This is to certify that the

dissertation entitled

Conservation tillage, chemical input and manure history in regulating corn and soybean production and fate of nitrogen in soil

presented by

Chuanguo Xu

has been accepted towards fulfillment of the requirements for

PhD degree in Soil Science

Francis J. Pierce
Major professor

Date 6/17/94

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.

DATE DUE	DATE DUE	DATE DUE
[illegible]		

CONSERVATION TILLAGE, CHEMICAL INPUT AND MANURE HISTORY IN REGULATING CORN (*Zea mays L.*) AND SOYBEAN (*Glycine max (L)*. Merr.) PRODUCTION AND FATE OF NITROGEN IN SOIL

By

Chuanguo Xu

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Crop and Soil Sciences

1994

ABSTRACT

CONSERVATION TILLAGE, CHEMICAL INPUT AND MANURE HISTORY IN REGULATING CORN (*Zea mays L.*) AND SOYBEAN (*Glycine max (L.)* Merr.) PRODUCTION AND FATE OF NITROGEN IN SOIL

By

Chuanguo Xu

The role of conservation tillage and chemical inputs on N leaching is uncertain. This study evaluated three conservation tillage systems, as well as chemical input, and manure application history, in relation to soil stratification, in regulating corn and soybean production, soil physical properties, and the fate of N in soil. Field experiments were conducted on the Kalamazoo loam soil (Typic Hapludalf, fine loamy, mixed, mesic) at Kellogg Biological Station, Hickory Corners, Michigan for the period 1990 to 1993. The study consisted of two manure history treatments (with and without manure applications from 1981 to 1989), three tillage treatments (chisel plow (CP), no-tillage (NT) and ridge till (RT)), and two chemical input levels (140 kg N ha^{-1} with broadcast herbicides (HI) and no nitrogen fertilizer application with herbicides banded (LI)). A Br tracer was used in three tillage treatments to monitor soil solution movement in 1992 and 1993. Three chemical leaching models were tested using soil profile bromide content.

Manure application history decreased soil bulk density and increased total porosity. The effect of manure history was to increase N mineralization resulting higher in the soil profile and to increase soil solution NO_3-N, thereby increasing the potential for NO_3-N leaching. High chemical input increased corn grain yield, N concentrations in corn tissue and N uptake. Soil profile and suction lysimeter data indicated that NO_3-N was leached out of the root zone soon after N fertilization. Without N fertilization, NT and RT corn were generally more deficient in nitrogen and yielded less than CP. Soybean yields were affected by soil crusting in CP and weed pressure in manure history. Ridge till had the highest soil solution NO_3-N concentration. Bromide placement in the row in RT resulted in less Br leaching than CP and more Br leaching with Br placement in the midrow. The Burns equation, TFE and MACRO models successfully predicted Br movement for RT and failed to predict Br contents under NT and CP. This study suggests that RT had the greatest impact on chemical leaching potential based on chemical placement position. Using average row and midrow values, NT had higher leaching potential than CP and RT. Additional N fertilizer contributed to additional N leaching throughout the year.

ACKNOWLEDGMENTS

I express my sincere appreciation to my advisor, Dr. Francis Pierce, for his guidance, encouragement and constant friendship throughout this study, and for his invaluable and time assistance in the preparation of this manuscript. Appreciation is also extended to Dr. Boyd Ellis, Dr. James Crum and Dr. James B. Hart, Jr. for serving on my the guidance committee and for their advice.

Acknowledgement is also made to Charlotte Gaye Burpee for her help in the preparation of the manuscript. I thank Brian Long for his technical assistance on the research. Thanks are also due to Moacir Dias for assistance in graphics preparation.

I am also grateful to the undergraduate students who assisted in this research.

I would like also to thank to Dr. Earl Erickson, who originally gave me the opportunity to study in the United States. Without that opportunity, this dissertation would not been possible.

I also want to thank to my wife, Yun Wang and my daughter, Yue Xu for their consistently support me to complete this program.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

CHAPTER 2

CHAPTER 3

LIST OF FIGURES

CHAPTER 1

CHAPTER 2

CHAPTER 3

INTRODUCTION

Every soil and water management problem, including water quality, erosion, productivity, investment risk, international competitiveness, and long-term sustainability, is influenced by the basic condition of the soil resource and how the soil is managed (Karlen et al., 1990). The research need with regard to soil tillage with chemical input is to understand how soil should be manipulated to provide optimum conditions for each of the problems list above.

Conventional Tillage and Conservation Tillage

The primary purposes of tillage are to control weeds and create a favorable soil environment for seed emergence, plant growth and crop production. As stated by Schafer and Johnson (1982), "Any mechanical manipulation that changes a soil condition may be considered tillage". Conventional tillage, is defined here as moldboard plow, with overall plowing to 20-cm depth (fall or spring), followed by secondary tillage to 10 cm with a disc, following planting and possibly post-emergence cultivation.

Conservation tillage systems are systems of managing crop residue on the soil surface with minimum or no tillage. The systems are frequently referred to as stubble mulching, limited tillage, reduced tillage, minimum tillage, no-tillage, and direct drill. The goal of these systems of plant residue management is threefold: to leave enough plant residue on the soil surface at all times for water and wind erosion control, to reduce energy use, and to conserve soil and water (Unger and McCalla, 1980).

The evolution in tillage practices for corn has leaned strongly toward no-tillage in recent years, due to the energy and cost factors (Olson and Sander, 1988). The reduction in erosion and energy input for no-tillage has meant a greatly modified soil-temperature-water-air environment compared to conventional tillage.

Chisel plowing is a tillage procedure that is accomplished by chisel points or sweeps attached to shanks spaced from 20 to 40 cm apart that allow penetration to depths of 15 to 30 cm (Olson and Sander, 1988). The soil is lifted and loosened in the tillage zone with little soil turnover, leaving most of the prior crop's residue on the surface. The chisel plow is an excellent erosion control tool compared to the moldboard plow (Wischmeier, 1973).

Ridge till is a soil management tool used to improve the plant root environment. Walter at el. (1991) summarized four ridge till advantages: 1) increased surface drainage and warmer soil temperatures in the vicinity of the ridge, which promotes seed germination and seedling growth; 2) elimination of fall plowing and increased soil residue cover, which decrease soil erosion by wind and water; 3) the use of cultivation and banded application of herbicides, which reduces the need for chemical weed control; 4) banded fertilizer applications, in which improve yields in both uninfected and root worm-infested plants.

Tillage Management and Crop Production

Crops respond to changes in soil water content, soil temperature, nutrient supply, composition of the soil atmosphere, and to the strength of the soil. The specific tillage practice employed influences all these plant growth factors, although the effects may be different in different soils and under different weather conditions. The specific response to a soil physical change may depend on the plants' physiological growth stage.

Unger and McCalla (1980) summarized the role of conservation tillage on the crop production. Grain yields were little effected by tillage practices under conditions of adequate soil water, favorable precipitation, and good drainage, provided other factors such as soil fertility, weed control, and plant populations were equal. Under conditions of limited soil water and limited precipitation or irrigation, crop yields were equal and often significantly higher with reduced- and no-tillage systems than with conventional tillage.

Wagger and Denton (1992) reported that no-tillage can significantly increase the yield of corn. This yield enhancement can be attributed to the surface residue cover minimizing soil crusting, thereby reducing runoff and improving soil water availability. Moreover, after 5 yr there was no drawback to continuous no-tillage corn production systems, but rather an overall yield advantage compared with no-tillage following conventional tillage. Soybean yields during the 5 yr period were 5% higher with no-tillage. They suggested that continuous no-tillage should be the system of choice on upland Piedmont soils.

Tyler et al. (1983) found that full-season soybean yields were unaffected by tillage system on silty soils in western Tennessee. On heavy clay soils in the Mississippi Blaclands Prairie region, no-tillage resulted in a 20% soybean yield reduction compared with conventional tillage (Hairaton al., 1984). These yield variations illustrate the need to determine regional or local suitability for a given tillage system. Joint Nebraska and Illinois studies over a 3-yr period showed slightly higher yields with moldboard plowing than with chisel plowing (Cihacek et al., 1974). Chisel plow and moldboard plow treatment gave comparable average corn grain yields when compared over four years on five soils in Indiana (Griffith et al., 1973).

Considerable research has demonstrated the importance of a combination of conservation tillage and crop rotation in maintaining corn yield compared with continuous monoculture (Adams et al., 1970; Barber, 1972; Edwards et al., 1988; Meese et al., 1991), even though the reason is not well understood. Crop rotation in conjunction with various tillage systems has also received attention; however, results have been conflicting. Dick and Van Doren (1985) reported that rotating corn with soybean, oat and alfalfa (Medicago sativa L) minimized the negative effects of NT on a very poorly drained Hoytille soil. In the Appalachian Plateau region of Alabama, Edwards et al. (1988) found corn yield unaffected by tillage or crop rotation in two out three years. Strip tillage or NT in conjunction with soybean in the rotation increased corn grain yield by 12%.

Results from the few studies involving rotation of tillage systems have been contradictory. On poorly drained soils in Ohio, corn yield reductions for the second and succeeding two years of no-tillage, compared with continuous fall moldboard plowing, were alleviated when no-tillage followed conventional tillage (Triplett and Van Doren, 1985). Shear and Moschler (1969), however, found no benefit to corn grain and stover yields from moldboard plowing in alternate years, compared with six years of continuous no-tillage.

Soil management and Environmental Considerations

The concern over elevated nitrate levels in groundwater has increased during the past few years. Numerous studies have shown that the nitrate concentration in groundwater in agricultural watersheds is considerably higher than in forested watersheds (Hallberg, 1989; Juergens-Gschwin, 1989; Pionnke and Urban, 1985). Swistock et al. (1993) found that nitrate concentrations were significantly higher in wells closer to corn fields. Leaching losses of N as NO_3-N, are most significant when fertilizer addition exceeds the crop N requirement (Roth and Fox, 1990; Meisinger et al., 1982).

Kladivko et al. (1991) conducted a drainage research study on a Clermont silt loam (Fine-silty, mixed, mesic Typic Glossaqalf) in Indiana. Nitrate concentration in tile drainage water under a corn crop fertilized with 285 kg N ha^{-1} were seldom less than 10 mg N L^{-1} and usually within the 20 to 30 mg N L^{-1} range, with annual losses ranging between 18 and 70 kg N ha^{-1}, depending on tile drain spacing. The concentration of NO_3^- in tile drainage and the amount of NO_3^- loss was proportional to the amount of N fertilizer applied to a Webster silt loam (fine-loamy, mised, mesic

Typic Haplaquoll) in Iowa (Baker and Johnson, 1981). In particular, Baker and Johnson (1981) found that N fertilization rates of corn between 90 and 100 kg N ha^{-1} resulted in flow-weighted NO_3^- concentrations of 20 mg N L^{-1} in tile drainage, with a total annual loss of 27 kg N ha^{-1}; where N fertilizer rates between 240 and 250 kg ha^{-1} resulted in flow-weighted NO_3^- concentration of 40 mg N L^{-1} and total annual N losses of 48 kg N ha^{-1}. Prunty and Montgomery (1991) found that flow-weighted NO_3^- concentrations from lysimeters in a Hecla loamy fine sand (sandy, mixed Aquic Haploboroll) in North Dakota were 8.6 mg N L^{-1} for low N management (95 kg N ha^{-1} added fertilizer) and 12.3 mg N L^{-1} for high management (145 kg N ha^{-1}) corn production systems. However, the addition of 95 kg N ha^{-1} was below the maximum economical rate of fertilizer use for yield. In many other studies with corn production systems, the concentration of NO_3^- in tile drainage exceeded the 10 mg N L^{-1} limit for potable water. For example, the range of NO_3^- concentrations in leaching from lysimeters in Uppsala, Sweden, ranged from 10 mg N L^{-1} in clay soils to 50 mg N L^{-1} in sandy soils (Bergstrom and Johansson, 1991). Annual N losses from lysimeters seeded with spring barley (Hordeum vulgare L.) and fertilized with 100 kg N ha^{-1} were 20 kg N ha^{-1} or less for clay soils, 25 and 40 kg N ha^{-1} for loamy soils, and 65 kg N ha^{-1} for sandy soils. Rainfall and irrigation also contributed to the extent and timing of NO_3^- loss. In several studies, increase in NO_3^- concentration in tile drainage appeared within 2 to 3 months after N was applied (Hubbard et al., 1984; Baker and Johnson, 1981) and persisted up to 3 yr following the last application of N fertilizer. It has been well-documented that manure applications, when applied to soil in addition to normal fertilizer application, are a significant source of excessive soil N. Unless the N contribution of manure is accounted for, N applications to soil may exceed crop requirements, thereby resulting in leaching losses of significant quantities of NO_3^- (Roth and Fox, 1990).

Tillage has also been shown to affect N use efficiency and the subsequent potential for NO_3^- leaching. The tillage can influence macropore development, distribution, persistence, and continuity. Conservation tillage, and especially no-tillage, in medium- and fine-textured soils facilitate the development of a stable macropore network due to uninterrupted earthworm activity (Edwards et al., 1988). The preferential water flow through vertical channels created by earthworms in no-till soils is a possible mechanism responsible for accelerated transport of chemicals (Ehlers, 1975; Thomas and Phillips, 1979; Kanwar et al., 1985; Lee, 1985; Wagenet, 1987; Dick et al., 1989). Rapid leaching of chemical through macropores may cause groundwater contamination and less availability of nutrients to plants. Beven and Germann (1982) have discussed factors that influence the dynamics of macroporosity. They concluded that the volume and structure of the macropore system represents a dynamic balance between constructive and destructive processes.

In contrast, several studies have shown disagreement. When studying Brookston soil with shrinking and swelling characteristics, Drury (1993) reported that the increased yield and N uptake in grain resulting from the no-tillage and ridge till reduced the amount of NO_3^- available for leaching. Conservation tillage also reduced these losses somewhat, as there were lower volume of water lost and lower concentrations of NO_3^- in tile drainage. The cracks that formed on the soil surface were greater with the conventional tillage treatment than the conservation tillage treatments. Therefore the conventional tillage treatment probably had more water lost through preferential flow, which would increase the relative amount of tile drainage and decrease the relative amount of surface runoff. When studying with a Manor loam soil in Maryland, Angle et al. (1993) found that nitrate concentration under the no-tillage plots were consistently lower when compared with concentrations under the conventional-till plots. They concluded: "the use of no-tillage cultivation may reduce the leaching of nitrates beyond the crop root zone, and suggested that no-tillage cultivation is a true best management practice as related to both surface and groundwater quality".

Chemical Leaching and Chemical Leaching Models

Numerous tracer studies have indicated that in soils containing macropores, both water and agricultural chemicals can move preferentially (Jabro et al., 1994). Preferential movement of water can allow surface-applied agricultural chemicals to move rapidly through the root zone, thereby contributing significantly to groundwater contamination problems. Computer simulation models have become a useful tool in understanding and predicting environmental problems resulting from the movement of agricultural chemicals through soil into the groundwater (Jabro et al.,1994; Jarvis et al. 1991).

A simple chemical leaching equation, derived by Burns (1975) gives the distribution of surface-applied nitrate after a given quantity of applied water has passed through the soil profile. Later on, Towner (1983) and Scotter et al. (1993) examined the theoretical basis of equation and derived a simplified form. However, reports of field tests of this model are limited.

The transfer function model, as a non-mechanistic stochastic model, was an approach to measure the distribution of solute travel time from the soil surface to some reference depth. Field comparisons have shown good agreement between measured and predicted bromide concentrations (Jurry et al., 1982), and indicate that this model could be useful as a stochastically-based management model for solute movement. The most important characteristic of such a model is that it attempts to simulate spatially-variable field processes with only a minimum of input data. But it is not yet known whether the approach will be satisfactory in vertically non-homogeneous soils (Addicott and Wagenet, 1985).

The deterministic MACRO model was developed by Jarvis in 1991. The model assumes that the total porosity in each layer is divided into two components, micropores and macropores, with a specified boundary water potential. The MACRO model has been employed to simulate movement of conservative tracers and pesticides in the soil water. When used to predict Br^- losses from corn in Hagerstown silt loam, MACRO performed reasonablely well after calibration. The information on model testing on different tillage systems is limited.

Presently, Interactions between tillage, manure application and chemical input impact on N leaching have received limited attention. The effects of conservation tillage systems on groundwater NO_3-N concentration are still unclear.

The objectives of this study were (1) to examine the influences of various combinations of tillage, the long-term efficacy of animal manure applications, and chemical inputs on corn and soybean production and on selected soil physical properties; (2) to evaluate the role of conservation tillage systems, chemical inputs, and manure history in relation to soil stratification in regulating the fate of N in soils; (3) using bromide as a tracer, to evaluate movement and distribution of chemicals under ridge till, chisel plow and no-tillage; (4) to test the Burns leaching equation, the Transfer Function Model of solute transport and the MACRO model in three tillage and two row positions under field and natural rainfall conditions.

LIST OF REFERENCES

Adams, W.E., H.D. Morris, and R.N. Dawson. 1970. Effect of cropping systems and nitrogen levels on corn (Zea may L.) in the Southern Piedmont Region. Agron. J. 62:655-659.

Addiscott, T. M. and R. J. Wagenet. 1985. Concepts of solute leaching in soils: a review of modeling approaches. J. Soil. Sci. 36:411-424.

Angle, J.S. C. M. Gross, R. L. Hill, and M.S. McIntosh. 1993. Soil nitrate concentration under corn as affected by tillage, manure, and fertilizer application. J. Environ. Qual. 22:141-147.

Baker, J.L. and H.P. Johnson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. J. Environ. Qual. 10:519-522.

Barber, S.A. 1972. Relation of weather to the influence of hay crops on subsequent corn yields on a Chalmenrs silt loam. Agron. J. 64:8-10.

Bergstrom, L., and R. Johansson. 1991. Leaching of nitrate from monolith lysimeters of different types of agricultural soils. J. Environ Qual. 20:801-807.

Beven, K., and P. Germann. 1982. Macropores and water flow in soils. Water Resour. Res. 18:1311-1325.

Burns, I. G. 1974. A model for predicting the redistribution of salts applied to fallow soils after excess rainfall or evaporation. J. Soil Sci. 25:165-178.

Cihacek, L.J., D.L. Mulvaney, R.A. Olson, L.F. Welch, and R.A. Wiese. 1974. Phosphate placement for corn in chisel and moldboard plowing systems. Agron. J. 66:665-668.

Dick, W.A., R.J. Roseberg, E.L. McCoy, W.M. Edwards, and F. Haghiri. 1989. Surface hydrologic response of soils to no-tillage. Soil. Sci. Soc. Am. J. 53:1520-1526.

Dick, W.A., and D.M. Van Doren, Jr. 1985. Continuous tillage and rotation combinations effects on corn, soybean, and oat yields. Agron. J. 77:459-465.

Drury C. F., D. J. McKenney, W.I. Findly, and J.D. Gaynor. 1993. Influence of tillage on nitrate loss in surface runoff and tile drainage. Soil Sci. Soc. Am. J. 57:797-802.

Edwards, J.H., D.L.Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean, and wheat. Agron. J. 80:76-80.

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean and wheat. Agron J. 80:76-80.

Ehlers, W. 1975. Observations on earthworm channels and infiltration on tilled and untilled loess soil. Soil Sci. 119:242-249.

Griffith, D.R., Mannering, J.V. Galloway, H.M., Parsons, S.D. and C.B.Richey. 1973. Effect of eight tillage-planting systems on soil temperature, percent stand, plant growth, and yield of corn on five Indiana soils. Agron. J. 65:321-326.

Hairaton, J.E., J.O. Sanford, J.C. Hays, and L.L. Reinschmidt. 1984. Crop yield, soil erosion, and net return from tillage systems in the Mississippi Blacklands Prairie. J. Soil Water Conserv. 39:392-395.

Hallberg, G. R. 1989. Nitrate in groundwater in the United States. p. 35-74. (ed.). Nitrogen management and ground water protection. Elsevier, New York.

Hubbard, R.K., L.E. Asmussen, and H.D. Allison. 1984. Shallow groundwater quality beneath an intensive multiple-cropping system using center pivot irrigation. J. Environ. Qual. 13:156-161.

Jabro, Jalal D., John M. Jemoson, JR, Richard H. Fox, and Daniel D. Fritton. 1994. predicting bromide leaching under field conditions using SLIM and MACRO. Soil Sci. 157:215-223.

Jarvis, N. J., L. Bergstrom, and P. E. Dik. 1991. Modeling water and solute transport in macro-porous soil. II Chloride breakthrough under non-steady flow. J. Soil Sci. 42:71-81.

Juergens-Gschwin, S. 1989. Ground water nitrate in other countries (Europe)-Relationships to land use patterns. p. 75-138. in R.F. Folllett (ed.).

Nitrogen management and ground water protection. Elsevier, New York.

Kanwar, R.S., J.L. Baker, and J.M. Laflen. 1985. Nitrate movement through the soil profile in relation to tillage system and fertilizer application method. Trans. ASAE 28:1802-1807.

Karlen, D.L., D.C. Erbach, T.C. Kaspar, T.S. Colvin, E.C. Berry, and D.R. Timmons. 1990. Soil tilth: a review of past perception and future needs. Soil Sci. Soc. Am. J. 54:153-161.

Kladivko, E. J., G.E. Van Scoyoc, E.J. Monke, K.M. Oates, and W. Pask. 1991. Pesticide and nutrient movement into subsurface tile drains on a silt loam soil in Indiana. J. Environ. Qual. 20:264-270.

Lee, K.E. 1985. Earthworms - Their ecology and relationships with soils and land use. Academic Press, New York.

Meese, B.G., P.R. Carter, E.S. Oplinger, and J.W. Pendleton. 1991. Corn/soybean rotation effect as influenced by tillage, Nitrogen, and hybrid/cultivar. J. Prod. Agric. 4:74-80.

Meisinger, J.J, T.H. Carski, M.A. Ays, and V.A. Bandel. 1982. Residual nitrate nitrogen in Maryland. p.215. in Agronomy abstracts. ASA, Madison, WI.

Olson R.A. and D.H. Sander, 1988. Corn production. In Corn and corn improvement-agronomy monograph no. 18, 3rd edition.

Pionnke, H.B. and J. B. Urban. 1985. Effect of agricultural land use on ground-water quality in a small Pennsylvania watershed. Ground Water 23:68-80.

Prunty, L., and B.R. Montgomery. 1991. Lysimeter study of nitrogen fertilizer irrigation rates on quality of recharge water and corn yield. J. Environ. Qual. 20:373-380.

Roth, L.W., and R.H. Fox. 1990. Soil nitrate accumulations following nitrogen-fertilized corn in Pennsylvania. J. Environ. Qual. 19:243-248.

Schafer, R. L. and C. E. Johnson. 1982. Changing soil condition- The soil dynamics of tillage. In: Predicting tillage effects on soil physical properties and processes. ASA spec. Publ. No. 44:13-27.

Scotter, D. R., R. E. White and J. S. Dyson. 1993. The Burns leaching equation. J. Soil Sci. 44:25-33.

Shear, G.M., and W.W. Moschler. 1969. Continuous corn by the no-tillage and conventional tillage methods: A six-year comparison. Agron. J. 61:524-526.

Swistock, B.R., W.E. Sharpe, and P.D. Robillard. 1993. A Survey of lead, nitrate and radon contamination of private individual water systems in Pennsylvania. J. Environ. Health. 55:6-12.

Thomas, G.W., and R.E. Phillips. 1979. Consequences of water movement in macropores. J. Environ. Qual. 8:149-152.

Towner, G. D. 1983. A theoretical examination of Burns' (1975) equation for predicting the leaching of nitrate fertilizer applied to a soil surface. J. Agric. Sci., Camb. 100:293-298.

Triplett, G.D., and J.H. Van Doren. 1985. An overview of the Ohio conservation tillage research. p 59-68. In F.D'Itri (ed.) A systems approach to conservation tillage. Lewis Publ., Chelsea, MI.

Tyler, D.D., J.R. Overton, and A.Y. Chamber. 1983. Tillage effects on soil properties, diseases, cyst nematodes, and soy bean yields. J. Soil Water Conserv. 38:374-376.

Unger, P.W. and T. M. McCalla. 1980. Conservation tillage systems. Adv. Agron. 33:1-57.

Wagenet, R.J. 1987. Processes influencing pesticide loss with water under conservation tillage. p. 189-204. In T.J. Logan et al. (ed.) Effects of conservation tillage on ground water quality: Nitrates and pesticides. Lewis Publ. Chelsea, MI.

Wagger, M.G., and H.P. Denton. 1992. Crop and tillage rotations: Grain yield, residue cover, and soil water. Soil Sci. Soc. Am. J. 56:1233-1237.

Walter E. Riedell, Ralph D. Gustin, Dwayne L. Beck, and Denise G. Hanson, 1991. Westen corn rootworm damage: effect of tillage on plant response and grain yield. Crop Sci. 31:1293-1297.

Wischmeier, W.H. 1973. Conservation tillage to control water erosion p.133-141. In Conservation tillage. Proc. Natl. Conf., Des Moines, IA. 28-30 March. Soil Conserve. Soc. Am., Ankeny, IA.

CHAPTER 1

Corn and Soybean Response to Manure Application, Tillage, and Chemical Input

Conservation tillage is generally accepted as the most successful technology currently available for reducing soil loss and runoff. Conservation tillage includes any tillage-planting system that leaves at least 30% of the soil surface covered with crop residue after planting and is recommended as a cost-effective means of reducing soil erosion (Unger and McCalla, 1980).

Chisel plowing is a tillage operation that is accomplished by chisel points or sweeps attached to shanks spaced from 20 to 40 cm apart that allow penetration to depths of 15 to 30 cm (Olson and Sander, 1988). The soil is lifted and loosened in the tillage zone with little soil turnover, leaving most of the prior crop's residue on the surface. Certainly, the chisel plow is an excellent erosion control tool compared to the moldboard plow (Wischmeier, 1973). Joint Nebraska and Illinois studies over a 3-yr period showed slightly higher yields with moldboard plowing than with chisel plowing (Cihacek et al., 1974). Chisel plow and moldboard plow gave comparable average corn (*Zea mays L.*) grain yields when compared over four years on five soils in Indiana (Griffith et al., 1973).

The evolution in tillage practices for corn has leaned strongly toward no-tillage due to the energy and cost factors of recent years (Olson and Sander, 1988). The reduction in erosion and energy input for no-tillage has meant a greatly modified soil-temperature-water-air environment compared to conventional tillage. Yield results for no-tillage systems vary. Both yield losses and reduced fertilizer-use-efficiency attributed to weed competition have been recorded in a number of studies on no-tillage (Griffith et al., 1973; Van Doren et al, 1977). On the other hand in many studies, better yields were found for no-tillage compared to conventional tillage (Moschler et al. 1972; Al-Darby and Lowery, 1986; Phillips et al., 1980), especially on medium to coarse-textured soils with good internal drainage. Initially, much of the benefit was attributed to greater soil moisture storage and preservation in the root zone. After several years of continuous no-tillage, there were greater reserves of potentially mineralizable N because of increased surface soil levels of organic matter, microbial biomass, and aerobic organisms. Poorest results from no-tillage occurred on poorly drained soils, where surface residues accentuate the cool temperature problem early in the growing season.

A ridge surface configuration is often used as a soil management tool to improve the plant root environment. Walter at el. (1991) summarized four ridge till advantages: 1) increased surface drainage and warmer soil temperatures in the vicinity of the ridge which promotes seed germination and seedling growth; 2) elimination of fall plowing and increased soil residue cover, which decrease soil erosion by wind and water; 3) the use of cultivation and banded application of herbicides which reduces the need for chemical weed control; 4) banded fertilizer applications improve yields in both uninfected and root worm-infested plants. Yield increases may occur because the highly fertilized microenvironment promotes root growth and lateral root proliferation.

