To the Graduate Council:

I am submitting herewith a dissertation written by Richard Allen Straw entitled "Effect of Nitrogen Fertilization and Tillage Method on Water Quality and Tomato Productivity." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

David L. Coffey, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor
and Dean of The Graduate School

EFFECT OF NITROGEN FERTILIZATION AND TILLAGE METHOD ON WATER QUALITY AND TOMATO PRODUCTIVITY

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Richard Allen Straw

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DEDICATION

This dissertation is dedicated to the Lord Jesus Christ, without whose strength and grace this degree would not have been possible.

"But seek first the kingdom of God and His righteousness, and all these things shall be added to you." (Matthew 6:33)

"I can do all things through Christ who strengthens me." (Philippians 4:13)

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May God bless and keep each of you.

ABSTRACT

Yield and plant characteristics of tomatoes were evaluated under nitrogen fertilization rates of 0, 112, or 336 kg ha^{-1} in 1990 and 1991; and two tillage systems, no tillage (NT) and conventional tillage (CT), in 1989, 1990, and 1991. In 1989, tillage treatments had no effect on yield of tomatoes (Lycopersicon esculentum Mill.). In 1990, nitrogen fertilization rate had little influence on yield or plant characteristics. When differences occurred, treatments receiving 112 or 336 kg ha^{-1} nitrogen fertilization were significantly different from treatments receiving 0 kg ha^{-1}, but were not different from one another. Although total and marketable yields of NT tillage tomatoes were not significantly different from CT tomatoes, the NT tomatoes produced considerably more fruit and appeared to be more vigorous. In 1991, the addition of nitrogen fertilization increased the average fruit weight of tomatoes, while few differences were observed in plant characteristics. Tomatoes grown under the CT system produced significantly higher yields and much more vigorous plants than tomatoes grown under the NT system, the opposite of what was observed in 1990.

Production of NT tomatoes appears feasible into small grain stubble; however, long term continuous NT is not

recommended. A nitrogen fertilization rate of 112 kg ha^{-1} appeared to be adequate for production of NT tomatoes on the soils of the Cumberland Plateau of Tennessee.

Conservation tillage systems have been shown to reduce erosion. However, results of runoff and infiltration characteristics under tillage systems are not as conclusive. Simulated rainfall events were conducted to evaluate runoff and factors influencing runoff on a Lonewood silt loam (Typic Hapludult) soil with a 6% slope. The antecedent soil water content was observed to be unaffected by tillage treatment. The NT treatment produced considerably more cover in the form of crop residue and plant biomass than did the CT treatment. This additional cover increased the interception of raindrops, thus reducing clay dispersion on the surface. The cover also decreased surface water movement, allowed more time for infiltration, as well as reduced erosion. In general, less runoff occurred from NT plots than from CT plots due to increased infiltration. When runoff did occur, sediment concentrations in runoff were considerably greater from CT plots than from NT plots. Total sediment losses were often an order of magnitude greater from CT plots than from NT plots.

Conservation tillage systems have been found to decrease the quantity of surface runoff. However, the quality of surface runoff from conservation tillage systems

is unknown. Water samples collected from individual runoff events were evaluated for metribuzin, NO_3-N, PO_4-P, and potassium concentrations. When runoff does occur, runoff from NT generally carried higher concentrations of metribuzin, NO_3-N, PO_4-P, and potassium than runoff from CT, especially in the first simulated rainfall event after agrichemical application. Concentrations were generally higher in runoff from CT later in the growing season due to the greater zone of mixing in CT soils. Concentrations of these agrichemicals were observed to decrease during simulated rainfall events. Total losses of metribuzin, NO_3-N, PO_4-P, and potassium in runoff were similar for NT and CT in the first two years of this study. During the third year; however, greater losses were observed from the CT plots than from the NT plots due to the significantly greater runoff volumes from CT plots.

Conservation tillage systems reduce erosion and may reduce runoff. Therefore, increased infiltration is often observed with conservation tillage systems. Pan lysimeters were installed to evaluate the effect of tillage treatment on water and agrichemical movement through the soil profile. Greater movement of water, NO_3-N, and metribuzin was observed under NT soil than under CT soil. Increased cover of the NT treatment slowed water movement, decreasing runoff and increasing infiltration. The infiltrating water

probably entered the undisturbed macropores of the NT systems allowing faster movement of water and less reactivity of fertilizer and pesticides with the soil. This may result in higher resident concentrations in CT soils than in NT soils or visa versa depending upon the hydrological conditions during and following chemical applications. Due to the channelization of the subsurface soil, the small pans (12.7 cm X 30.5 cm) collected flow from an area considerably larger than their size. The two larger pans (45.7 cm X 35.6 cm or 61 cm X 76.2 cm) appeared to produce more accurate flow measurements. Soil water content was observed to be slightly higher under NT soil in the top 15 cm and below 60 cm. However, soil water contents of CT soil was as great or greater between 15 and 60 cm. Residual NO_3-N and metribuzin concentrations were generally higher (at least in the top 15 cm) in CT soil than in NT soil. These differences were most likely a result of the water moving through the macropores and by-passing soil matrix pores in the NT soils, while water movement would have been more evenly distributed through CT soils.

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PART 1: GENERAL INTRODUCTION AND OVERVIEW

CHAPTER I

INTRODUCTION

Tomatoes are an important vegetable crop grown in Tennessee, with an estimated 2,025 ha grown each year. In addition to economic importance from the standpoint of the number of acres grown, is the ecological impact from relatively high levels of pesticides that are utilized in tomato production. Tomatoes are generally sprayed with fungicides and insecticides every week, or more often once fruit production begins.

Conservation tillage is defined as any tillage system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water. Conservation tillage methods have not become useful for most vegetable crops for three main reasons: 1) lack of highly effective herbicides, 2) reduced plant growth, and 3) reduced production levels. Recent labeling of new herbicides now makes it possible to obtain effective weed control in reduced tillage culture of tomatoes. Thus, conservation tillage systems appear more promising for tomatoes than in the past.

Some soil loss occurs from conservation tillage systems (Baker and Laflen, 1983a); however, this loss is much less than the larger soil loss that occurs during conventional tillage of vegetables such as tomatoes. In addition, many of the soils found on the Cumberland Plateau of Tennessee are subject to extreme erosion. The Lonewood silt loam soil is a deep well drained soil with moderate permeability and high water holding capacity. However, on slopes of 5 to 12%, the Lonewood silt loam soil is highly erodible (U. S. Soil Conservation Service, 1989). Severe erosion problems have been observed in commercial tomato production in this area, because the summer rainfall is relatively high and often intensive. The rolling terrain of the Cumberland Plateau enhances the problem of erosion. In a three to four year period, a shallow surface pond was nearly filled with sediment when tomatoes were grown above the pond using conventional tillage methods (Mullins, personal communication).

The rate and amount of nutrient movement through the soil profile varies with tillage method. Some results from work with nutrient movement are contradictory, but in general, these results show less subsurface movement with conservation tillage systems. The 1.8 m row spacing, commonly used in tomato production in this area, offers good potential for the application of conservation tillage

systems. Sod strips between rows should reduce erosion. These strips of sod may also reduce movement of nutrients and pesticides in surface runoff water. However, the effect of these sod strips on soil water movement and quality are unknown.

In a five-year study at three locations in Tennessee, optimum tomato yields were obtained at fertilizer levels of 112, 49, and 93 kg ha^{-1} nitrogen, phosphorus, and potassium, respectively. However, many growers in Tennessee may use three times this much fertilizer. Part of this misuse is based on data obtained from trials on sandy coastal plain soils of Georgia and Florida. Many growers and salespeople have the misconception that if a little fertilizer gives a large yield response, a lot of fertilizer will give an even larger yield response. Many growers use high fertilization rates as insurance that nutrients are not limiting since fertilizer materials are a small percentage of the total production costs for tomatoes. However, this excess usage of fertilizer costs the growers money and may directly affect pollution in surface water, soil, and groundwater.

Fertility requirements for tomatoes have not been determined in Tennessee with the various tillage methods. Tomatoes may respond like other crops in that they require higher nitrogen levels with no tillage systems than with conventional tillage systems.

CHAPTER II

OBJECTIVES

The five primary objectives of this study were as follows:

To Evaluate the Effect of Tillage Systems on Water Movement:

Specific secondary objectives included: 1) to determine the amount of runoff water from different tillage systems and 2) to obtain some preliminary information indicative of the amount of water moving through the soil profile toward ground water under different tillage systems.

To Evaluate the Effect of Tillage Systems on Water Quality:

Specific secondary objectives included: 1) to determine the concentration and mass of sediment, metribuzin, and nutrients in runoff water from different tillage systems and 2) to determine the concentration and mass of metribuzin, and nutrients moving out of the root zone.

To Evaluate the Effect of Nitrogen Fertilization Rate on Water Quality:

Specific secondary objectives included: 1) to determine the concentration of nitrogen in runoff water from different nitrogen fertilization rates and 2) to determine the concentration of nitrogen moving out of the root zone.

To Evaluate the Effect of Tillage Systems on Tomato Production:

Specific secondary objectives included: 1) to evaluate plant growth characteristics and 2) to evaluate yield performance characteristics of tomato plants grown under different tillage systems.

To Evaluate the Effect of Nitrogen Fertilization Rate on Tomato Production:

Specific secondary objectives included: 1) to evaluate plant growth characteristics, 2) to evaluate yield performance characteristics, and 3) to determine tissue N concentrations of tomato plants grown at different nitrogen fertilization rates.

CHAPTER III

LITERATURE REVIEW

The use of the term, conservation tillage, may be quite ambiguous. For the purpose of this review, conservation tillage shall be defined as any tillage or planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water (Conservation Tillage Information Center, 1986). No tillage (NT) shall be defined as a tillage system that leaves the soil undisturbed prior to planting, and planting is completed in a narrow slit 2-8 cm wide. (Conservation Tillage Information Center, 1986). Conventional tillage (CT) shall be defined as any system that disrupts the soil surface, leaving the surface virtually residue free.

Recent statistics indicate that approximately 30% of cropland in the United States is planted in some form of conservation tillage (Conservation Tillage Information Center, 1986). Myers (1983) predicts that by the year 2010, 95% of the cropland in the U.S. will be in some form of conservation tillage. Increased acceptance of conservation tillage systems by farmers has resulted from: 1) reduced erosion and 2) increased profit due to decreases in fuel and labor costs (Ladewig and Garibay, 1983). However, as of

late there has been concern that extensive shifts from CT to NT systems may increase the potential for groundwater contamination by pesticides.

Tillage Effects on General Soil Properties

Research using NT culture has resulted in changes in several soil properties. Conservation tillage practices, especially NT practices, have been found to increase the overall organic matter content of the soil (Anonymous, 1983; Blevins et al., 1977; Blevins et al., 1983; Dick, 1983; Doran, 1983; Groffman,1985; Juo and Lal, 1979; Shuman and Hargrove, 1985; Stearman et al., 1989; Valiulis, 1983; Van Doren et al., 1977). Blevins et al. (1983) and Dick (1983) have reported a stratification of organic matter in NT soils, with a doubling of organic matter content near the soil surface and decreasing with depth.

Conservation tillage systems have been found to reduce evaporation and promote better drainage than CT systems (Gold and Loudon, 1982; Phillips, 1981; Tyler and Thomas, 1977). However, the net effect is generally higher soil water contents under conservation tillage systems as reported by Blevins et al., 1971 and Shear, 1985.

A decrease in soil pH has been reported in long term NT experiments (Blevins et al., 1983; Griffith et al., 1977;

Triplett and Van Doren, 1969). This change in pH results from prolonged surface applications of ammoniacal nitrogen sources, which undergo nitrification and release hydrogen ions into the soil.

Thomas (1985) reported 5°C cooler average soil temperatures in June under NT systems as compared to CT systems. He also found maximum soil temperatures to be considerably lower, 32°C and 40°C for NT and CT systems, respectively.

According to Thomas (1985), tillage effects on bulk density are not well defined. Conservation tillage seems to compact Alfisols and Ultisols very little (i.e. little effect on bulk density), while Mollisols increase in bulk density under conservation tillage practices. Gebhardt et al. (1985) have shown that by the end of the growing season, compaction from natural processes was greater than compaction resulting from wheel traffic on NT soils.

Tillage Effects on Biological Conditions and Microbial Activity

Soil enzyme levels were found to be greater in the top 1 to 1.25 cm of NT systems, while deeper in the profile, 22.5 to 30 cm, enzyme levels were greater in CT systems (Dick et al., 1986a; Dick et al., 1986b). This difference

most likely resulted from the stratification of organic matter in NT systems and the associated changes in biological and chemical conditions.

It was originally believed that conservation tillage practices increased insect pest populations (Musick, 1973; Gregory and Musick, 1976). However, more recent work has shown an increase in the populations of beneficial insects (All et al., 1981; House and All, 1981; House and Stinner, 1983; Stinner et al., 1986). Stinner et al. (1986) stated that insect pest problems may be indirectly related to tillage systems, as in the case of increased weed populations, which provide a suitable environment for insects to live.

Much concern has been expressed as to disease pressure under conservation tillage systems. Cook et al. (1978) stated that plant pathogens could over-winter on the plant residue left by conservation tillage practices. However, Martenson (1981) concluded that some new corn diseases have been seen in conservation tillage systems, while some of the more traditional corn diseases have been on the decline.

Several studies of earthworms have shown many resultant soil benefits. These benefits include: 1) increased residue decomposition (Mackay and Kladivko, 1985), 2) increased aggregate stability (Hopp and Hopkins, 1946; Mackay and Kladivko, 1985), 3) increased water holding capacity

(Stockdill, 1982), 4) increased pore size (Ehlers, 1975), 5) increased infiltration rate (Ehlers, 1975), and 6) reduced soil crusting (Kladivko et al., 1986). Little difference has been observed in the number of earthworms found in NT as compared to those found in CT systems. However, NT systems do not disturb the channels formed (De St. Remy and Daynard, 1982; Mackay and Kladivko, 1985). Ehlers (1975) found a network of earthworm channels extending to a depth of 180 cm. Edwards and Norton (1985) found similar networking with dye studies indicating rapid water movement through worm channels, even with little precipitation.

Hendrix et al. (1986) stated that CT treatments distribute plant residue throughout the tillage zone, promoting bacterial activity. Therefore, decomposition of organic matter and mineralization of organic nitrogen are rapid. On the other hand, NT treatments maintain high levels of plant residue at or near the soil surface, which promotes fungal activity near the surface. Generally, mineralization proceeds more slowly under NT systems than under CT systems. Doran (1980) found microbial populations in the soil to be about equal under NT and CT systems from 0 to 15 cm. However, NT systems had greater populations from 0 to 7.5 cm, while CT systems had greater populations from 7.5 to 15 cm. Dawson et al. (1948) and Norstadt and McCalla (1969) found higher microbial populations near the

surface of conservation tillage systems than in CT systems. Fairchild and Staley (1979) found differences in microbial populations in samples from 0 to 30 cm deep in West Virginia. Doran (1980) found populations of denitrifiers and facultative anaerobes greater in NT than CT systems. In general, NT systems promote anaerobic conditions, favoring denitrification, while CT systems promote aerobic conditions and aerobic processes like nitrification.

Levels of organic and biomass carbon were found to be higher in the top 7.5 cm of soil from a NT system than in soil from a CT system, while little difference was observed in carbon levels from 7.5 to 15 cm (Doran et al., 1985). However, Carter and Rennie (1982) found organic carbon levels to be higher in CT systems, while biomass carbon was found to be higher in NT systems. Little differences were found between tillage systems deeper in the soil profile. The differences observed in organic carbon levels between these two studies may be attributed to a difference in quantities of crop residue (more in the first, less in the latter).

Tillage Effects on Soil Chemical Concentrations

Chemicals have been observed to accumulate in the top 5 to 10 cm of soil under NT systems, while at greater depths

in the profile there is a reversal of this trend (Hendrix et al., 1976). However, with less disturbed earthworm channels in NT systems (Ehlers, 1975), there is a potential for faster and increased chemical movement out of the root zone (Edwards and Norton, 1985; Ehlers, 1975).

Several researchers have reported greater available phosphorus levels in the top 5 cm of soil from conservation tillage systems than in the top 5 cm of soil from CT systems (Dick et al., 1986a; Eckert and Johnson, 1985; Fink and Wesley, 1974; Moschler et al., 1972; Triplett and Van Doren, 1969). Other studies have shown a stratification of potassium, calcium, magnesium, manganese, iron, copper, and zinc in conservation tillage systems, with concentrations decreasing with depth through the soil profile (Blevins et al., 1983; Chandhi and Takkar, 1982; Hargrove et al., 1982; Hendrix et al., 1986; Lal, 1976; Shuman and Hargrove, 1985).

Soil nitrate concentrations have been observed to be greater under CT soil in the fall after plowing than in soil under NT plots; although, by spring no differences in nitrate concentrations were observed (Carter and Rennie, 1984a; Dowdell et al., 1983; Linn and Doran, 1984; Rice and Smith, 1983).

