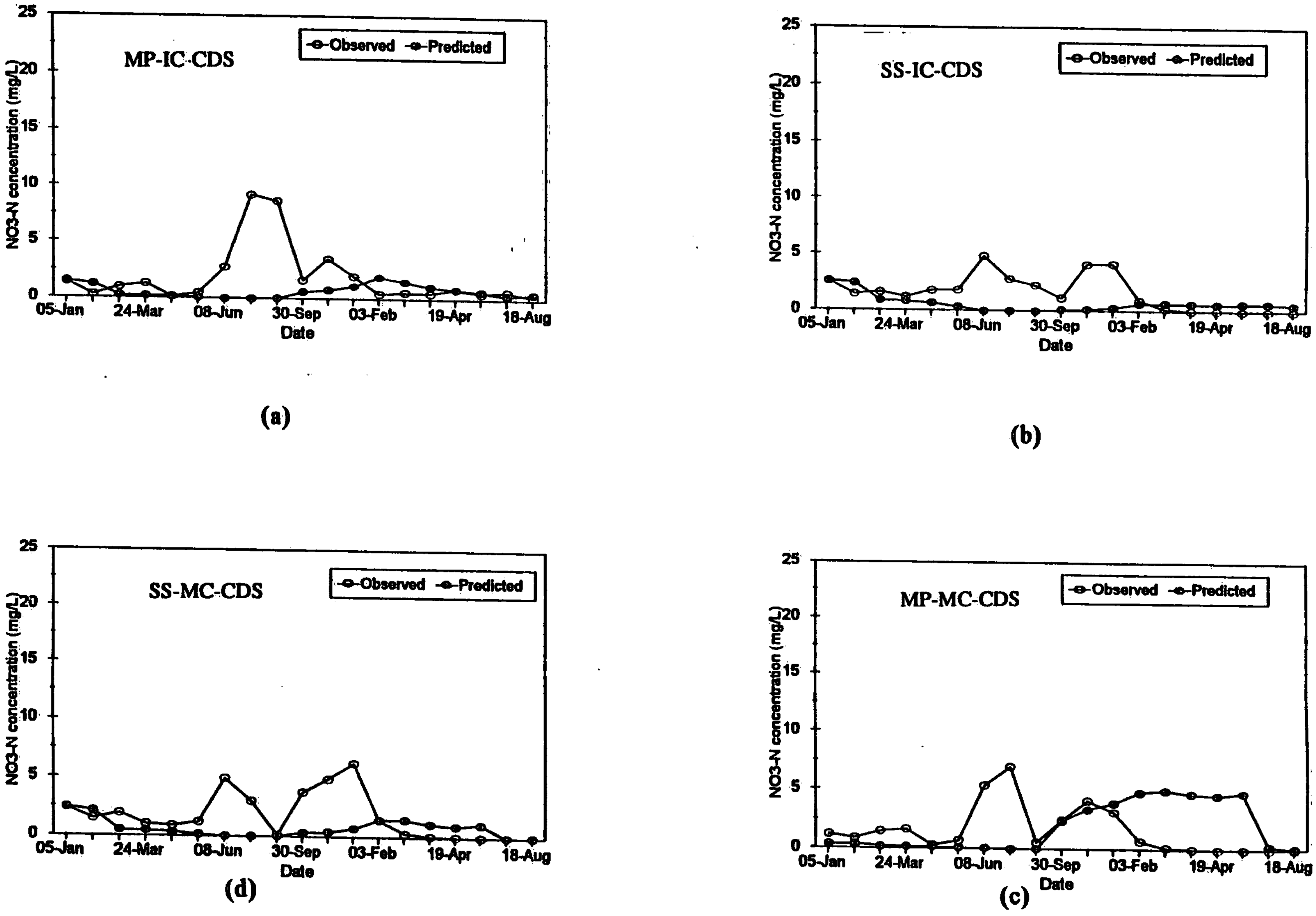

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Figure 4. Nitrate concentrations in drain water under controlled water table and subirrigation conditions. Study period 1993-94.