In a 20 year study with soybeans (*Glycine max (L.) Merr.*), Dick and Van Doren (1985) reported that the advantage of different tillage systems is dependent on soil type. On a well-drained silt loam soil, soybeans grown under no-till consistently had a yield advantage over soybeans grown under conventional tillage. While on a poorly drained silty clay loam soil, conventional tillage had the yield advantage. Other scientists have shown a reduction in yield with no-till on silty clay loam soils with poor internal drainage (Webber et. al., 1987)

Tillage systems can affect soil physical properties and, thus, have a direct bearing on crop performance. As tillage is reduced, bulk density and soil strength increase, air-filled porosities decrease, soil moisture at shallow depths increases, and soil temperature decreases, especially early in the growing season (Bauder et al., 1981; Soane and Pidgeon, 1975). As soil strength increases, root elongation rates decrease. Therefore, tillage would be expected to affect the ability of plants to utilize soil nutrients.

It has been well-documented that animal manure, as an organic fertilizer, supplies substantial amounts of plant nutrients. Manure can increase soil productivity and improve soil physical properties and water holding capacity (Olson et al., 1970). The type of crop grown, crop rotations, and tillage also affect soil physical condition (Warren, 1985). In recent years, environmental concerns about huge manure stockpiles have renewed interest in the use of manure for agronomic applications.

However, very few experiments on long-term efficiency of animal manure for crop production have been conducted.

In recent years, interest in developing low chemical input systems for crop production has grown. This interest has been fueled by a diversity of factors, including groundwater and surface water degradation, increased soil erosion, health hazards of agricultural chemicals and the economic farm crisis of the mid-1980s. There are three important components included in low-input systems: crop rotation, use of animal manure and appropriate conservation tillage systems. Interactions between tillage, manure application and chemical input have received limited attention.

This study examined the influences of conservation tillage systems, residual benefits of long-term animal manure applications, and chemical inputs on corn and soybean production, N uptake, and on soil physical properties over a four-year period.

MATERIALS AND METHODS

A four-year experiment was conducted from 1990 to 1993 at the Kellogg Biological Station (KBS), Hickory Corners, Michigan, as an extension of an experiment that was initiated in 1981 to examine the effect of tillage system on corn production and soil properties on a Kalamazoo Loam (Bronson, 1989). The soil was a Kalamazoo loam (fine loamy, mixed, mesic, Typic Hapludalf), with Ap horizon (loam) 20 cm thick overlying a Bt horizon (clay loam) approximately 50-60 cm thick which was underlain by a coarse glacial outwash parent material. The near surface aquifer was approximately 10 m deep, and the soil was well-drained with a 2% slope.

The experimental design was a strip-plot with randomized complete block split-plot, with manure application arranged as the main plots and tillage and chemical input as the randomized complete block with four replications. Individual plots measured 14.1 by 9.1 m. Rainfall data was obtained from the W.K. Kellogg Biological Station about four kilometers northwest of the experimental plot.

In the initial experiment, manure applications were made to the appropriate plots in the early spring from 1981 to 1988 using manure from the KBS dairy operation. The manure included significant amounts of straw. Rates of application were approximate, but ranged from 22-27 Mg ha^{-1} of dry matter (Bronson, 1989). Manure applications ceased after 1988 in order to evaluate the residual effects of manure history in this study. Tillage systems included spring chisel plowing with secondary tillage (CP), no-till (NT), and ridge tillage (RT). All NT plots were slot planted with no other soil disturbance. Ridges, made during the last cultivation of the previous crop, were scraped with sweeps and planted in the same operation. The two chemical input treatments were high chemical input (HI), which included recommended rates of fertilizers and pesticides, and low chemical input, which included no fertilizer applications and banded herbicides at areal rates equivalent to those used in HI. The fertilizer for corn included 33 L ha^{-1} of 10-34-0 starter fertilizer applied with the planter and 140 kg N ha^{-1} as NH_4-NO_3 applied as a pre-emergence broadcast application. No fertilizers were applied for soybeans as soil fertility was adequate. Standard herbicides for corn and soybeans grown in rotation were applied at labeled rates, including a contact herbicide applied in NT. Corn was grown in rotation with soybean and each crop appeared each year in separate experimental blocks.

Corn was planted in 76-cm row spacings at seeding rates of approximately 64,220 seeds ha^{-1} on 7 May, 1990, 8 May, 1991, 12 May, 1992, and 11 May, 1993 (Pioneer 3744, Pioneer 3704, Pioneer 3704 and Pioneer 3751, respectively). Soybean was planted at seedling rates of approximately 60.5 kg ha^{-1} on 25 May, 1990, 20 May, 1991, 19 May, 1992, and 12 May, 1993. Corn was harvested on 16 November, 1990, 22 November, 1991, 30 November, 1992, and 22 October, 1993. Grain yield and grain moisture were determined by combine-harvesting 6 rows of each plot. Corn grain yields were adjusted to the standard moisture content of 15.5%. Plant populations were calculated by counting the number of plants in a combine-harvesting the 6 rows of each plot. Soybeans were harvested on 23 October, 1990, 9 October, 1991, 27 October, 1992, and 8 October, 1993 by direct cutting with a plot combine. The harvest area for each plot was 2.28 m by 14.1 m. Soybean grain yields were adjusted to the standard moisture content of 14.0%. Plant populations were calculated by counting the number of plants in a 1 m length of three rows in each plot.

Plant Sampling

Five corn plants were sampled to determine above-ground biomass and nitrogen content when 50% of the plants were silking. After formation of a black layer, 10 plants were sampled from each plot to determine above-ground biomass. At harvest, stover and grain were analyzed separately for nitrogen content determination. Soybean leaves (20 per plot) were sampled when 50% of the plant were flowering in each plot to determine N content of leaves. Plant tissue was oven dried at 65°C and grounded to pass through a 30-mesh sieve. A 0.1 g tissue sample was digested using standard Kjeldahl procedures (Bremner and Mulvaney, 1982). The N concentration in the digestion was analyzed colorimetrically for NH_4-N using a Lachet injection flow analyzer.

Soil Sampling

Three intact soil cores (7.6 cm diameter by 7.6 cm height) were taken from the 0 to 7.6 cm and 7.6 to 15.2 cm depths from all tillage and manure treatments under high chemical input on 22 April, 1992 and from the 0 to 7.6 cm depth on 12 November, 1993. Soil cores were saturated by wetting from the bottom for 48 hours before the saturated hydraulic conductivities (K-sat) were determined by the constant head method (Klute and Disksen, 1986). The cores were resaturated and moisture retention determined at matric potentials of -1 and -2 kPa using the blotting paper method (Leamer and Shaw, 1941), and at matric potentials of -6, -33.3 and -100 kPa with a pressure chamber. In 1993, moisture retention was determined only at -6, -33 and -100 kPa of pressure. Cores were oven-dried at 105° C for 48 hours and weighed for bulk density determination (Blake and Hartge, 1986). Water loss between saturation and oven drying was taken to represent total soil porosity. Macroporosity (Carter, 1988; Hamblin, 1985) was determined by subtracting the measured volummetric water at -6 kPa (equivalent pore radius of 24 μm) from the total porosity (Carter, 1988).

The analysis of variance was performed using general linear models' procedures (SAS Inst., 1990) as detailed in Table 1. Mean differences were determined using a least significant difference (LSD) at the 0.05 level of probability.

RESULTS AND DISCUSSION

Effects of Rainfall and Temperature on Crop Production

A broad range of weather was encountered during the 4 year period of this study and this had a large impact, both positive and negative, on crop production. Both the amount and distribution of growing season rainfall varied, with seasonal rainfall high in 1990 and 1991 and average in 1992 and 1993 (Figure 1).

Cumulative growing degree days were exceptionally high in 1991 and exceptionally low in 1992, with 1990 and 1993 about average (Figure 2). Thus, 1990 had a cool, very wet spring followed by below normal rainfall for July, August and September. In 1991, it was a warm, moist year in which corn matured very early with high yields. In 1992, it was very dry in May and June, followed by a wet, very cool summer, and was a year in which corn matured very late, with grain moisture at harvest very high. Additionally, white mold was a major problem in soybean in 1992 and depressed yields statewide. 1993 was dry and cool in May followed by a very wet June, and had rather normal rainfall throughout the growing season. Thus, corn and soybean yields varied greatly with year, with the range in yields probably representative of the potential for this soil and climate.

Corn Response to Manure, Chemical Input, and Tillage Treatments

In 1990, corn yields were low, less than 4.05 Mg ha^{-1}, and were not affected by any treatment (Table 2). The low yields were associated with reduced plant populations (Table 3) and reduced plant biomass (Table 4), resulting from stand loss and reduced growth caused by cool, wet conditions during the early spring in 1990 (Figure 1 and 2). Corn grain moisture at harvest was not affected by treatments in any year. In 1991, under growing conditions of adequate moisture and high growing degree units, corn yields were highest under HI. However, the reduction in corn yield in LI was less where manure had been applied (-1.63 Mg ha^{-1}) than where no manure had been applied (-3.63 Mg ha^{-1}) and under CP (-1.56 Mg ha^{-1}) compared to

NT (-4.10 Mg ha^{-1}) and RT (-2.22 Mg ha^{-1}) (Table 2). It appears that both manure and soil disturbance by chisel plowing increased N supply to the corn, although there were no differences in N content of corn tissue at silking or harvest due to manure or tillage in 1991 (Table 4). Ridge till had lower plant populations than CP in 1991 and this may be partially responsible for lower yields in RT. Corn stover was not affected by input level where manure had been applied but was reduced under LI where no manure had been applied (Table 4). Stover was higher in CP than either NT or RT, indicating reduced growth in these tillage systems. In 1992, only input affected corn yield, with LI 42% lower than HI (Table 2). Corn stover was lower in LI than HI, with the difference larger in CP than in NT or RT and was lower in RT than CP (Table 4). Plant populations were lower in CP than NT (Table 3) but this had no effect on grain or stover yields. In 1993, a year of normal rainfall with slightly lower temperatures, there were no interaction effects on grain yield. Grain yields were increased by manure application and chemical application but not affected by tillage (Table 2). Corn stover was considerably lower under LI than HI, although the difference between HI and LI varied with tillage (Table 4). No-till had lower corn stover under HI than CP and RT and RT had the lowest stover under LI. Plant populations were slightly lower in RT and CP under LI than HI (Table 3).

Over the 4 year period, corn yields were greatly reduced under LI, slightly higher where manure had been applied, and not greatly affected by tillage. Lower input had less effect where manure had been applied and under CP in 1991, indicating a lower potential for yield reductions under LI where mineralization of N is enhanced.

Corn stover was lower under LI, no manure, and NT or RT, but the differences were not as large as in grain yield. Plant population and grain moisture were not greatly affected by treatments but varied considerably with year.

N Uptake in Corn

With N limiting corn yields, N uptake differences would be expected. N concentration at silking was greatly reduced in LI corn plants each year and N concentration in LI corn at silking appeared to decline each year (Table 5). LI reduced N content in the corn grain and stover each year. Manure increased N content in the grain in all but 1991 but not in the stover. Tillage had little effect on tissue N concentration, with the exception of an increase in stover N in RT and a decrease in tissue N at silking in NT, both in 1990.

Corn whole-plant N uptake at silking was higher for high chemical treatments in all four years (Table 6, 7, 8, 9), with NT higher than CP and RT under HI but not different under LI in 1990 only (Table 6). N uptake at silking was higher in CP than either NT or RT in 1991 and 1992, and lower in NT than CP and RT in 1993. Manure narrowed the difference between HI and LI in 1992, but otherwise had no effect on N uptake at silking.

N uptake in corn grain was much higher in HI than LI but the difference was affected by tillage in all four years (Tables 6, 7, 8, 9). In 1991, N uptake was similar for tillage systems under HI but much higher in CP than either NT or RT, reflecting the higher yield (Table 2). In 1992 and 1993, N uptake in CP was generally higher than RT and NT under HI but similar under LI. In 1990, N uptake was low due to low yields and NT had higher N uptake than CP. In 1992, manure increased N uptake in NT and RT but not in CP (Table 8). N uptake in the corn stover was much higher in HI than LI but the difference was slightly affected by tillage in 1991 and 1993 and reduced by manure application in 1991 and 1992. In 1992, manure reduced the difference between HI and LI and decreased N uptake in the stover in CP but increased it in NT (Table 8). Total N uptake was much higher in HI than LI but the difference varied with tillage. N uptake tended to be higher in CP than NT and RT under HI but similar under LI except in 1991 where CP in LI was not reduced as much as in NT and RT. In 1992, manure reduced the difference in total N uptake between HI and LI and increased N uptake in NT and RT but not CP.

Over the four year period, chemical input had the greatest impact on N concentration in corn tissue and N uptake. The difference in N uptake between HI and LI was tempered by manure application and affected by tillage. Manure, and to some extent chisel plowing, tended to increase N uptake in corn.

Soybean Response to Manure, Chemical Input, and Tillage Treatments

Soybean yields were less affected by treatments than corn (Table 10). The major effect of tillage was a reduction in yields under CP in 1990 and 1993. In 1990, soybeans were replanted due to poor emergence in a soil crusted under the impacts of high rainfall in 1990. In 1993, the stand was poor also but soybeans were not replanted (Table 11). Stands were also reduced in CP in 1992, but plant populations were sufficient given low yields in a year characterized by white mold infestations statewide. The effect of manure was primarily to increase weed pressure due to weed seeds added in the bedding straw during the years of manure application. This is evident in yields in the tillage by manure interaction in 1990, 1992, and 1993. The effect of manure was also evident in the reduced plant populations in 1992 and 1993 in the manured soybeans. Chemical input had little effect on soybean yield, except in 1992, when HI had higher yields than LI. Again, this was the year of white mold and weed control may have been important in the development of the disease. Under high yields of 1991, treatments had no effect on soybean.

Over the four year period, soybeans were affected mainly by soil crusting in CP and weed pressure in manured treatments but were relatively unaffected by chemical input treatments. Treatments had little important effects on grain moisture or N content of seed or leaves at flowering.

Effects of Manure and Tillage Treatment on Soil Physical Properties

Bulk density at the 0 to 7.6 cm depth under RT was significantly lower than those under CP and NT treatments in 1992 (Table 12). Ridge till also had higher saturated conductivity (K-sat) and higher total porosity compare to CP and NT. There were no differences in macroporosity ($>24\mu m$ in diameter) between the three tillage treatments and no difference in bulk density at the 7.6 to 15.2 cm depth between tillage treatments. Saturated conductivity was higher for RT than for NT and

CP. Total porosity at the 7.6 to 15.2 cm depth was slightly higher for the CP. Air-filled porosity was only slightly higher for RT at the 0 to 7.6 cm depth at matric potentials of -1 kPa. At the depth of 7.6 to 15.2 cm, CP had higher air-filled porosity at matric potentials between -1 and -100 kPa (Figure 3).

In 1993, total porosity under RT was slight higher compared to NT and CP. Chisel plow had higher air-filled porosity at matric potentials of -10, -33.3 and -100 kPa (Table 13). Manure application reduced bulk density, increased total porosity and macroporosity. Manure application also increased air-filled porosity at matric potential of -10 and -100 kPa (Figure 4).

SUMMARY AND CONCLUSIONS

Corn response to tillage varied greatly depending on temperature, rainfall distribution and other factors. In years with low rainfall and/or poor rainfall distribution, tillage did not affect yields. In years with sufficient rainfall, interaction effects between tillage systems and chemical inputs occurred. Corn grain yield and stover weight were higher for NT under HI, and lower for NT under LI. At low rates of N fertilizer, NT and RT corn were generally more deficient in nitrogen and yields were less than under CP. For maximum corn yields, more N fertilizer would be required for NT and RT soils. Both low and high chemical input treatments did not affect weed control, since there was no difference in corn plant populations under both systems. The reason for low corn yields under ridge till was also attributed lower plant populations caused by cultivation.

High chemical input increased N uptake and N concentrations in corn tissue and N uptake. The differences in N uptake between HI and LI were tempered by manure applications and affected by tillage. Manure application history with chisel plowing tended to increase N uptake in corn.

Manure application history resulted in higher weed populations causing lower soybean plant populations and ultimately decreased soybean production. Chemical inputs to corn did not affect soybean grain yield. Both NT and RT are preferable tillage methods for soybean production in the Kalamazoo loam soil of Michigan. Under those two tillage systems, weed control was improved, plant population was well-distributed, plant growth was good, and yields were increased, compared to CT treatment.

The effects of tillage treatments on soil physical properties varied depending on sampling time. Ridge till increased air-filled porosity at 7.5 to 15 cm depths before planting and at 0-7.5 cm depths after harvest. Bulk density was lower and total porosity was higher in ridge till after harvest, but there was no difference in tillage treatments before planting. Manure applications decreased bulk density and increased total porosity, macroporosity, air-filled porosity.

Al-Da

Baud

Blake

Brem

Bron

Cart

Ciha

Dick

Griffi

LIST OF REFERENCES

Al-Darby, A. M., and B. Lowery. 1986. Evaluation of corn growth and productivity with three conservation tillage systems. Agron. J. 8:901-907.

Bauder, J.W., G. W. Randall, and J.B. Swan. 1981. Effect of four continuous tillage systems on mechanical impedance of a clay loam soil. Soil Sci. Soc. Am. J. 45:802-806.

Blake, G. R. and K. H. Hartge. 1986. Bulk density. In: A. Klute (editor), Methods of soil Analysis, Part 1. Physical and Mineralogical Methods, 2nd ed. American Society of Agronomy, Madison, WI, pp 363-376.

Bremner, J. M., and C. S. Mulvaney. 1982. Nitrogen - Total. pp. 595-624 In A. L. Page, R. H. Miller, and D. R. Keeney (ed.) Methods of Soil Analysis. Part 2. Chemical and Microbiological properties. Second Edition. Agronomy 9. ASA-CSSA-SSSA, Madison, WI.

Bronson, J. A. 1989. The effect of tillage system on corn production and soil properties on a Kalamazoo Loam. M.S. Thesis. Michigan State university. East Lansing, MI.

Carter, M.R. 1988. Temporal variability of soil macroporosity in a fine sandy loam under moldboard ploghing and direct drilling. Soil tillage Res. 12:37-51.

Cihacek, L.J., D.L. Mulvaney, R.A. Olson, L.F. Welch, and R.A. Wiese. 1974. Phosphate placement for corn in chisel and moldboard plowing systems. Agron. J. 66:665-668.

Dick, W.A., and D.M. Van Soren, Jr. 1985. continuous tillage and rotation combinations defects on corn, soybean, and oat yields. Agron. J. 77:459-465.

Griffith, D.R., Mannering, J.V. Galloway, H.M., Parsons, S.D. and C.B. Richey. 1973. Effect of eight tillage-planting systems on soil temperature, percent stand, plant growth, and yield of corn on five Indiana soils. Agron. J. 65:321-326.

Hamblin, A.P. 1985. The influence of soil structure on water movement, crop root growth, and water uptake. Adv. Agron. 38:95-158.

Klute, A. and Dirksen, C. 1986. Hydraulic conductivity and diffusivity: laboratory methods. In: A. Klute (editor), Methods of soil Analysis, Part 1. Physical and Mineralogical Methods, 2nd ed. American Society of Agronomy, Madison, WI, pp 687-770.

Leamer, R.W. and B. Shaw. 1941. A simple apparatus for measuring non-capillary porosity on an extensive scale. J. Am. Soc. Agron. 33:1003-1008.

Moschler, W.W., G.M. Shear, D.C. Martens, G.D. Jones, and R.R. Wilmouth. 1972. Comparative yield and fertilizer efficiency of no-tillage and conventionally till corn. Agron. J. 64:229-231.

Olson R.A. and D.H. Sander. 1988. Corn production. In G.F. Sprague and J.W. Dudley (ed) Corn and corn improvement 3rd edition. Agronomy 18:639-685.

Olson, R.J., R.F. Hensler, and O.J. Attoe. 1970. Effect of manure application aeration, and soil pH on soil nitrogen transformation and on certain soil test values. Soil Sci. Sco. Am Proc. 38:830-836.

Phillips , R.E., R.L. Blevins, G.W. Thomas W.W. Frye, and S.H. Phillips. 1980. No-tillage agriculture. Science (Washington, DC) 208:1108-1113.

SAS Institute. 1990. SAS/STAT user's guide. Version 6. SAS Inst., Cary, NC.

Soane, B.D. and J.D. Pidgeon. 1975. Tillage requirements in relation to soil physical properties. Soil Sci. 119:376-384.

Unger, P., and T.M. McCalla. 1980. Conservation tillage systems. Adv. Agron. 33:1-58.

Van Doren, D.M., Jr., G.B. Triplett, Jr.,and J.E. Henry. 1977. Influence of long-term tillage and crop rotation combinations on crop yields and selected soil parameters for Aeric Ochraqualf soil. Ohio Agric. Res. and Dev. Ctr. Res. Bull. 1091.

Walter E. Riedell, Ralph D. Gustin, Dwayne L. Beck, and Denise G. Hanson, 1991. Western corn rootworm damage: effect of tillage on plant response and grain yield. Crop Sci. 31:1293-1297.

Warren W. Sahs and Gary Lesoing. 1985. Crop rotation and manure versus agricultural chemicals in dryland grain production. J. Soil and Water Conserv. 40:511-516.

Webber III, C. L. , M.R. Gebhaedt, and H.D. Kerr. 1987. Effect of tillage on soybean growth and seed production. Agron. J. 78:952-956.

Wischmeier, W.H. 1973. Conservation tillage to control water erosion p.133-141. In Conservation tillage. Proc. Natl. Conf., Des Moines, IA. 28-30 March. Soil Conserve. Soc. Am., Ankeny, IA.

Table 1. Analysis of variance table.

SOURCE	DEGREE OF FREEDOM	
Total	R*M*T*C-1	4*2*2*3*3-1=47
R†	R-1	4-1=3
M‡	M-1	2-1=1
ERROR I	(R-1)*(M-1)	(4-1)*(2-1)=(4-1)*(2-1)=3
T§	T-1	3-1=2
C¶	C-1	2-1=1
T*C	(T-1)*(C-1)	(3-1)*(2-1)=2
ERROR II	(R-1)*(T*C-1)	(4-1)*(3*2-1)=15
M*T	(M-1)*(T-1)	(2-1)*(3-1)=2
M*C	(M-1)*(C-1)	(2-1)*(2-1)=1
M*C*T	(M-1)*(C-1)*(T-1)	(2-1)*(2-1)*(3-1)=2
ERROR III	(R-1)*(M-1)*(T*C-1)	(4-1)*(2-1)*(3*2-1)=15

† replication
‡ manure
§ Tillage
¶ chemical input

Table 2. Corn grain yield (@15.5% moisture) as affected by manure application history, chemical input, and tillage treatments for the period 1990 to 1993.

Treatment	1990	1991	1992	1993	4-yr mean
	Mg ha^{-1}				
Manure/High input	3.4	9.7	8.2	10.1	7.9
Manure/Low input	3.3	8.1	5.1	6.6	5.8
No-manure/High input	3.7	10.0	7.9	9.7	7.8
No-manure/Low input	2.9	6.39	4.3	5.3	4.7
LSD(0.05)	NS	***	NS	NS	
High input/Chisel plow	3.1	10.2	9.0	10.3	8.1
High input/No-tillage	4.1	10.3	7.4	9.6	7.8
High input/ridge till	3.4	9.1	7.7	9.8	7.5
Low input/Chisel plow	2.8	8.6	4.4	5.8	5.4
Low input/No-tillage	3.2	6.2	4.8	5.7	5.0
Low input/Ridge till	3.2	6.9	4.8	6.3	5.3
LSD(0.05)	NS	***	NS	NS	
Chisel plow/Manure	3.2	9.7	6.6	8.6	7.0
Chisel plow/No-manure	2.7	9.1	6.8	7.5	6.5
No-tillage/Manure	3.5	8.8	6.4	8.0	6.7
No-tillage/No-manure	3.7	7.8	5.9	7.3	6.2
Ridge till/Manure	3.3	8.2	6.9	8.6	6.8
Ridge till/No-manure	3.3	7.8	5.6	7.5	6.1
LSD(0.05)	NS	NS	NS	NS	
Manure	3.3	8.9	6.6	8.4	6.8
No-manure	3.3	8.2	6.1	7.5	6.3
LSD(0.05)	NS	NS	NS	0.44	
High Input	3.5	9.9	8.0	9.9	7.8
Low Input	3.1	7.2	4.7	6.0	5.2
LSD(0.05)	NS	0.8	1.32	1.1	
Chisel plow	2.9	9.4	6.7	8.0	6.8
No-tillage	3.6	8.3	6.1	7.7	6.4
Ridge till	3.3	8.0	6.3	8.1	6.4
LSD(0.05)	NS	0.7	NS	NS	

NS: not significant.

*** Significant at 0.01 probability levels.

Table 3. Corn plant population as affected by manure application history, chemical input and tillage treatments for the period 1990 to 1993.

Treatment	1990	1991	1992	1993	4-yr mean
	-----------	-----------	1000 plants ha^{-1}	-----------	-----------
Manure/High input	26.9	59.4	55.1	60.3	50.4
Manure/Low input	29.4	61.8	53.4	50.2	50.2
No-manure/High input	33.2	63.2	53.5	51.8	51.8
No-manure/Low input	32.9	59.9	52.8	49.7	49.7
LSD(0.05)	NS	NS	NS	NS	
High input/Chisel plow	27.7	63.2	53.3	51.5	51.4
High input/No-tillage	34.3	62.5	55.1	51.7	51.7
High input/ridge till	28.1	58.2	54.5	50.3	50.3
Low input/Chisel plow	24.7	63.7	51.4	49.8	49.8
Low input/No-tillage	36.0	60.2	56.3	51.6	51.6
Low input/Ridge till	32.8	58.6	51.5	48.3	48.3
LSD(0.05)	*	NS	NS	**	
Chisel plow/Manure	26.4	63.6	53.6	61.3	51.2
Chisel plow/No-manure	26.0	63.3	51.1	59.5	50.0
No-tillage/Manure	29.8	61.0	55.6	57.0	50.8
No-tillage/No-manure	40.6	61.7	55.9	51.8	52.5
Ridge till/Manure	28.3	57.2	53.5	56.2	48.8
Ridge till/No-manure	32.6	59.6	52.5	54.5	49.8
LSD(0.05)	NS	NS	NS	NS	
Manure	28.1	60.6	54.2	58.2	50.3
Non-Manure	33.0	61.5	53.2	55.3	50.7
LSD(0.05)	NS	NS	NS	NS	
High Input	30.0	61.3	54.3	58.9	51.1
Low Input	31.2	60.8	53.1	54.6	49.9
LSD(0.05)	NS	NS	NS	NS	
Chisel plow	26.2	63.5	52.4	60.4	50.6
No-tillage	35.2	61.3	55.7	54.4	51.7
Ridge till	30.4	58.4	53.0	55.4	49.3
LSD(0.05)	4.30	3.50	3.13	NS	

NS not significant.
*, ** Significant at 0.1 and 0.05 probability levels.

Table 4. Corn stover weight (Mg ha^{-1}) at black layer as affected by manure application history, chemical input and tillage treatments for the period 1990 to 1993.