Thomas et al. (1973) found higher nitrate concentrations in soils from CT systems than in soils from reduced tillage systems. Several other studies evaluated

soon after the implementation of tillage practices showed similar results (Dowdell and Cannell, 1975; House et al., 1984; NaNagara et al., 1976). Lamb et al. (1985) reported increased inorganic nitrogen concentrations from plowed wheat-fallow systems early in the experiment; however, after two to six years they observed no significant differences in nitrogen concentrations due to tillage treatments. Rice et al. (1986) found soil nitrogen levels reached a steady state approximately five years after initiation of tillage treatments. After 12 years they measured no differences in ammonium or nitrate between soils of NT and CT treatments.

Factors Affecting Pesticide Persistence

Taylor (1978) reported that for most pesticides, degradation was more important in dissipation than was volatilization. However, volatilization losses of pesticides were much greater than losses from plant uptake, runoff, or leaching.

Degradation

Small changes in soil pH may have a many fold effect on pesticide degradation (Kells et al., 1980). These resultant degradation changes may be due to rate changes of chemical

reactions or changes in microbial populations. To expand on the latter possibility; a pH of 7.5 to 8.0 generally promotes actinomycete populations, a pH of 6.0 to 7.5 promotes bacteria populations, while a pH of less than 6.0 promotes fungi populations which are better than either bacteria or actinomycetes at dealkylation reactions. Frederickson and Shea (1986) reported increased degradation of chlorsulfuron at a pH range of 5.6 to 5.9 as compared to a pH of 7.5.

Organic matter also influences microbial activity, and hence, pesticide degradation. Organic matter usually results in increased microbial activity and organic chemical adsorption; although, increased adsorption usually decreases degradation. Therefore, increased organic matter may result in no net change in pesticide degradation.

Soil temperature may also influence pesticide degradation. Thomas (1985) reported cooler soil temperatures under NT conditions, which in turn usually slows the rate of chemical reactions.

Burnside and Wicks (1980), Kells et al. (1980), and Lynch and Panting (1980) reported less triazine carryover when using conservation tillage systems. Bauman and Ross (1983) also reported less atrazine persistence for coulter tillage than for CT systems in the first year. However, atrazine residues were higher in the coulter tillage system

after five years. Hamaker (1972) found that increased pesticide concentrations decreased degradation rate.

Overall, tillage effects on pesticide degradation may be offsetting. Increased microbial activity, moisture content, and organic matter content may be offset by increased adsorption and decreased soil temperatures under NT.

Volatilization

Soil water content has been reported to affect pesticide volatility. Pesticides may be reversibly adsorbed to dry soil; thereby, reducing volatilization (Spencer and Claith, 1984). However, a dry layer of soil near the soil surface may reduce volatilization (Glotfelty et al., 1984). Conventional tillage systems have a greater tendency to create a dry surface layer than do conservation tillage systems, possibly reducing volatilization from CT systems.

Pesticides have been found to be less strongly adsorbed to vegetation than to soil (Willis et al., 1985). Therefore, more loss from volatilization might be expected of pesticides intercepted by the mulch layer and plant canopy. The pesticide is held up in the vegetation resulting in more surface area being exposed to the wind and

more gaseous exchange resulting from the rougher surface of the mulch as compared to the soil.

Volatilization can be reduced by as much as 50% by doubling organic matter levels (Spencer and Claith, 1974). Therefore, conservation tillage systems, especially NT treatments, may reduce pesticide volatilization.

Cooler soil temperatures associated with NT systems (Thomas, 1985) may reduce pesticide volatilization. Overall, different tillage systems may have little effect on pesticide volatilization due to offsetting factors.

Plant uptake

Soybeans grown in the greenhouse were found to remove 0.02% to 0.61% of a chlorinated insecticide from the soil (Beall and Nash, 1971). Corn had an average uptake of 0.14% and 0.01% for carbofuran and dieldrin, respectively (Caro et al., 1976). Frederickson and Shea (1986) found that a pH range of 5.6 to 5.9 increased plant uptake of chlorsulfuron. However, these concentrations were a very small percentage of the total pesticide applied.

Tillage, Traffic, and Natural Process Effects on Hydrological Parameters

Rough soils have exhibited higher infiltration rates (Larson, 1962), greater temporary water storage, and more depressional sediment trapping (Larson, 1964) than do smooth soils. Voorhees et al. (1981) reported that primary tillage (i.e. moldboard plowing and disking) temporarily increases the total pore volume of a soil; however, subsequent wheel traffic (Voorhees et al., 1978), tillage, and natural processes through the growing season (Rawls et al., 1983) reduce porosity and negate the tillage effects. Wheel traffic has been shown to increase depressional water storage, and usually results in earlier sealing of the soil surface that results in increased runoff (Lindstrom and Voorhees, 1985; Young and Voorhees, 1982).

Wheel traffic may reduce the porosity of the soil deeper than the soil was originally tilled (Ericksson et al., 1974; Sommer, 1976; Voorhees et al., 1986). Soil compaction has been shown to affect many soil characteristics. Voorhees et al. (1979) showed ponding and subsequent runoff occurred faster from compacted soils. Subsoil compaction from heavy equipment (especially harvest equipment) may affect: 1) water movement through the soil (Voorhees et al., 1986) and 2) soil erosion across several

seasons (Fullen, 1985). Allmaras et al. (1982) reported that a compacted tillage pan only a few cm thick can reduce water movement through the soil profile.

Addition of 15 cm of rainfall to a freshly tilled surface resulted in a 20% increase in the bulk density and a 74% decrease in the saturated hydraulic conductivity of the soil (Onstad et al., 1984). Burwell et al. (1966) found that when water was applied to freshly plowed soil at a rate of 12.5 cm per hour, total pore space decreased from 13.7% to 11.2% after 5.0 cm of runoff with 80% of the decrease occurring before runoff. Total pore space accounted for 60% of variation associated with the initiation of runoff.

Lindstrom and Voorhees (1980) and Lindstrom et al. (1981) found NT to have lower porosity than CT and predicted lower infiltration for NT than for CT. They believed that total porosity controls infiltration. However, it is the size of the pores, and therefore, the pore size distribution that most significantly controls the infiltration rate (Wilson, personal communication). Edwards and Norton (1985) and Lal (1978) found that infiltration was greater for NT treatments than for CT treatments and attributed the greater infiltration of NT to macropores created by earthworm activity.

Tillage Effects on Water Movement and Quality

Stewart (1975) stated that most land management practices that result in less erosion, also reduce runoff volume. Drastic reductions of erosion and runoff and near elimination of pesticide losses have been reported from NT systems (Edwards, 1972; Foy and Hiranpradit, 1977; Triplett et al., 1978). However, Ritter et al. (1974) and Smith et al. (1978) found conservation tillage systems may suffer some losses of sediment, water, and pesticides.

In general, quantity of runoff water from NT treatments has been less than from CT systems (Andraski et al., 1985a; Angle et al., 1984; Hall et al., 1984; Harold et al., 1970; Johnson et al., 1979; Laflen et al., 1978; Laflen and Colvin, 1981; Lal, 1976; McDowell and McGregor, 1980; Romkens et al., 1973; Shelton and Bradely, 1987; Siemens and Oschwald, 1978; Triplett et al., 1978; Van Doren et al., 1984). However, Laflen and Colvin (1981), Lindstrom et al. (1984), Mueller et al. (1984), McDowell and McGregor (1980), and Shelton et al. (1982) have observed greater runoff from NT systems. Baker and Laflen (1983a) contend there is little difference in the quantity of runoff water measured between NT and CT systems, while erosion is significantly decreased with NT systems. These discrepancies among researchers are most likely attributed to factors such as 1)

surface condition of CT soils (crusted or freshly tilled), 2) amount of residue present on the surface of NT soils, 3) antecedent soil water content, 4) pore size distribution of the soils, and 5) time from the initiation of the tillage systems.

Bovey et al. (1974) and Martin et al. (1978) contend that residue reduces soil loss; however, the residue may provide a source of pesticide that is easily mobilized. Wauchope (1978) stated that NT systems will reduce losses of soil adsorbed, sediment-carried herbicides, while possibly increasing losses of highly water soluble herbicides.

Increasing the amount of corn stalk residue was found to increase the initial infiltration rate; thereby, increasing the time before runoff began and decreasing runoff volume (Baker et al., 1982). Cogo et al. (1984) reported the effect of surface conditions of different tillage systems minus residue on runoff. The NT system had a much lower initial infiltration; thereby, decreasing the time to initiate runoff and producing more runoff than other conservation and CT systems. Baker and Laflen (1983a) applied 111 mm of simulated rainfall six days after fall tillage and measured 2.5%, 10%, and 15% of applied water as runoff from chisel-plow, disk, and NT systems, respectively. When 72 mm of simulated rainfall was applied 12 days later

13%, 48%, and 19% of the water applied was measured as runoff from chisel-plow, disk, and NT systems, respectively.

Chemical concentrations of surface water have been found to decrease with time during a runoff event (Baker et al., 1978; Baker et al., 1982; Barius et al., 1978). The first 0.5 cm of runoff removed as much pesticide as the remaining 3 cm of runoff (Martin et al., 1978). Wauchope (1987) reported that in tilted-bed simulations the first 5% of runoff water by volume removed 20% of the total pesticide mass lost. Ahuja and Lehman (1983) have explained this phenomenon as a decrease in the chemical concentration of the mixing zone, a region 1-2 cm deep that is the main source of chemicals to the surface water. As surface water flows across the soil surface it mixes with infiltrating water near the soil surface resulting in more reactivity of surface runoff with the soil than if mixing did not occur. The first storm after application of nutrients or pesticides best exemplifies this mixing effect as well as results in the greatest percentage of chemical lost with runoff, especially if occurring within two weeks of pesticide application (Wauchope, 1978; Baker, 1980; Baker and Laflen, 1983b). Baker and Johnson (1979) stated that time of chemical application prior to first runoff was more important than tillage system.

Baker et al. (1978) and Baker and Johnson (1979) reported higher sediment and pesticide concentrations in runoff from conservation tillage treatments than in runoff from CT treatments. Baker et al. (1982) reported that increasing the amount of corn stalk residue decreased alachlor losses. Some researchers have found that the cover associated with conservation tillage techniques can intercept pesticides which in turn become a source of pesticide in runoff water (Deuel et al., 1977; Hall et al., 1984; Martin et al., 1978; Trichell et al., 1968). However, others have found mulch and grass cover to remove herbicide from runoff (Hall et al., 1984; Rhode et al., 1980; Trichell et al., 1968). Baker et al. (1982) working with three different herbicides, found no differences in runoff above and below mulch applications of herbicides. From these studies, it would appear that the type of herbicide (cationic, anionic, or non-ionic) would greatly affect the sorption or release from the cover.

Soils with low organic matter content and high percentages of sand may allow more leaching than soils with higher organic matter content and greater percentages of clay. Nitrogen movement into groundwater has been found to depend on rainfall (timing, rate, and duration), fertilizer application rate and placement, and many soil parameters, including the aforementioned. According to the U. S.

Environmental Protection Agency (EPA) National Pesticide Survey (1990), over 50% of the wells sampled contained detectable levels of NO_3-N. However, only 1.2% of community water supply wells and 2.4% of rural domestic wells contained more than the 10 mg L^{-1} concentration proposed by EPA as the maximum contaminant level.

Concentrations of soluble phosphorus have been found to be greater in runoff water from conservation tillage systems than in runoff from CT systems (Baker and Laflen, 1983a; Logan and Adams, 1981; McDowell and McGregor, 1981; Romkens et al., 1973). However, when optimizing fertilizer management practices Andraski et al. (1985b) found less algal available phosphorus loading (water quality parameter) from conservation tillage than from CT systems.

Burnside et al. (1963) showed monuron, simazine, and atrazine could be leached into the subsoil where they can persist due to cooler soil temperatures and less microbial activity than in surface soil. Similar results have been found with picloram (Glass and Edwards, 1974) and triazines (Hall and Hartwig, 1978; Muir and Baker, 1976). However, Sheets et al. (1972) and White et al. (1976) found many compounds to be quite immobile. Lee et al. (1976) found the degradation products of aldicarb to be much more mobile than the parent compound. Muir and Baker (1976) found similar results with atrazine and cyanazine.

Recently, atrazine and metolachlor were detected in corn fields in Connecticut to a depth of 2.25 m (Huang and Frink, 1989). In a sandy soil, 900 ug L^{-1} atrazine and 846 ug L^{-1} metolachlor were detected at a soil depth of 0 to 27 cm. Concentrations at 1.77 and 2.25 m were 9.3 and 5.8 ug L^{-1} for atrazine and metolachlor, respectively. Atrazine and metolachlor levels remaining in the soil profile were extrapolated to equal 3.9 and 3.6 kg active ingredient ha^{-1}, respectively (Huang, 1989). The results of this study have far reaching implications in that pesticide residues are present below the root zone and impose a threat to ground water. Numerous studies have shown that microbial degradation is slower in subsoils (Cohen et al., 1984), which suggests herbicide residues found in the subsoil could potentially leach into the groundwater before they are microbially degraded.

Hall et al. (1989) compared leaching and distribution of atrazine and metolachlor in CT and NT soils. They found atrazine residues consistently at all soil depths to 122 cm. When analyzing pan lysimeter percolates, they found more herbicide leaching from NT soil than from CT soil. Helling et al. (1988) and Isenee et al. (1988) found atrazine to be more mobile than alachlor, and both were more mobile than cyanazine in NT plots. Sonon and Schwab (1989) reported that sandy soils in Kansas exhibited significant leaching of

atrazine to depths of 90 cm, 30 days after application. Clay soils exhibited only a minimal amount of atrazine residue at a depth of 15 cm. Adsorption coefficients, determined by batch equilibrium, were highly dependent on: (1) soil type, (2) soil horizon, and (3) solution concentration. Klaine et al. (1988) reported that the total loss of atrazine in runoff water accounted for approximately 1.5 % of the total atrazine applied in an 18 ha, single field watershed located in West Tennessee. Concentrations as high as 0.25 mg L^{-1} were detected in runoff water. Wauchope (1978) presented a review of pesticide losses in runoff water from agricultural fields, and stated that behavior and fate of pesticides within streams receiving runoff is generally unknown. Unless severe rainfall occurs within one to two weeks after pesticide application, total losses for most pesticides were less than 0.5 % of the amount applied.

Tillage and Soil Parameter Effects on Fate of Metribuzin

Metribuzin is an asymmetrical member of the triazine family, with a water solubility of 1220 mg L^{-1} (Weed Sci. Soc. Am., 1989). Due to its high water solubility, Wauchope et al. (1985) predicted 90% to 100% of metribuzin lost in runoff water will be in the aqueous fraction.

Savage (1974) reported soil organic matter content and clay content to be correlated with metribuzin sorption, while metribuzin mobility was negatively correlated with clay content and positively correlated with sand content. Movement of metribuzin was found not to be significantly correlated with organic matter content of the soil. In a later study, Savage (1976) found sorption and mobility of metribuzin to be correlated with one another and with clay content, organic matter content, and water content of the soil. Peter and Weber (1985) showed metribuzin activity to be correlated with organic matter content, clay content, and specific surface area of the soil; while soil organic matter content and specific surface area were highly correlated with metribuzin sorption. Talbert et al. (1974) found metribuzin sorption to be highly correlated with total carbon, CEC, and total clay; while metribuzin activity was correlated with total carbon, CEC, and course clay. They also reported a correlation between sorption and activity. However, Harper (1986) found only a slight increase in metribuzin adsorption with increased clay content and no correlation with the organic content of the soil. In 1988, Harper reported that clay content and pH of the soil were important in sorption of metribuzin, while organic matter had no effect on its sorption. Peek and Appleby (1989b) found metribuzin activity to decrease as sand content

increased; and attributed this loss of activity to leaching. Sharom and Stephenson (1976) found metribuzin to be mobile in mineral soils and immobile in muck soils.

Ladlie et al. (1974) stated that pH affects the binding of metribuzin in the soil. Further work by Ladlie et al. (1976b), showed that pH affected the efficacy of metribuzin; and explained this reduced efficacy as pH affecting the availability of metribuzin for plant uptake. However, Peek and Appleby (1989c) found similar pH effects and explained them as affecting herbicide availability in the soil. Robinson (1982) found optimum metribuzin activity at a pH range of 6.8 to 7.2.

Metribuzin degradation by soil microbes decreased as pH decreased (Ladlie et al., 1976a). Adsorption was found to increase as pH decreased due to the protonation of the amine group. This increased adsorption resulted in lower phytotoxicity, microbial degradation, and mobility of metribuzin (Ladlie et al., 1976b).