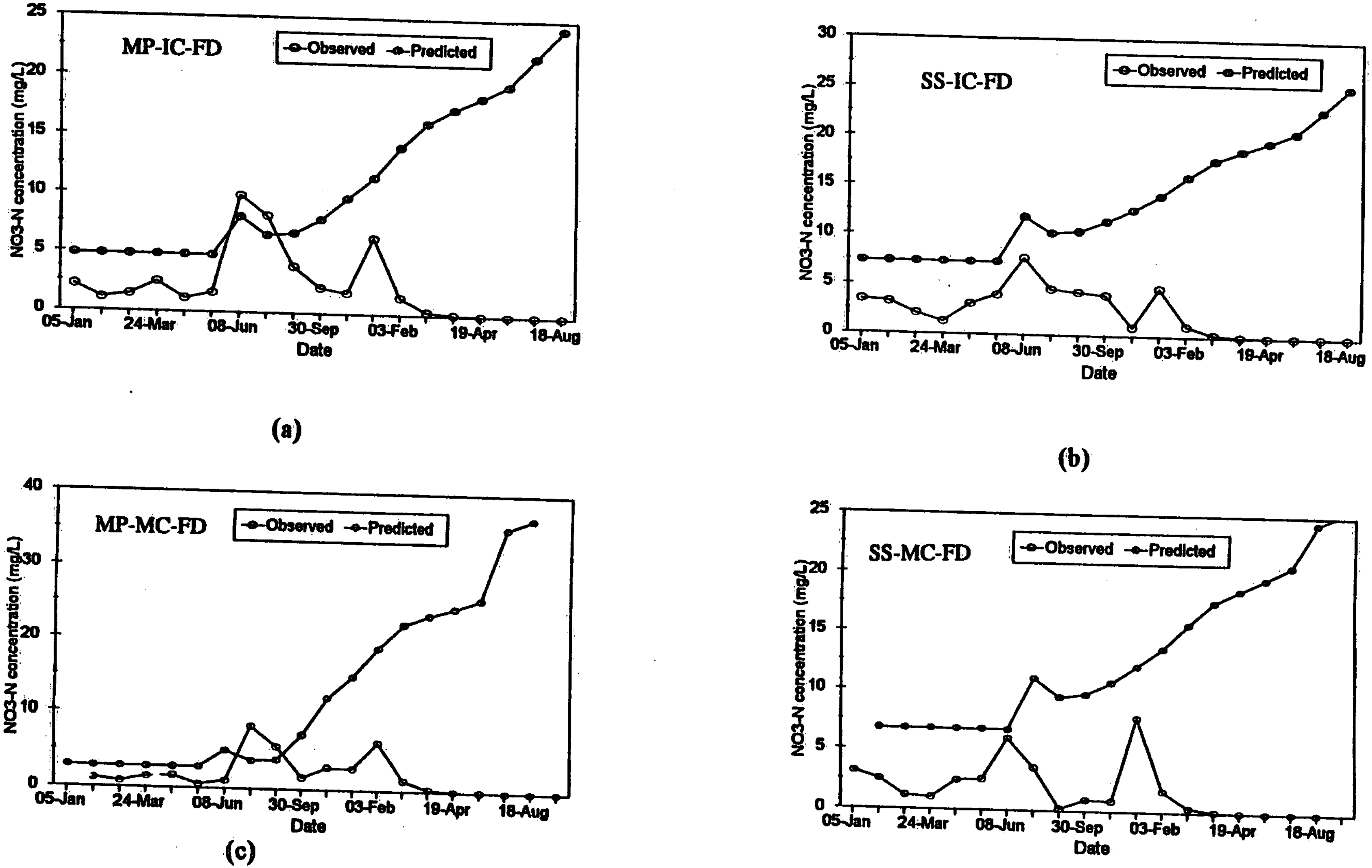

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Figure 5. Nitrate concentrations in drain water under free drainage conditions. Study period 1993-94.