Treatment	1990	1991	1992	1993	4-yr mean
	------------------------Mg ha^{-1}------------------------				
Manure/High input	1.8	5.1	4.8	7.7	4.8
Manure/Low input	1.9	4.8	3.6	5.5	3.9
No-manure/High input	2.2	5.3	4.2	7.3	4.7
No-manure/Low input	1.8	3.9	3.1	4.7	3.4
LSD(0.05)	NS	**	NS	NS	
High input/Chisel plow	1.9	5.5	5.0	8.1	5.1
High input/No-tillage	2.3	5.3	4.3	6.6	4.6
High input/ridge till	1.7	4.7	4.2	7.9	4.6
Low input/Chisel plow	1.8	5.2	3.5	5.5	4.0
Low input/No-tillage	1.9	3.9	3.7	5.0	3.6
Low input/Ridge till	1.9	3.9	3.0	4.7	3.4
LSD(0.05)	**	NS	*	***	
Chisel plow/Manure	2.0	5.6	4.3	7.1	4.7
Chisel plow/No-manure	1.7	5.1	4.2	6.5	4.4
No-tillage/Manure	1.9	4.8	4.5	6.3	4.4
No-tillage/No-manure	2.3	4.5	3.4	5.3	3.9
Ridge till/Manure	1.7	4.4	3.8	6.3	4.1
Ridge till/No-manure	1.9	4.2	3.3	6.2	3.9
LSD(0.05)	NS	NS	NS	NS	
Manure	1.7	4.9	4.2	6.6	4.4
Non-manure	2.0	4.6	3.6	6.0	4.1
LSD (0.05)	NS	NS	NS	NS	
High Input	2.0	5.2	4.5	7.5	4.8
Low Input	1.9	4.3	3.4	5.1	3.7
LSD(0.05)	NS	0.66	0.54	0.4	
Chisel plow	1.9	5.3	4.3	6.8	4.6
No-tillage	2.1	4.6	4.0	5.8	4.1
Ridge till	1.9	4.3	3.5	6.3	4.0
LSD(0.05)	NS	0.61	0.50	0.40	

NS not significant.

*, *** Significant at 0.1 and 0.01 probability levels.

Table 5. Nitrogen concentration of corn grain, stover at black layer, and tissue on silking for the period 1990 to 1993.

Treatment	1990	1991	1992	1993	4-yr mean
	Grain Nitrogen (mg kg^{-1})				
Manure	14,344	15,921	12,795	10,822	13,470
Non-Manure	12,958	14,722	11,817	10,315	12,453
LSD(0.05)	548	NS	107	321	
High input	14,758	16,945	13,440	12,360	14,375
Low input	12,543	13,748	11,173	8,778	11,560
LSD(0.05)	900	1,879	656	769	
Chisel plow	13,468	15,823	12,207	10,866	13,091
No-tillage	13,637	15,440	12,606	10,199	12,970
Ridge till	13,845	14,776	12,106	10,641	12,842
LSD(0.05)	NS	NS	NS	NS	
	Stover Nitrogen (mg kg^{-1})				
Manure	10,735	9,947	9,788	7,042	9,378
Non-Manure	9,414	8,890	10,539	6,447	8,822
LSD(0.05)	NS	NS	NS	NS	
High input	12,193	10,666	11,233	8,276	10,592
Low input	7,956	8,170	9,094	5,213	7,608
LSD(0.05)	1,541	1,499	1,700	1,583	
Chisel plow	9,835	9,271	9,686	6,901	8,923
No-tillage	9,322	9,537	10,514	6,561	8,983
Ridge till	11,066	9,447	10,289	6,772	9,393
LSD(0.05)	1,442	NS	NS	NS	

Table 5 (cont'd)

	-----------Whole plant Nitrogen on Silking(mg kg^{-1})----------				
Manure	24,116	18,461	14,964	15,022	18,140
Non-Manure	22,423	17,946	14,520	14,357	17,311
LSD(0.05)	NS	NS	NS	NS	
High input	26,038	20,667	16,876	18,785	20,591
Low input	20,501	15,740	12,616	10,595	14,863
LSD(0.05)	1,960	3,332	1,264	2,190	
Chisel plow	23,388	18,491	14,902	14,712	17,873
No-tillage	21,845	17,164	14,173	14,617	16,949
Ridge till	24,575	18,955	15,150	14,740	18,355
LSD(0.05)	1,833	NS	NS	NS	

Table 6. Corn plant tissue N content at silking, N content of grain and stover, and total N uptake at black layer as affected by manure application history, chemical input and tillage treatments in 1990.

Treatment	Whole Plant	Grain	Stover	Total Uptake
	---------------------kg ha^{-1}---------------------			
Manure/High input	73.9	50.5	26.0	76.5
Manure/Low input	58.7	42.4	16.6	58.9
No-manure/High input	76.5	51.3	24.7	75.9
No-manure/Low input	54.5	33.6	13.7	47.3
LSD(0.05)	NS	NS	NS	NS
High input/Chisel plow	72.9	44.3	23.7	68.0
High input/No-tillage	85.8	58.5	27.1	85.6
High input/ridge till	67.0	49.8	25.3	75.1
Low input/Chisel plow	53.4	33.6	14.0	47.6
Low input/No-tillage	59.1	40.0	13.0	53.1
Low input/Ridge till	57.3	40.5	18.4	58.7
LSD(0.05)	**	***	**	*
Chisel plow/Manure	68.9	43.6	21.8	65.4
Chisel plow/No-manure	57.4	34.3	15.9	50.2
No-tillage/Manure	71.5	48.8	20.3	69.2
No-tillage/No-manure	73.4	49.7	19.8	69.5
Ridge till/Manure	58.5	46.9	21.8	68.6
Ridge till/No-manure	65.8	43.3	22.0	65.2
LSD(0.05)	NS	NS	NS	NS
Manure	66.3	46.4	21.3	67.7
Non-manure	65.5	42.4	18.2	61.6
LSD(0.05)	NS	NS	NS	NS
High Input	75.2	50.9	25.4	76.2
Low Input	56.6	38.0	15.1	53.1
LSD(0.05)	18.2	12.2	8.8	11.8
Chisel plow	63.1	38.9	18.9	57.8
No-till 72.4	49.3	20.0	69.3	
Ridge till	62.1	45.1	21.3	66.9
LSD(0.05)	NS	NS	NS	NS

NS not significant. *, **, *** Significant at 0.1, 0.05, and 0.01 probability levels.

Table 7. Corn plant tissue N content at silking, N content of grain and stover, and total N uptake at black layer as affected by manure application history, chemical input and tillage treatments in 1991.

Treatment	Whole Plant	Grain	Stover	Total Uptake
	--------------------kg ha^{-1}	-------	-------	-------
Manure/High input	102.7	171.5	55.1	226.5
Manure/Low input	67.5	126.4	43.0	169.8
No-manure/High input	92.7	162.8	54.9	217.4
No-manure/Low input	47.8	85.2	36.1	114.6
LSD(0.05)	NS	NS	**	NS
High input/Chisel plow	104.6	167.9	54.8	224.1
High input/No-tillage	91.5	174.1	57.8	232.9
High input/ridge till	97.2	159.4	52.5	208.9
Low input/Chisel plow	79.7	132.0	36.9	175.8
Low input/No-tillage	46.5	87.7	42.7	119.0
Low input/Ridge till	46.8	97.7	39.2	131.8
LSD(0.05)	NS	***	NS	*
Chisel plow/Manure	109.6	163.9	55.5	219.4
Chisel plow/No-manure	74.7	136.0	36.2	180.5
No-tillage/Manure	76.3	142.1	44.9	187.0
No-tillage/No-manure	61.7	119.1	55.5	164.9
Ridge till/Manure	69.5	140.8	46.8	188.2
Ridge till/No-manure	74.5	116.3	44.9	152.5
LSD(0.05)	NS	NS	NS	**
Manure	85.1	150.0	49.1	127.8
Non-manure	70.3	123.0	42.0	114.1
LSD(0.05)	NS	18.6	NS	NS
High Input	97.7	167.1	54.8	157.6
Low Input	57.6	105.4	36.2	84.3
LSD(0.05)	18.4	17.8	9.4	17.5
Chisel plow	92.1	149.9	50.0	126.7
No-tillage	68.9	130.9	45.1	121.3
Ridge till	72.0	129.5	41.5	114.8
LSD(0.05)	17.2	16.7	8.7	NS

NS not significant. *, **, *** Significant at 0.1, 0.05, and 0.01 probability levels.

Table 8. Corn plant tissue N content at silking, N content of grain and stover, and total N uptake at black layer as affected by manure application history, chemical input and tillage treatments in 1992.

Treatment	Whole Plant	Grain	Stover	Total Uptake
	--------------------kg ha^{-1}	------------------------------		
Manure/High input	129.9	110.2	48.1	158.3
Manure/Low input	84.3	62.4	34.8	97.3
No-manure/High input	122.2	105.7	51.1	156.8
No-manure/Low input	63.3	43.8	27.6	71.4
LSD(0.05)	**	NS	**	**
High input/Chisel plow	144.7	122.9	52.5	175.4
High input/No-tillage	117.9	98.2	49.1	147.3
High input/ridge till	115.5	102.7	47.3	150.0
Low input/Chisel plow	80.6	47.1	31.0	78.1
Low input/No-tillage	71.4	59.2	36.2	95.3
Low input/Ridge till	69.5	53.1	26.7	79.6
LSD(0.05)	NS	**	NS	**
Chisel plow/Manure	121.1	83.3	36.9	123.2
Chisel plow/No-manure	104.1	83.7	46.6	130.3
No-tillage/Manure	101.4	85.7	49.1	134.8
No-tillage/No-manure	87.9	71.7	36.2	107.9
Ridge till/Manure	98.8	87.0	38.5	125.4
Ridge till/No-manure	86.2	68.9	35.4	104.2
LSD(0.05)	NS	**	**	**
Manure	107.1	86.3	41.5	127.8
Non-manure	92.7	74.7	39.4	114.1
LSD(0.05)	NS	NS	NS	NS
High Input	126.0	107.9	49.6	157.6
Low Input	73.8	53.1	31.2	84.3
LSD(0.05)	14.5	17.4	11.8	17.5
Chisel plow	112.6	85.0	41.7	126.7
No-tillage	94.6	78.7	42.6	121.3
Ridge till	92.5	77.9	36.9	114.8
LSD(0.05)	13.5	16.3	NS	NS

NS not significant. ** Significant at 0.05 probability levels.

Table 9. Corn plant tissue N content at silking, N content of grain and stover, and total N uptake at black layer as affected by manure application history, chemical input and tillage treatments in 1993.

Treatment	Whole Plant	Grain	Stover	Total Uptake
	----------kg ha^{-1}----------			
Manure/High input	88.9	128.8	65.1	193.8
Manure/Low input	35.5	60.2	30.8	91.0
No-manure/High input	91.9	116.1	59.2	175.2
No-manure/Low input	27.0	44.9	22.1	67.1
LSD(0.05)	NS	NS	NS	NS
High input/Chisel plow	96.8	133.2	73.6	206.8
High input/No-tillage	75.0	110.3	51.3	161.6
High input/ridge till	99.4	123.8	61.4	185.2
Low input/Chisel plow	30.9	51.5	25.8	77.2
Low input/No-tillage	32.5	51.1	27.2	78.2
Low input/Ridge till	30.4	55.1	26.6	81.6
LSD(0.05)	NS	**	***	**
Chisel plow/Manure	67.0	99.7	52.5	152.1
Chisel plow/No-manure	60.6	85.0	46.9	131.8
No-tillage/Manure	50.4	87.8	47.0	134.8
No-tillage/No-manure	57.1	73.6	31.4	105.0
Ridge till/Manure	69.1	96.0	44.3	140.3
Ridge till/No-manure	60.7	82.9	43.7	126.6
LSD(0.05)	NS	NS	NS	NS
Manure	62.2	94.5	47.9	142.4
Non-manure	59.5	80.5	40.7	121.1
LSD(0.05)	NS	6.2	NS	9.4
High Input	90.4	122.4	62.1	184.5
Low Input	31.3	52.5	26.5	79.0
LSD(0.05)	23.2	12.8	12.8	21.8
Chisel plow	63.8	92.3	49.7	142.0
No-tillage	53.8	80.7	39.2	119.9
Ridge till	64.9	89.4	44.0	133.4
LSD(0.05)	NS	NS	NS	20.4

NS not significant. **, *** Significant at 0.05, and 0.01 probability levels.

Table 10. Soybean yield as affected by manure application history, chemical input and tillage treatments for the period 1990 to 1993.

Treatment	1990	1991	1992	1993	4-yr mean
	----------------------	---Mg ha-1---	----------------------		
Manure/High input	2.1	3.4	1.6	1.9	2.3
Manure/Low input	2.0	3.3	1.2	2.3	2.1
No-manure/High input	2.1	3.6	1.2	2.0	2.4
No-manure/Low input	2.0	3.4	1.4	2.3	2.3
LSD(0.05)	NS	NS	***	***	
High input/Chisel plow	1.9	3.5	1.6	1.3	2.1
High input/No-tillage	2.6	3.4	1.6	2.3	2.5
High input/ridge till	2.1	3.5	1.6	2.7	2.5
Low input/Chisel plow	1.9	3.5	1.3	1.3	2.0
Low input/No-tillage	2.0	3.4	1.4	2.5	2.3
Low input/Ridge till	2.1	3.3	1.2	2.7	2.3
LSD(0.05)	***	NS	NS	***	
Chisel plow/Manure	1.7	3.6	1.5	1.0	1.9
Chisel plow/No-manure	2.1	3.5	1.4	1.5	2.1
No-tillage/Manure	2.3	3.2	1.4	2.3	2.3
No-tillage/No-manure	2.3	3.5	1.6	2.5	2.5
Ridge till/Manure	2.2	3.3	1.4	2.6	2.4
Ridge till/No-manure	2.1	3.5	1.5	2.8	2.5
LSD(0.05)	***	NS	***	***	
Manure	2.1	3.4	1.4	2.0	2.4
Non-Manure	2.1	3.5	1.5	2.3	2.6
LSD(0.05)	NS	NS	NS	0.08	
High Input	2.2	3.5	1.6	2.1	2.6
Low Input	2.0	3.4	1.3	2.1	2.4
LSD(0.05)	NS	NS	0.34	NS	
Chisel plow	1.9	3.5	1.44	1.3	2.2
No-tillage	2.3	3.4	1.51	2.4	2.6
Ridge till	2.1	3.4	1.41	2.7	2.6
LSD(0.05)	0.2	NS	NS	0.30	

NS not significant.
*** Significant at 0.01 probability levels.

Table 11. Soybean population as affected by manure application history, chemical input and tillage treatments for the period 1990 to 1993.

Treatment	1991	1992	1993	3-yr Mean
	------------------1000 plants ha^{-1}	------------------	------------------	------------------
Manure/High input	280.2	186.7	91.6	186.2
Manure/Low input	261.1	197.6	103.8	187.5
No-manure/High input	277.2	202.9	126.8	202.3
No-manure/Low input	258.4	222.0	119.5	200.0
LSD(0.05)	NS	NS	NS	
High input/Chisel plow	288.7	108.6	48.1	148.4
High input/No-tillage	278.1	233.6	142.0	217.9
High input/ridge till	269.4	242.2	137.6	216.4
Low input/Chisel plow	252.2	157.9	43.3	151.1
Low input/No-tillage	277.6	255.8	163.4	232.3
Low input/Ridge till	249.4	215.9	128.3	197.8
LSD(0.05)	**	**	NS	
Chisel plow/Manure	272.7	188.0	36.0	142.2
Chisel plow/No-manure	268.2	148.4	55.4	157.3
No-tillage/Manure	272.3	233.6	129.4	211.8
No-tillage/No-manure	283.4	255.8	176.0	238.4
Ridge till/Manure	267.0	224.9	127.8	206.6
Ridge till/No-manure	251.8	233.2	138.2	207.7
LSD(0.05)	NS	NS	NS	
Manure	270.7	192.2	152.8	153.9
Non-manure	267.8	212.4	187.2	166.9
LSD(0.05)	NS	17.5	19.1	
High input	278.7	194.8	171.0	161.1
Low input	259.7	209.8	169.7	159.8
LSD(0.05)	14.3	NS	NS	
Chisel plow	270.5	133.2	70.7	118.6
No-tillage	277.8	244.7	232.1	188.6
Ridge till	259.4	229.0	202.1	172.6
LSD(0.05)	13.3	226.0	28.8	

NS not significant.
** Significant at 0.05 probability levels.

Table 12. Effects of tillage on bulk density, saturated hydraulic conductivity, total porosity and pore-size distribution of 0-7.6 cm and 7.6-15.2 cm soil depth on April 22, 1992.

Treatment	Bulk density	Ksat	Total porosity	>24μm	24-4.3μm	4.3-1.4μm
0-7.5 cm	(g cm^{-3})	(cm hr^{-1})	(m^3 m^{-3})	(m^3 m^{-3})	(m^3 m^{-3})	(m^3 m^{-3})
Chisel plow	1.40	8.00	0.43	0.17	0.03	0.02
No-tillage	1.40	18.26	0.43	0.13	0.03	0.01
Ridge till	1.28	21.64	0.46	0.16	0.03	0.02
LSD(0.05)	0.077	11.903	0.027	NS	NS	0.003
7.5-15 cm						
Chisel Plow	1.51	5.34	0.40	0.11	0.02	0.02
No-tillage	1.60	2.78	0.37	0.09	0.03	0.02
Ridge till	1.60	7.21	0.37	0.08	0.03	0.02
LSD(0.05)	NS	4.612	0.028	NS	0.009	NS

Table 13. Effects of tillage and manure on bulk density, total porosity and pore-size distribution of 0-7.6 cm soil depth on November 12,1993.

Treatment	Bulk density ($g\ cm^{-3}$)	Total porosity ($m^3\ m^{-3}$)	$>24\mu m$ ($m^3\ m^{-3}$)	$24\text{-}4.3\mu m$ ($m^3\ m^{-3}$)	$4.3\text{-}1.4\mu m$ ($m^3\ m^{-3}$)
Manure/chisel plow	1.30	0.45	0.14	0.08	0.02
Manure/no-tillage	1.23	0.49	0.13	0.10	0.02
Manure/ridge till	1.23	0.50	0.09	0.03	0.03
No-manure/chisel plow	1.32	0.45	0.11	0.10	0.02
No-manure/no-tillage	1.49	0.41	0.07	0.06	0.02
No-manure/ridge till	1.42	0.42	0.08	0.07	0.02
Manure	1.25	0.48	0.13	0.09	0.02
No-manure	1.41	0.43	0.09	0.08	0.02
LSD(0.05)	0.032	0.012	0.014	0.008	NS
Chisel plow	1.31	0.45	0.13	0.09	0.02
No-tillage	1.36	0.45	0.10	0.08	0.02
Ridge till	1.32	0.46	0.11	0.08	0.02
LSD(0.05)	NS	NS	0.014	NS	NS

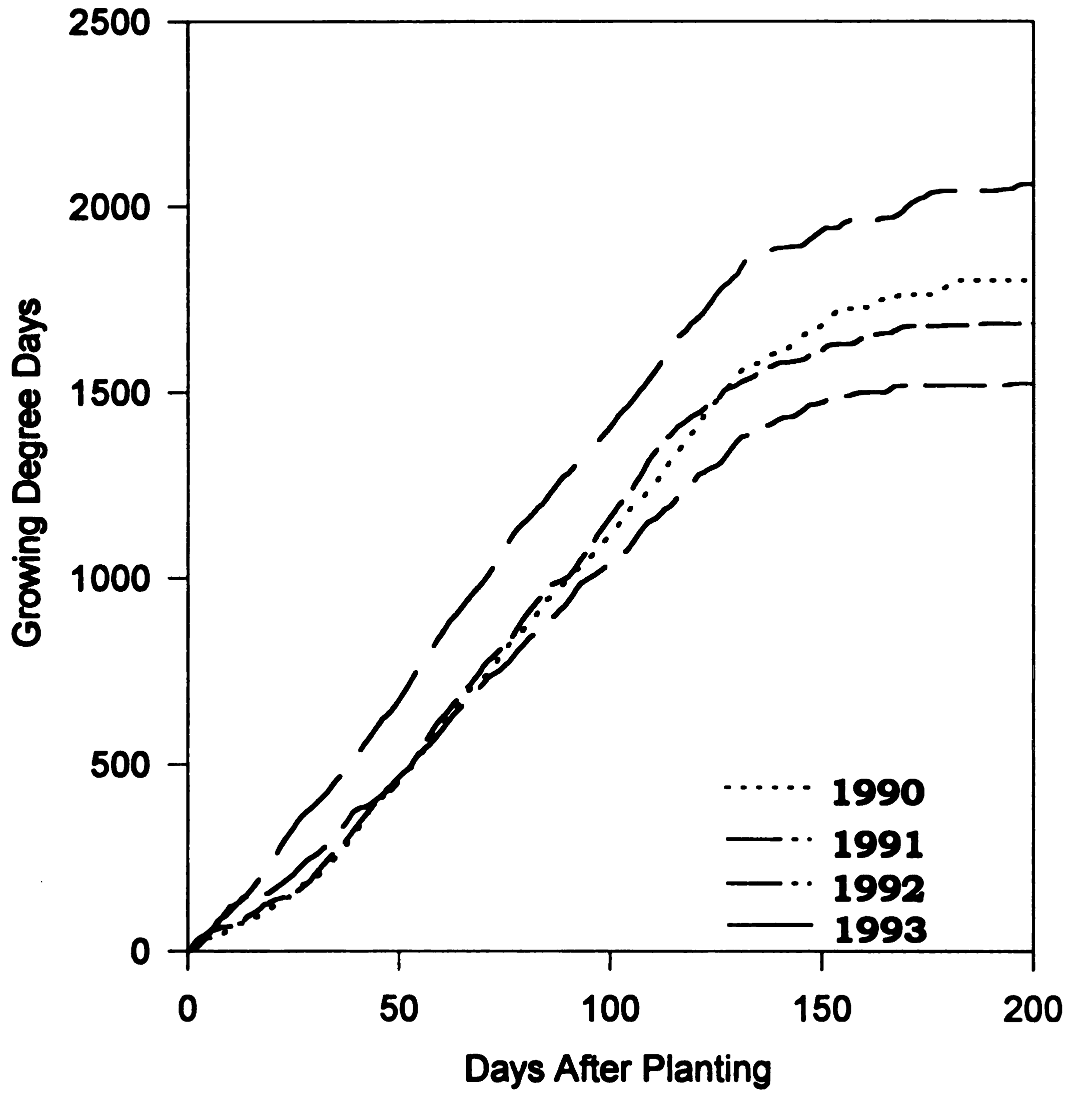


Figure 1. Cumulative growing degree days after planting for the period 1990 to 1993 at the Kellogg Biological Station.

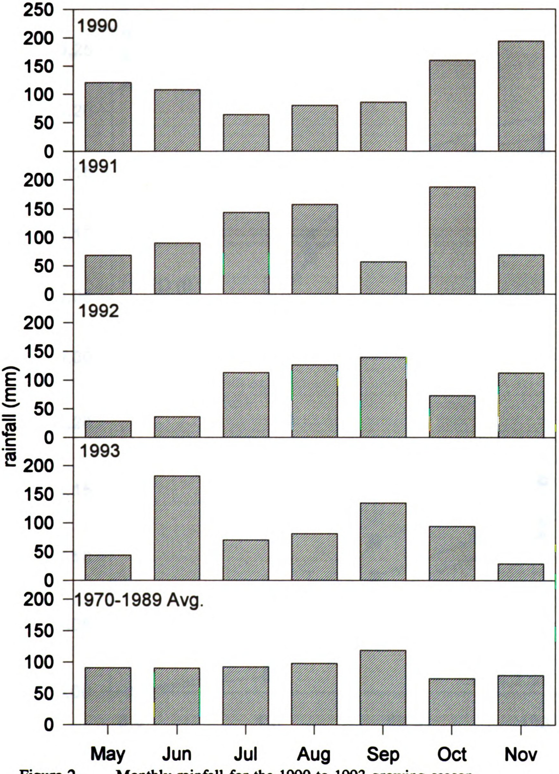


Figure 2. Monthly rainfall for the 1990 to 1993 growing season.

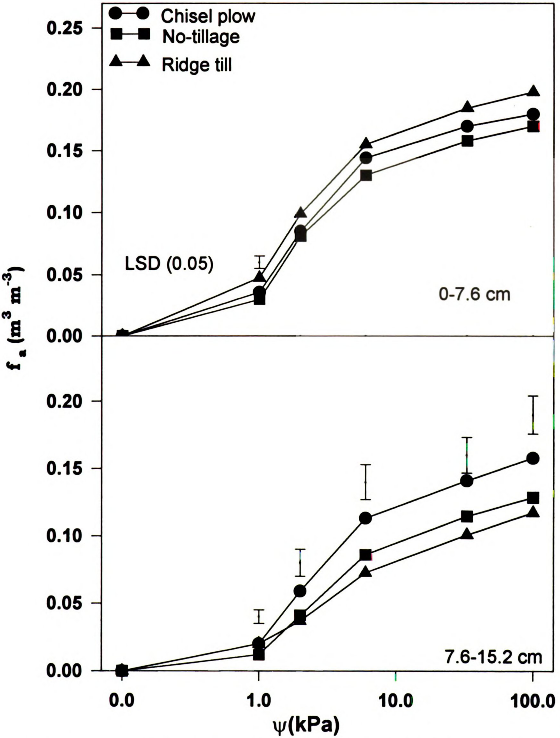


Figure 3. Effects of tillage on air-filled porosity at 0 to 7.6 cm and 7.6 to 15.2 cm depths for the Kalamazoo loam soil sampling on April 22, 1992.

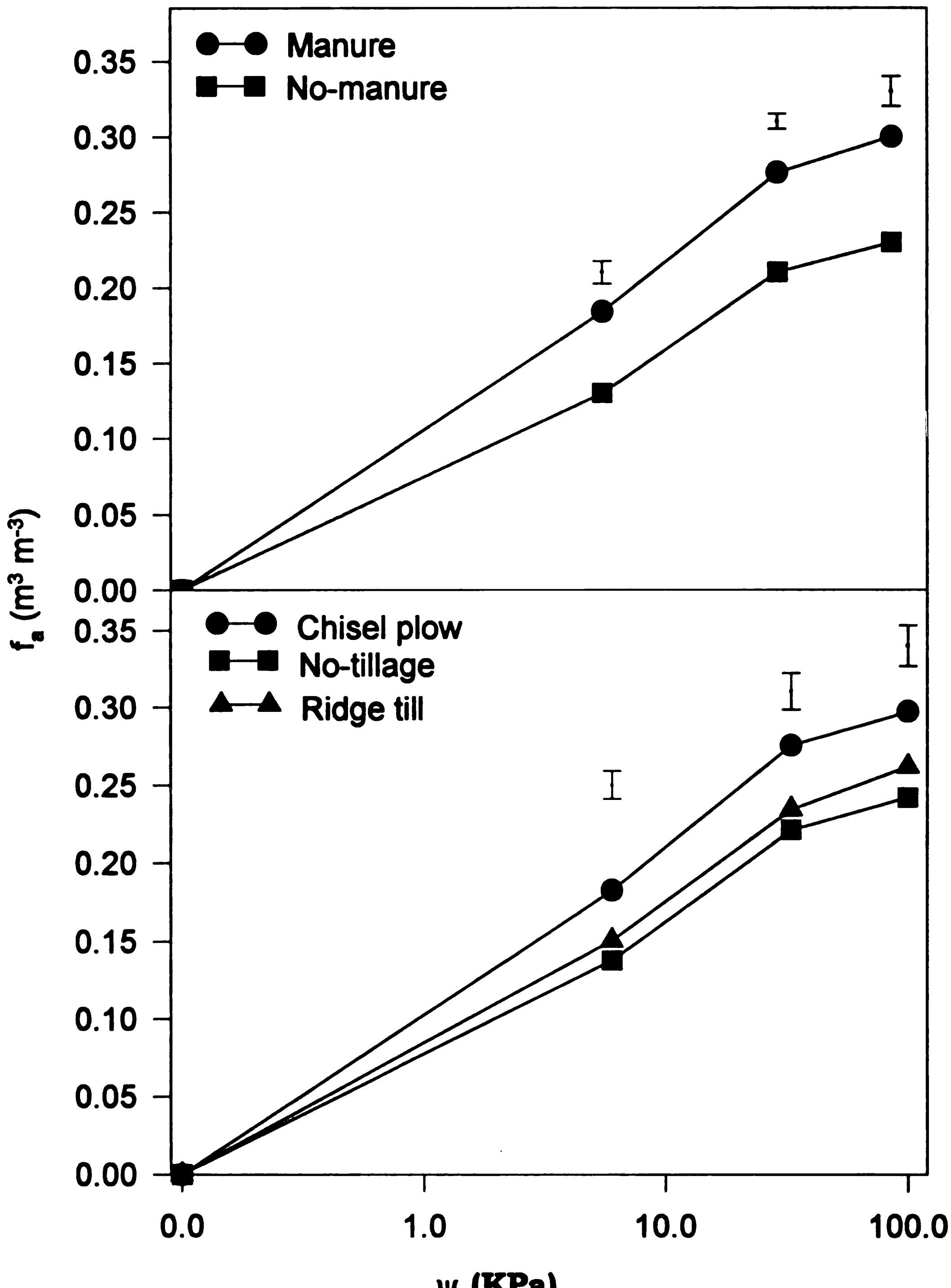


Figure 4. Effects of manure history and tillage on air-filled porosity at 0 to 7.6 cm depth for the Kalamazoo loam soil sampling on November 12, 1993.