Under greenhouse conditions, metribuzin half-life ranged from 17 to 28 days. Microbial degradation of metribuzin was believed to be important in its dissipation in the soil (Savage, 1977). Rapid volatilization and/or photodecomposition of metribuzin was observed under warm temperatures and high light intensities. The resultant half-life was 4 to 5 days (Savage, 1980). However, Peek and

Appleby (1989a) found significant volatilization, but little photodegredation of metribuzin under similar conditions. Banks and Robinson (1982) reported the half-life of metribuzin to be 5.3 and 12.5 days when rainfall or irrigation occurred 10 and 0 days after herbicide application, respectively.

Straw mulch was observed to influence the amount of initial and total amount of metribuzin reaching the soil surface (Banks and Robinson, 1982). Brown et al. (1985) found the least runoff and lowest metribuzin losses from NT plots. Brown et al. (1985) examined the effect of tillage and crop management on downward movement of metribuzin during growth of winter wheat in Washington. Analysis of multiple core samples at 0 to 7 or 0 to 15 cm showed that NT resulted in lower herbicide residues than CT. Moorman and Harper (1988) reported longer persistence of metribuzin at a soil depth of 10 to 20 cm than at a soil depth of 0 to 10 cm, which could result in greater opportunity for further movement of metribuzin once it enters the subsoil.

Jones et al. (1990) observed metribuzin to be more mobile than alachlor. They also reported that metribuzin moved faster under NT conditions than under CT conditions. The addition of 2800 kg ha^{-1} of straw was found to increase metribuzin movement. Metribuzin dissipated faster at a depth of 8 cm than at a depth of 58 cm.

Tillage Effects on Nitrogen Loss and/or Movement

Volatilization

With most nitrogen sources, few difference have been observed in volatilization of nitrogen between conservation tillage and CT systems. However, urea forms of nitrogen tend to volatilize when surface applied as in NT situations and have resulted in increased volatilization over CT systems (Bandel et al., 1980; Carter and Rennie, 1984; Mengel et al., 1982; Touchton and Hargrove, 1982).

Denitrification

Groffman (1985) found that under low soil water conditions nitrogen by denitrification losses were greater from NT than from CT, while denitrification losses were equal from the two systems under high soil water conditions. Losses from NT treatments were less than 10 kg N ha^{-1} $year^{-1}$ under low water conditions, while losses from both systems were greater than 25 kg N ha^{-1} $year^{-1}$ under high water conditions. Linn and Doran (1984b) reported that the higher water levels maintained under NT systems could result in as much as 9.4 times more nitrogen loss as a result of denitrification. Dowdell et al. (1983) concluded that NT

plots would lose more nitrogen to denitrification than would CT plots. Rice and Smith (1982), working in a well drained soil, found denitrification to be greater under NT due to the higher moisture levels. In a three year experiment at the same site in Kentucky, Kitur et al. (1984) found little or no denitrification. Wells (1984) found denitrification to be of little importance in NT systems in Kentucky. However, when denitrification was observed, it was greater under NT systems. Aulakh et al. (1984) reported more denitrification from NT than from CT systems and contributed the differences to higher soil water levels and higher bulk densities under NT situations. House et al. (1984) reported less denitrification in NT due to increased immobilization.

Linn and Doran (1984a) found 1.27 to 1.31 times more anaerobic microbes in the top 7.5 cm of NT soils than in the top 7.5 cm of CT soils. Doran (1980) found seven times more microbes in the top 7.5 cm of NT soils than in the top 7.5 cm of CT soils, while facultative anaerobes and denitrifiers were twice as high in NT systems at the 7.5 to 15 cm depth.

Nitrification

Potential mineralizable nitrogen (PMN) was found to be greater in NT soils than in CT soils. It was believed that more nitrogen was immobilized and/or less mineralization

occurred in previous years resulting in a higher PMN and thus less nitrate produced. A reduction in nitrifier population was found to parallel a decrease in nitrate concentration of NT soils (Broder et al., 1984).

Rice and Smith (1982) concluded that no differences in nitrification exist between tillage systems as long as soil water levels are the same. However, increased nitrification was found under NT culture in Kentucky due to higher soil water levels. Rice and Smith (1983) showed a higher nitrate:ammonium ratio for CT soils as compared to NT soils. Nitrification rates were found to be very similar between the two tillage systems. Increased soil water under NT systems resulted in higher nitrate concentrations when soils were fertilized. However, NT soils that received no fertilizer exhibited less mineralization and subsequently less nitrification. Dowdell and Cannell (1975) found 2 to 5 times more nitrate in CT soil than in NT soils in the winter, but by spring no difference was found between the two tillage systems. Groffman (1985) found more nitrification in the 0 to 5 cm depth and less nitrification in the 13 to 21 cm depth of NT soils than CT soils, with an overall net effect of no annual difference in nitrification between NT and CT systems.

Immobilization and Demineralization

Organic nitrogen levels were found to be greater in NT (Ferrer et al., 1984; Ortiz and Gallaher, 1984; Stinner et al., 1983) and mulch tillage systems than in CT systems (Stanford et al., 1973). On highly erodible soils in Nigeria, organic carbon loss was slower and organic nitrogen increased under NT conditions as compared to CT systems (Lal, 1976). Doran and Power (1983) stated that increased water levels under NT conditions would result in: 1) less oxidation, 2) more root formation in the surface layer, 3) enhanced microbial populations, and 4) greater potential for soil immobilization of nitrogen.

Increased immobilization and retention of nitrogen were observed in soils from NT systems (House et al., 1984). No tillage soils were observed to immobilize 15.2% of fall applied nitrogen into the organic nitrogen pool, while 51.4% was recovered as mineral nitrogen. A total of 74.8% and 66.6% (54% and 51.4% as mineral nitrogen) of applied nitrogen was recovered from CT and NT systems, respectively. Nitrogen not recovered was attributed to denitrification losses (Aulakh and Rennie, 1984). In a 25 year stubble mulch study, Bauer and Black (1981) reported 23% nitrogen losses from the stubble mulched system as compared to 33% nitrogen losses from the CT system. This difference was

attributed to more erosion and greater oxidation potential from the CT system.

In general, NT systems gain considerably more organic nitrogen than did CT systems (Bandel et al., 1975; Bauer and Black, 1981; Blevins et al., 1977; Blevins et al., 1983; Free, 1970; Groffman, 1985; Moschler et al., 1972; Stinner et al., 1983). However, Bandel et al. (1975) found more organic nitrogen accumulation in CT soils than in NT soils at one location. This difference was attributed to weather conditions among locations. As compared with grassland, NT systems lost less nitrogen than did CT systems (Blevins et al., 1977; Blevins et al., 1983).

When changing tillage systems considerable changes can occur in the organic nitrogen content of the soil. Fleige and Baeumer (1974) found significant increases of 72, 66, and 54 kg N ha^{-1} $year^{-1}$ when changing from a CT system to a NT system. When grasslands or old fields were brought into production, NT systems lost some organic nitrogen, but less than was observed from CT systems (Doran and Power, 1983; Stinner et al., 1983). When a CT system was maintained as a CT system, nitrogen losses were 6 kg N ha^{-1} $year^{-1}$ (Doran and Power, 1983).

Losses by Surface Runoff

Baker and Laflen (1983) and Wendt and Burwell (1985) predicted the average reduction in nitrogen runoff loss from implementation of conservation tillage systems to be 20 to 25%. Their estimate of total N runoff loss is probably not far off, but results from several experiments have shown substantial increases in dissolved nitrogen concentrations from conservation tillage systems (Alberts et al., 1981; Angle et al., 1984; Baker and Laflen, 1982; Baldwin et al., 1985; Barisas et al., 1978; Johnson et al., 1979; Laflen et al., 1978; Laflen and Colvin, 1981; Laflen and Tabatabai, 1984; McDowell and McGregor, 1980; Romkens et al., 1973; Siemens and Oschwald, 1978). This increase in concentration of dissolved or solution nitrogen has been attributed to several factors: 1) the surface applications of fertilizer in conservation tillage systems (McDowell and McGregor, 1980; Timmons et al., 1970; Wells, 1984), 2) increased concentrations of nitrogen at the soil surface of conservation tillage systems (Doran, 1980; House et al., 1984; Powlson and Jenkinson, 1981), and 3) leaching of nitrogen from plant residue on the surface of conservation tillage systems (McDowell and McGregor, 1980; Timmons et al., 1970). Concentrations of nitrate have been found to be greater in runoff water from conservation tillage systems

than in runoff water from CT systems (Baker and Laflen, 1983; Logan and Adams, 1981; McDowell and McGregor, 1981; Romkens et al., 1973).

Losses by Leaching

Tyler and Thomas (1977) found greater nitrate leaching during the spring under NT conditions than under CT conditions when nitrogen was added to the soil. Similar results were reported by Thomas et al., 1973 and 1981. They reasoned that water carried surface applied nitrogen through macropores, by-passing soil aggregate pores. Wild (1972) and Kanwar et al. (1985) found less nitrate movement under NT conditions. This difference was attributed to the water moving through the macropores and by-passing the nitrate present within soil aggregate pores. Gold and Loudon (1982) observed higher nitrate-nitrogen concentrations from tile drainage of conservation tillage systems than from tile drainage of CT systems. Kitur et al. (1984) found no difference in nitrogen leaching between tillage systems.

Schuman et al. (1975) documented nitrate leaching under conservation tillage systems and found it to be influenced by the amount of nitrogen fertilizer applied. However, Muir et al. (1973) reported that groundwater nitrate-nitrogen concentration was not only positively correlated with

nitrogen fertilizer usage, but also with irrigation well density and livestock density, while significant negative correlations were found with percent clay in soil, irrigation well depth, and water pH.

Tillage and Nitrogen Fertilization Effects on Tomato Production

Reduced tillage systems have worked very well with many agronomic crops; however, there has been limited success in trials with vegetables (Doss et al., 1984; Mueller, 1988; Mullins et al., 1980; Valiulis, 1983). The lack of success with vegetables has been due to erratic stand establishment and poor weed control (Beste, 1973; Mullins et al., 1980; Perkins-Veazie and Cantliffe, 1989). Crop growth was also reduced in some trials (Doss et al., 1981; McKeown et al., 1988; Mullins et al., 1980). Tomatoes grown in Alabama, Kentucky, and Florida had lower yields as the amount of tillage was reduced (Doss et al., 1984; Knavel et al., 1977; Valiulis, 1983). Tomatoes grown in Tennessee had equivalent or higher yields with NT practices than with CT practices (Shelby et al., 1988). Drost and Price (1991b) found plant height and yield of transplanted tomatoes to be unaffected by tillage system. Other work by Drost and Price (1991a) with direct seeded tomatoes showed plant stand was greater,

while days required for plant emergence were less for NT systems. Yields were greater from the CT systems at earlier planting dates, but at later dates yields were unaffected by tillage systems.

Label approval of sethoxydim has improved the weed control potential for tomatoes grown using conservation tillage practices as well as CT practices. Combinations of grass herbicides similar to sethoxydim and metribuzin have given excellent weed control in tomato production (Mullins and Coffey, 1983; Shelby et al., 1988).

Fertility studies conducted at three locations in Tennessee, showed the yield of tomatoes grown under CT did not respond to fertilizer rates greater than 112, 49, and 93 kg ha^{-1} of nitrogen, phosphorus, and potassium,respectively (Coffey et al., 1981). Several researchers have reported deficiency problems with nitrogen fertilizers applied directly to the soil surface. This deficiency results from fertilizer contact with large amounts of organic matter (Richardson, 1984). In Tennessee, slightly higher nitrogen levels than recommended for CT grain sorghum were needed to maintain maximum yields of NT grain sorghum (Howard, 1987).

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PART 2: EFFECT OF TILLAGE TREATMENTS AND NITROGEN FERTILIZATION RATES ON YIELD AND PLANT CHARACTERISTICS OF TOMATOES

CHAPTER I

ABSTRACT

Yield and plant characteristics of tomatoes were evaluated under nitrogen fertilization rates of 0, 112, or 336 kg ha^{-1} and two tillage systems, no tillage (NT) and conventional tillage (CT). In 1989, tillage treatments had little effect on yield of tomatoes (Lycopersicon esculentum Mill.). In 1990, nitrogen fertilization rate had little influence on yield or plant characteristics. When differences occurred, tomatoes receiving 112 or 336 kg ha^{-1} nitrogen fertilization were more vigorous and contained significantly higher tissue nitrogen levels than tomatoes receiving 0 kg ha^{-1}, but were not different from one another. Although total and marketable yields of NT tillage tomatoes were not different from CT tomatoes in 1990, the NT tomatoes produced considerably more fruit and appeared to be more vigorous. In 1991, the addition of nitrogen fertilization increased the average fruit weight of tomatoes, while few differences were observed in plant

characteristics. In 1991, tomatoes grown under the CT system produced significantly higher yields and much more vigorous plants than tomatoes grown under the NT system, the opposite of what was observed in 1990.

Production of NT tomatoes following a wheat cover crop appears feasible; however, long term continuous NT is not recommended. Reviewed literature indicates that most tillage research of vegetable crops includes fall tillage, planting of small grain cover crop, with NT management of crop in the spring. A nitrogen fertilization rate of 112 kg ha^{-1} appeared to be adequate for production of NT tomatoes on the soils of the Cumberland Plateau of Tennessee.

CHAPTER II

INTRODUCTION

In recent years, conservation tillage practices have proved very successful in agronomic crop production and have been adopted heavily. However, trials with vegetables have been much less successful (Doss et al., 1984; Mueller, 1988; Mullins et al., 1980; Valiulis, 1983). The lack of success with vegetables has primarily been due to erratic stand establishment and poor weed control (Beste, 1973; Mullins et al., 1980; Perkins-Veazie and Cantliffe, 1989); although, reduced crop growth was also evident in some trials (Doss et al., 1981; McKeown et al., 1988; Mullins et al., 1980). Tomatoes grown in Alabama, Kentucky, and Florida had lower yields as the amount of tillage was reduced (Doss et al., 1984; Knavel et al., 1977; Valiulis, 1983), while tomatoes grown in Tennessee had equivalent or higher yields with NT than with CT (Shelby et al., 1988). Drost and Price (1991b) working in Michigan found plant height and yield of transplanted tomatoes to be unaffected by tillage system. Other work by Drost and Price (1991a) with direct seeded tomatoes revealed that the number of days required for plant emergence was less and the subsequent stand was greater for NT systems than for CT systems. Yields were greater from

the CT system at earlier planting dates. However, yields at later dates were unaffected by tillage system.

Labeling of sethoxydim has improved the weed control potential for tomato production. Grass herbicides such as sethoxydim and fluazifop-p-butyl combined with metribuzin have given excellent weed control (Mullins and Coffey, 1983; Shelby et al., 1988). The use of such herbicide combinations has improved the feasibility of tomato production using conservation tillage practices.

Fertility studies conducted at three locations in Tennessee, showed yields of tomatoes grown under CT did not respond to fertilizer rates greater than 112, 49, and 93 kg ha^{-1} nitrogen, phosphorus, and potassium, respectively (Coffey et al., 1980). However, many growers in Tennessee may use up to three times this level of fertilization. This misuse is based on: 1) data obtained from trials on sandy coastal plain soils of Georgia and Florida, 2) growers not relying on soil tests and subsequent recommendations, and 3) excessive fertilizer recommendations by fertilizer salespeople. Many growers and salespeople still believe if a little fertilizer gives a large yield response, a lot of fertilizer will give an even larger yield response. This excess usage of fertilizer costs the growers money and may directly contribute to pollution in surface water, soils, and groundwater.

Fertility requirements for tomatoes have not been determined using NT practices in Tennessee. Tomatoes may respond like other crops in that they require higher nitrogen levels with NT than with CT systems. Several researchers have reported deficiency problems with nitrogen fertilizers applied directly to the soil surface under NT systems, especially urea-containing nitrogen sources (Bandel et al., 1980; Fox and Hoffman, 1981; Touchton and Hargrove, 1982). Large amounts of organic matter present on the surface of NT soils may tie up surface applied nitrogen as well as reduce nitrogen efficiency (Richardson, 1984). Slightly higher nitrogen levels were needed to maintain maximum yields of NT grain sorghum (Sorghum bicolor) in Tennessee (Howard, 1987). The objectives of this experiment were: 1) to evaluate plant growth characteristics of tomatoes throughout the growing season, 2) to determine the nitrogen status of tomato plant tissue, and 3) to determine yields and quality of tomatoes grown at three different nitrogen fertilization rates and under CT and NT systems.

CHAPTER III

MATERIALS AND METHODS

In 1989, an experiment was conducted comparing NT and CT tomatoes at the University of Tennessee Plateau Experiment Station near Crossville, Tennessee. The trials were conducted on a Lonewood silt loam soil (Typic Hapludult) with a 6% slope. After evaluation of the 1989 data, the experiment was modified in 1990 and 1991 to include three nitrogen fertilization rates in conjunction with the tillage treatments already imposed.