Table 2a. Sensitivity tests for selected parameters In LEACHM model

Observed data from plots 1&13 (MP-IC-CDS) wer were used in the test.

Data year = 1991 NO3-N concentration in the tile drains at 0.6 m depth, mg/L

Parameter	value	06-Jan	11-Feb	19-Feb	02-Mar	24-Mar	09-Apr	27-Apr	14-May	26-May	08-Jun	22-Jun
Observed		21.67	14.16	13.06	13.75	11.85	9.77	6.67	4.65	3.63	4.76	4.64
D. coef	60.00	23.20	17.00	13.30	12.20	8.65	5.33	4.58	3.27	2.45	1.37	0.00
mm^2/d)	120.00	23.20	17.00	13.30	12.20	8.69	5.37	4.63	3.31	2.49	1.42	0.00
Disprs=(120)	150.00	23.20	17.10	13.30	12.20	8.71	5.39	4.65	3.34	2.51	1.44	0.00
Disprs.	120.00	23.20	17.00	13.30	12.20	8.69	5.37	4.63	3.31	2.49	1.42	0.00
(mm)	60.00	23.10	16.60	12.70	11.50	7.63	4.26	3.49	2.10	1.46	0.51	0.00
(D. coef=120)	10.00	23.00	9.32	7.00	5.25	2.24	1.19	0.58	0.27	0.18	0.13	0.09
Bk. density	1.00	23.2	17.3	13.5	12.2	8.67	5.37	4.42	3.21	2.46	1.38	3.09E-05
(g/cm3)	1.18	23.20	17.00	13.30	12.20	8.69	5.37	4.63	3.31	2.49	1.42	0.00
	1.30	23.1	16.9	13.3	12.2	8.75	5.41	4.91	3.51	2.64	1.58	1.87E-05
Hd. cond.	10.00	23.4	23.7	22.6	21.5	19.8	18.2	16.8	17	18.4	16	0.00207
(mm/d)	58.00	23.20	17.00	13.30	12.20	8.69	5.37	4.63	3.31	2.49	1.42	0.00
	100.00	23.00	15.2	12.2	11.5	7.73	4.29	4.77	2.59	2.23	1.68	4.06E-05