CHAPTER 2

Nitrate-Nitrogen in Stratified Soils under Variable Tillage, Chemical Input, and Manure History

Conservation tillage systems are characterized by their alteration of the physical, chemical, and biological properties of soils. Benefits from adoption of conservation tillage have historically focused on decreased soil erosion and decreased sediment and contaminant delivery to surface water (Baker, 1987). In recent years, however, increased emphasis has been placed on evaluating the impacts of conservation tillage on groundwater quality. Changes in soil porosity and pore geometry associated with conservation tillage significantly affect water infiltration, runoff, and evaporation (Griffith et al., 1986), such that water losses by deep percolation in some conservation tillage systems may exceed that in conventionally plowed systems. A number of investigators have suggested that greater infiltration and permeability of soils managed under conservation tillage may increase the potential for groundwater contamination from agricultural chemicals (Baker and Laflen, 1983; Donigian and Carsel, 1987; Edwards et al., 1988; Helling, 1987; Wagenet, 1987). Tyler and Thomas (1979) and Thomas et al. (1973) attributed increased N leaching in no-tillage to macroporous flow, while Angle et al. (1993)

showed that the use of no-tillage cultivation may reduce the leaching of nitrates beyond the crop root zone. Ridge till, as an important conservation tillage system, is often used as a soil management tool to improve the plant root environment. Ridge surface configuration is a more favorable water and temperature environment for early spring plant growth (Buchele et al. 1955; Burrows, 1963), provides better residue management for erosion control (Radke, 1982), and results in increased root development from controlled wheel traffic (Bauder et al., 1985) compared with flat surfaces. Quantitative studies on the direct effects of ridge till system on N leaching are limited. Conclusive studies on the dynamics of the leaching process, as affected by ridge till, have not been reported.

Soil profile stratification of nutrient and organic matter in conservation tillage systems is well documented (Thomas, 1986). Smucker (personal communication) reported root stratification responses in corn to tillage and soil morphologic differences in soil horizons in a Kalamazoo loam soil (Typic Hapludalf, fine, loamy, mixed, mesic). Their data suggested that differences in pore size and continuity between adjacent horizons results in stratification of water and nutrients, to which the plants respond by proliferation at horizon boundaries. It would appear that soil morphologic changes at horizon boundaries will regulate, to some extent, water movement and the persistence and fate of N in soils. Therefore, the combined effects of conservation tillage and soil profile stratification will regulate the fate and movement of N in soils.

While fertilizer N has been implicated in NO_3-N contamination of groundwater, other sources of N can also be responsible. Applications of animal wastes have been reported to increase concentrations of NO_3-N below the rooting zone (Liebhardt et al., 1979; Meek et al., 1974; Olson et al., 1982; Haghiri et al., 1978). The interaction of tillage systems and manure have not been thoroughly examined and tested.

This study evaluated role of conservation tillage systems, chemical inputs, and manure history, in relation to soil stratification, in regulating the fate of N in soils.

MATERIALS AND METHODS

Soil profile inorganic N and soil solution N were measured as part of a study designed to evaluate the effects of tillage, manure history, and chemical inputs on corn and soybean grown in rotation at the Kellogg Biological Station, Hickory Corners, Michigan, over the period 1990 to 1993. The soil was a Kalamazoo loam (Typic Hapludalf, fine loamy, mixed, mesic) underlain by coarse glacial outwash parent material, with an aquifer present within 10 m. The experiment was described in detail in Chapter 1. Briefly, the study consisted of two manure history treatments (with and without), three tillage treatments (chisel plow (CP), no-till (NT), and ridge till (RT)), and two chemical input levels (high (HI) and low (LI)). The treatments were arranged in a randomized complete block strip-plot design with four replications, with a split plot, with manure as the strip and tillage and chemical input as the split plot treatments. Of importance to this study was the application of 140 kg N ha^{-1} of fertilizer in the HI treatments compared to none in the LI treatment. Manure applications were made from 1981 to 1988 at an approximate rate of 22 to 27 Mg ha^{-1} (Bronson, 1989). Manure applications ceased after 1988 in order to evaluate the effects of manure history on soil N.

Composite soil samples were taken in the spring and fall for analysis of NO_3-N and NH_4-N. Spring soil samples were taken after N fertilization in 1990 but prior to N fertilization in 1991 to 1993. Two 5 cm diameter cores were collected from the center portion of each plot to a depth of 100 cm at increments of 0 to 5 cm, 5 to 15 cm, 15 to 30 cm, 30 to 45 cm, 45 to 60 cm and 60 to 100 cm. Soil samples were also collected above and below the horizon contacts of the Ap/Bt and the Bt/C horizons and to a depth of 50 cm below the Bt/C contact (Figure 1). Two samples from each plot were mixed and combined into a single sample at each depth. Soil samples were air-dried and ground to pass through a 2 mm diameter sieve. Ten g of ground soil were extracted with 100 ml of 1.0 M KCl, shaken for 1 hr, and filtered through Whatman #2 filter paper. The filtrate was analyzed colorimetrically for NO_3-N and NH_4-N using a Latchet injection flow analyzer.

Ceramic cup solution samplers were installed in the crop row position of the CP and NT in both manure treatments, but only in the HI treatments. In the ridge till treatment, samplers were installed in the row and between row for all chemical input and manure treatments. Samples of solution were taken approximately twice a month, depending on soil moisture content. A vacuum was applied to the sampling tube using a hand pump, the tube sealed from the atmosphere, and the soil solution withdrawn the next day.

Inorganic N budgets were calculated in order to estimate the potential for NO_3-N leaching (Meisinger and Randall, 1991). Inorganic N balance (N_b) is based on the difference between N_{inputs} and $N_{outputs}$, adjusted for the change in soil N (ΔN_{st}). For our study, N_b was calculated as the difference between inorganic N_{inputs} from fertilizer and precipitation and $N_{outputs}$ taken as the sum of N in the grain, stover, and roots. The value of ΔN_{st} is dominated by the change in soil NO_3-N because soil NH_4-N levels were low and change little over the long term (Meisinger and Randall, 1991). In this study, $\Delta N_{st} = N_{end} - N_{begin}$, where N_{end} is soil NO_3-N content at the end of the analysis season and N_{begin} is soil NO_3-N content at the beginning of analysis season. Nitrogen input from precipitation was estimated as the seasonal precipitation times an estimated average N content of 2 mg N L^{-1} precipitation (Meisinger and Randall 1991). Estimated N inputs from precipitation for the period 1990 to 1993 ranged from 12 to 15 kg N ha^{-1} in the growing season and 6 to 16 kg N ha^{-1} during the fallow season (Table 1). Nitrogen in the root was calculated as 20 % of that in the grain plus shoot (Pierce at el. 1991). The N_b for over winter fallow period was calculated as ΔN_{st} between the fall sampling following corn and the spring sampling preceding soybean planting. The N_b term is an aggregation of all remaining components of the N cycle, including net mineralization, denitrification, volitalization, leaching, runoff, and N fixation, and is used here as an indicator of the potential for nitrate leaching. If N_b is positive, the potential for N loss by leaching is considered high, although other mechanisms besides leaching could account for N_b. Overwinter, however, N losses are most likely attributable to leaching since soil temperatures are low. A negative N_b is indicative of high net N mineralization and a low potential for leaching.

Soil volumetric moisture content (θ) was monitored using time domain reflectometry (TDR) for all tillage and manure treatments in 1991 and 1992, in the crop row for all tillage treatments and additionally in the midrow for the RT treatment (Figure 1). The TDR probes consisted of two parallel steel rods (4.8 mm diameter), placed 50 mm apart. Two probe pairs were inserted vertically for depths of 0 to 15 cm, 0 to 30 cm, and 0 to 75 cm, with each probe placed a distance of 10 cm from the adjacent probe. The TDR readings were taken weekly during the growing season. Volummetric soil moisture content was calculated using Topp's equation (Dalton, 1992).

The analysis of variance was performed using general linear model procedures (SAS Inst., 1990). Soil profile NO_3-N and NH_4-N were analyzed for each depth and date separately. Soil solution NO_3-N and NH_4-N were analyzed for each date separately. Mean differences were determined using a least significant difference (LSD) at the 0.05 level of probability.

RESULTS AND DISCUSSION

The interaction of NO_3-N between manure, chemical inputs, and tillage was limited to three occurences. In the fall of 1990, at the 5 to 15 cm depth, NO_3-N was higher in the manure under low chemical input, but lower under high chemical input. In May of 1991, under low chemical input, NO_3-N was lower in CP than other tillage systems but higher in CP under high chemical input. However, since there were few interactions among manure history, tillage and chemical input levels, and those that were significant were of minor importance, only the main effects will be discussed relative to soil N. Additionally, the amounts of exchangeable NH_4-N in soil were low and relatively constant at all sampling dates. Therefore, NH_4-N has not been discussed.

MANURE HISTORY

Manure generally increased profile NO_3-N content to a depth of 60 cm in the spring in all four years following soybeans, although differences were usually less than 1 g m^{-3} below 5 cm (Figures 2, and 3). However, manure increased NO_3-N only in the surface following corn in 1991 and 1992 but not 1993 (Figure 4). The higher NO_3-N in the surface 5 cm indicates greater mineralization in the manured than non-manured soil even 5 years after manure applications ceased. Nitrate-N was highest following corn in 1991 than in other years, reflecting the high NO_3-N measured in December, 1990 (Figure 5). The effect of manure on soil NO_3-N was variable following corn (Figure 5). In 1990, residual NO_3-N was relatively high in the 30 to 60 cm depth and was higher for the non-manure than the manure treatment (Figure 5). The higher residual NO_3-N was due to a poor corn crop, but the reason for the higher NO_3-N in the non-manured soil was not apparent, as there were no differences in corn yield (Chapter 1). In 1992, NO_3-N was considerably higher throughout the soil profile in the manured treatment, as much as 2 g N m^{-3}. There were mixed but minor differences due to manure in NO_3-N in December of 1991 and 1993, although manure was almost 2 g N m^{-3} higher in the 0 to 5 cm of the manured treatment in 1993. In comparing Figures 4 and 5, it would appear that residual NO_3-N was leached by spring. Soil NO_3-N in December following soybeans was not affected by manure history in 1992 (Figure 6).

Soil solution NO_3-N under corn was highly variable in 1991 and 1992 (Figure 7). The only measurable differences between treatments occurred on the 25 July, 1991 and 19 August, 1992, and these were reversed relative to manure effects. The weather in 1991 was warm and moist and ideal for N mineralization (favoring the manured treatment) while 1992 was cold and wet. Prior to fertilization, soil solution NO_3-N was low prior to N fertilization, which dramatically increased soil solution NO_3-N. In either case, the potential for NO_3-N leaching was high in both years until mid August when the corn crop had depleted soil N reserves during the grain fill period.

In 1990, a year with high rainfall and low crop yields, less N was taken up by the crop, and the potential for NO_3-N leaching was high in all treatments (Figure 8). The N_b was 26.2 kg ha^{-1} higher in the manure treatment than in the no-manure treatment. In 1991, 1992 and 1993, when crop uptake N exceeded fertilizer application, the growing season N_b was negative, indicating that considerable N was mineralized to supply the N needs of corn. Net mineralization was at least 45, 29 and 18 kg ha^{-1} higher in the manure treatment than in the no-manure treatment in 1991, 1992 and 1993, respectively. Therefore, the residual effects of manure were evident 5 years after applications ceased.

The NO_3-N loss over winter was highest under no-manure in 1990, due to the higher profile NO_3-N (Figure 8). Because of the high N uptake in the 1991 growing season and lower soil nitrogen content after harvest, N_b over winter was very low, with no differences between manure treatment. Over winter losses in 1992-93 were considerably higher in the manured treatment, largely because of the higher soil profile NO_3-N in the manured treatment in December, 1992.

In general, the effect of manure was to increase net mineralization but at the cost of increasing the potential for NO_3-N leaching, although this was not consistent in all years. The effects of manure were still evident to a depth of 1 m 5 years after manure applications ceased.

CHEMICAL INPUT

The direct effects of N fertilization were measured in 1990 when soils were sampled after application (Figure 2). Concentrations of NO_3-N were considerably higher in the HI than LI treatment in the 0 to 30 cm depth increments but not below. In 1991 to 1993, NO_3-N in HI was not different than LI following soybeans and slightly higher in the surface 5 cm in 1993 following corn in soil profiles sampled in the spring prior to planting (data not shown). There were, however, large differences due to input treatment in December of each year, with HI having much higher NO_3-N below 30 cm to a depth of 100 cm than LI (Figure 9). Since few differences were found in the spring soil profile sampling, the residual NO_3-N in HI was apparently leached over winter. The high leaching potential for the HI treatment was also very apparent in the soil solution samples in both 1991 and 1992 (Figure 10). The LI solution concentrations of NO_3-N were low all season (< 15 mg L^{-1}) and represent baseline levels of NO_3-N in soils under no fertilizer application. The N_b was positive in 1990 due to the poor corn yield and higher for HI than LI, as would be expected (Figure 11). In 1991 to 1993, growing season N_b was negative, with LI showing some indication of increased net mineralization in an attempt to supply the corn crop with N. The over winter N_b were higher for HI than LI only in 1990. However, the calculation of over winter N budget would underestimate N_b since any N mineralized in the spring would reduce the apparent N losses. Soil NO_3-N in the fall following corn was lower than following soybeans (Figure 6 and 9) indicating a release of N from the soybeans and a slight build up NO_3-N in the fall.

Inputs of N fertilizer, as would be expected, resulted in more N in the soil profile, higher soil solution N concentrations, and higher NO_3-N leaching potential than no fertilizer N input. The lack of difference between soil profile NO_3-N in the spring between HI and LI confirms that residual soil NO_3-N was leached over winter on this soil. The large differences soil solution NO_3-N between HI and LI at the base of the soil profile indicates that leaching occurred in HI during the growing season as well.

TILLAGE

In June, 1990, following N fertilization, tillage had little effect on soil profile

NO_3-N, although RT was higher in the 5 to 15 cm depth (Figure 2). In the spring of 1991 and 1992, NO_3-N in CP was often higher than RT and NT following either soybeans or corn (Figure 12 and 13). In May 1991, NO_3-N was higher following corn than soybeans, after a year of low corn grain yields and high residual NO_3-N in 1990, and differences between tillage treatments were greater. In May 1992, differences between tillage systems were greater following soybeans than corn, reflecting high corn grain yields in 1991. In May of 1993, following soybeans, NO_3-N in CP was higher in the 5 to 30 cm depth and lower in the 30 to 45 and 45 to 60 cm depths than in NT and RT, while following corn, NO_3-N was higher in CP to a depth of 45 cm. In the December, NO_3-N following corn was generally higher in CP than NT and RT, and generally the lowest in RT in all but 1993 (Figure 14). Following soybeans in 1992, NO_3-N was higher than following corn and higher in NT at 15 to 45 cm and higher in CP than RT in 5 to 15 cm (Figure 6). This reflects the release of N by soybeans in the fall and the higher yields in NT than the other treatments. Ridge till had significantly higher soil solution NO_3-N in both years, particularly after N fertilization, than the other tillage treatments (Figure 15). The lower soil profile NO_3-N and higher solution NO_3-N indicate that the potential for NO_3-N leaching during growing season was higher in RT than in CP or NT.

In 1990 growing season, RT lost about 60 kg N ha^{-1} compared to 40 and 10 kg N ha^{-1} for NT and CP, respectively, indicating that leaching occurred during the growing season (Figure 16). In 1991, when crop N demand was high, CP seemed to release more N due to soil surface disturbances by chiseling and enhancement of m

R

til

N

to

wa

for

wi

NO

nit

obs

cm

val

SO

ma

sys

had

NT

diff

microbial activities. Net mineralization rates for CP were 53 kg N ha^{-1} higher than RT and 35 kg N ha^{-1} higher than NT. Nitrogen balance was not different between tillage treatments in 1990. Again in 1993, mineralization was higher for the CP than NT, but there was no difference for RT. In the winter of 1990 to 1991, N_b was 13 to 18 kg ha^{-1} and there were no difference between tillages. The following winter, N_b was 12 kg ha^{-1} for chisel plow, as compared to 2 kg ha^{-1} for NT and negative value for RT. Nitrogen balance was 11 to 14 kg ha^{-1} for all three tillage systems in the winter 1992 to 1993. The negative over winter N_b in 1991 would also indicate that NO_3-N was lower in RT by fall sampling.

We might expect that the row position under ridge till may leach more nitrogen during rainfall event due to accumulation surface water. This was not observed (data not shown) because the samplers in-row and mid-row were only 36 cm apart. Samples collected from both sampler position was mixed from ridge and valley, and we could not distinguish between the two position by this method.

SOIL MOISTURE

There were no differences in soil volumetric moisture content (θ) due to manure history or chemical input. The seasonal distributions of θ for three tillage systems are given in Figures 17 and 18 for 1991 and 1992, respectively. In 1991, RT had lower θ than the CP at both depths during most of the growing season. The θ in NT was higher than in RT frequently but less often than CP in 1991. There were no differences in θ between NT and CP in either year. In 1992, θ in RT again was lower than CP at the 0 to 15 cm depth between 3 June and 3 August. There were no differences in θ due to tillage at 15 to 30 cm depth in 1992, with the exception of higher θ in CP than NT on 8 September. There was no differences in θ due to tillage at 30-75 cm depth in either year.

NITRATE-N STRATIFICATION

Nitrate-N stratification was expressed as a stratification index (SI), defined as the ratio of soil NO_3-N concentration in upper to lower layer. Stratification index values larger than 1 indicated that soil NO_3-N had accumulated in the upper layer of the horizon contact. The degree of stratification of NO_3-N was minimal under manure and chemical input (Table 3). Most differences in SI were related to tillage, with mixed results. The greatest stratification was measured in NT in the spring of 1990 after N fertilization, at which time the NT had an SI of 1.6 and CP and RT were less than 1.0. The SI was higher for CP in the fall in 1990 and 1991. In general, however, the degree of stratification was weak, probably due to the fact that most soil samples were take prior to fertilization in the spring and after harvest. Based on these data, stratification of NO_3-N in this soil was minimal.

SUMMARY AND CONCLUSION

Soil profile and soil solution NO_3-N were evaluated along with N balance in response to manure history, tillage system, and chemical input levels in a corn-soybean rotation. There were no interactions between treatments over a four year period. The main effect of manure was to increase residual profile NO_3-N, soil solution NO_3-N , and N_b and thereby increase the potential for NO_3-N leaching. This study indicates that the residual effects of manure history were evident in increased N mineralization 5 years after manure application ceased.

Nitrogen fertilizer was the major source contributing to NO_3-N leaching, especially in low yielding years when crops could not utilize additional N. High chemical input treatments potentially lost more than 50 kg ha^{-1} nitrogen in the 1990 growing season while potential losses in LI were 18 kg ha^{-1} and contributed to increased over-winter soil N loss. Baseline levels of NO_3-N at the base of the soil profile, represented by levels under LI, were near 15 mg N L^{-1} in soil solution in the spring and declined to below 10 mg N L^{-1} during the growing season. Fertilizer elevated concentrations to > 25 mg N L^{-1} soon after N application. Thus, the 10 mg N L^{-1} EPA standard would be exceeded in the soil solution at the base of the soil profile even under LI in the spring. However, even though solution NO_3-N was below 10 mg N L^{-1} under LI during the growing season, soil NO_3-N content was too low to meet the N requirement of corn.

The CP had consistently higher soil profile NO_3-N than NT and RT in spring and fall. This suggests that the disturbed soil surface under CP enhanced mineralization in early spring. The higher NO_3-N for CP in fall contributed higher N_b over winter. Ridge till had consistently lower profile NO_3-N but high soil solution NO_3-N, indicating RT had the highest potential for NO_3-N leaching during the growing season. Ridge till had consistently lower θ than other tillage systems in the row, indi

movemen

solution.

T

boundar

applicat

manure

row, indicating water movement in the valley of the midrow. The preferential movement of water in the ridge valley may explain the lower θ and higher NO_3-N in solution.

There was little evidence of profile stratification of NO_3-N at horizon boundaries. This was in part related to the sampling times occurring before N application and after harvest. Overall, the more intensely managed the system, that is manure, chemicals and chisel plowing, the higher the potential for NO_3-N leaching.

LIST OF REFERENCES

Angle, J. S., C. M. Gross, R. L. Hill, and M. S. McIntosh. 1993. Soil nitrate concentration under corn as affected by tillage, manure, and fertilizer application. I. Environ. Qual. 22:141-147.

Baker, J. L., and Laflen. 1983. Runoff losses of nutrients and soil from ground fall-fertilized after soybean harvest. Trans ASAE 25:344-348.

Bauder, J.W., G.W. Randall, and Schuler. 1985. Effects of tillage with controlled wheel traffic on soil properties and root growth of corn. J. Soil Water Conserv. 40:382-385.

Bronson, J. A. 1989. the effect of tillage system on corn production and soil properties on a Kalamazoo Loam. M.S. Thesis. Michigan State university. East Lansing, MI.

Buchele, W.F., E.V. Collins, and W.G. Lovely. 1955. Ridge farming for soil and water control. Agric. Eng. 36:324-329.

Burrows, W.C. 1963. Characterization of soil temperature distribution from various tillage-induced microreliefs. Soil Sci. Soc. Am Proc. 27:350-353.

Dalton F. N. 1992. Development of time-domain reflectometry for measuring soil water content and bulk soil electrical conductivity. p. 143-167 *in* G.Clarke Topp, W. Daniel Reynolds, and Richard E. Green (eds.) Advances in measurement of soil physical properties: Bring theory into practice. ASA, CSSA, and SSSA, Madison, WI.

Donigian, A.S., Jr., and R.F. Carsel, 1987. Modeling the impact of conservation tillage practices on pesticide concentrations of ground and surface water. Environ. Topical. Chem. 6:241-250.

Edwards, W.M., L.D. Norton, and C.E. Redmond. 1988. Characterizing macropores that affect infiltration into non-tilled soils. Soil Sci. Soc. Am. J. 53:483-487.

Griffith, D.R. and , J.V. Mannering , and J.E.Box. Soil andmoisture management with reduced tillage. p. 19-58. In M.A.Sprague and G.B.Triplett (eds) No-tillage and surface -Tillage Agriculture -The Tillage Revolution. John Wiley & Sons, New York.

Haghiri, F., R.H. Miller, and T.J. Logan. 1978. Crop response and quality of soil leachate as affected by land application of beef cattle waste. J.Environ. Qual. 7:406-412.

Helling, C.S 1987; Effects of conservation tillage on pesticide dissipation. p. 179-187. In T.J. Logan et al. (ed.) Effects of conservation tillage on ground water quality: Nitrates and pesticides. Lewis Publ. Chelsea, MI.

Liebhardt, W. C., C. Golt , and J. Tupin. 1979. Nitrate and ammonium concentrations of ground water resulting from poultry manure applications. J. Environ. Qual. 8:211 -215.

Meek, B.D., A.J.Mackenzie, T. J. Donovan, and W. F. Spenser. 1974. The Effect of large applications of manure on movement of nitrate and carbon in an irrigated desert soil. J. Environ . Qual. 3:235 - 258.

Meisinger, J. J. and G.W. Randall. 1991. Estimate nitrogen budgets for soil-crop systems. p.85-124. In R. F. Follott, D. R. Keney, and R. M. Cruse (ed.) managing nitrogen for groundwater quality and farm profitability. ASA, Madison, WI.

Olson, R. V., R. V. Terry, W. L. Powers, C. W. Swallow, and E. T. Kanemasee. 1982. Disposal of feedlot - lagoon water by irrigation Brown grass: II. Soil accumulation and leaching of nitrogen. J. Environ. Qual. 11:400 - 405.

Pierce, F.J., M. J. Shaffer and A. D. Halvorson. 1991. Screening procedure for estimating potentially leachable nitrate-nitrogen below the root zone. p.259-283. In R. F. Follott, D. R. Keney, and R. M. Cruse (ed.) managing nitrogen for groundwater quality and farm profitability. ASA, Madison, WI.

Radke, J.K. 1982. Management early season soil temperatures in the northern Corn Belt using configured soil surfaces and mulches. Soil Sci. Soc. Am. J. 46:1067-1071.

SAS Institute. 1990. SAS/STAT user's guide. Version 6. SAS Inst., Cary, NC.

Thomas, G. W. 1986. Mineral nutrition and fertilizer placement. P. 93 - 116. In M. A. Sprague and G. B. Triplett (eds) No - tillage and Surface - Tillage Agriculture - The Tillage Revolution. Johnn Willey & Son, New York.

Tyler, D. D. and G. W. Thomas. 1979. Lysimeter measurements of nitrate and chloride losses from conventional and no - tillage corn. Agron. J. 74:823 - 826.

Wagenet, R.J. 1987. Processes influencing pesticide loss with water under conservation tillage. p. 189-204. In T.J. Logan et al. (ed.) Effects of conservation tillage on ground water quality: Nitrates and pesticides. Lewis Publ. Chelsea, MI.

Tab

199
199
199
199

Table 1. Precipitation and estimated precipitation nitrogen input in growing season and fallow period in 1990, 1991, 1992 and 1993.

	May 1 - November 30		December 1 - April 30	
	Precipitation (mm)	N-input (kg ha^{-1})	Precipitation (mm)	N-input (kg ha^{-1})
1990	714	14.2	837	16.6
1991	691	13.8	347	6.9
1992	599	12.0	556	10.7
1993	591	11.8		

Table 2. Stratification index for the Ap/Bt and Bt/C horizons in the Kalamazoo Loam soil over 1990 to 1993.