A cover crop of winter wheat was established each fall to control erosion during the winter and to provide a source of stubble for the following spring. The cover crop was mowed in the spring to a height of 15 cm. The NT plots were sprayed with paraquat, a non-selective burndown herbicide, and a fluted coulter was used to open a 3.8 cm wide furrow for transplanting. Conventional tillage plots were tilled with a tractor mounted rotary tiller to a depth of 15 cm. 'Mountain Pride' tomatoes were hand transplanted on June 28, 1989, June 8, 1990, and May 13, 1991 in rows 1.8 m apart and at an in-row spacing of 46 cm. All plots were fertilized with 49 and 93 kg ha^{-1} of phosphorus and potassium, respectively. Nitrogen fertilization consisted of 112 kg

ha^{-1} in 1989 and 0, 112, or 336 kg ha^{-1}, in 1990 and 1991. Fertilizer was incorporated in CT plots in 1989 and 1990. However, in 1991 fertilizer was surface applied due to wet soil conditions. All nitrogen was applied in the form of ammonium nitrate. Tomato plants were trained to the Florida weave system. Weed control was accomplished using metribuzin (4-Amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one) and sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) at 0.84 and 0.42 kg ha^{-1}, respectively for both NT and CT systems. Secondary and tertiary tillage was conducted as needed for weed control in CT plots. Disease control consisted of mancozeb (a product of zinc ion and manganese ethylene bisdithiocarbamate) at 1.79 kg ha^{-1} applied on a 10 day schedule. Insect control was accomplished using esfenvalerate ((S)-cyano-(3-phenoxyphenyl)methyl-(S)-4-chloro-alpha-(1-methylethyl)benzeneacetate) at 0.06 kg ha^{-1} on the same 10 day schedule.

Plant characteristics of height and vigor were evaluated on July 18, August 13, September 5, and September 25 in 1990 and June 26, July 18, and August 8 in 1991. July 18, 1990 and June 26, 1991 correspond to 40 and 45 days after transplanting, respectively. Plant height was measured in cm, while the vigor rating consisted of a

subjective scale of 1 to 10; where 1 represented poor plant growth and 10 represented excellent, thriving plant growth.

Whole plant samples were collected for tissue nitrogen concentration determination in 1990, while the last fully expanded leaf was collected for tissue nitrogen concentration determination in 1991. Tissue samples were dried at 67°C, ground, and analyzed using a Carlo Erba NA 1500 total nitrogen analyzer.

Tomatoes were harvested eight times in 1990 and seven times in 1991. Harvested fruit were sorted into U.S. No. 1, U.S. No. 2, and cull grades, counted, and weighed. U.S. No. 1 and U.S. No. 2 grades were combined and reported as marketable yield, while culls were considered unmarketable. Average fruit weights were then calculated for total and marketable yield. The statistical model used to evaluate yield and plant characteristic data in 1989 was a randomized complete block design with three replications. The statistical model used to evaluate yield and plant characteristic data in 1990 and 1991 was a randomized complete block with a split-plot factorial arrangement of treatments, replicated three times. Three nitrogen fertilizer rates constituted main plot treatments, while two tillage methods constituted split-plot treatments. The nitrogen fertilizer rates employed in 1990 and 1991 were a zero rate, a recommended rate (112 kg ha^{-1}), and a high rate

often used by producers (336 kg ha^{-1}). Statistical analysis of the collected data was done using analysis of variance procedures. Means of dependant variables found significant at the 0.05 level of probability were separated using Duncan's Multiple Range Test.

CHAPTER IV

RESULTS AND DISCUSSION

Differences in environmental conditions and management practices among years in addition to the dynamic nature of establishing tillage systems complicated the analysis of data across years. Therefore, data were analyzed separately for each year. In the fall of 1988 and 1989, all plots were tilled prior to sowing of the winter wheat cover crop, while in the fall of 1990 NT plots were not tilled prior to seeding of the cover crop in an effort to create a "true" NT environment.

Nitrogen fertilization rate had no significant affect on yield of tomatoes in 1990 or 1991 (Table 1). Tillage systems had no significant affect on tomato yields in 1989 or 1990 (Table 1). However, in 1991 both total and marketable yields were significantly greater from tomato plants grown on plots receiving CT as compared to those grown on plots receiving the NT treatment.

In 1989 (the first year of the experiment), yields of NT and CT tomatoes were equal (42.9 t ha^{-1}), while apparent differences were observed in the other two years (Table 1). Tomato yields were significantly lower in 1990. The yield of CT tomatoes decreased more dramatically in 1990 (25.2 t

Table 1. Yield of tomatoes grown under three nitrogen fertilization rates and two tillage treatments, 1989-1991.

Treatment	Total Yield			Marketable Yield		
	t ha^{-1}			t ha^{-1}		
	1989	1990	1991	1989	1990	1991
Nitrogen						
kg ha^{-1}						
0	--	22.3 a[x]	16.1 a	--	21.9 a	14.3 a
112	--	37.3 a	23.2 a	--	36.4 a	20.6 a
336	--	35.5 a	14.5 a	--	34.5 a	12.7 a
Tillage						
CT	42.9 a	25.2 a	24.3 a	33.8 a	24.6 a	21.6 a
NT	42.9 a	38.2 a	11.6 b	36.2 a	37.3 a	10.2 b
Interaction						
Nit x Till	--	N.S.	*	--	N.S.	*

[x] Treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability.
N.S. indicates no significant differences. (*) indicates significant differences at the 0.05 level of probability.

ha^{-1}) as compared to the yield of NT tomatoes (38.2 t ha^{-1}). In 1991, yields of CT tomatoes seemed to remain constant (24.3 t ha^{-1}), while yields of NT tomatoes decreased to less than a third of that observed in the previous two years (11.6 t ha^{-1}).

In 1991, there was a significant interaction of nitrogen fertilization rate and tillage treatment on both total and marketable tomato yields (Table 1). The NT treatment had considerably lower yields than the CT system under all nitrogen fertilization rates. This effect was even more dramatic at the 0 kg ha^{-1} nitrogen fertilization treatment (26.5 t ha^{-1} for total yield of CT vs. 5.6 t ha^{-1} for total yield of NT) resulting in a much greater increase in yield between the 0 and 112 kg ha^{-1} for the NT treatment (12.8 t ha^{-1}) than for the CT system (1.5 t ha^{-1}).

In 1990, nitrogen fertilization rate had no affect on average fruit weight; although, in 1991, the two treatments receiving nitrogen fertilization produced significantly larger tomatoes than the treatment that received no nitrogen fertilization (Table 2). The only tillage effect observed in 1990 was in average fruit weight of tomatoes which was greater for tomatoes produced on NT plots than for tomatoes produced on CT plots (Table 2).

Table 2. Average fruit weight of tomatoes grown under three nitrogen fertilization rates and two tillage treatments, 1989-1991.

Treatment	Overall Fruit Weight of Tomatoes			Fruit Weight of Marketable Tomatoes		
	grams			grams		
	1989	1990	1991	1989	1990	1991
Nitrogen						
kg ha^{-1}						
0	--	156 a[x]	125 b	--	157 a	130 b
112	--	162 a	140 a	--	163 a	144 a
336	--	165 a	136 a	--	169 a	141 a
Tillage						
CT	163 a	153 b	136 a	175 a	155 a	142 a
NT	168 a	169 a	131 a	176 a	171 a	135 a
Interaction						
Nit x Till	--	N.S.	*	--	N.S.	*

[x] Treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability. N.S. indicates no significant differences. (*) indicates significant differences at the 0.05 level of probability.

A significant interaction existed between nitrogen fertilization rate and tillage treatment for average fruit weight of both total and marketable tomatoes in 1991 (Table 2). Average fruit weights of marketable and all tomatoes produced from CT plots were consistent across nitrogen fertilization rates (average marketable fruit weights of 140, 143, and 142 g with increasing nitrogen fertilization rates). However, average fruit weight of marketable tomatoes produced on NT plots increased sharply from the 0 kg ha^{-1} (120 g) to the 112 kg ha^{-1} (147 g) and then decreased as the nitrogen fertilization rate continued up to 336 kg ha^{-1} (138 g).

Tomato plant height was found to be relatively unaffected by nitrogen fertilization rates at most evaluation dates. However, at the 9/05/90 date the two treatments receiving nitrogen fertilization produced taller tomato plants than the treatment receiving no nitrogen fertilization (89 and 90 cm for 112 and 336 kg ha^{-1} rates, respectively vs. 72 for the 0 kg ha^{-1} rate). Tomato plant height did vary due to tillage treatment. At the 8/13 and 9/05 evaluation dates in 1990, plants grown under NT treatments were taller than plants from the CT treatment (65 and 79 cm for CT vs. 79 and 88 cm for NT, respectively). However, in 1991 at the 7/18 and 8/08 evaluation dates the

opposite trend was true with CT treatments producing taller plants (56 and 80 cm for CT vs. 50 and 63 for NT).

The growth rate (height) of tomatoes grown under the different nitrogen fertilization rates and tillage combinations were compared (Figure 1). In 1990, the CT plots receiving 0 kg ha^{-1} of nitrogen fertilization had a very consistent height increase between sampling dates, while the other treatment combinations appeared to have two distinctly different rates of height increase. This difference is attributed to a slower rate of height increase between the 7/18/90 and 8/13/90 evaluations dates for the CT plots receiving 0 kg ha^{-1} nitrogen fertilization (0.6 cm day^{-1}) than for all other treatment combinations (> 0.9 cm day^{-1}). In 1991, all NT plots exhibited similar increases in plant height across evaluation dates, while CT plots appeared to have an increased rate of height increase between the later two observations.

Vigor of tomato plants was significantly greater for the two treatments receiving nitrogen fertilization at the last two rating periods in 1990 (Table 3); however, no other nitrogen fertilization effects on plant vigor were observed. Tomato plants from the NT treatment were more vigorous at the last three rating dates in 1990, while tomato plants from CT plots were more vigorous at the last two rating dates in 1991 (Table 3).

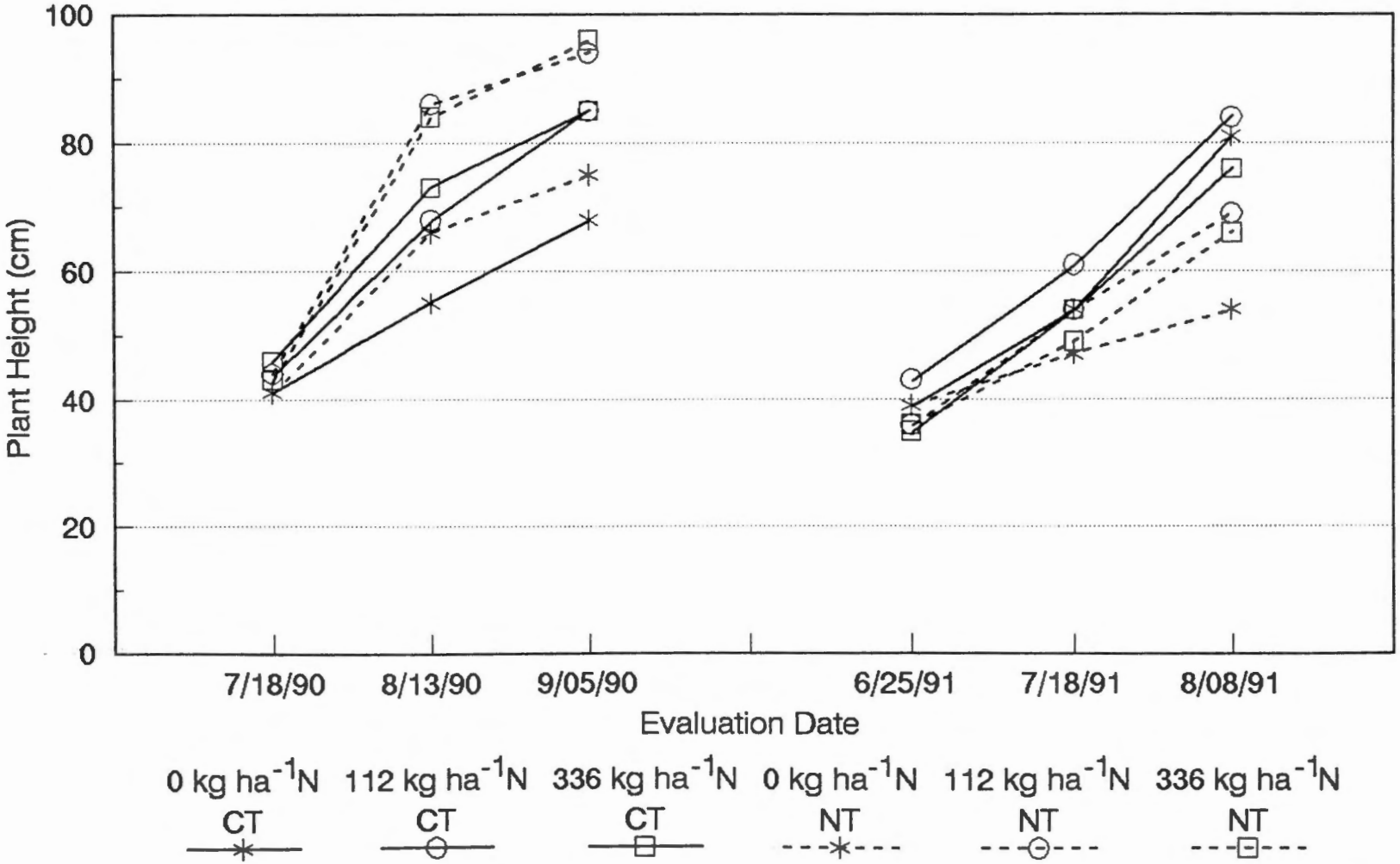

Figure 1. Height of tomatoes grown under three nitrogen fertilization rates and two tillage treatments, 1990-1991.

Table 3. Vigor rating of tomato plants grown under three nitrogen fertilization rates and two tillage treatments, 1990-1991.

Treatment	Vigor Rating 1-10[X]						
	1990				1991		
	7/18	8/13	9/05	9/25	6/25	7/18	8/08
Nitrogen kg ha^{-1}							
0	6.7 a[Y]	5.3 a	5.0 b	4.5 b	5.5 a	6.2 a	6.2 a
112	8.2 a	8.2 a	8.5 a	7.0 a	6.5 a	6.8 a	7.7 a
336	8.0 a	8.2 a	8.7 a	7.5 a	4.7 a	6.2 a	7.0 a
Tillage							
CT	7.6 a	6.2 b	6.8 b	5.8 b	6.4 a	7.1 a	8.0 a
NT	7.7 a	8.2 a	8.0 a	6.9 a	4.6 a	5.7 b	5.9 b
Interaction							
Nit x Till	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*

[X] Vigor rating of 1 to 10; where 1 = poor and 10 = excellent.

[Y] Treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability. N.S. indicates no significant differences. (*) indicates significant differences at the 0.05 level of probability.

A significant nitrogen fertilization rate by tillage interaction was observed in the plant vigor rating at the last rating date in 1991 (Table 3). This interaction resulted from a sizable difference in vigor between CT (8.3) and NT (4.0) treatments at the 0 kg ha^{-1} nitrogen fertilization rate, while differences in vigor between tillage treatments at the other nitrogen fertilization rates were 1.3 and 0.6 for the 112 and 336 kg ha^{-1} rates, respectively.

Nitrogen concentration of plant tissue increased as nitrogen fertilization rate increased from 0 kg ha^{-1} to 112 kg ha^{-1} at the 7/18/90 and the 7/10/91 sampling dates (Table 4). The nitrogen concentration in plant tissue was greater from plants grown on NT plots than from plants grown on CT plots at the last two sampling dates in 1990 (Table 4). A significant nitrogen fertilization rate by tillage treatment interaction was observed at the 7/10/91 sampling date. This interaction was a result of the nitrogen concentration being lower from plants of the NT treatment than the CT treatment at the 0 kg ha^{-1} (3.2% for NT vs. 4.2% for CT), while being higher at the two rates of applied nitrogen (4.6% and 4.7% for NT vs. 4.3% and 4.4% for CT, respectively).

Differences in tillage systems among years appeared to be related to soil nitrate levels and soil property

Table 4. Nitrogen concentration of selected tissue from tomato plants grown under three nitrogen fertilization rates and two tillage treatments, 1990-1991.

Treatment	Nitrogen Concentration %N				
	1990			1991	
	7/18	8/14	9/06	7/10	8/02
Nitrogen kg ha^{-1}					
0	2.0 b[x]	2.3 a	1.7 a	3.7 b	4.4 a
112	3.4 a	2.5 a	2.1 a	4.4 a	5.0 a
336	3.8 a	2.7 a	2.2 a	4.5 a	5.7 a
Tillage					
CT	2.8 a	2.4 b	1.9 b	4.3 a	5.0 a
NT	3.3 a	2.7 a	2.1 a	4.1 a	5.0 a
Interaction					
Nit x Till	N.S.	N.S.	N.S.	*	N.S.

[x] Treatment means within a column followed by the same letter are not significantly different at the 0.05 level of probability. N.S. indicates no significant differences. (*) indicates significant differences at the 0.05 level of probability.

Table 5. Effect of three nitrogen fertilization rates and two tillage treatments on the NO_3-N concentration in the soil profile, 1991.