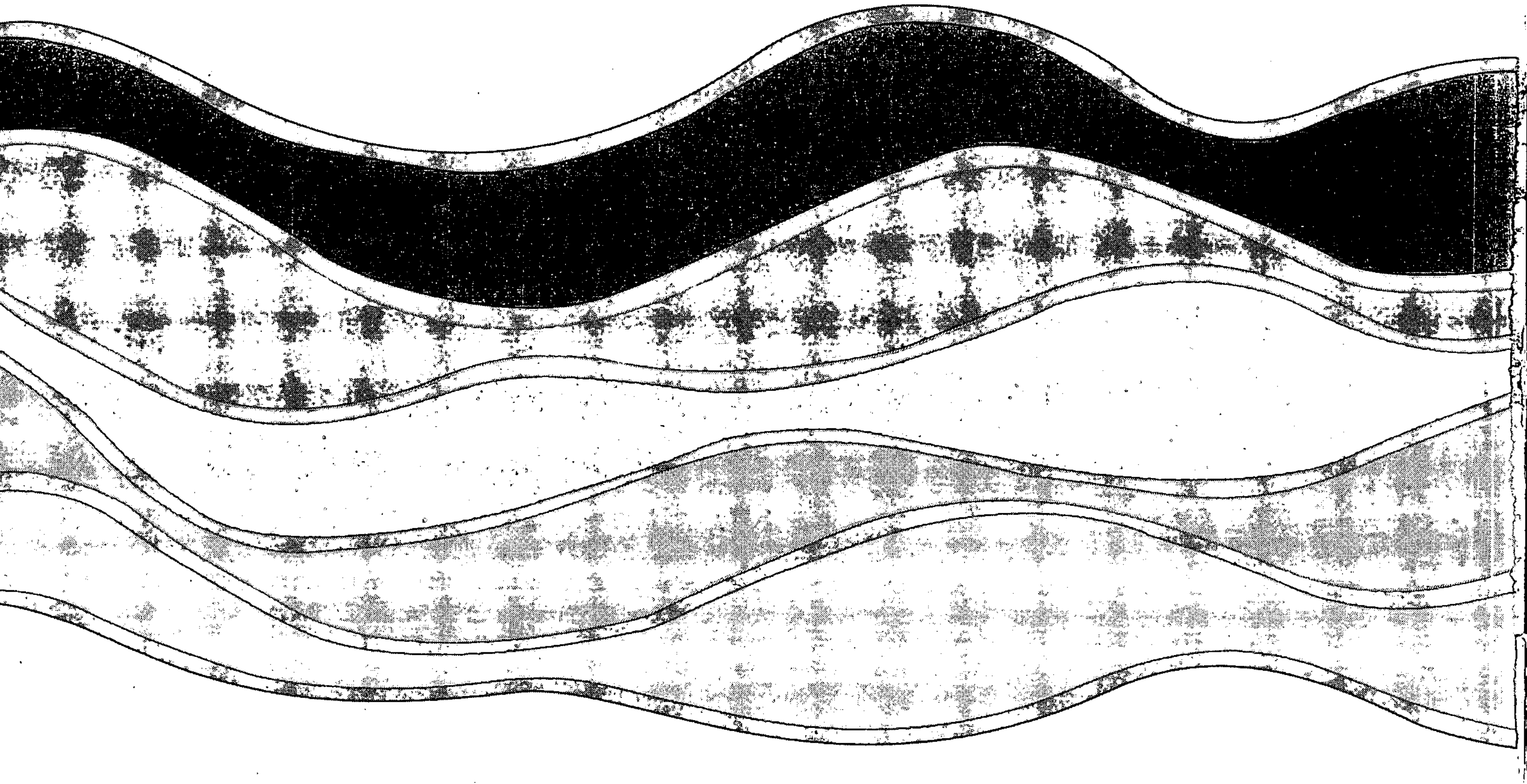
Parameter	value	15-Jul	21-Jul	10-Aug	26-Aug	23-Sep	26-Oct	05-Nov	17-Nov	14-Dec
Observed		2.95	6.82	2.63	3.65	2.48	0.97	0.46	0.74	0.63
D. coef	60.00	0.07	0.03	0.00	0.03	0.11	0.16	0.18	0.21	0.30
mm^2/d)	120.00	0.07	0.03	0.00	0.03	0.12	0.18	0.20	0.23	0.33
Disprs=(120)	150.00	0.07	0.03	0.00	0.03	0.12	0.19	0.21	0.24	0.35
Disprs.	120.00	0.07	0.03	0.00	0.03	0.12	0.18	0.20	0.23	0.33
(mm)	60.00	0.05	0.02	0.00	0.00	0.01	0.01	0.01	0.01	0.01
(D. coef=120)	10.00	0.05	0.05	0.05	0.04	0.02	0.01	0.01	0.01	0.02
Bk. density	1.00	0.0938	1.2	3.96E-05	0.11	0.451	0.659	0.713	0.77	0.932
(g/cm3)	1.18	0.07	0.03	0.00	0.03	0.12	0.18	0.20	0.23	0.33
	1.30	0.266	2.51	2.77E-05	0.0523	0.118	0.162	0.173	0.211	0.387
Hd. cond.	10.00	0.00175	0.0202	2.64E-07	0.00296	0.0286	0.077	0.0926	0.112	0.16
(mm/d)	58.00	0.07	0.03	0.00	0.03	0.12	0.18	0.20	0.23	0.33
	100.00	1.04	4.05	0.0444	0.371	0.588	0.592	0.716	1.28	1.8

D. coef = diffusion coefficient, (D_o).

Disprs. = dispersivity, (λ).

Hd. cond. = hydraulic conductivity, (K_s).

Bk. density = bulk density,



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