Treatments	1990 Ap/Bt	1990 Bt/C	1991 Ap/Bt	1991 Bt/C	1992 Ap/Bt	1992 Bt/C	1993 Ap/Bt	1993 Bt/C
Spring								
Manure	0.9	1.1	1.0	1.1	1.0	1.1	1.0	1.1
Non-manure	1.3	1.0	1.1	1.1	1.1	1.1	1.0	1.0
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
High Input	0.9	1.1	1.0	1.1	1.1	1.1	1.0	1.0
Low Input	1.3	1.1	1.0	1.1	1.0	1.1	1.0	1.0
LSD(0.05)	0.3	NS	NS	NS	NS	NS	NS	NS
Chisel plow	0.8	1.1	1.1	1.1	1.1	1.2	1.1	1.0
No-tillage	1.6	1.1	1.0	1.0	1.0	1.1	1.0	1.1
Ridge till	0.9	1.0	1.0	1.2	1.1	1.0	0.9	1.1
LSD(0.05)	0.3	NS	NS	0.1	NS	NS	NS	0.1
Fall								
Manure	0.9	1.2	1.1	1.1	1.0	1.2	1.0	1.1
Non-manure	1.0	1.1	1.0	1.1	1.1	1.0	1.1	1.1
LSD (0.05)	NS	NS	NS	NS	NS	NS	0.1	NS
High Input	1.0	1.2	1.1	1.2	1.0	1.1	1.0	1.1
Low Input	1.0	1.1	1.0	1.0	1.0	1.1	1.1	1.0
LSD(0.05)	NS	NS	NS	0.2	NS	NS	0.04	NS
Chisel plow	0.9	1.2	1.2	1.3	1.0	0.9	1.0	1.1
No-tillage	1.0	1.2	1.0	1.0	1.0	1.1	1.1	1.1
Ridge till	1.0	1.0	1.0	1.1	1.0	1.2	1.0	1.1
LSD(0.05)	0.1	0.2	0.1	0.2	NS	NS	0.04	NS

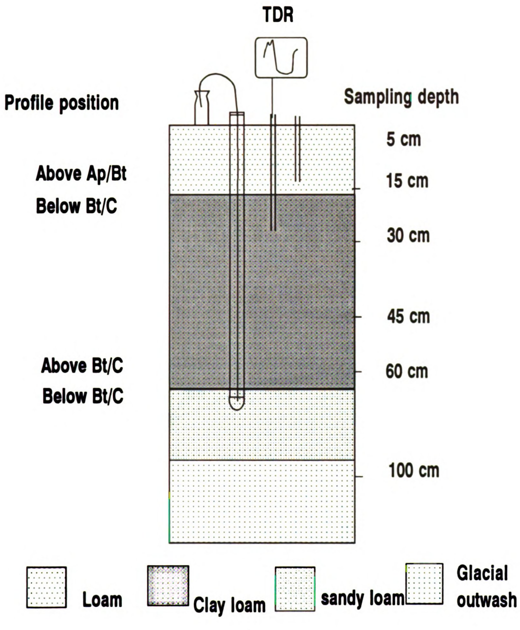


Figure 1. Illustration of soil profile horizons, soil sampling depths, soil solution sampler installation, and TDR placement for the Kalamazoo loam soil at Hickory Corners, MI.

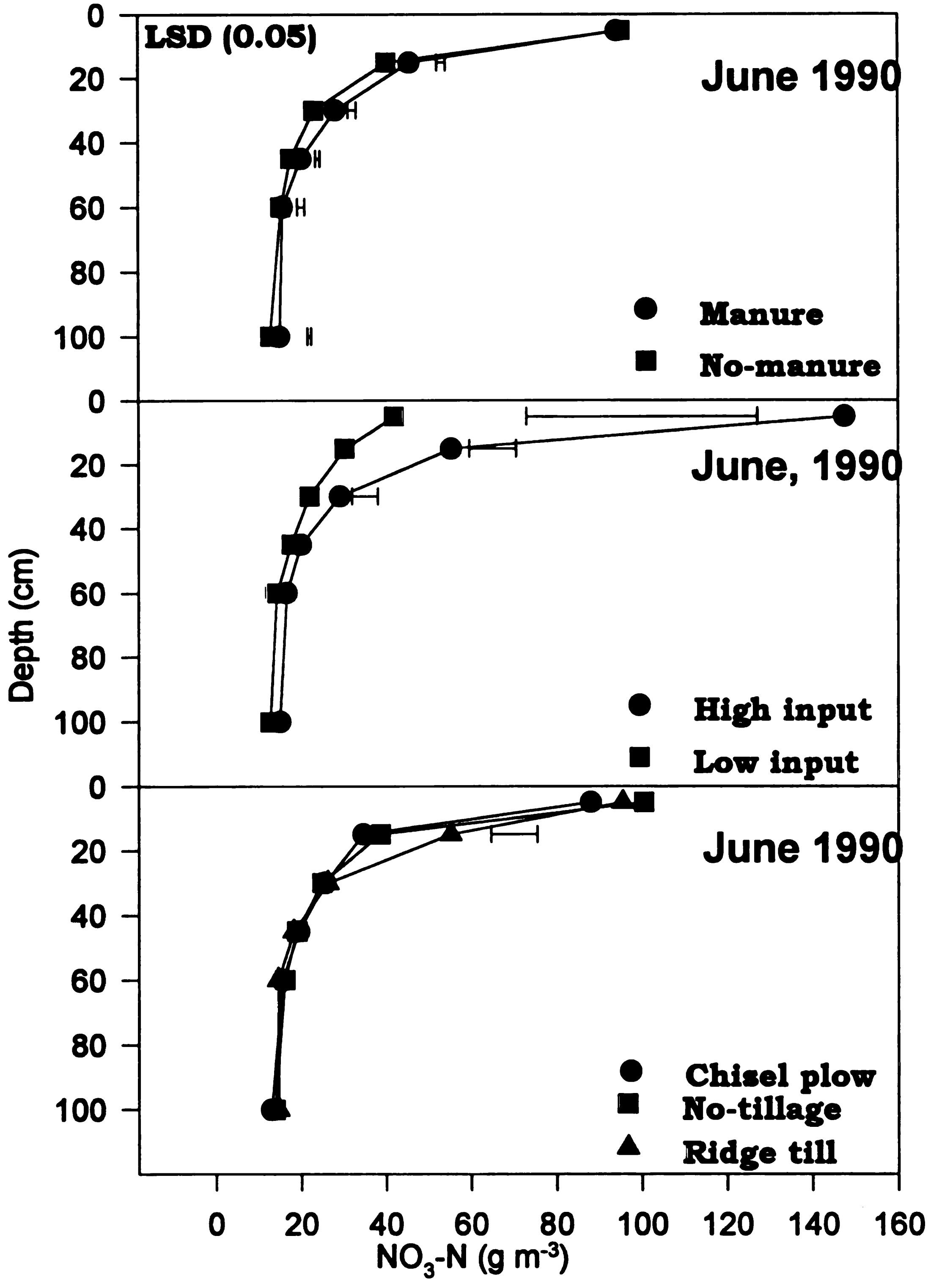


Figure 2. Soil profile NO_3-N as affected by manure history, tillage, and chemical input following corn for the Kalamazoo loam soil for the June, 1990 soil sampling date.

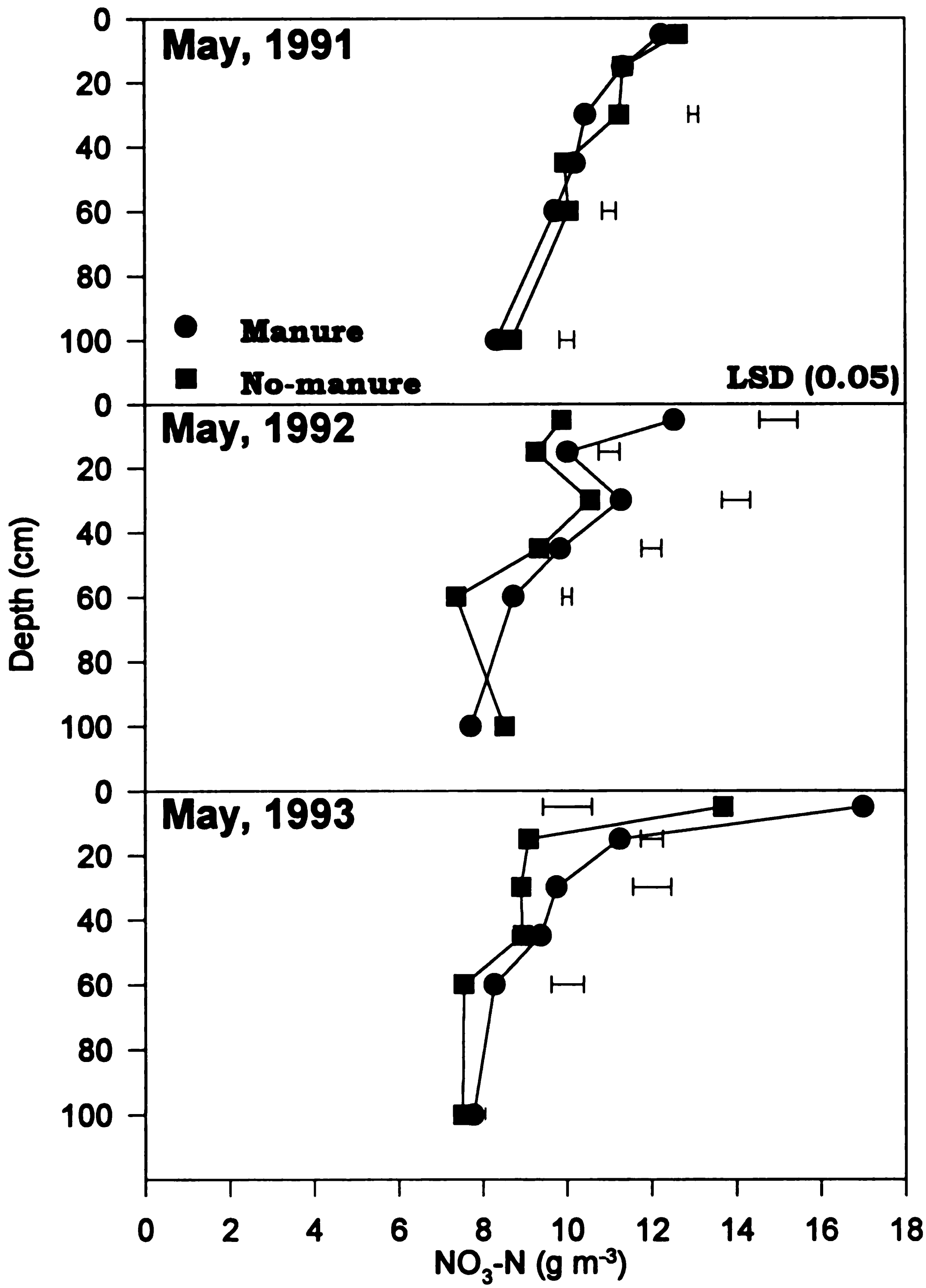


Figure 3. Soil profile NO_3-N in the spring as affected by manure history following soybeans in the previous year for the Kalamazoo loam soil for the period 1991 to 1993.

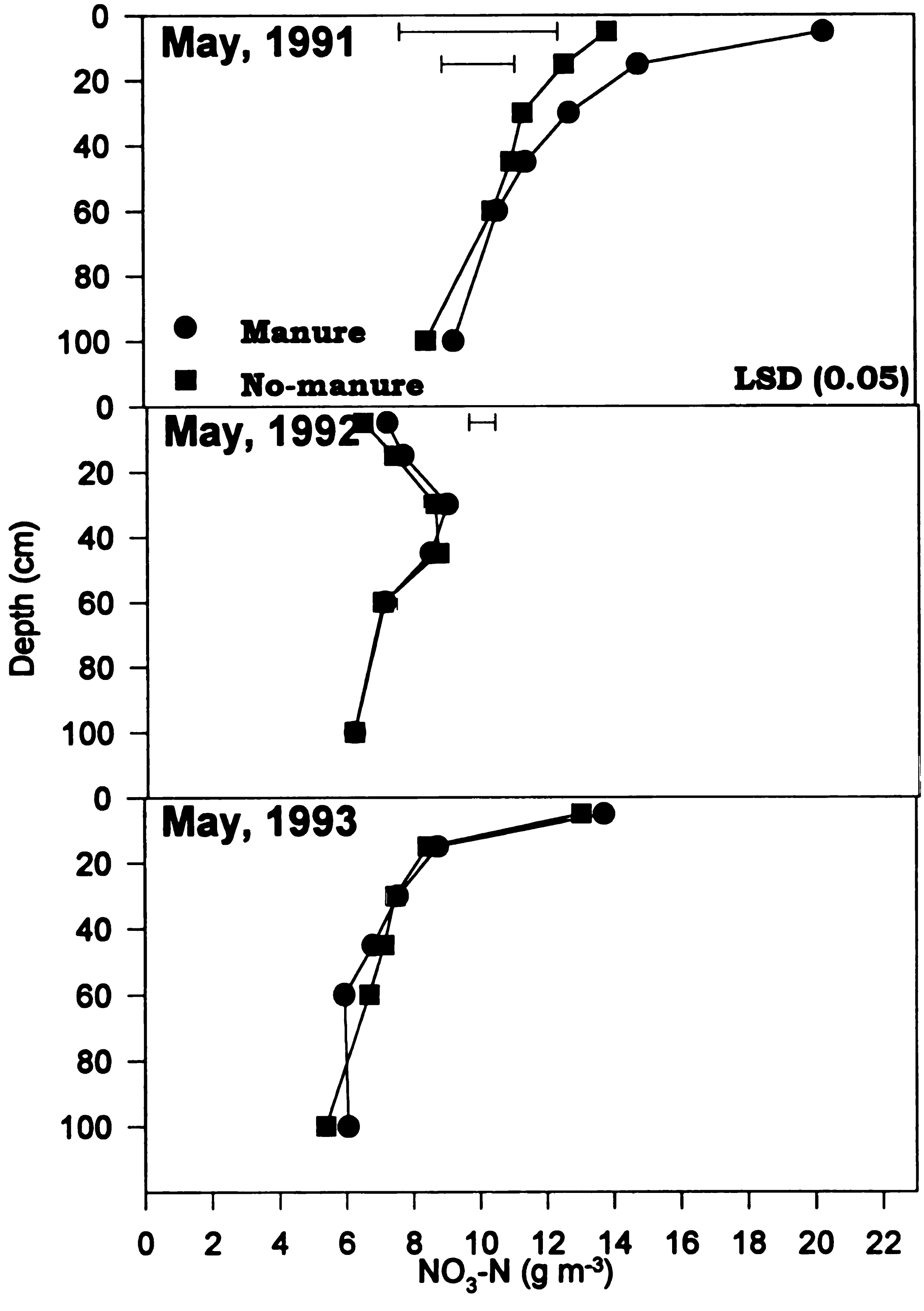


Figure 4. Soil profile NO_3-N in the spring as affected by manure history following corn in the previous year for the Kalamazoo loam soil for the period 1991 to 1993.

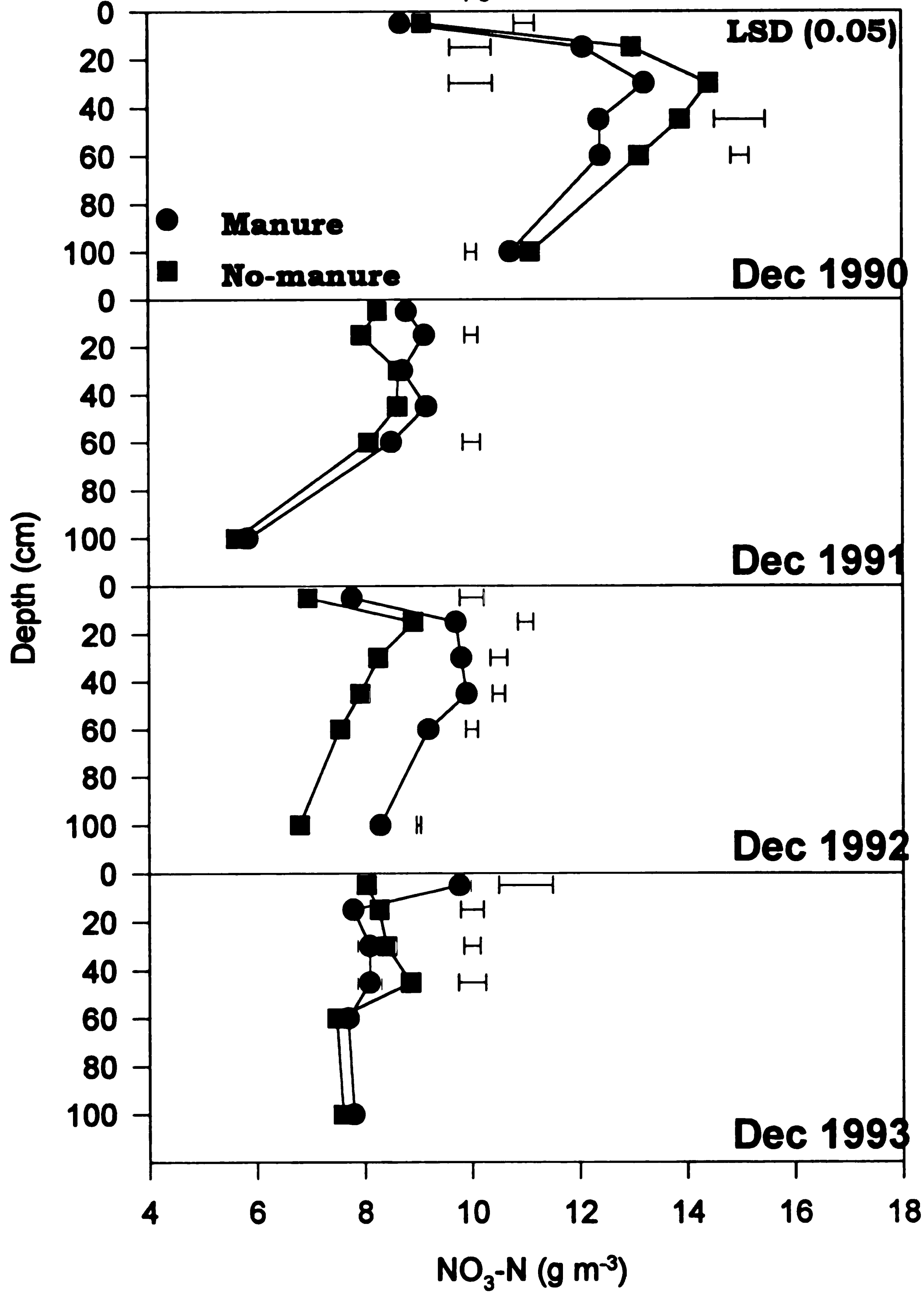


Figure 5. Soil profile NO_3-N in the fall as affected by manure history following corn for the Kalamazoo loam soil for the period 1990 to 1993.

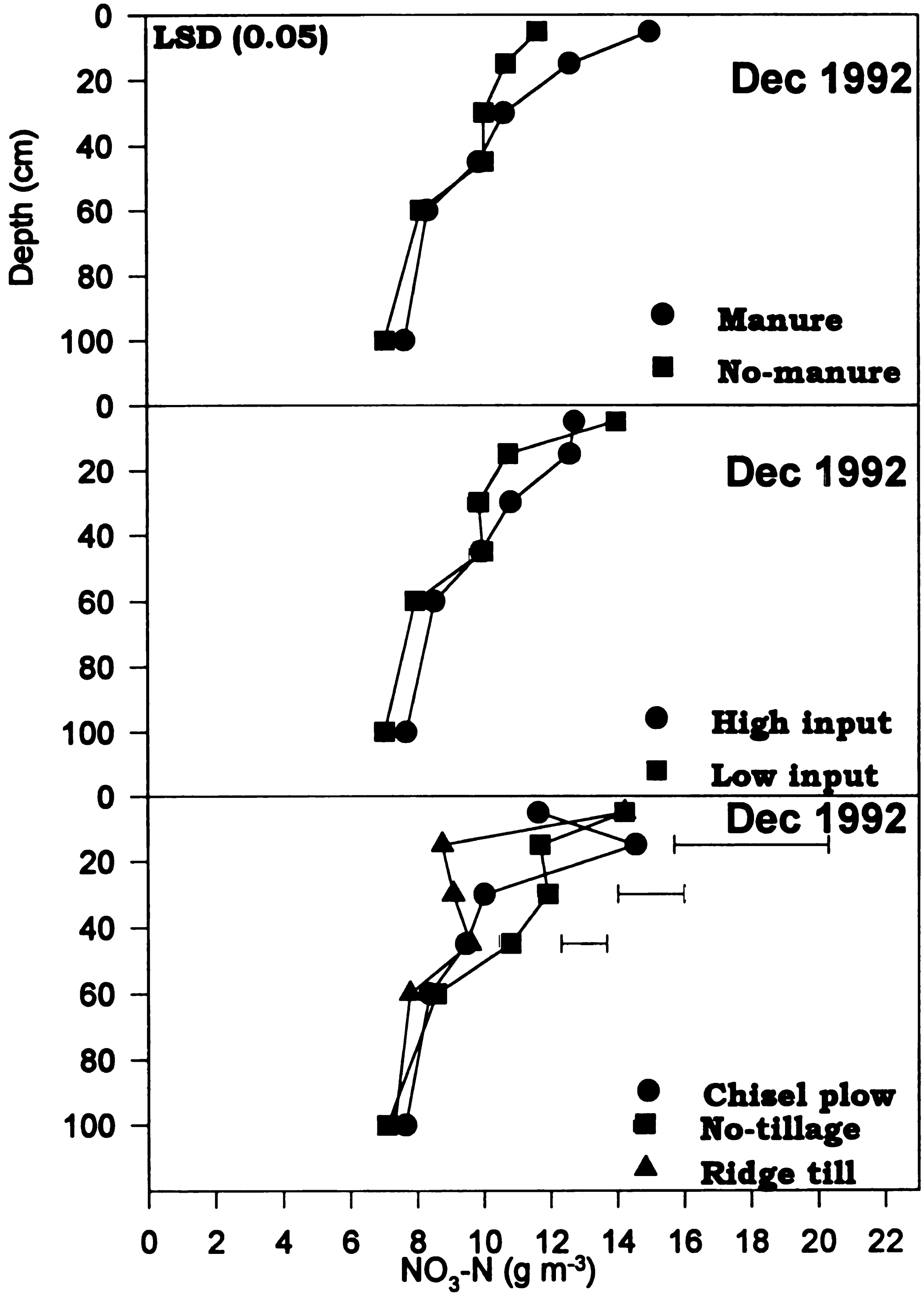


Figure 6. Soil profile NO_3-N as affected by manure history, tillage, and chemical input following soybeans for the Kalamazoo loam soil for the December, 1992 soil sampling date.

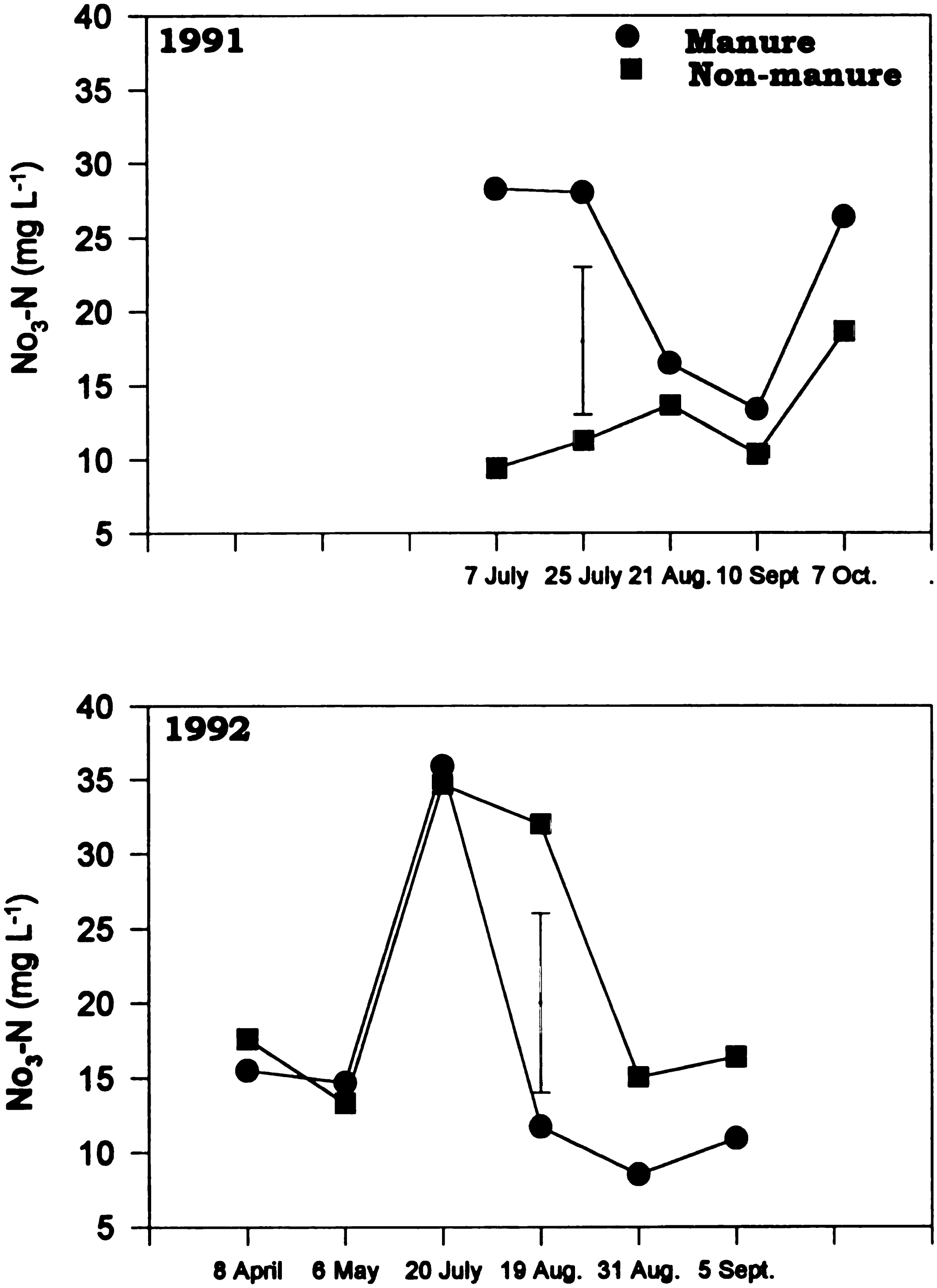


Figure 7. Soil solution NO_3-N in response to manure history sampled at the Bt/C horizon contact of a Kalamazoo loam soil during the 1991 and 1992 growing season.

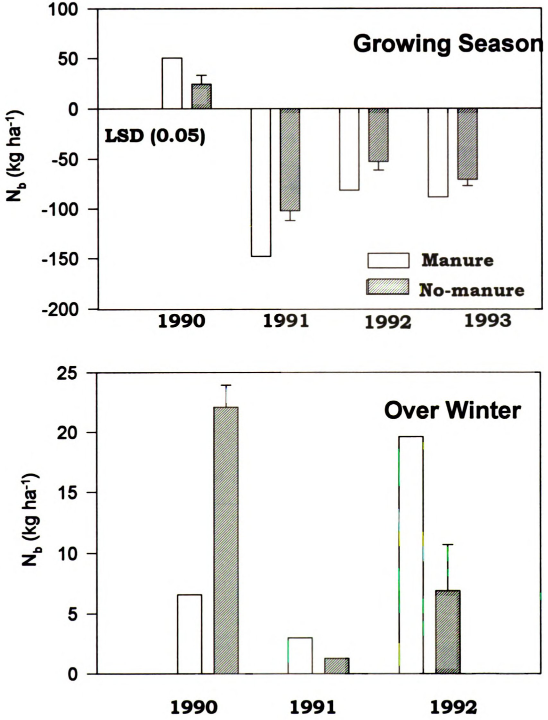


Figure 8. Nitrogen balance (N_b) for the growing season and over winter period as affected by manure history over the period 1990 to 1993.