Depth	NO_3-N Concentration					
cm	mg kg^{-1}					
	0 kg N ha^{-1}		112 kg N ha^{-1}		336 kg N ha^{-1}	
	CT	NT	CT	NT	CT	NT
			7/10/91			
0-15	21.4	5.3	55.5	34.2	94.1	78.4
15-30	4.0	0.5	6.9	1.8	23.3	4.0
30-45	6.1	0.6	5.0	1.7	16.3	6.6
45-60	1.0	0.0	2.6	0.6	6.4	1.3
60-75	1.4	0.0	2.9	1.8	15.4	2.3
75-90	0.6	0.0	1.4	4.4	9.4	5.3
			8/02/91			
0-15	40.6	2.3	36.9	21.2	73.8	56.4
15-30	7.1	1.3	6.5	9.8	33.7	28.9
30-45	5.4	1.1	5.0	4.7	15.8	9.4
45-60	1.8	0.6	4.5	2.3	11.2	2.8
60-75	1.5	0.2	2.9	1.8	16.0	3.4
75-90	1.1	0.2	1.8	3.6	18.6	6.0

differences (Table 5). Soil NO_3-N concentrations were lower under NT soils than under CT soils in 1991. Soil NO_3-N concentrations were extremely low in the NT treatment with 0 kg ha^{-1} of nitrogen fertilization. This would explain several of the nitrogen fertilization rate by tillage treatment interactions observed in that greater differences were observed between the NT tomatoes receiving 0 and 112 kg ha^{-1} than the CT tomatoes receiving the same nitrogen fertilization. These low levels of NO_3-N were a result of two factors: 1) no nitrogen fertilization and 2) a lack of tillage that would incorporate organic matter which could be decomposed and add nitrogen to the soil (mineralization). Also evident is the nitrogen cycling ability of the incorporated cover crop and subsequent mineralization in the CT plots receiving no nitrogen fertilization as indicated by the large increase in NO_3-N concentration between sampling dates.

In addition to differences in NO_3-N concentration differences, soil compaction appeared to be a problem in NT plots in 1991. Tomato production requires significant foot traffic in spraying, tieing, and harvesting. Since the NT plots were not tilled in the fall of 1990, the compaction effect of traffic was not nullified as it was in CT plots each year an NT plots the previous year. The tomato plants appeared to be stunted, especially early in the growing

season. Root penetration was observed to be poor. When tomato grown under NT were pulled, roots appeared to run parallel with and just under the soil surface as compared to CT tomato roots that generally grew downward.

CHAPTER V

SUMMARY AND CONCLUSIONS

In 1989, tillage treatments had little effect on yield of tomato plants. In 1990, nitrogen fertilization rate had little influence on yield or plant characteristics; however, when differences occurred, treatments receiving 112 or 336 kg ha^{-1} nitrogen fertilization were significantly different from treatments receiving 0 kg ha^{-1}, but were not different from one another. Although total and marketable yields of NT tomatoes were not different from CT tomatoes, the NT plants produced considerably more fruit and appeared to be more vigorous. In 1991, the addition of nitrogen fertilization increased the average fruit weight of tomatoes, while few differences were observed in plant characteristics. Tomatoes grown under the CT system produced significantly higher yields and much more vigorous plants than tomatoes grown under the NT practice, the opposite of what was observed in 1990.

Production of NT tomatoes following a winter wheat cover crop appeared feasible; however, long term continuous NT practices are not recommended, based on the results of this study. The recommended nitrogen fertilization rate of 112 kg ha^{-1} appeared to be adequate for production of NT

tomatoes on the soils of the Cumberland Plateau of Tennessee.

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PART 3: TILLAGE TREATMENTS AND NITROGEN FERTILIZATION RATES FOR TOMATO PRODUCTION. I. EFFECT ON QUANTITY OF RUNOFF

CHAPTER I

ABSTRACT

It is generally agreed that conservation tillage systems reduce erosion. However, there is no general consensus on the results of runoff and infiltration characteristics under tillage systems. Simulated rainfall events were conducted to evaluate runoff and factors influencing runoff on a Lonewood silt loam (Typic Hapludult) soil with a 6% slope. The antecedent soil water content was observed to be slightly higher (1% to 3%) from NT plots than from CT plots. However, we believe that the small differences in water content between the tillage treatments would have had no effect on infiltration or runoff. The NT treatment produced considerably more cover in the form of crop residue and growing tomatoes than did the CT treatment. This additional cover increased the interception of raindrops, thus reducing clay dispersion on the surface. The cover also decreased surface water movement, allowed more time for infiltration, as well as reduced erosion. In

general, less runoff occurred from NT plots than from CT plots due to increased infiltration. When runoff did occur, sediment concentrations in runoff water were considerably greater from CT plots than from NT plots. Total sediment losses were often an order of magnitude greater from CT plots than from NT plots.

CHAPTER II

INTRODUCTION

The use of the term, conservation tillage, can be quite ambiguous. For the purpose of this study, conservation tillage was defined as any tillage or planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water (Conservation Tillage Information Center, 1986). No tillage (NT) was defined as a tillage system that leaves the soil undisturbed prior to planting, and planting is completed into an extremely narrow seedbed, 2 to 8 cm (Conservation Tillage Information Center, 1986). Conventional tillage (CT) was defined as any system that disrupts the soil surface, leaving the surface virtually residue free.

Recent statistics indicate that approximately 30% of cropland in the United States is planted in some form of conservation tillage (Conservation Tillage Information Center, 1986). Myers (1983) predicts that by the year 2010, 95% of the cropland in the U.S. will be in some form of conservation tillage. Increased acceptance of conservation tillage systems by farmers has resulted from: 1) reduced erosion and 2) increased profit due to decreases in fuel and labor costs (Ladewig and Garibay, 1983). However, as of

late there has been concern that extensive shifts from CT systems to NT systems may increase the potential for groundwater contamination by pesticides.

Conservation tillage systems have been found to reduce evaporation and transpiration and promote better drainage than CT systems (Gold and Loudon, 1982; Phillips, 1981; Tyler and Thomas, 1977). However, the net effect of conservation tillage is generally higher soil water contents than under conventional tillage systems (Blevins et al., 1971; Shear, 1985).

Stewart (1975) stated that most land management practices that result in less erosion, also reduce runoff volume. Drastic reductions of erosion and runoff and near elimination of pesticide losses were reported from NT systems (Edwards, 1972; Foy and Hiranpradit, 1977; Triplett et al., 1978). However, Ritter et al. (1974) and Smith et al. (1978) found conservation tillage systems may suffer some losses of sediment, water, and pesticides.

Quantity of runoff from NT treatments has generally been less than from CT systems (Andraski et al., 1985; Angle et al., 1984; Hall et al., 1984; Harold et al., 1970; Johnson et al., 1979; Laflen et al., 1978; Laflen and Colvin, 1981; Lal, 1976; McDowell and McGregor, 1980; Romkens et al., 1973; Shelton and Bradley, 1987; Siemens and Oschwald, 1978; Triplett et al., 1978; Van Doren et al., 1984). However, Laflen and Colvin (1981), Lindstron et al.

(1984), Mueller et al. (1984), McDowell and McGregor (1980), and Shelton et al. (1982) have observed as much or more runoff from NT systems. Baker and Laflen (1983) contend there is little difference in the quantity of runoff water measured between NT and CT systems. Part of this variance might possibly be explained by plot size. For example, tilted-bed studies would have no traffic and only "natural processes" influencing soil characteristics, while small research plots would have small equipment and extensive foot traffic affecting the soil. An even more dramatic example would be on a large field scale (watershed) study with the use of heavy planting and harvesting equipment, which can cause significant compaction and destruction of soil properties. From these scenarios, one might expect more infiltration and less subsequent runoff from tilted-bed studies and experimental plots than from large scale field or watershed experiments.

Baker et al. (1978) stated that the amount of soil covered by residue plays an important role in the quantity and quality of runoff. Bovey et al. (1974) and Martin et al. (1978) observed that residue decreased soil loss. Increasing the amount of corn stalk residue was found to increase the initial infiltration rate, thereby increasing the time to runoff and decreasing runoff volume (Baker et al., 1982). An evaluation of the effect of surface

conditions of different tillage systems minus residue revealed the NT system had a much lower initial infiltration rate than CT, that in turn produced quicker initial runoff and considerably more runoff than other conservation and CT systems (Cogo et al., 1984). Baker and Laflen (1983) applied 111 mm of simulated rainfall six days after fall tillage and measured 2.5%, 10%, and 15% of applied water as runoff from chisel-plow, disk, and NT systems, respectively. When 72 mm of simulated rainfall were applied 12 days later 13%, 48%, and 19% of the water applied was measured as runoff from chisel-plow, disk, and NT systems, respectively. At the first simulated rainfall event after tillage, CT soils were generally loose with a higher porosity and infiltration rate than at the subsequent rainfall event. However, this effect was nearly negated after the first simulated rainfall event. Dispersion of clay resulted in surface sealing, while bulk density increased as the soil settled during rainfall. Severe surface crusting can also result after a rain, decreasing infiltration and increasing the amount of runoff. The advantages of a freshly worked seedbed are quickly lost and result in lower infiltration rates for CT soils than for NT soils. Tillage prior to every rainfall event would minimize erosion with CT; however, such a practice would be cost prohibitive and physically impossible.

The objectives of this study were: 1) to determine the effect of tillage treatment on the quantity of runoff, 2) to determine the effect of tillage treatment on sediment losses, and 3) to evaluate the effect of tillage treatment on general soil and management practices that in turn influence water movement.

CHAPTER III

MATERIALS AND METHODS

Runoff experiments were conducted at the University of Tennessee Plateau Experiment Station located near Crossville, TN. The trials were conducted on a Lonewood silt loam soil (Typic Hapludult) with a 6% slope. Tillage treatments were imposed on plots 4.1 m wide by 11.1 m long, bordered with galvanized metal to prevent surface water movement between plots and adjacent sod strips. Troughs, manufactured from PVC pipe, were installed at the bottom of each plot to collect and direct runoff into HS type flumes. Quantity of runoff water was determined by periodically monitoring (5 to 10 min) the depth of flow from the flumes during each runoff event. Samples were collected periodically (approximately every 15 min) during the runoff event and flow weight composited for determining sediment concentrations. Sprinklers (Toro, model 423) were installed on 3 m high risers to provide water for simulated rainfall events.

In 1989, CT sweet corn, NT sweet corn, CT tomatoes, NT tomatoes, and a fallow plot were compared using existing tillage plots. After evaluation of the 1989 data, the experiment was modified in 1990 and 1991 to include three

nitrogen fertilization rates in conjunction with CT and NT tomatoes. Three additional plots were taken from sod fallow and initiated as NT treatments to accommodate treatment changes. Beginning in 1990, NT plots were maintained continuously NT. Prior to 1990 all plots (CT, NT, and fallow) were tilled each fall and sowed in winter wheat, which negated any long term NT effects.

Winter wheat was established each fall to provide cover over the winter and a source of stubble for the following crop. The cover crop was mowed in the spring to a height of 15 cm. No tillage plots were treated with a non-selective herbicide and a fluted coulter was used to open a narrow (3.8 cm) furrow for transplanting. CT plots were tilled with a tractor mounted rotary tiller to a depth of 15 cm. 'Mountain Pride' tomatoes were hand transplanted in rows 1.8 m apart and at an in-row spacing of 46 cm.

Four simulated rainfall events were conducted in 1989 and 1991, while five were conducted in 1990. Dates of runoff events were as follows: July 25, August 29, September 21, and October 5 in 1989; June 27, July 18, August 13, and September 5, and September 25 in 1990; and June 13, June 25, July 18, and August 8 in 1991. Simulated rainfall was applied at an approximate rate of 80 mm h^{-1}. Each event lasted 0.75 h in 1989 and 1.5 h in 1990 and 1991.

Antecedent soil water content was calculated from soil samples taken at a depth of 15 cm prior to each simulated runoff event. Percentage of cover was evaluated prior to each simulated runoff event in 1990 and 1991. Cover included crop residue, weeds, and crop canopy.

The statistical model used to evaluate collected parameters was a randomized complete block, replicated 9 times. Means of dependant variables found significant at the 0.05 level of probability were separated using Duncan's Multiple Range Test. Values presented are the average of the 9 plots in each treatment.

CHAPTER IV

RESULTS AND DISCUSSION

Soil Coverage

In 1990, NT plots had significantly more cover than CT plots at all simulated rainfall events, except at the 7/18 event (Figure 1). The dramatic decrease in cover of CT plots between 7/18 and 8/13 was a result of secondary tillage and herbicide application, while the decrease in cover of NT plots between the two dates was attributed to herbicide application. Increases in the percentage of cover after 8/13 were attributed to subsequent regrowth. In 1991, weed management was better in CT, resulting in percentage cover ratings averaging 16% to 18% (Figure 2). No tillage plots maintained significantly more cover than did CT plots in 1991 at all evaluation dates (Figure 2). Cover ratings for NT were 99% and 100% all season long due to increased crop residue and poorer weed control than observed in the previous year. Essentially no crop residue was present on the surface of the CT plots. Therefore, cover ratings of CT plots included the crop canopy and weed growth, while cover ratings of NT plots included the crop canopy, weed growth, and crop residue. Crop residue of NT plots appeared to

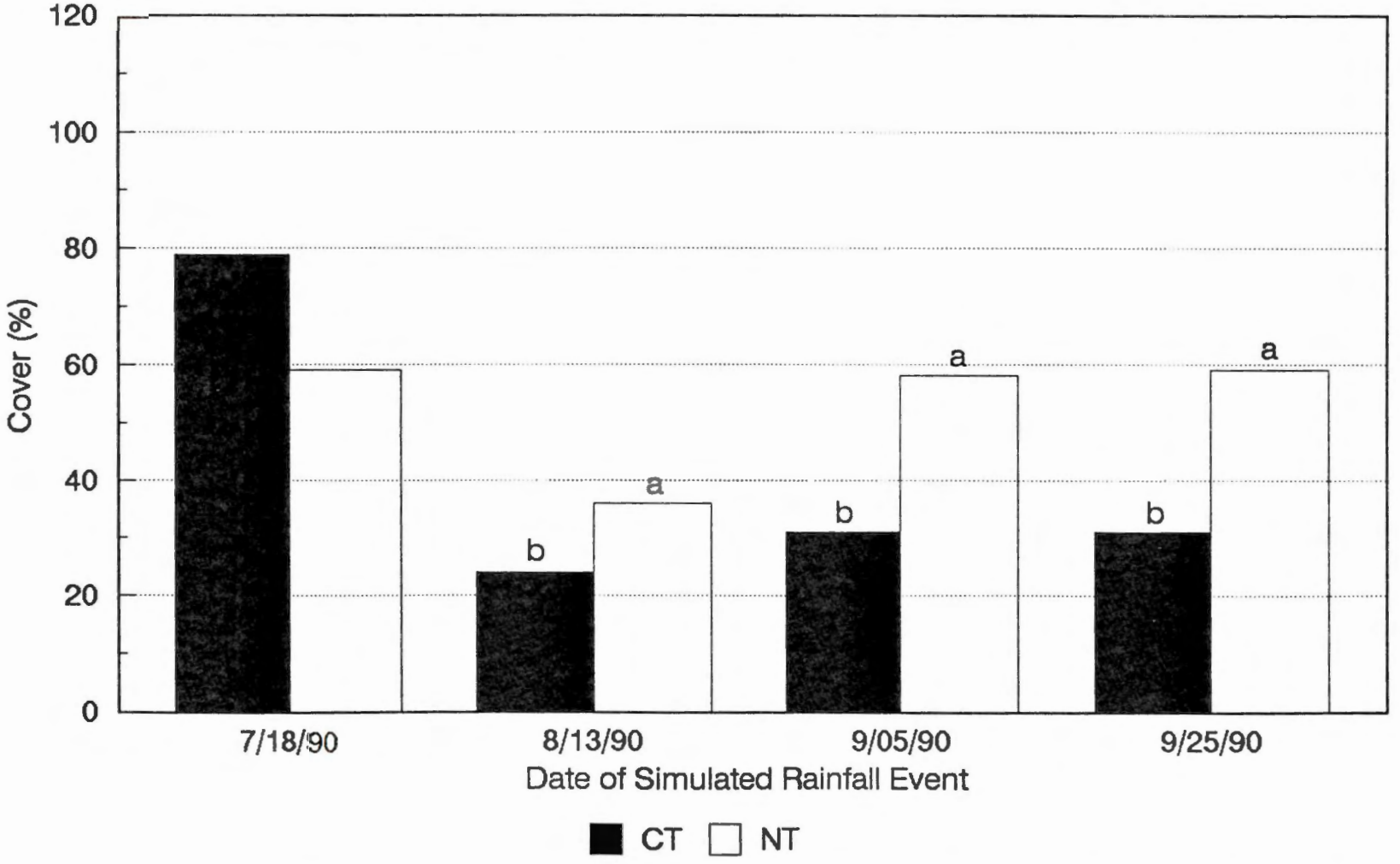

Figure 1. Effect of tillage treatments on percentage of surface cover, 1990.