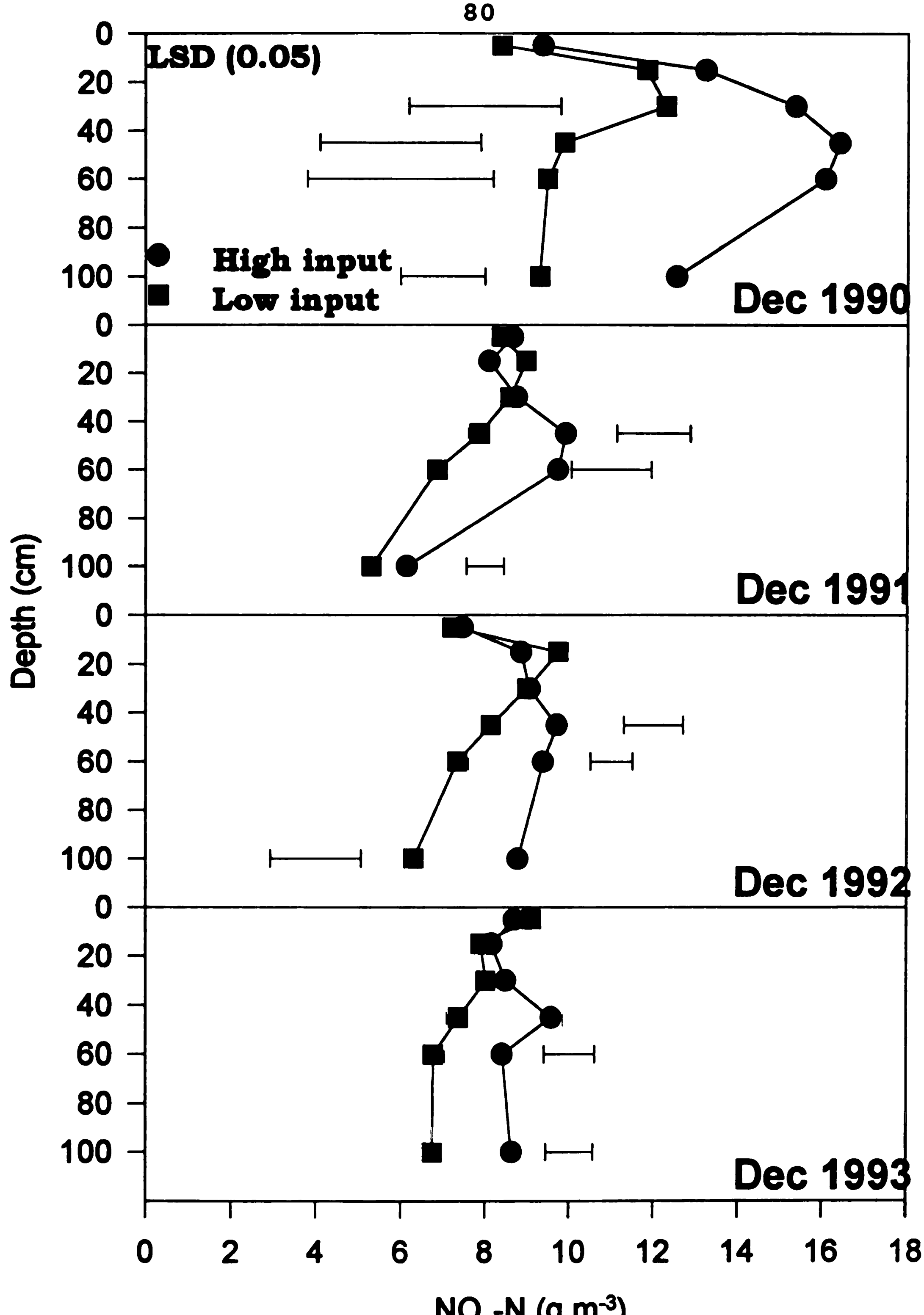


Figure 9. Soil profile NO_3-N in the fall as affected by chemical input levels history following corn for the Kalamazoo loam soil for the period 1990 to 1993.

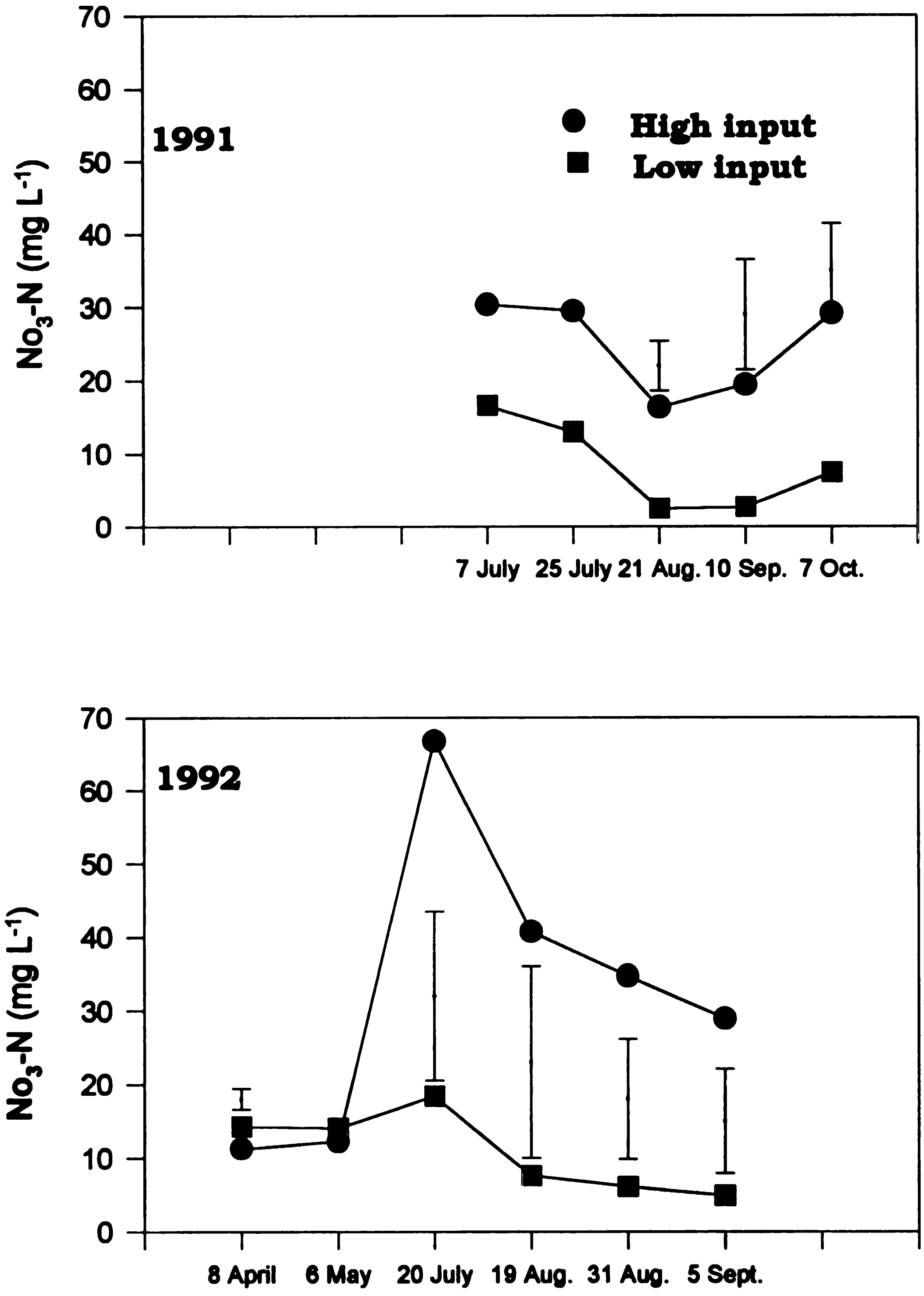


Figure 10. Soil solution NO_3-N in response to chemical input levels sampled at the Bt/C horizon contact of a Kalamazoo loam soil during the 1991 and 1992 growing season.

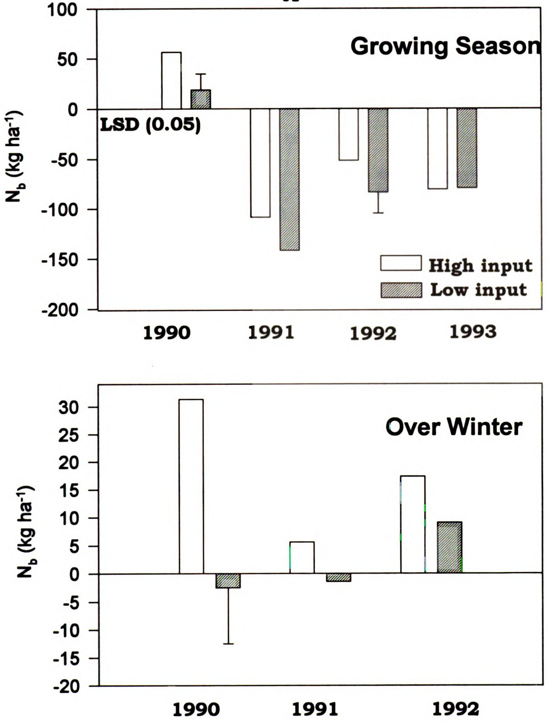


Figure 11. Nitrogen balance (N_b) for the growing season and over winter period as affected by chemical input levels over the period 1990 to 1993.

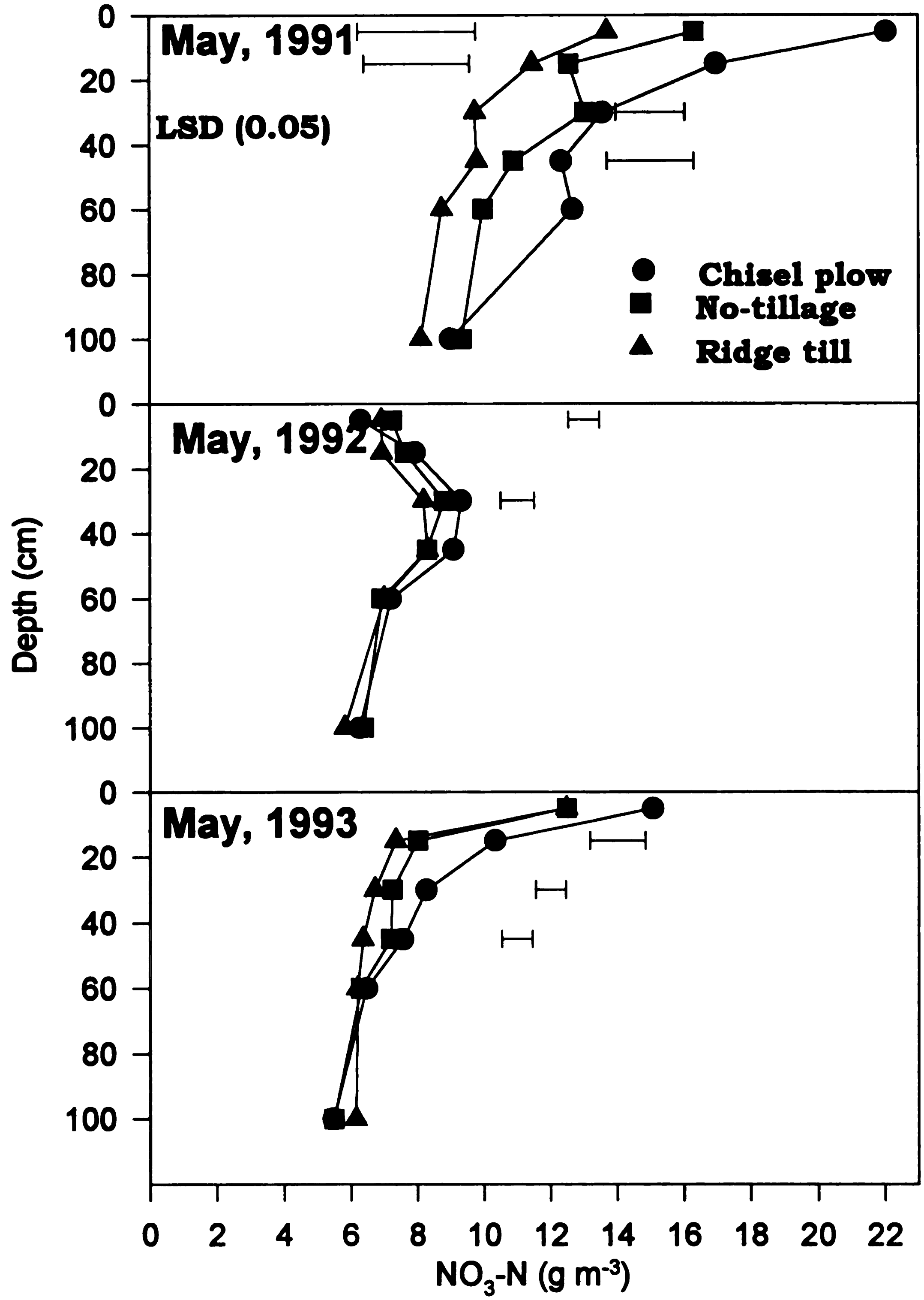


Figure 12. Soil profile NO_3-N in the spring as affected by tillage systems following corn in the previous year for the Kalamazoo loam soil for the period 1991 to 1993.

Depth (cm)

Figure

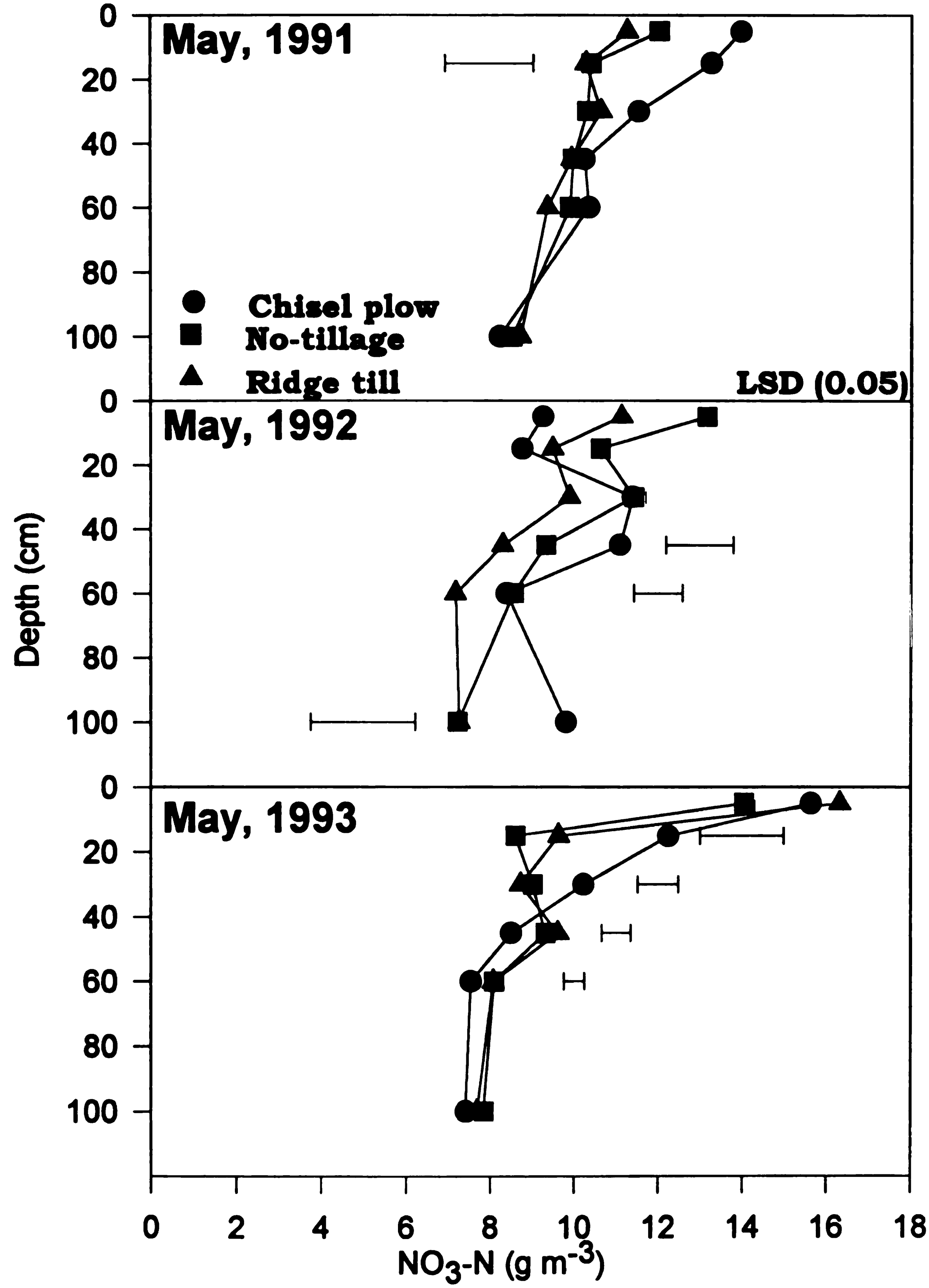


Figure 13. Soil profile NO_3-N in the spring as affected by tillage systems following soybeans in the previous year for the Kalamazoo loam soil for the period 1991 to 1993.

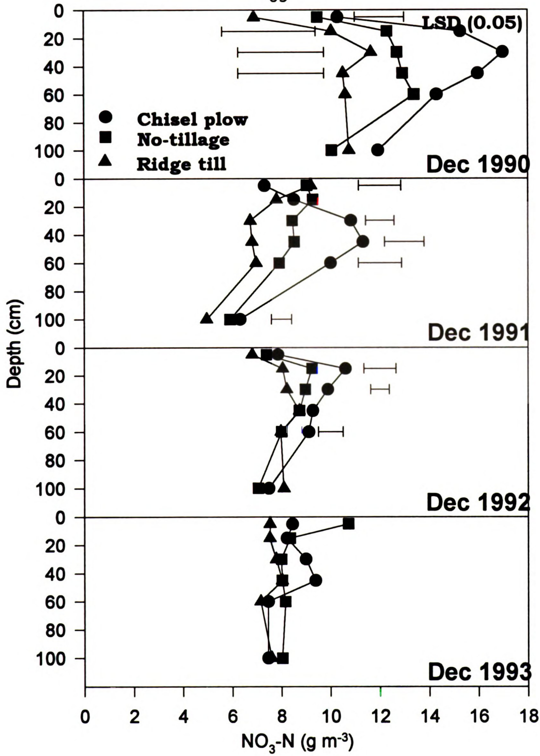
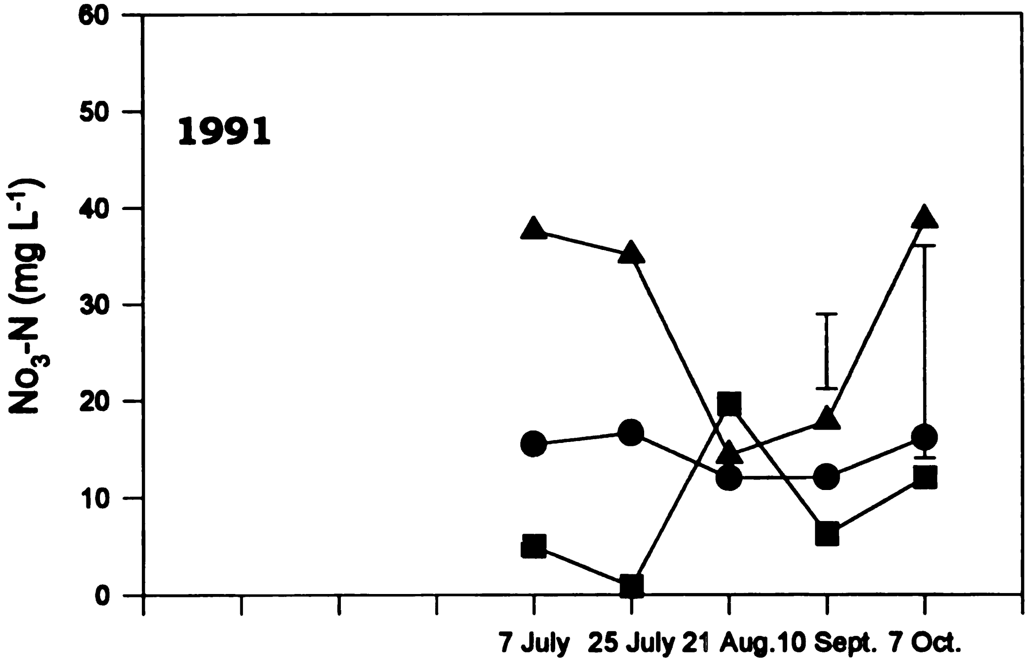


Figure 14. Soil profile NO_3-N in the fall as affected by tillage systems following corn the Kalamazoo loam soil for the period 1991 to 1993.



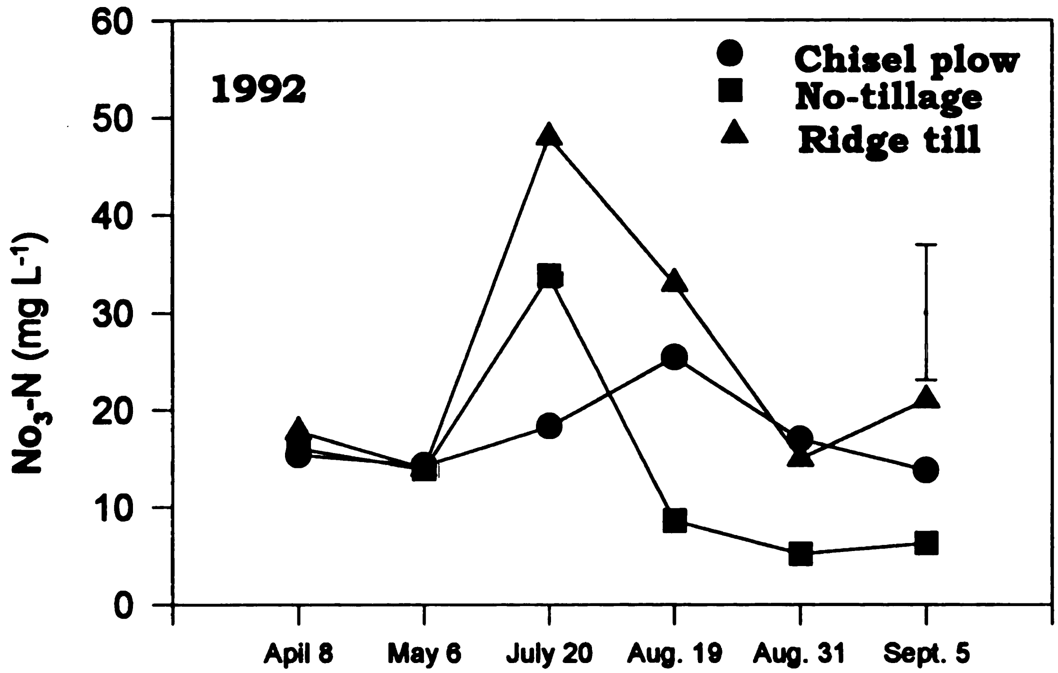


Figure 15. Soil solution NO_3-N in response to tillage systems sampled at the Bt/C horizon contact of a Kalamazoo loam soil during the 1991 and 1992 growing season.

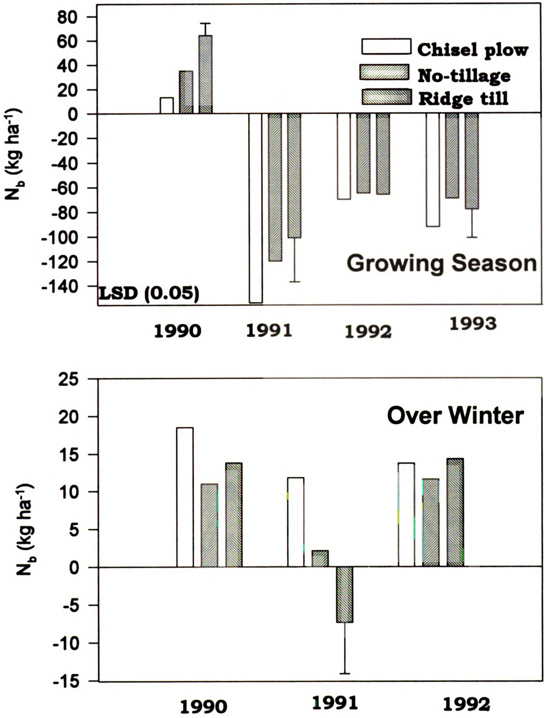


Figure 16. Nitrogen balance (N_b) for the growing season and over winter period as affected by tillage systems over the period 1990 to 1993.

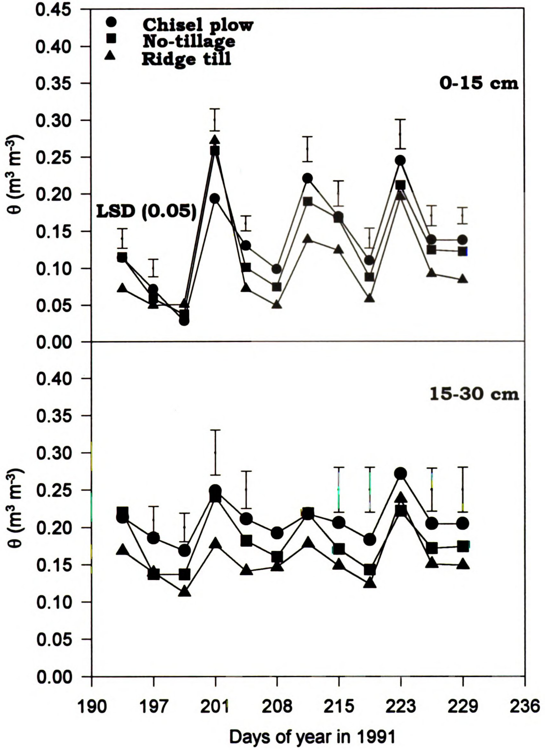


Figure 17. Soil volumetric moisture content (θ) as affected by tillage system for the 0 to 15 and 15 to 30 cm depths of a Kalamazoo loam soil in 1991.

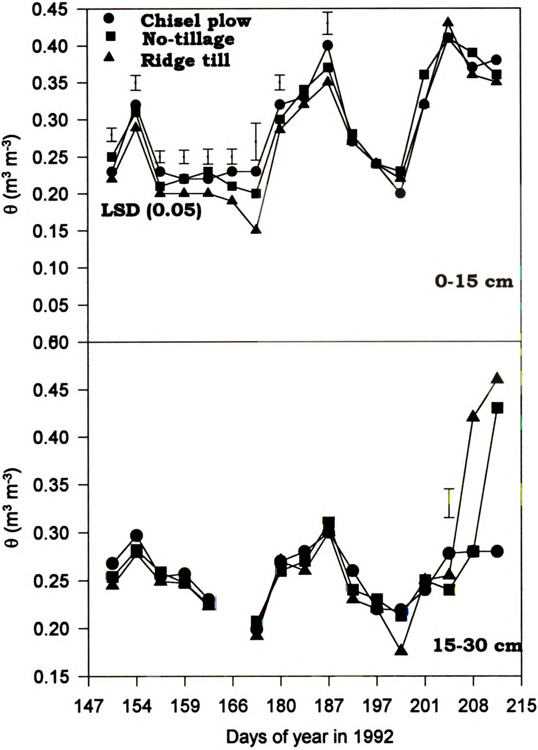


Figure 18. Soil volumetric moisture content (θ) as affected by tillage system for the 0 to 15 and 15 to 30 cm depths of a Kalamazoo loam soil in 1992.

CHAPTER 3

Bromide Movement Related to Tillage and Positions on a Glacial Outwash Soil

Ridge till (RT) is accepted as successful conservation tillage technology for improving the plant root environment. Ridge till has been shown to accelerate drying and warming of the seed zone of moderately to well drained soils (Potter et al. 1985; Al-Darby and Lowery 1987). Ridge till systems have been show to achieve yields equivalent to moldboard plow systems on poorly drained soil (Eckert 1987). In an experiment of identical nitrogen application amounts for RT and flat plots under 24, 50, and 72 mm of simulated rainfall, Hamlett (1990) reported that the RT configuration, with placement of NO_3-N in the elevated portion of the ridge, could potentially isolate fertilizer from downward water flow and minimize nitrate leaching.