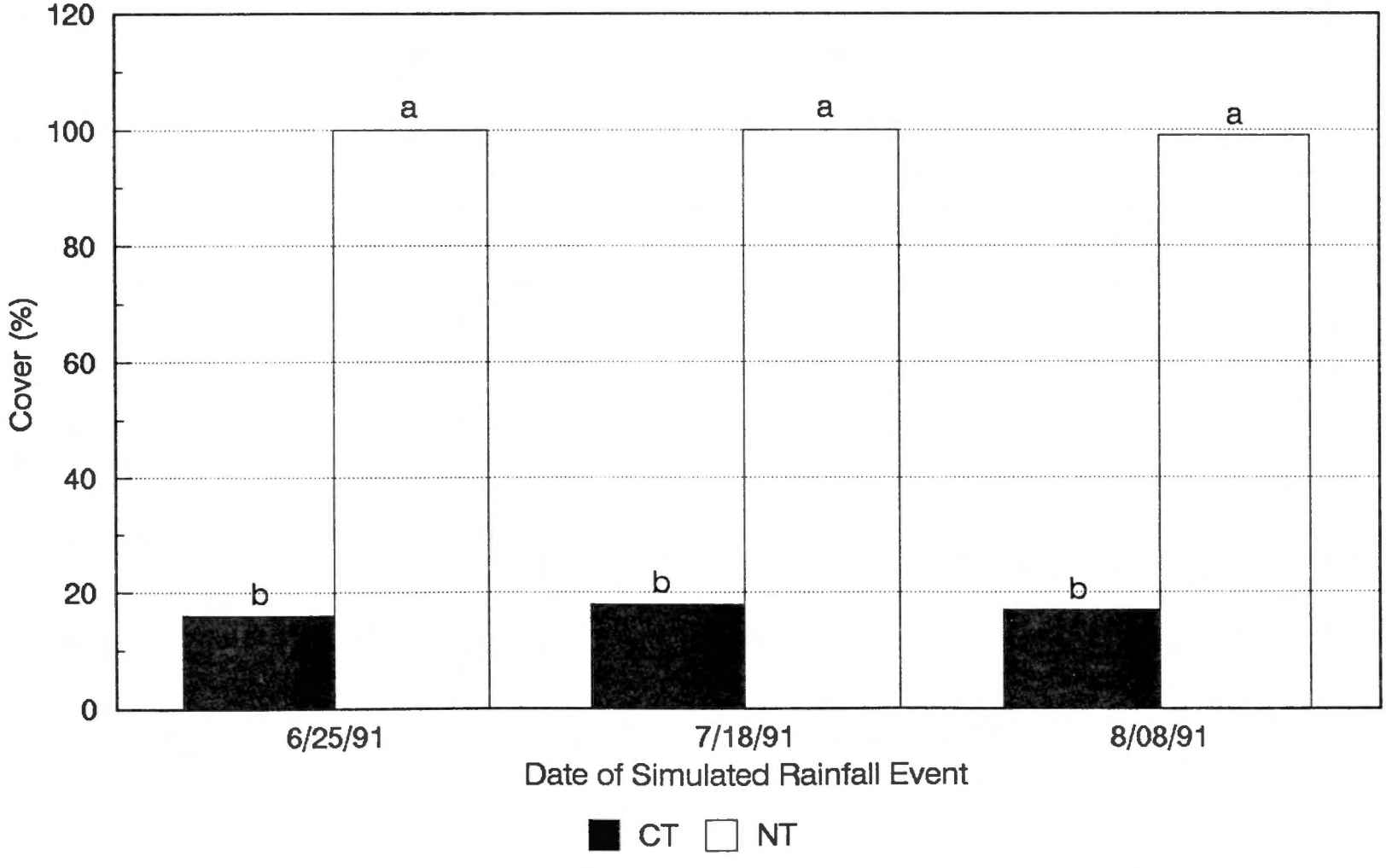

Figure 2. Effect of tillage treatments on percentage of surface cover, 1991.

accumulate from year to year, resulting in increased cover. As cover increases one would expect slower water movement, allowing increased infiltration and less erosion.

Antecedent Water Content

In 1989, antecedent water content of the soil surface was slightly higher (1% to 3% by weight) for NT plots than for CT plots (Figure 3). In 1990, the same trend for antecedent water content was evident with the exception of the 9/05 sampling date, when the surface of CT plots contained slightly higher soil water (Figure 4). The antecedent soil water content in 1991 was found to be very comparable to the previous two years (Figure 5). Given the variability and resolution of gravimetric sampling, the differences observed in soil water content are likely lower than the experimental error. They are likely too small to influence differences in runoff or infiltration. Differences observed in runoff; therefore, were not attributed to differences in soil water content between tillage systems. If soil water contents were slightly higher under NT than CT. This supports the findings of Blevins et al., 1971 and Shear, 1975.

Differences in antecedent soil water content among sampling dates within years were a result of 1) elapsed time

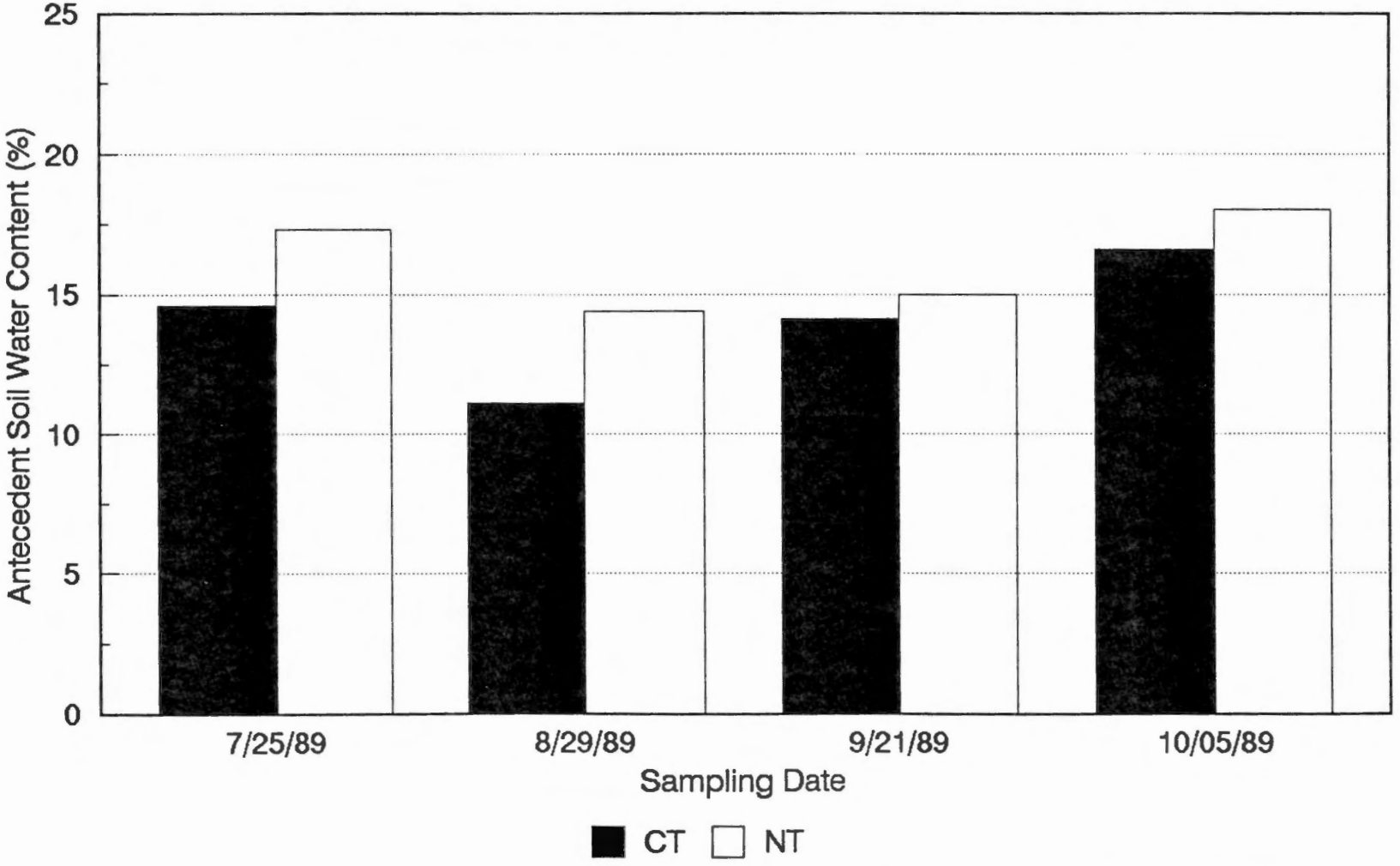

Figure 3. Effect of tillage treatments on antecedent soil water content, 1989.

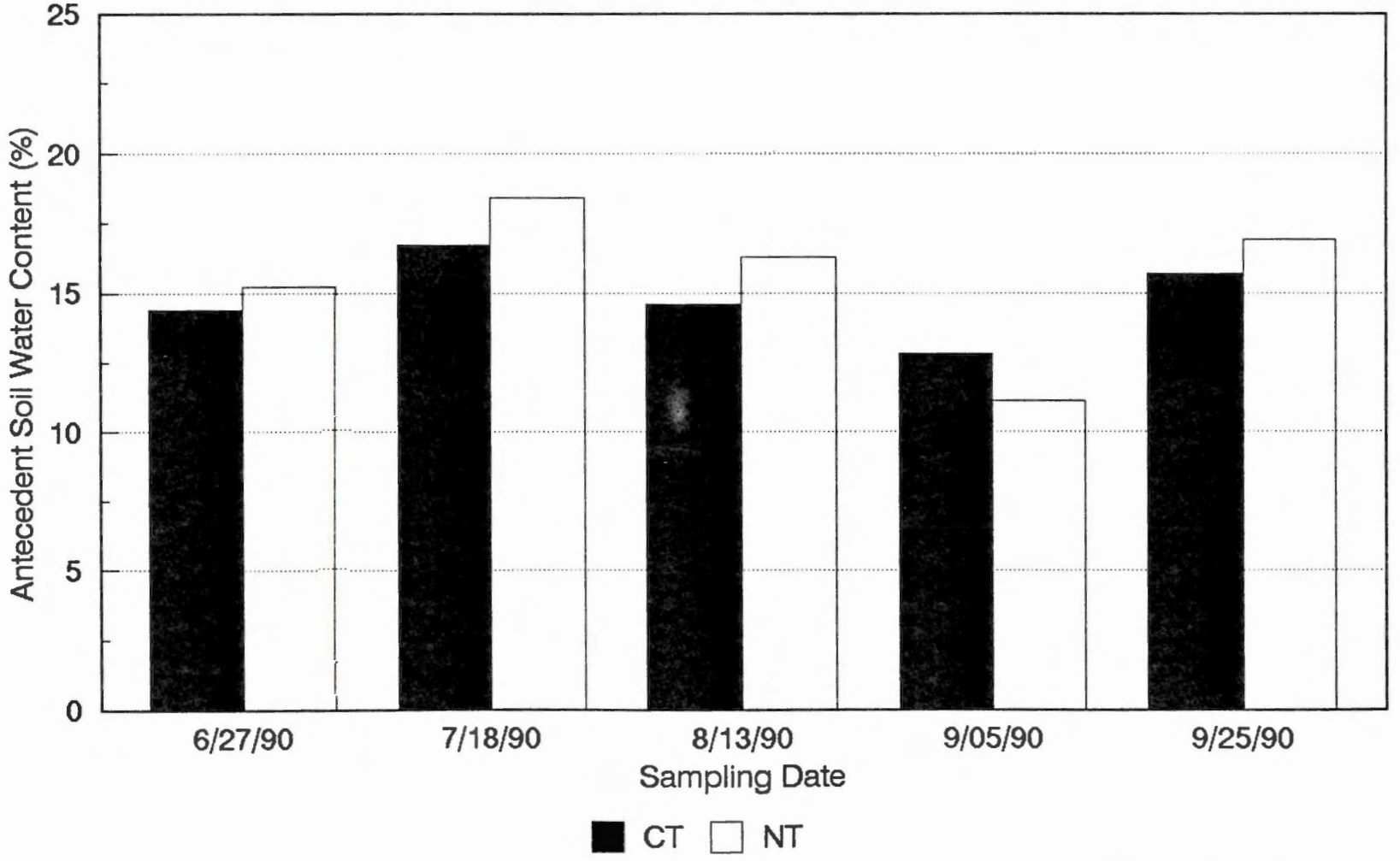

Figure 4. Effect of tillage treatments on antecedent soil water content, 1990.

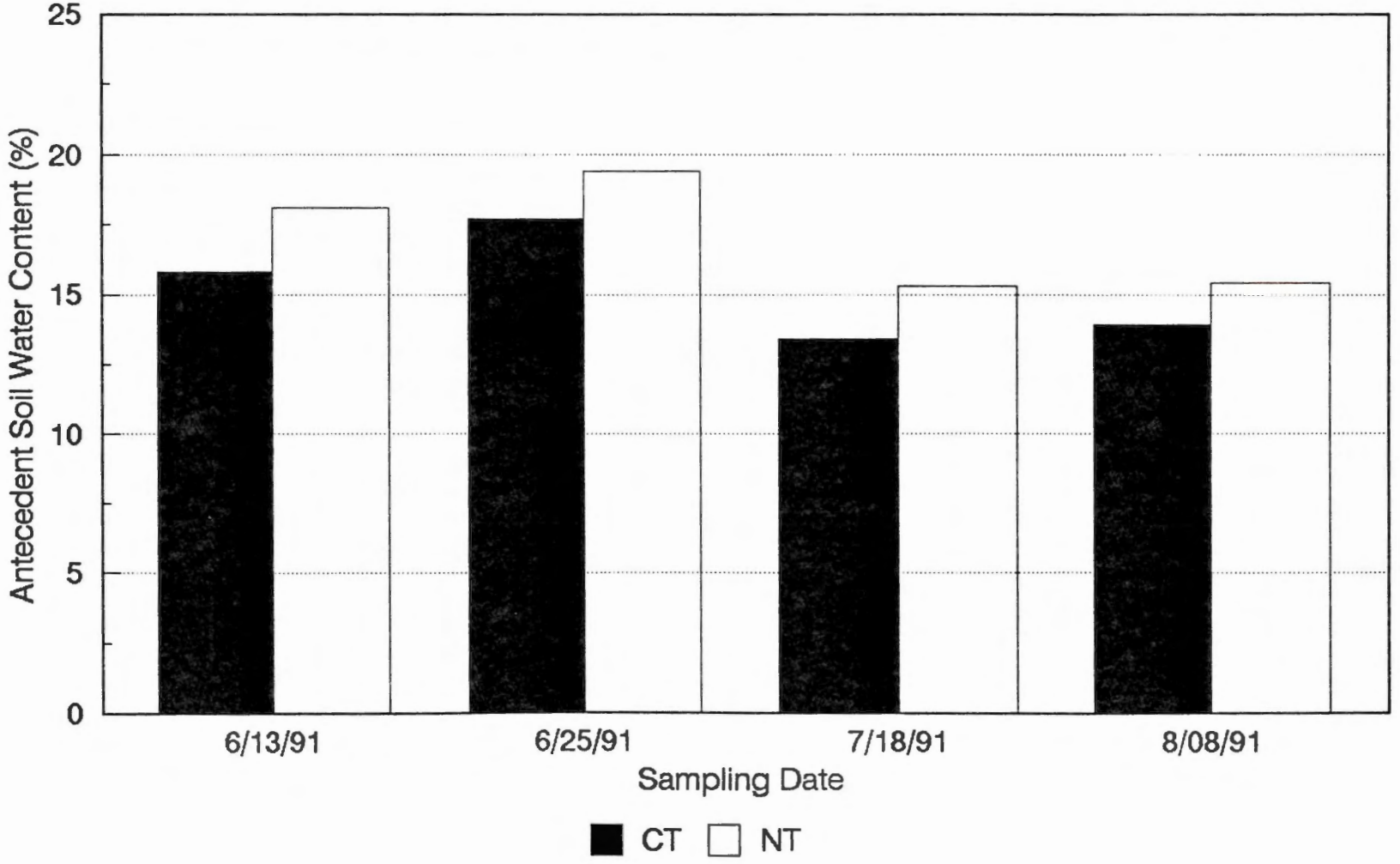

Figure 5. Effect of tillage treatments on antecedent soil water content, 1991.

since last simulated rainfall event, 2) precipitation received, 3) evaporation, and 4) water usage of the crop. In 1989, 174 mm of precipitation was measured during the 3 weeks prior to the 7/25/89 sampling date. Whereas, only 97 mm were received in the 5 weeks following said sampling date. After the 8/29/89 sampling date, pan evaporation decreased, as did the time interval between sampling, while precipitation increased resulting in increasing soil water contents at the 9/21/89 and 10/05/89 sampling dates. In 1990 and 1991, antecedent soil water contents responded to changes in the aforementioned parameters between sampling dates in a manner similar to that observed in 1989.

Differences in the average antecedent soil water content across years were very minute, with an increase of 1.1% by weight for CT and 0.9% by weight for NT from 1989 to 1991. Therefore, it would appear that the total water received (precipitation and simulated rainfall) influenced the water content of the soil more than changes in soil properties due to implementation of tillage systems. Measurements of total water received between the first and last sampling dates support this conclusion (525 mm in 1989, 725 mm in 1990, and 550 mm in 1991). The difference in water received in 1991 is amplified by the fact that it was received during a much shorter period of time than during the first 2 years.

Runoff Volumes

In 1989, tillage treatment had no significant effect on the quantity of applied water observed as runoff (Figure 6). Prior to the 7/25/89 simulated rainfall event, CT plots were tilled. A considerably smaller quantity of runoff was observed during the simulated runoff event conducted on 7/25 due to the freshly tilled soil adsorbing considerable water before runoff began. Runoff was considerably higher at subsequent events as a result of the crust formed from the first simulated runoff events and natural rainfall that occurred. This supports the conclusion of Baker and Laflen, 1983 in that tillage increases the infiltration during the initial rainfall event following tillage with subsequent events having reduced infiltration.

In 1990, CT plots produced a significantly higher quantity of runoff than did the NT plots at the 8/13 and 9/25 simulated rainfall events (Figure 7). There appeared to be an increase in runoff of both tillage treatments with time during 1990. This trend was especially noticeable in the CT treatments. The exception to this trend occurred at the 9/05 event. However, simulated rainfall was only applied for 1.3 h and 0.7 h to the first and second blocks during the 9/05 event resulting in a termination of surface flow at the time when runoff was rapidly increasing. This

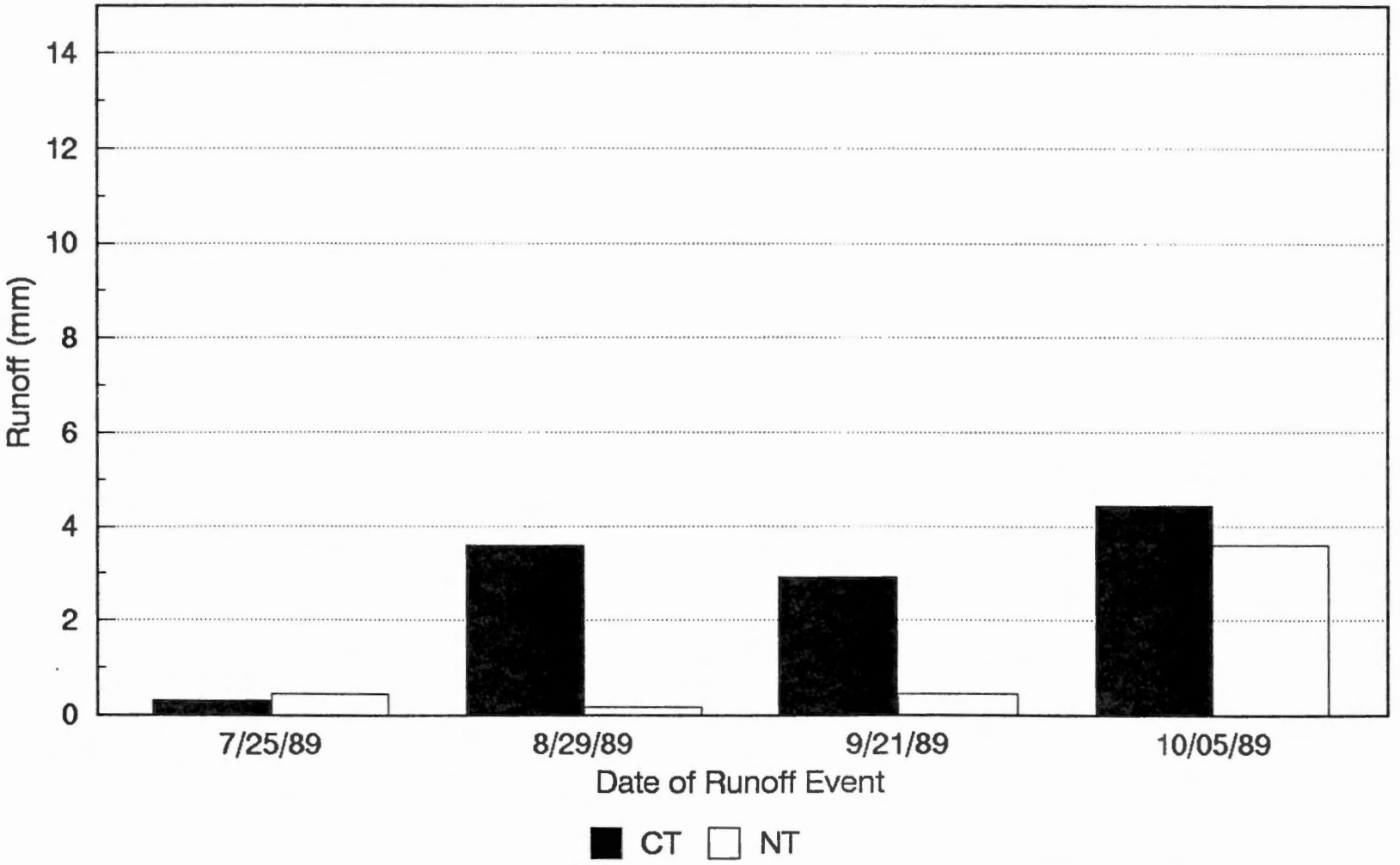

Figure 6. Effect of tillage treatments on quantity of runoff water, 1989.

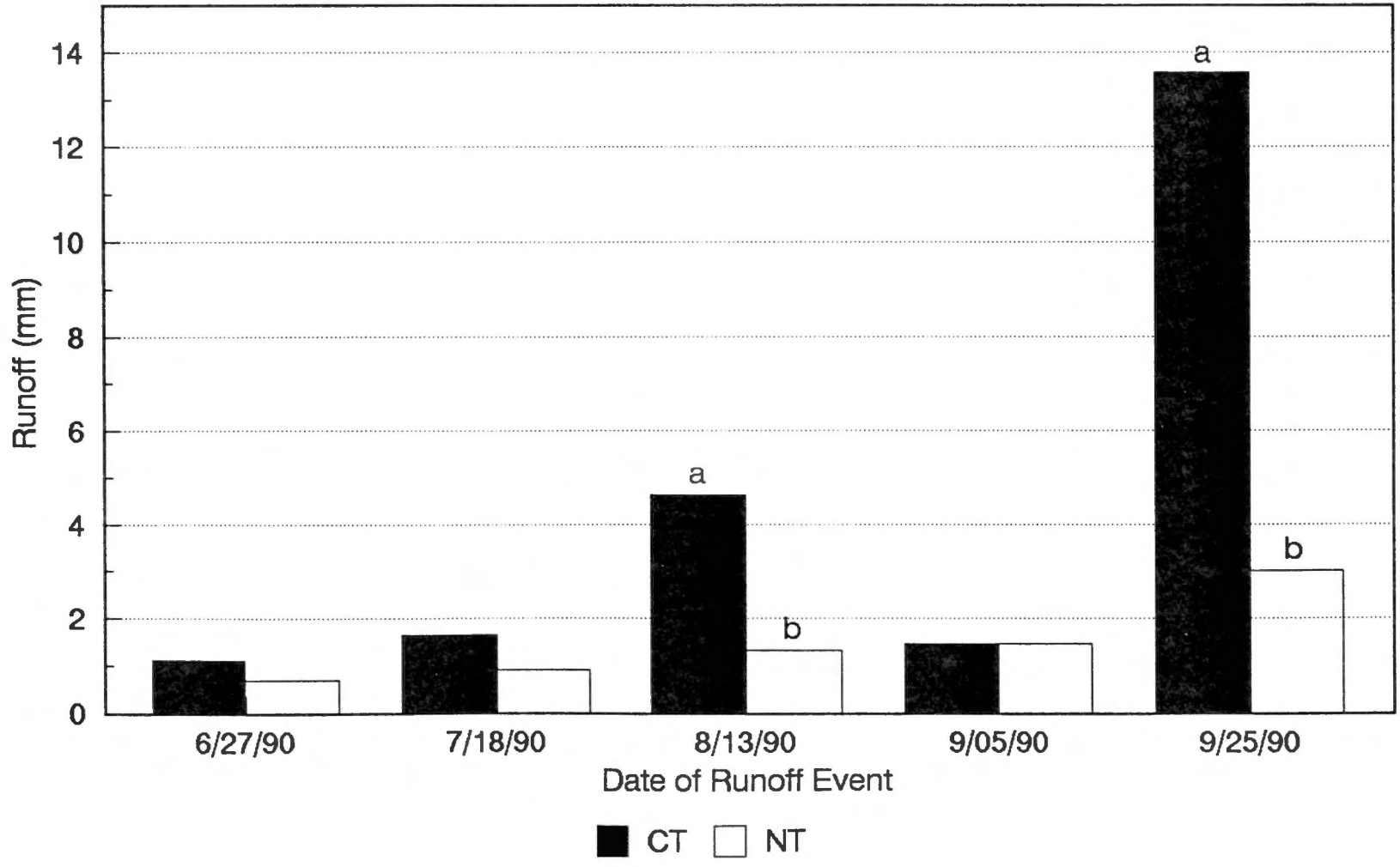

Figure 7. Effect of tillage treatments on quantity of runoff water, 1990.

increase in runoff from CT plots was likely attributed to increasing clay dispersion on the soil surface and subsequent crusting throughout the season.

In 1991, the quantity of runoff was significantly greater from CT plots than from NT plots at all simulated rainfall events (Figure 8). The 6/13 simulated rainfall event lasted only 0.8 h, resulting in less runoff. The general trend observed in 1991, was a decrease in the quantity of runoff from the 6/25 event through the 8/08 event. This observed trend may be attributed to lower antecedent soil water contents at the last 2 simulated rainfall events.

Percentage of runoff from CT plots was very consistent between 1989 and 1990 (10.4% and 10.3%, respectively). However, in 1991, CT plots produced 16.7% of the water applied as runoff. The difference between the first two years and 1991 resulted from tillage prior to the first runoff event in both 1989 and 1990, while a surface crust was allowed to develop prior to the first runoff event in 1991. Therefore, infiltration rates were higher for CT plots at the beginning of the first two years and subsequently less runoff occurred early in the season. The average percentage of runoff observed from NT plots showed a decrease over the three year period (4.3% in 1989, 3.1% in 1990, and 0.5% in 1991). The greatest decrease

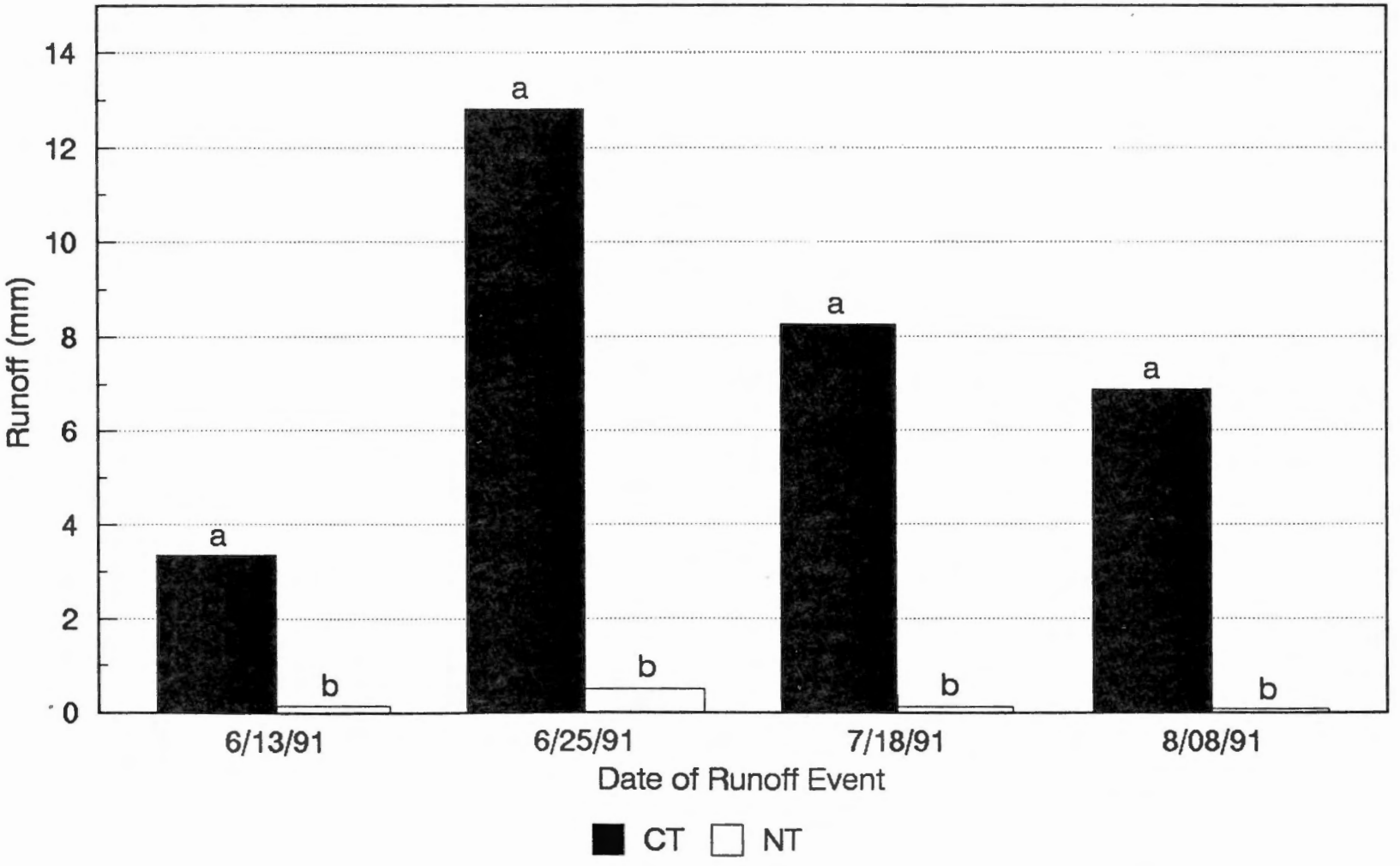

Figure 8. Effect of tillage treatments on quantity of runoff water, 1991.

occurred in 1991 after the NT plots remained undisturbed from the previous year. This decrease in runoff may be attributed to higher infiltration and percolation rates due to undisturbed macropore development.

In addition to the decrease in percentage of runoff was a decrease in the total number of NT plots exhibiting runoff. In 1989, an average of 5 out of 6 NT plots produced runoff. In 1990, and even lower percentage of plots produced runoff (6 of 9), while in 1991, only an average of 2 out of 9 NT plots produced runoff at any given time. At the start of the 1991 season 3 of 9 NT plots exhibited runoff, while only 1 NT plot produced runoff at the last simulated rainfall event. This trend further illustrates the increasing infiltration rate of continuous NT soils.