Ridge till treatments tended to have higher nitrate leaching than no-tillage (NT) and chisel plow (CP) as evidenced by lower NO_3-N in soil and higher solution NO_3-N at the base of the soil profile. Comparing with CP and NT, ridge till had lower surface soil moisture contents, quicker recharge and depletion soil of moisture content and lower nitrogen content after crop harvest. Knowledge of soil nutrient distribution, as affected by RT, will help to identify optimum fertilizer management, but little work has been completed in this area. To test the conclusion that RT creates a higher risk for nitrogen leaching, bromide (Br) was used as a tracer to monitor soil solution behavior under different tillage systems and row positions. Bromide was selected as a tracer, because its weak tendency for adsorption would permit monitoring of water movement through the soil. In addition, the behavior of Br in soil water systems is similar to that of NO_3^- (Smith and Davis, 1974), and its natural occurrence in soils is usually limited.

The Burns leaching equation (Burns, 1975; Scotter et al., 1993), a transfer function model (Jury, 1982), and the MACRO model (Jarvis et al., 1991) were tested using the field date and natural rainfall in this experiment. Burns (1975) applied a simple model to derive an equation giving the distribution of surface-applied nitrate after a given quantity of applied water had passed through the soil profile. Towner (1983) and Scotter et al. (1993) examined theoretically the equation and derived a simplified form.

The Transfer Function Equation (TFE), as a non-mechanistic stochastic model, was an approach to measure the distribution of solute travel time from the soil surface to some reference depth. Field comparisons have shown good agreement between measured and predicted Br concentrations (Jury et al., 1982), and indicate that this model could be useful as a stochastically-based management model for solute movement. The most important characteristic of such a model is that it attempts to simulate spatially-variable field processes with only a minimum of input data. But it is not yet known whether the approach will be satisfactory in vertically non-homogeneous soils (Addicott and Wagenet, 1985).

MACRO is a mechanistic model of non-steady-state transport of water and solutes in a macroporous soil, developed by Jarvis (1991). The model is deterministic and considers non-steady-state fluxes of water and solutes in a macroporous, layered soil profile. The model assumes that the total porosity in each layer is divided into two components, micropores and macropores, with a specified boundary water potential. The hydraulic conductivity at that given soil-water potential must also be specified. The model has been successfully tested against field leaching measurements in structured clay soils (Jarvis et al. 1991; Jabro et al. 1994). However, it is not known how the model simulates different tillage and row positions.

This study (1) evaluated the movement of Br by row position under CP, NT and RT and within RT as affected by Br placement in the row (ridge) or midrow (valley); and (2) tested the Burns leaching equation, the TFE of solute transport, and the MACRO model using field data under natural, non-steady state rainfall conditions.

MATERIALS AND METHODS

Field Experiment

The fate of Br was evaluated as part of a study designed to evaluate the effects of tillage, manure history, and chemical inputs on corn and soybean grown in rotation at the Kellogg Biological Station, Hickory Corners, Michigan, over the period 1990 to 1993. The soil was a Kalamazoo loam (Typic Hapludalf, fine loamy, mixed, mesic) underlain by coarse glacial outwash parent material, with an aquifer present within 10 m. The experiment was described in detail in Chapter 1. Briefly, the study consisted of two manure history treatments (with and without), three tillage treatments (CP, NT, and RT), and two chemical input levels (high (HI) and low (LI)). The treatments were arranged in a randomized complete block strip-plot design with four replications, with a split plot, with manure as the main treatment and tillage and chemical input as the split plot treatments. Only the tillage plots under no-manure and high chemical input were used in this study.

Two Br transport experiments were performed in 1992 and 1993. The first experiment evaluated the effect of row placement of Br on its transport in soil under RT. Potassium bromide (KBr) was applied at a rate of 300 kg Br ha^{-1} in the row or in the midrow in 3 replications in 1992 and again in 1993. The area for the row application was separated from the area for the midrow application to avoid cross contamination of Br (Figure 1) and each year was applied in a different location within the same 3 replications. The KBr applications were made on 30 June, 1992 and 30 June, 1993, shortly after the ridge was built, to an area of 0.75 by 3 m. The second experiment evaluated the transport of Br in CP and NT. Potassium bromide was applied uniformly to an area 2.28 by 3 m (across three rows) in three replications at a rate of 300 kg Br ha^{-1} on 15 June, 1993. In both experiments, KBr was dissolved in water at a concentration of 500 mg Br L^{-1} and was sprayed uniformly with a hand-held sprayer in three equal applications to insure uniform coverage.

In the first experiment, conducted in 1992 and repeated in 1993, soil samples were taken in the row and in the midrow position for both placement treatments on 16

July, 31 August, 29 September in 1992, and 16 April in 1993. In 1993, soil samples were taken on 15 July, 25 August, 14 September and 15 October. In the second experiment, conducted only in 1993, soil samples were taken on the CP and NT in the row and midrow position in 1993 on 1 September, 21 September and 15 October. Sampling depths were 0 to 20 cm, 20 to 40 cm, and 40 to 60 cm for 1992, with an additional sampling at 60 to 80 cm for April 1993. At each sampling, the sample hole was carefully refilled by untreated soil. All plants within the application area were sampled at harvest and stover and grain analyzed for Br content. Soil Br concentration was determined by extracting 10 grams of soil with 50 ml of water and shaking vigorously for 1 hr. Five grams plant tissue samples were extracted with 100 ml water and shaking vigorously for 1 hr. The supernatant was measured for Br concentration using an Orion bromide ion selective electrode.

Analysis of variance was performed using general linear model in SAS (SAS, Inst., 1990). The ridge experiment was analyzed as a randomized complete block split plot design with 3 replications, with application position (row versus midrow) as the main plot and sampling position (row versus midrow) as the split. The second experiment was analyzed as a randomized complete block split plot design with 3 replications, with tillage (CP versus NT) as the main plot and sampling position (row versus midrow) as the split.

Model Validation

Three models were evaluated using the Br data from the above experiments and daily rainfall, temperature and pan evaporation data obtained from the weather station located at the Kellogg Biological Station. The first model uses a modification of the Burns (1975) equation for the leaching of a surface-applied solute (Towner, 1983). The Burns equation is:

$$\frac{C_{OUT}}{C_O}=\left(\frac{I}{I+\theta_m/100}\right)^Z \tag{1}$$

where C_O is solute input to the soil, C_{OUT} is solute leached below depth Z, in a uniform soil with volumetric water content at 'field capacity' θ_m by water application, I. Towner (1983) analyzed the Burns equation as a solution of the differential equation for pure convection of solute moving at the average soil water velocity with no dispersion. He then modified Equation (1) to the simplified form used in this analysis:

$$\frac{C_{OUT}}{C_O}=\exp\left(-Z\theta_m/I\right). \tag{2}$$

The second model predicts average solute concentration as a function of depth and as a function of spatially uniform water application, I, using a transfer function equation (Jury, 1982) expressed as:

$$C(Z,I)=\int_0^\infty C_{EN}(I-I')\,\frac{L}{Z}f_L\left(\frac{I'L}{Z}\right)dI' \tag{3}$$

where $C\,(Z, I)$ is outflow of solute at Z depth and drainage I, and L is the depth of the outflow surface. For the input

$$C_{EN}=0 \qquad I \leq 0$$
$$C_{EN}=C_O \qquad I > 0 \tag{4}$$

Equation (3) yields the result

$$\frac{C_{OUT}}{C_o} = \frac{1}{2}\left(1 + erf\left(\frac{[\ln\,(IL\,/\,Z) - \mu]}{(2)^{1/2}\sigma}\right)\right) \tag{5}$$

where μ is the mean of the distribution of $\ln I$, σ is the corresponding variance and *erf* is the error function. For computational purposes, Van et al. (1977) reported that when L = 100 cm, μ =4.08 and σ = 0.56. This distribution was used in subsequent computations.

The third model evaluated was the MACRO model developed by Jarvis (1991). The fluxes in the MACRO model, both within and between the flow domains and at the boundary of the profile, are illustrated in Figure 2. The various equations describing these fluxes, and a full description of the MACRO model were given in Jarvis et al. (1991).

Input requirements for the first two models consisted of weather data only. There were 33 inputs required for the MACRO model (Jarvis, 1991). The inputs for the MACRO simulations were obtained in one of three ways: from direct measurements, from general knowledge or literature sources, or through the process of model calibration (Jarvis, 1991). Soil saturated hydraulic conductivity was measured from intact soil core samples. Intact soil cores (7.6 cm diameter, 7.6 cm height) were collected from NT, CP and RT plots on 13 October, 1993. Three cores were taken at the 0 to 10, 10 to 20 cm, 20 to 40 cm, 40 to 60 cm, and 60 to 80 cm. Soil core samples were obtained with a Uhland double-cylinder, hammer-driven sampler (Blake and Hartge, 1986). Saturated hydraulic conductivity was determined using the constant head method (Klute and Dirksen, 1986). Cores were oven dried at 105°C for 48 hours and weighed for bulk density determination. Water loss between saturation and oven dry was taken to represent total soil porosity. The average three plots measured value was given in Table 1. The value of the boundary tension was 40 cm, based on a definition of macropores as all pores larger than 75 μm in diameter (Jarvis, 1991). The other input parameter values used in the model simulation were obtained from model sensitivity analyses conducted by Jarvis (1991).

Model performance and simulation accuracy were evaluated based on ability to predict Br content in each layer. The four combinations of statistical criteria were used to assess the accuracy and simulation capacity of the models (Jabro et al., 1994). The correlation coefficient (r) is a measure of the degree of association between simulated and measured values. The mean difference between simulated and measured values (M_d) is a measure of the average deviation of the simulated values from the measured values. The formula is

$$M_d = \sum \frac{(S-U)}{n} \tag{6}$$

where S is the simulated value, U is the measured value, and n is the number of observations. The positive sign of the M_d represents overestimated simulation, and the negative sign of M_d suggests underestimated simulation. A t test was used to determine whether M_d was significantly different from zero (Addiscott and Whitmore, 1987). The degree of coincidence of the simulated and measured values was also determined using the root mean square error (RMSE), that is

$$RMSE = \sqrt{\left[\frac{\Sigma(S-U)^2}{n} \right]} \times \left[\frac{100}{\bar{U}} \right] \qquad (7)$$

where $\bar{U}$ is the measured mean value. The lower values of RMSE suggest greater simulation accuracy than the higher RMSE values.

RESULTS AND DISCUSSION

Bromide Movement Under Three Tillage System

The variation in Br concentration in soil encountered in these experiments was large (CV > 100%) and no differences in treatments were detected in the analysis of variance. Typically, studies on Br transport in soils report only means without reporting variance (Butters and Jury, 1989; Dyson and White, 1987; Germann et al., 1984; Gish et al., 1986; Hamlett et al. 1990; Zachmann et al., 1987). Because solute concentration was affected by the spatial variation, Pol at al. (1977) suggested that reliable estimates of their values are required. Therefore, only simple means are reported in the following tables and soil profile Br concentrations are presented graphically to aid in their interpretation.

Ridge position effects on Br transport

The typical soil profile distribution of Br after application and as a function of cumulative rainfall is illustrated in Figure 3 for the ridge placement. Initially, Br content is high near the soil surface. On 16 July, 1992, all of the applied Br remained in the 60 cm soil profile in the row placement treatment. The distribution of Br content was 82%, 14%, and 4% at 0 to 20 cm, 20 to 40 cm and 40 to 60 cm depths, respectively. As rainfall increases, Br content transports from the soil surface to deeper in the soil profile. For the 239 mm cumulative rainfall on 31 August, about 48% of applied Br was not detected and presented below 60 cm of the profile. The recovery of the applied Br was 36%, 6% and 10% at 0 to 20 cm, 20 to 40 cm and 40 to 60 cm depths, respectively. On 29 September, when cumulative rainfall was 378 mm, 60% of applied Br was not detected and presented below 60 cm of the profile. Recovery of applied Br was 26%, 7%, and 7% at each depth. By 259 days after Br application, on 16 April, 1993, when cumulative rain was 835 mm, 95% of the applied Br was leached out of the 60 cm soil profile. The recovery of Br was about 1 to 2% of applied Br at each layer.

When KBr was applied to the midrow position, Br leached much quicker than when applied to the row (Figure 4). For the 16 July, 1992, when cumulative rainfall since application was 66 mm, 34% of applied Br was leached out of the 60 cm depth as compared to no Br leaching out of 60 cm under row application. Bromide contents were similar between row placement and midrow placement at the 20 to 60 cm depths. However, differences occurred at the surface layer. For the 239 mm cumulative rainfall, 60% of applied Br was leached from the midrow placement below 60 cm depth compared to 48% leaching in the row placement treatment. By 378 mm of cumulative rainfall, 70% of applied Br leached out of the 60 cm depth in the midrow position. The faster Br leaching under midrow placement than row placement was attributed to the midrow receiving more water than the ridge surface (Chapter 2). During a storm event, once the soil surface was saturated, runoff can be channeled to the midrow, as evidenced by visual ponding and increased water contents in the upper soil profile (Hamlett, 1990). Ponded soil surfaces may result in water movement horizontally (surface runoff) or vertically (downward infiltration), or both movements can occur simultaneously. Both types of water movement probably reduced profile Br contents. After 66 mm of cumulative rainfall, Br content differences between the row and the midrow placement only occurred in the surface layer and may have been due to midrow surface runoff. However, in the following rainfall events, Br content at deeper layers was higher for the midrow placement, indicating that predominant water movement was downward infiltration. After 835 mm of cumulative rainfall, by 16 April, 1993, the profile Br contents were low and were similar for the row placement and midrow placement treatments.

As indicated above, water movement from the row top to the midrow valley was responsible for increased leaching of Br in the midrow position. However, the lateral movement of Br applied to the row to the midrow was extremely low in 1992

(Figure 5), a dry June, but considerable in 1993 (Figure 6), a wet June. This suggests that once Br moves into the soil, little Br moved with surface water into the midrow, but lateral movement can be considerable when rainfall follows soon after application. When Br was applied to the midrow, Br was transported to the ridge position (Figure 7 and 8), with the midrow near 50 kg Br ha^{-1} in 1993 but 12 kg Br ha^{-1} in 1992. The movement of Br to the row position probably relates to plant extraction of water under the row position and subsequent transport of Br with the redistributing water.

Chisel plow and no-tillage and row position effects on Br transport

In both the NT and CP, Br in both row positions was highest in the soil surface and had not leached below 60 cm after 197 mm of cumulative rainfall (Figures 9, 10 , 11, and 12). In the row, Br content increased with depth as cumulative rainfall increased However, more Br appeared to have moved in the midrow, and movement appeared to be greater in the CP midrow than the NT midrow, with almost complete removal of Br from the surface of the CP and accumulation in the Bt horizon (Figures 10 and 12). This is evidence of within season stratification of nutrients, such as NO_3-N. Therefore, as was true in the RT system, more leaching occurred in the midrow than row position, at least during the growing season, as measured in 1993.

A comparison of soil profile Br movement for the 0 to 80 cm depth for three tillage and two row positions is given in Table 2. Recovery of Br was highest for RT in the row and lowest for RT in the midrow. This reflects the preferential movement of water through the midrow position of RT. The movement of Br was higher in CP than NT in both positions but positions were not different in these two tillage systems. Average across row positions, the Br recovery in CP was comparable to RT, and Br content in the profile was lower for NT. The lower recovery of Br under NT indicates more leaching occurred under NT and this may be associated with increased macropore continuity. As a consequence of disturbed soil surface with CP, continuity of pores was decreased, and larger amounts of Br accumulated in the Bt horizon under CP while Br under NT was leached to deeper zones, probably through macropores, since little Br was measured below 40 cm in the soil matrix (Table 2).

Plant Tissue Bromide Content

Although Br is not a required plant nutrient, the amount taken up has been reported to be similar to NO_3-N (Owens et al. 1985). In green house and field experiments, Jemison and Fox (1991) found that most of the Br absorbed by the plant was stored in the stover. In this study, Br was applied 48 days after corn planting. Bromide treatments significantly decreased grain yield (decreased 78% in CP, 72% in NT, and 78% and 68% for row application and midrow application in RT, respectively with LSD=5.6%) as compared with no Br treatment. Corn stover weight was decreased 61 to 66% for Br treatments. There were no differences in corn stover weight decreasing between tillage treatments and Br application position. Bromide concentration in both corn grain and stover was higher for the row Br application than midrow application in 1993. The stover Br concentration was higher for the NT than CP (Table 3). Because high Br concentration decreased crop yield, Br taken up by the grain was 0.03 kg ha^{-1}, for all three tillage treatments both in 1992 and 1993. Bromide taken up by stover ranged from 0.8 to 1 kg ha^{-1}, which was less than 0.3% of original Br application. These results are lower than Jabro (1994), who reported that 6.8 to 21.2 kg Br ha^{-1} were removed by stover and less than 3% of the applied Br was removed in the harvested grain when Br applied at the time of corn planting.

Model Validation

The statistical comparisons of field measured and model simulated values of Br content in the 0 to 60 cm soil profile are given in Table 4. The modified Burns equation (Equation 2) most successfully predicted Br content in the row application with row sampling (RR) and midrow application with midrow sampling (VV) in 1992 and RR in 1993. The M_d were not significantly different from zero, the RMSE were smaller and r were higher than other models. The modified Burns equation underestimated values in the 0 to 20 cm depth for RR in 1992 and 1993 (Table 5). For the 20 to 40 cm and 40 to 60 cm depths, the equation underestimated at the early sampling dates and overestimated at later sampling dates for both 1992 and 1993 (Table 6). For the VV in 1992, the equation overestimated for all three depths and for the entire season in 1992. Although the r value was high for the VV in 1993, significant M_d and high t value between predicted and measured values indicated that the equation failed to predict VV in 1993 (Tables 4 and 6). The modified Burns equation did not predict the CP and NT for both the row and midrow position samplings, as indicated by lower r value, significant t and larger RMSEs (Tables 4 and 7).

The Transfer Function Equation (TFE) performed reasonably well and gave satisfactory predictions of measured Br content for RR and VV in 1992, and RR in 1993. Satisfactory predictions were indicated by reasonable M_d's, non-significant t values, and high r values (Table 4). For RR in 1992, the model overpredicted at early sampling dates and underpredicted at later sampling dates at 0 to 20 cm depth, and underpredicted at early dates and overpredicted at later dates in the 0.2 to 0.6-m depths. For VV in 1992, the model overpredicted for the entire season at all depths (Tables 4 and 5). Overpredicted values were found at later times in deeper layers for RR in 1993. Similar to the Burns equation, the correlation coefficient was high for VV in 1993, but significant differences between measured and predicted value indicated that TFE did not successfully predict VV in 1993 (Tables 4 and 6). In contrast, the low r values, significant M_d's, and larger values of RSME indicated that TFE did not perform well for CP and NT for both row and midrow sampling (Tables 4 and 7).

In 1992, the agreement between measured and MACRO simulation was acceptable for RR and VV, and the model met the statistical criteria, as indicated by a M_d that was not significantly different from zero, a small RMSE, and a high r. The overpredicted values were found at 20 to 60 cm depths between 238 and 378 mm cumulative rainfall. The model over-predicted VV at early dates at the surface and later dates at deeper depths (Tables 4 and 5). In 1993, the model prediction was acceptable for RR with a reasonable r and a low M_d value (Table 4). The underpredicted values occurred at early sampling times and at three depths. In contrast, the MACRO predictions in 1993 failed to meet the statistical evaluation criteria for VV (Tables 4 and 6) in RT and all positions in CP and NT (Tables 4 and 7).

None of the models predicted the Br contents under NT and CP in 1993. All models predicted the Br contents in the RT system with the exception of the Br applied and sampled in the midrow of the ridge (VV). The modified Burns equation, the simplest model tested, was most successful in predicting Br contents of the models tested.

SUMMARY AND CONCLUSION

Bromide movement were evaluated in three conservation tillage systems and two row positions. Burns leaching equation, the TFE of solute transport, and the MACRO model were tested using field data under natural, non-steady state rainfall conditions.

This study suggested that RT with Br placement in the row results in less Br leaching than NT and CP. In contrast, Br placement in the midrow increased Br leaching. Average across row positions Br leaching rate under RT was compatible with CP. Low profile Br content for NT indicated that chemical leaching potential was higher for NT than for CP and RT. The higher leaching rate for NT was attributed to undisturbed soil surfaces with macropores flow. Stratification of Br occurred in Bt horizon in CP during growing season. This study also revealed that rates of chemical movement from midrow to row were higher than rates of chemical movement from the row to midrow under RT.

Model testing in this study demonstrated that the modified Burns equation, TFE and MACRO model successfully predicted Br movement for RR. None of the models predicted the Br contents under NT and CP. The Burns equation had the best accuracy of prediction, and the accuracy of the model prediction by TFE was better than MACRO. The input parameters of the MACRO model can be altered for variable field conditions. This suggests that MACRO may have the potential to predict chemical leaching under different tillage. It also appears that both the TFE and MACRO models overpredicted Br content for VV for the entire season and for all layers. To simulate chemical movement in the midrow under RT, the preceding models need to be modified, and input parameters need to be re-adjusted. The slope of the land, which causes to overestimation or under estimation of Br content due to surface water runoff, needs to be included in input parameters.

The MACRO model was supplied by Dr. N. Jarvis (Department of Soil Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden).

LIST OF REFERENCES

Addiscott, T.M. and R.J. Wagenet. 1985. Concepts of solute leaching in soils: a review of modeling approaches. J. Soil. Sci. 36:411-424.

Addiscott, T.M., and A.P. Whitmore. 1987. Computer simulation of changes in soil mineral nitrogen and crop nitrogen during autumn, winter and spring. J. Agric Sci. Camb. 109:141-157.

Al-Darby, A.M. and B. Lowery. 1987. Seed zone soil temperature and early corn growth with three conservation tillage systems. Soil Sci. Sco. Am J. 51:768-774.

Blake, G.R., and Hartge K.K. Hartge. 1986. Bulk density. In A. Klute (ed.) Method of soil analysis, part 1. 2nd. Agronomy 9:363-375.

Burns, I.G. 1975. An equation to predict the leaching of surface-applied nitrate. J. Agric. Sci., Camb. 85:443-454.

Butters, G.L. and W.A. Jury. 1989. Filed scale transport of bromide in an unsaturated soil 2. Dispersion modeling. Water Resour. Res. 25:1583-1589.

Dyson, J.S. and R.E. White. 1987. A Comparison of the convection-dispersion equation and transfer function model for predicting chloride leaching through an undisturbed, structured clay soil. J. Soil Sci. 38:157-172.

Eckert, D.J. 1987. Evaluation of ridge planting systems on a poorly drained lake plain soil. J. Soil Water Conserv. 42:208-211.

Germann, P.F., W.M. Edwards, and L.B. Owens. 1984. Profile of bromide and increased soil moisture after infiltration into soil with macropores. Soil Sci. Soc. Am. J. 48:237-244.

Gish, T.J., W. Zhuang, C.S. Helling, and P.C. Kearney. 1986. Chemical transport under no-till field conditions. Geodema. 38:251-259.

Hamlett, J.M., J.L. Baker, and R. Horton. 1990. Water and anion movement under ridge tillage: a field study. Trans. ASAE. 33:1859-1866.

Jabro, J.D., J.M. Jemoson, JR, Richard H. Fox, and D.D. Fritton. 1994. predicting bromide leaching under field conditions using SLIM and MACRO. Soil Sci. 157:215-223.

Jarvis, N.J. 1991. MACRO - A model of water movement and solute transport in macroporous soils. Report and dissertations #9. Department of Soil Sciences, Swedish University of Agricultural Sciences. Uppsala, Sweden.

Jarvis, N.J., L. Bergstrom, and P.E. Dik. 1991. Modeling water and solute transport in macro-porous soil. II Chloride breakthrough under non-steady flow. J. Soil Sci. 42:71-81.

Jemison, J.M., Jr., and R.H. Fox. 1991. Corn uptake of bromide under greenhouse and field conditions. Commun. Soil Sci. Plant Anal. 22:283-297.

Jury, William A. 1982. Simulation of solute transport using a transfer function model. Water Resour. Res. 18:363-367.

Jury, William A., Lewis H. Stolzy and Peter Shouse. 1982. A field test of the transfer function model for predicting solute transport. Water Resour. Res. 18:369-375.

Klute , A. and C. Dirksen. 1986. Hydraulic and diffusivity: Laboratory methods. In A. Klute (ed.) Methods of soil analysis, Part 1. n ed. Agronomy. 9:687-734.

Owens, L.B., R.W. Van Keuren and W.M. Edwards. 1985. Groundwater quality changes resulting from a surface bromide application to a pasture. J. Environ. Qual. 14:543-548.

Pol, R.M. Van De, P.J. Wierenga, and D.R. Nielsen. 1977. Solute movement in a field soil. Soil Sci. Sco. Am. J. 41:10-13.

Potter, K.N., R.M. Cruse, and R. Horton. 1985. Tillage effects on soil thermal properties. Soil Sci. Soc. Am. J. 49:968-973.

SAS Institute. 1990. SAS/STAT user's guide. Version 6. SAS inst., Cary, NC.

Scotter, D.R., R.E. White and J.S. Dyson. 1993. The Burns leaching equation. J. Soil Sci. 44:25-33.

Smith, S.J., and R.J. Davis. 1974. Relative movement of bromide and nitrate through soils. J. Environ. Qual. 3:152-155.

Towner, G.D. 1983. A theoretical examination of Burns' (1975) equation for predicting the leaching of nitrate fertilizer applied to a soil surface. J. Agric. Sci., Camb. 100:293-298.

Van, de Pol, R.M. , P.J. Wierenga, and D.R. Nielsen. 1977. Solute movement in a field soil. Soil Sci. Sco. Am. J. 41:10-13.

Zachmann, J.E., D.R. Linden, and C.E. Clapp. 1987. Macroporous infiltration and redistribution as affected by earthward, tillage, and residue. Soil Sci. Sco. Am. J. 51:1580-1586.

Table 1. Field measured soil physical properties used an input value for MACRO model

Depth (cm)	BD (g cm^{-3})	Total Porosity (%)	Sat. θ (%)	K_{sat} (cm hr^{-1})
0-10	1.46	45.1	41.2	13
10-20	1.68	36.4	35.1	2
20-40	1.72	34.3	33.5	1
40-60	1.68	37.7	35.4	11
60-80	1.67	36.7	34.7	15

BD=Bulk density
K_{sat}=Saturated hydraulic conductivity
Sat. θ = Saturated volummetric soil water content

Table 2. Comparison of Br^- recovery for the 0 to 80 cm depth under three tillage treatments and two position after 288 mm cumulative rainfall in 1993.

Depth (cm)	Chisel Plow		No-tillage		Ridge Till	
	row	midrow	row	midrow	row	midrow
	kg Br^- ha^{-1}					
0-20	43.9	13.2	35.7	32.2	70.2	9.1
20-40	58.2	109.7	29.8	61.0	96.1	16.1
40-60	19.2	8.8	11.6	4.6	64.1	16.0
60-80	20.4	2.3	5.4	2.0	21.6	7.5
Total	98.2	134.0	82.5	99.8	252.0	48.7

Table 3. Corn plant tissue Br^- concentration under three tillage treatments in 1992 and 1993.

Tillage	Br^{-1} applied position	1992 Grain	1992 Stoves	1993 Grain	1993 Stoves
		mg kg^{-1}			
Ridge till	row	10	341	22	145
Ridge till	midrow	10	310	17	93
Chisel plow	row & midrow			13	311
No-tillage	row & midrow			13	436

Table 4. Comparison of field measured and simulated values of Br^1 contents in 60 cm soil profile of Kalamazoo loam soil.

Year	1992				1993			
Tillage	Ridge rill				Chisel plow		No-tillage	
Br-applied position	row	midrow	row	midrow	row and midrow			
sampling position	row	midrow	row	midrow	row	midrow	row	midrow
Modified Burns equation								
M_d †	-0.95	14.85	-16.66	37.34	15.07	7.27	12.77	19.98
r ‡	0.94	0.91	0.93	0.95	0.26	0.14	0.77	0.28
t §	-0.14	1.52	-1.91	2.53*	2.73*	0.70	4.14*	3.49*
RMSE ¶	45.2	93.2	35.6	179.9	75.8	107.5	38.7	98.7
Transfer Function Equation								
M_d	14.49	30.29	10.37	64.37	42.96	35.16	40.66	47.87
r	0.82	0.77	0.80	0.85	0.33	0.56	0.50	0.45
t	0.92	1.65	0.68	2.44*	2.91*	2.77*	2.99*	3.14*
RMSE	102.9	174.9	61.9	321.6	202.7	131.8	170.6	262.8
MACRO Model								
M_d	11.65	27.45	-4.56	49.44	27.67	19.87	25.37	32.58
r	0.77	0.81	0.67	0.81	0.24	0.41	0.62	0.30
t	0.78	1.58	-0.28	2.43*	3.43*	2.08	4.26*	3.75*
RMSE	97.5	165.1	66.3	248.6	110.6	99.3	74.6	149.7

† mean difference between simulated and measured values
‡ correlation coefficient
§ t test
¶ root mean square error

Table 5. Comparison of predicted and measured Br^- contents for three simulation models for ridge till in 1992.

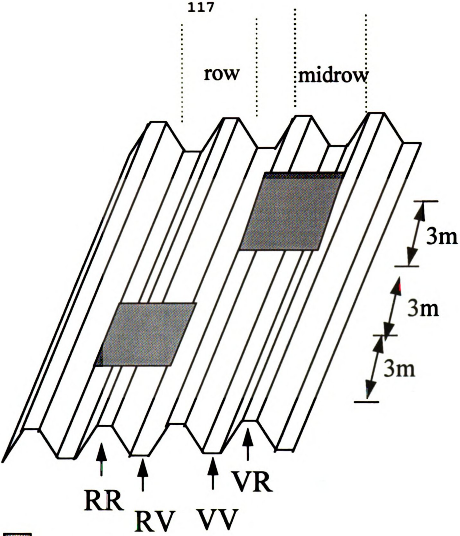
		Model Prediction			Field Measurement	
Depth (cm)	Cumu. Rain (mm)	Burns	TFE	MACRO	row	midrow
		kg Br^- ha^{-1}				
0-20	66	234.1	276.5	262.0	245.9	132.8
0-20	239	58.6	60.0	86.3	111.7	79.1
0-20	378	40.2	13.5	1.3	79.7	35.7
0-20	835	18.1	1.7	0.0	2.1	2.9
20-40	66	51.4	22.4	47.0	53.0	55.1
20-40	239	47.2	132.0	135.6	17.3	32.6
20-40	378	34.8	87.3	33.9	22.1	28.8
20-40	835	17.0	8.2	0.0	2.5	2.5
40-60	66	11.3	0.2	4.3	15.5	12.6
40-60	239	37.9	69.0	83.6	31.3	13.2
40-60	378	30.1	82.2	91.9	22.0	18.5
40-60	835	16.0	29.1	2.0	4.8	4.7

Table 6. Comparison of predicted and measured Br^- contents for three simulation models for ridge till in 1993.

Depth (cm)	Cumu. Rain (mm)	Model Prediction Burns	TFE	MACRO	Field Measurement row	midrow
		kg $Br^- ha^{-1}$				
0-20	30	243.3	299.3	249.9	280.7	120.3
0-20	130	95.8	175.2	99.3	106.3	47.9
0-20	218	61.5	85.8	9.9	83.8	14.1
0-20	288	47.8	34.5	1.0	70.2	9.1
20-40	30	46.0	0.6	56.9	89.1	29.3
20-40	130	65.2	100.8	126.1	65.3	18.0
20-40	218	48.9	127.2	93.8	26.9	23.3
20-40	288	40.2	123.0	26.9	96.1	16.7
40-60	30	8.7	0.2	7.3	39.3	17.0
40-60	130	44.4	18.9	63.3	37.6	3.3
40-60	218	38.9	56.4	101.9	14.8	11.2
40-60	288	33.8	77.0	83.5	64.3	16.1

Table 7. Comparison of predicted and measured Br^- contents for three simulation models for no-tillage and chisel plow in 1993.

Depth	Cumu. Rain	Model Prediction			Field Measurement			
		Burns	TFE	MACRO	No-tillage		Chisel plow	
					row	midrow	row	midrow
(cm)	(mm)	kg $Br^- ha^{-1}$						
0-20	70	67.2	77.6	94.4	57.7	31.1	38.2	60.8
0-20	91	47.1	28.8	35.7	35.7	32.1	43.8	12.5
0-20	115	40.2	15.0	25.7	31.7	12.4	18.5	8.3
20-40	70	52.2	150.4	77.6	50.5	12.9	7.7	12.2
20-40	91	39.7	121.3	62.7	29.8	61.6	58.8	110.9
20-40	115	34.8	102.0	50.4	27.7	24.6	34.7	61.0
40-60	70	40.5	48.0	52.0	8.9	1.9	5.3	7.4
40-60	91	33.5	78.0	54.5	11.5	4.2	18.9	8.1
40-60	115	30.1	82.2	48.9	32.7	31.9	37.6	70.0
60-80	70	31.4	16.5	32.9	4.0	1.7	0.0	2.1
60-80	91	28.2	39.0	44.2	5.4	1.9	6.17	2.29
60-80	115	26.1	46.8	42.9	22.1	14.8	20.4	28.1



 Br- application area

RR Row application and row sampling

RV Row application and midrow sampling

VR midrow application and midrow sampling

VV midrow application and midrow sampling

Figure 1. Illustration of Br^- application in the row and midrow position for ridge till.

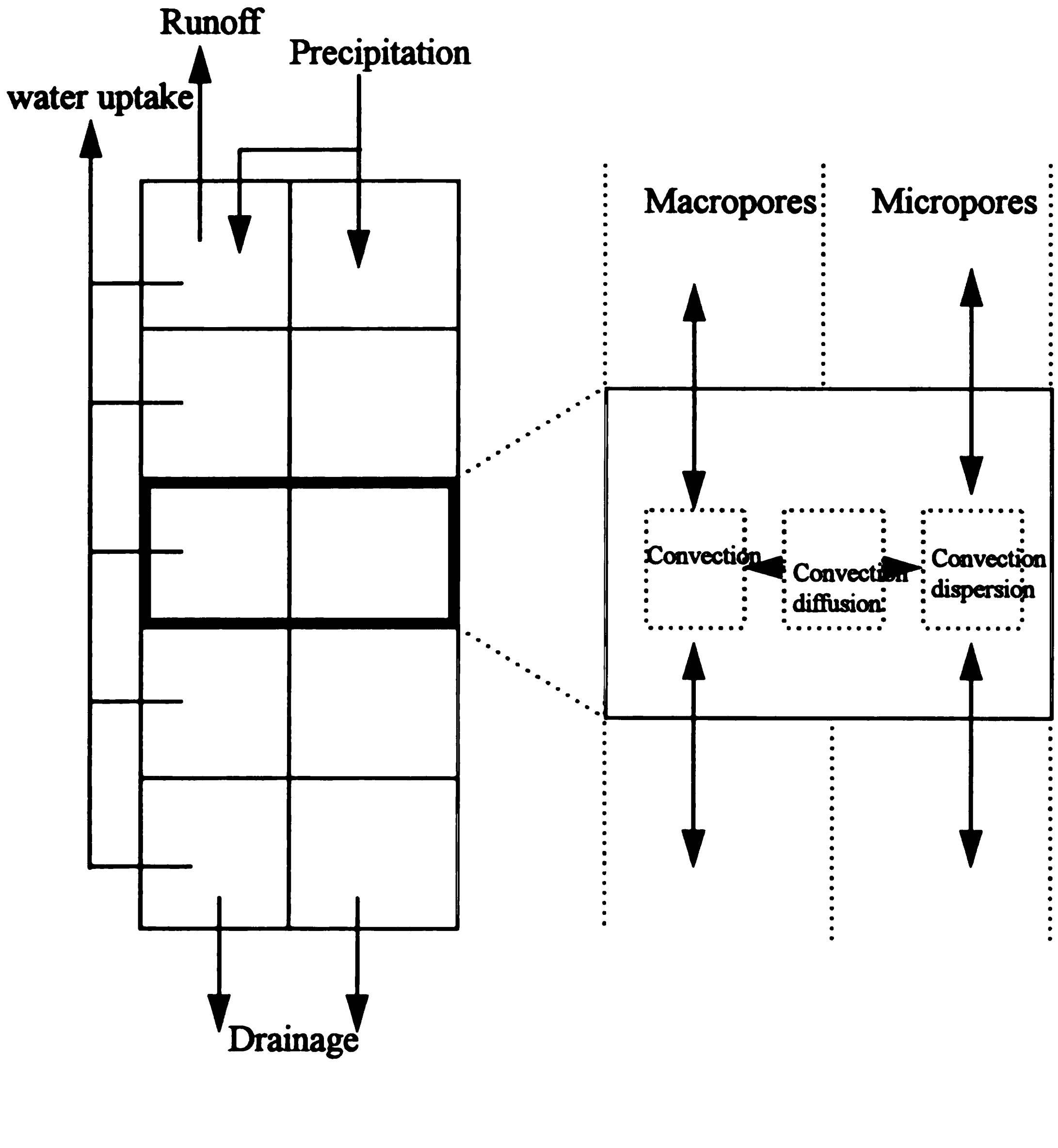


Figure 2. Illustration of precesses and fluxes in MACRO model (redraw from Jarvis, 1991).

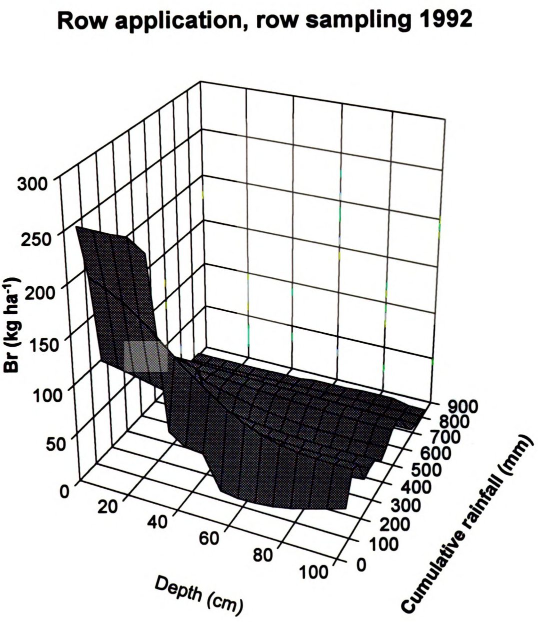


Figure 3. Br$^-$ concentration changes with cumulative rainfall and depths for the row Br$^-$ application and row sampling in ridge tillage in 1992.

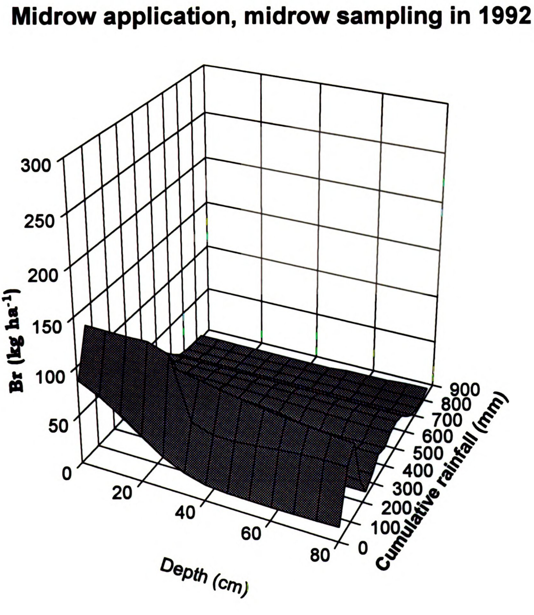


Figure 4. Br^- concentration changes with cumulative rainfall and depths for the midrow Br^- application and midrow sampling in ridge tillage in 1992.

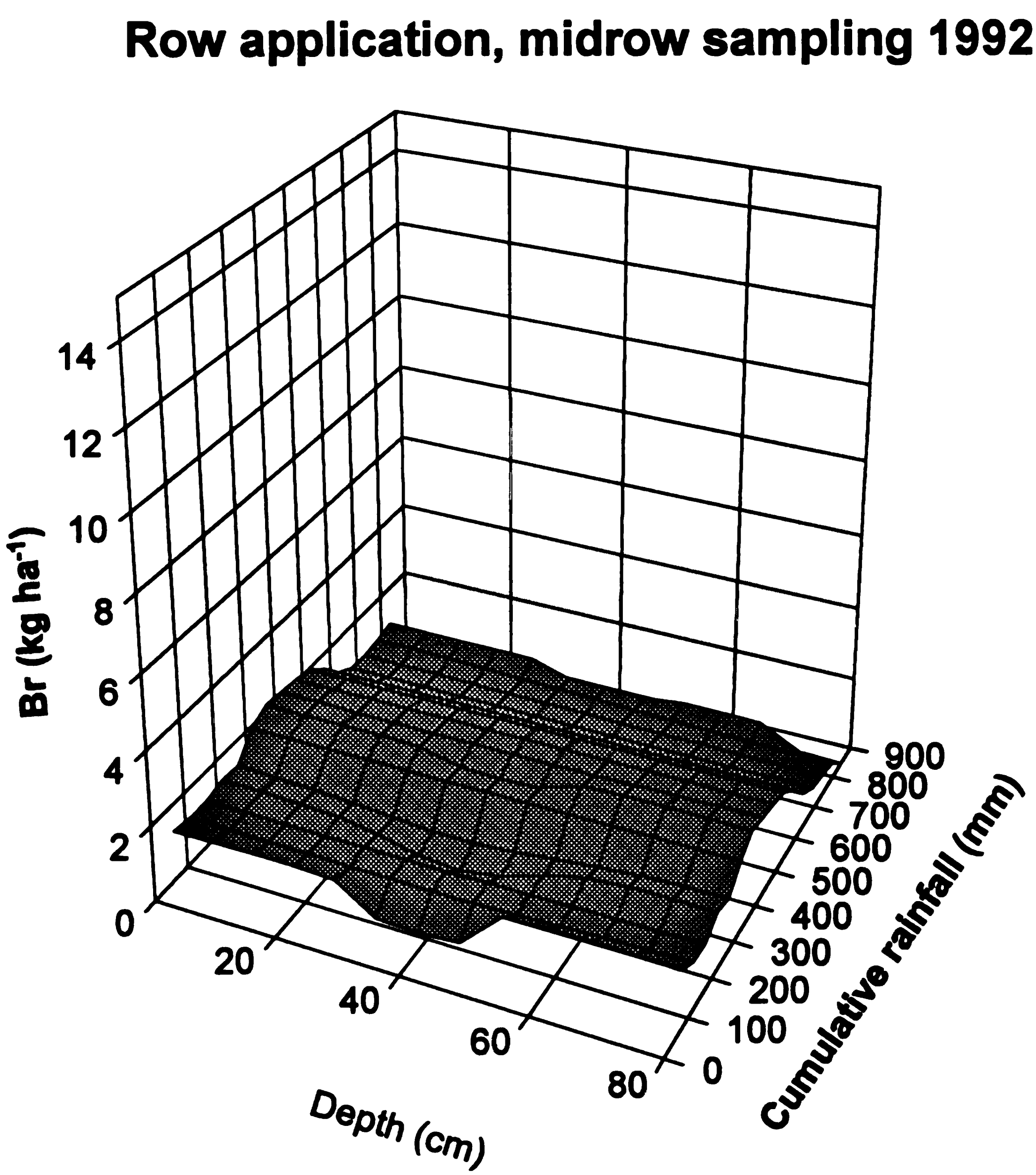


Figure 5. Br$^-$ concentration changes with cumulative rainfall and depths for the row Br$^-$ application and midrow sampling in ridge tillage in 1992.

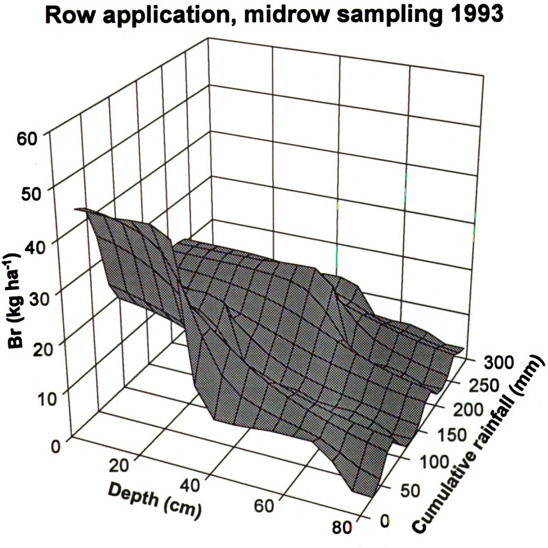


Figure 6. Br⁻ concentration changes with cumulative rainfall and depths for the row Br⁻ application and midrow sampling in ridge tillage in 1993.

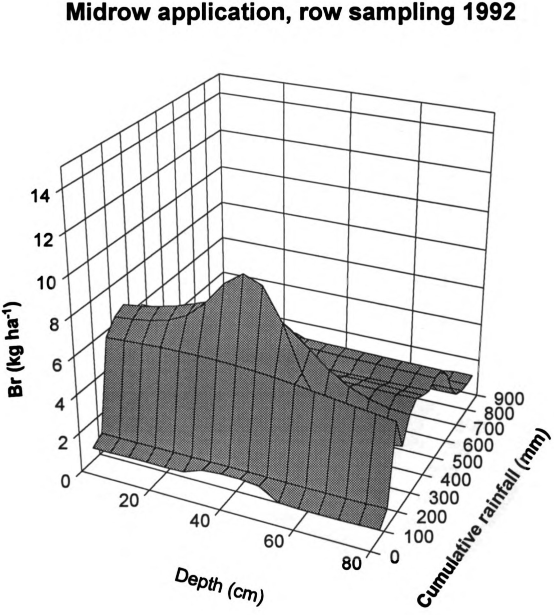


Figure 7. Br⁻ concentration changes with cumulative rainfall and depths for the midrow Br⁻ application and row sampling in ridge tillage in 1992.

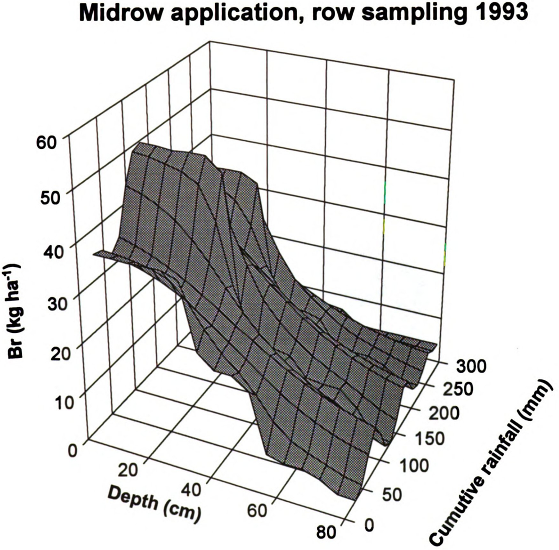


Figure 8. Br⁻ concentration changes with cumulative rainfall and depths for the midrow Br⁻ application and row sampling in ridge tillage in 1993.

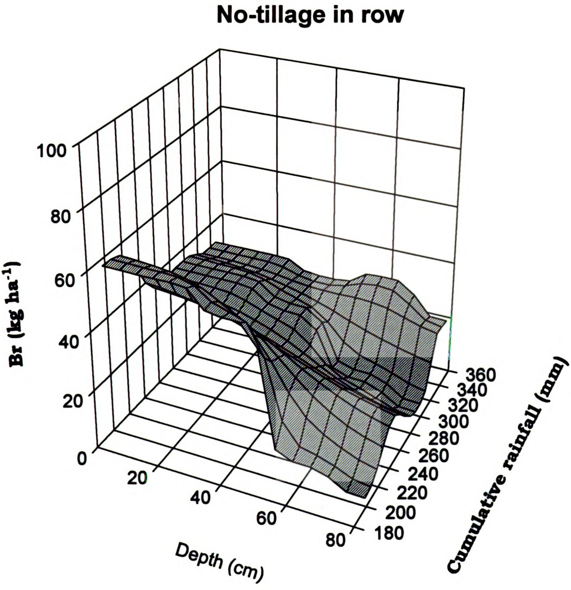


Figure 9. Br^- concentration changes with cumulative rainfall and depths for row sampling in no-tillage in 1993.

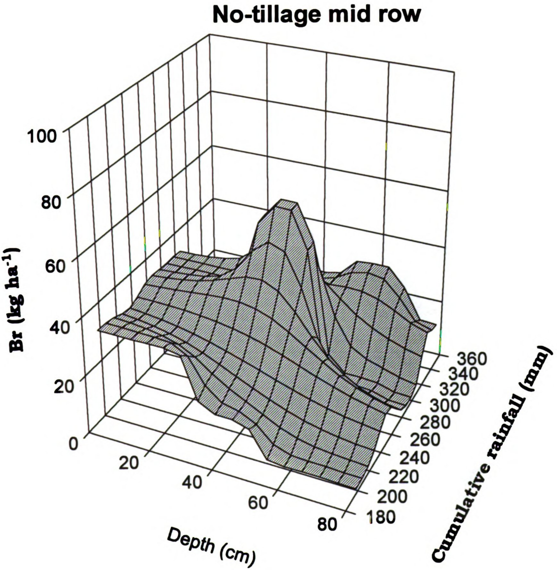


Figure 10. Br^- concentration changes with cumulative rainfall and depths for the midrow sampling in no-tillage in 1993.

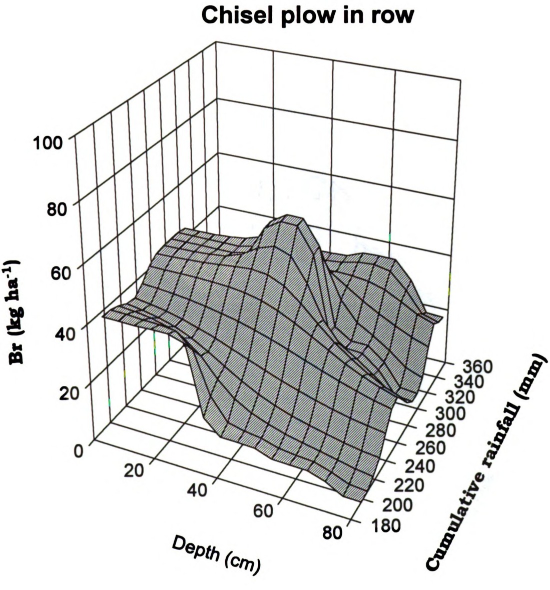


Figure 11. Br⁻ concentration changes with cumulative rainfall and depths for row sampling in chisel plow in 1993.

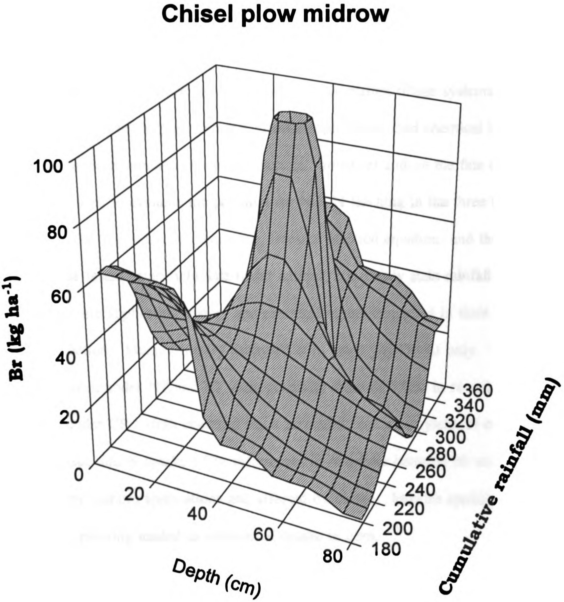


Figure 12. Br⁻ concentration changes with cumulative rainfall and depths for the midrow sampling in chisel plow in 1993.

SUMMARY AND CONCLUSION

This study examined the influences of conservation tillage systems, the residual benefits of long-term animal manure applications, and chemical inputs on corn and soybean production, on soil physical properties and on the fate of N. A Br tracer was used to evaluate the potential for NO_3-N leaching in the three tillage systems. The Burns leaching equation, transfer function equation, and the MACRO model were tested using field data under natural, non-steady state rainfall conditions.

Manure application history and chemical inputs interacted in their effects on corn production. Manure history increased corn grain yield in LI only. Without N fertilizer, corn under NT and RT were generally more deficient in N and yields were less than under CP. High chemical input increased corn grain yield, N concentrations in corn tissue and N uptake. The differences in N uptake between HI and LI were tempered by manure applications and affected by tillage. Manure application history with chisel plowing tended to increase N uptake in corn.

Manure application history increased weed populations, causing lower soybean plant populations and ultimately decreasing soybean yields. Both NT and RT are preferable tillage methods for soybean production in the Kalamazoo loam soil of Michigan, since crusting was a serious limitation in CP.

Ridge till increased air-filled porosity. Bulk density was lower and total porosity was higher in ridge till after harvest, but there were no differences in tillage treatments before planting. Manure applications decreased bulk density and increased total porosity, macroporosity and air-filled porosity. The effect of manure application history was to increase residual profile NO_3-N, soil solution NO_3-N, and N_b and thereby increase the potential for NO_3-N leaching. Nitrogen fertilizer was the major source contributing to NO_3-N leaching, especially in low yielding years when crops could not utilize additional N. Baseline levels of NO_3-N at the base of the soil profile, represented by levels under LI, were consistently below 15 mg N L^{-1} and were elevated to > 25 mg N L^{-1} soon after N fertilization. The CP had consistently higher soil profile NO_3-N than NT and RT in spring and fall. This suggests that the disturbed soil surface under CP enhanced mineralization in early spring. The higher NO_3-N for CP in fall contributed higher N_b over winter. Ridge till had consistently lower profile NO_3-N but high soil solution NO_3-N, indicating RT had the highest potential for NO_3-N leaching during the growing season. Ridge till had consistently lower θ in the row than other tillage systems, indicating water moved to the valley of the midrow. The preferential movement of water in the midrow may explain the lower θ and higher NO_3-N in solution. There was little evidence of profile stratification of NO_3-N at horizon boundaries. This was in part related to the sampling times occurring before N application and after harvest.

Ridge till with Br placement in the row resulted in less Br leaching than NT and CP. In contrast, Br placement in the midrow for RT leached more Br than CP and NT. Averaged across row positions, Br leaching rates were higher for NT than CP and RT, and RT was comparable to CP. This indicated that chemical leaching potential was higher for NT than for CP and RT. The higher leaching rate for NT was attributed to undisturbed soil surfaces with macroporou flow. Stratification of Br occurred in the Bt horizon in CP treatments during growing season. The rates of chemical movement from the midrow to row zone were higher than rates of chemical movement from the row to midrow zone under RT. Model evaluations demonstrated that the modified Burns equation, TFE and MACRO model successfully predicted Br movement for RT. None of the models predicted the Br contents under NT and CP. Conclusions of this study include:

1. The residual effects of manure history were evident in increased N mineralization 5 years after manure application ceased. As a result of higher NO_3-N concentration in the soil profile and soil solution, manure history increased N leaching potential.

2. Chemical inputs increased corn grain yield and N uptake consistently. It was apparent that NO_3-N leached out of the root zone soon after N fertilization. To reduce NO3-N leaching potential, the time and amount of N application needs to be managed properly.

3. Nitrate leaching potential was higher in NT and RT than CP during growing season. NO_3-N leaching for NT was attributed to macropores flow. The midrow zone of the RT contributed greater chemical leaching due to surface water redistribution, resulting from the surface configuration.

4. The CP, as a disturbed surface system, enhanced soil N mineralization, accumulated chemicals in the Bt and maintained residual NO_3-N higher in the soil profile NO_3-N after the growing season. Leaching potential was higher for CP during the winter season.