Sediment Yield

There were no significant differences in the mass of sediment lost due to tillage systems in 1989 (Figure 9). However, in 1990, sediment losses were significantly greater from CT plots than from NT plots during the 8/13 and 9/25 simulated rainfall events (Figure 10). In 1991, sediment losses from CT plots were observed to be one to two orders of magnitude greater than sediment losses from NT plots (Figure 11). The general trend observed in sediment losses

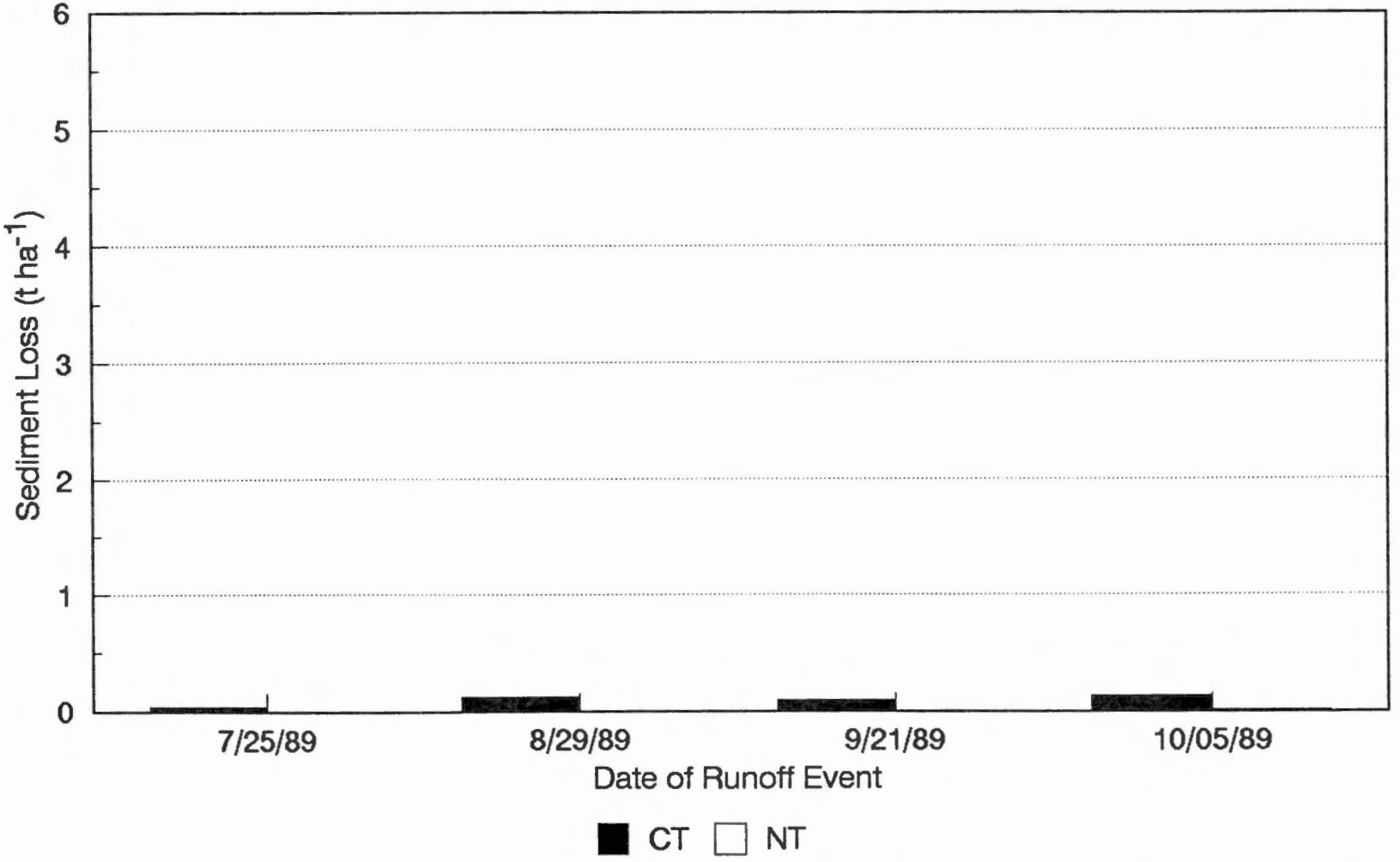

Figure 9. Effect of tillage treatments on sediment loss in runoff water, 1989.

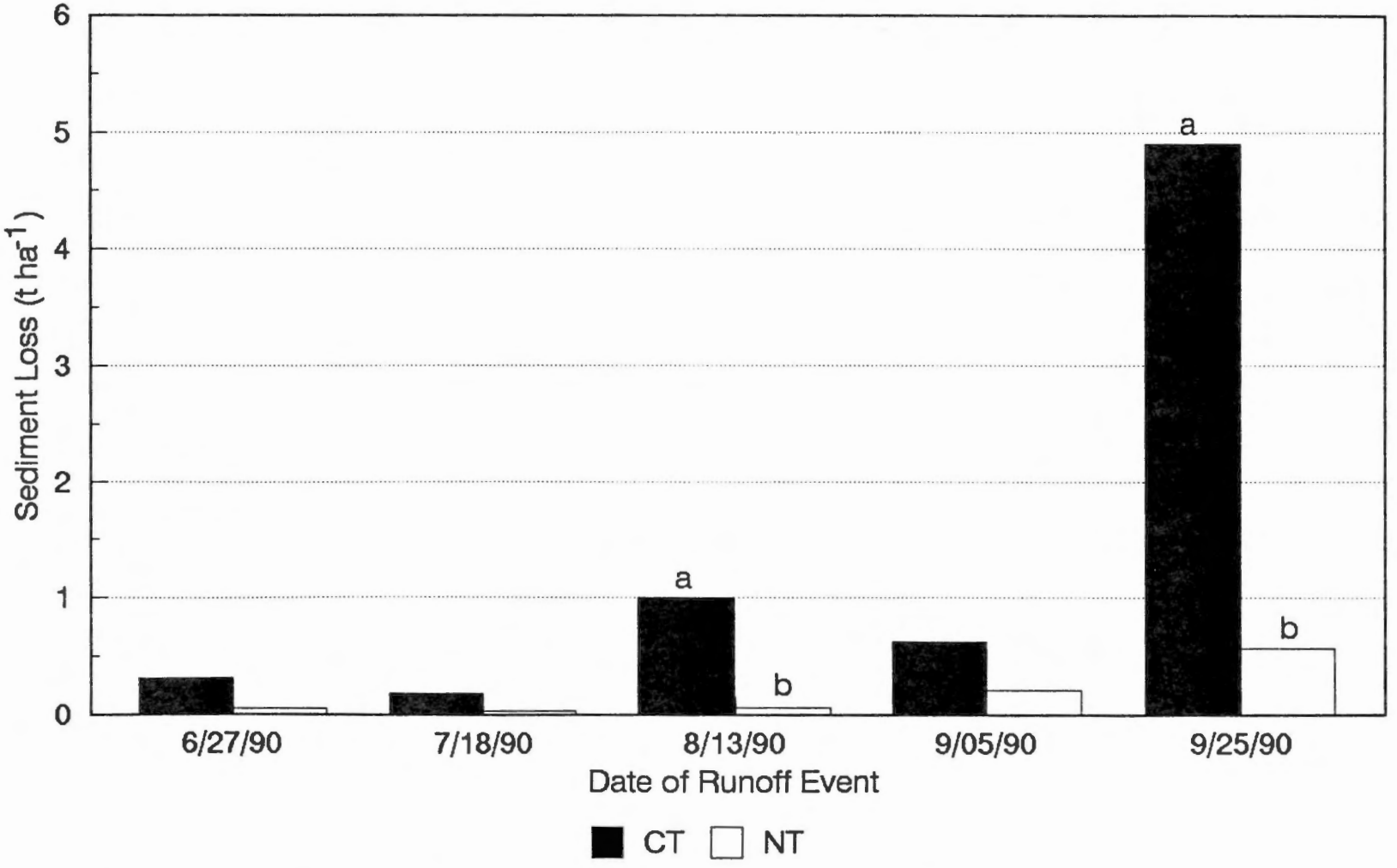

Figure 10. Effect of tillage treatments on sediment loss in runoff water, 1990.

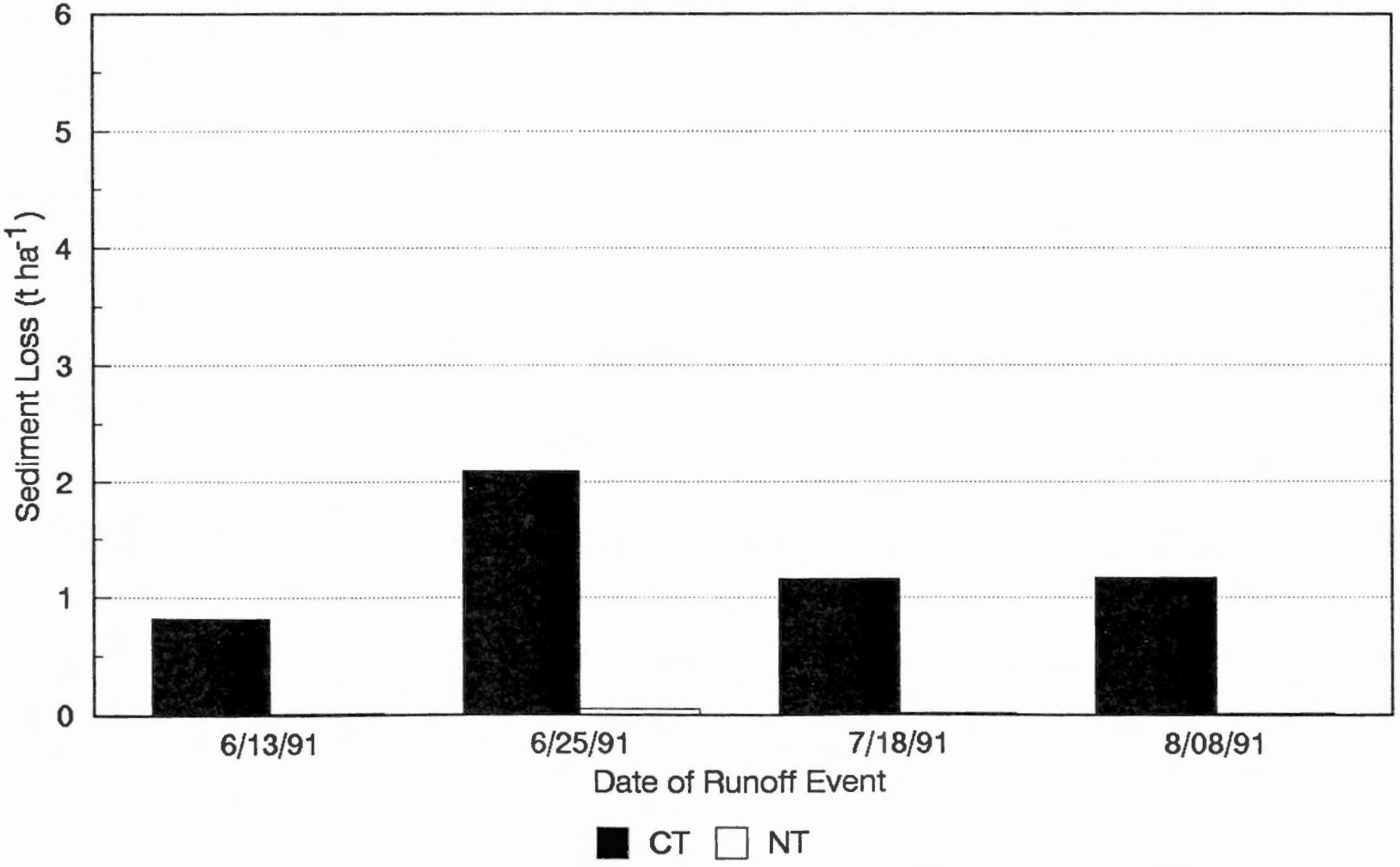

Figure 11. Effect of tillage treatments on sediment loss in runoff water, 1991.

among years was an increase in sediment loss from both tillage systems in 1990 and 1991. This increase in mass of sediment lost was a result of twice as much water applied in the latter two years as compared to 1989. The increase in water application not only increased the quantity of runoff, but likely increased the amount of erosion.

The concentration of sediment was found to be significantly greater in runoff from CT plots than NT plots at the last two simulated rainfall events in 1989 (31 g L^{-1} and 2.6 g L^{-1} for CT vs. 0.1 g L^{-1} for NT at both events). In 1990, sediment concentrations observed were greater in runoff from CT plots than NT plots at the last three simulated runoff events (20.4, 23.2, 35.3 g L^{-1} for CT vs. 3.7, 9.3, 11.0 g L^{-1} for NT). In 1991, sediment concentrations were greater in runoff from CT plots than in runoff from NT plots at all runoff events (average of 16.0 g L^{-1} for CT vs. average of 1.9 g L^{-1} for NT).

The sediment concentration in runoff was observed at selected points on the runoff hydrograph during simulated rainfall events (Figure 12). During the 6/13 and 7/18 events, rate of runoff and sediment concentration in runoff from NT plots remained fairly constant. The rate of runoff remained constant, while the sediment concentration under NT was fairly high (8 g L^{-1}) at the initiation of runoff for

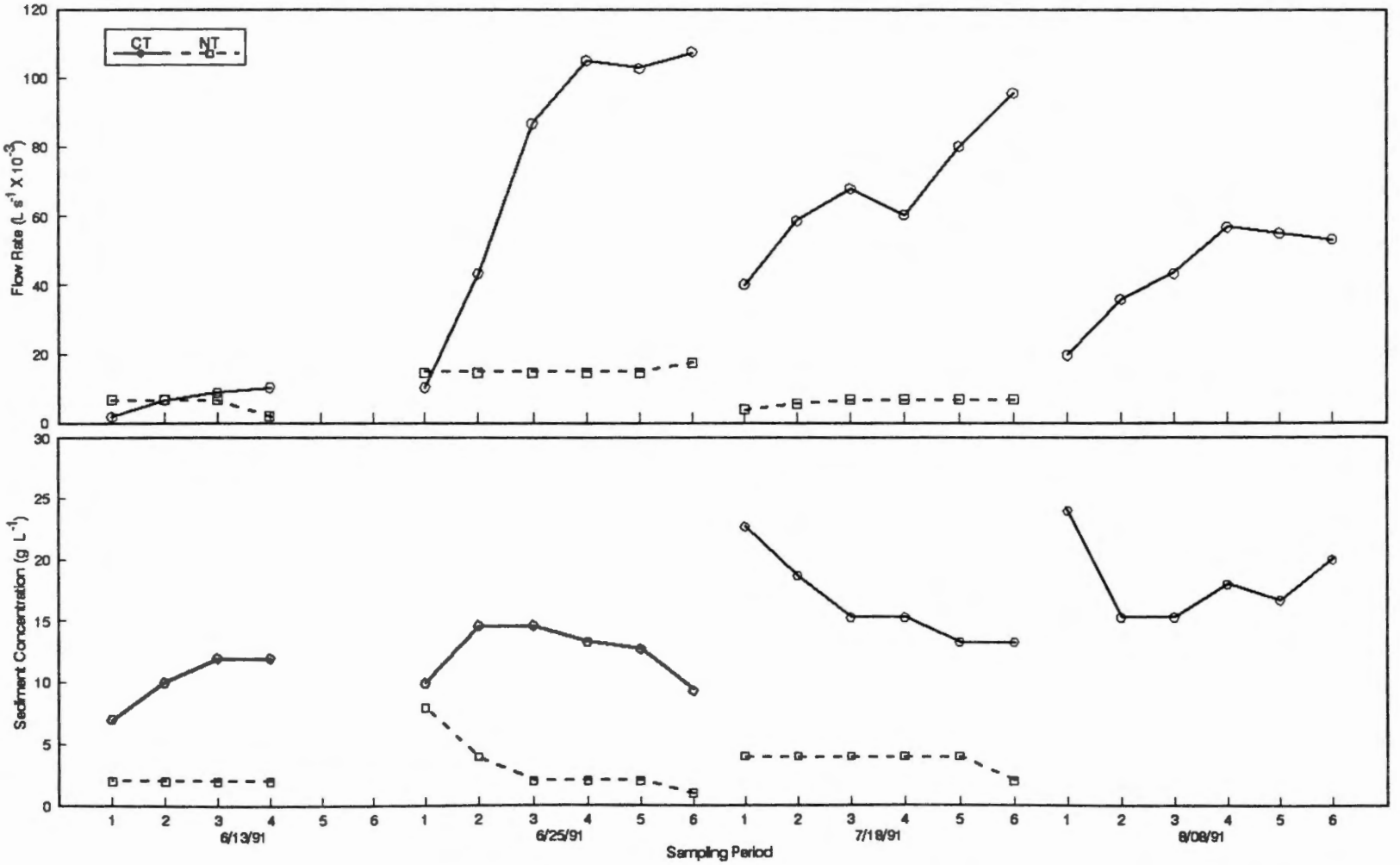

Figure 12. Effect of tillage treatments on sediment concentration during runoff, 1991.

the 6/25 event. The sediment concentration quickly decreased as runoff continued and stabilized at a level comparable to the other two runoff events. Runoff rates from CT generally increased as rainfall continued; whereas, the sediment concentration observed in runoff water showed no consistent pattern during the course of the runoff events. However, the average sediment concentration appeared to progressively increase between runoff events (an average of 10.3 g L^{-1} during the 6/13/91 runoff event vs. an average of 18.2 g L^{-1} during the 8/08/91 runoff event).

CHAPTER V

SUMMARY AND CONCLUSIONS

Runoff from CT plots appeared to increase as the experiment progressed for the three years, while runoff from NT plots appeared to decrease dramatically during the same time (Table 1). Runoff observed from NT plots was 42%, 33%, and 3% of that observed from CT plots in 1989, 1990, and 1991, respectively. Total sediment lost in runoff from CT plots was 7.0 and 5.3 t ha^{-1} in 1990 and 1991, respectively, while total sediment loss in runoff from NT plots remained below 1 t ha^{-1} during all three years and appeared to be decreasing as NT treatments were becoming established (Table 1). Lower runoff quantities and sediment loss were observed in 1989 than the other two years as a result of approximately one-half as much water applied.

The antecedent soil water content was observed to be slightly higher from NT plots than from CT plots. However, the small differences in water content between the tillage treatments would have had little or no effect on infiltration or runoff. The NT treatment produced considerably more cover in the form of crop residue and growing tomatoes than did the CT treatment. This added cover would aid in intercepting raindrops, thus reducing

Table 1. Cumulative totals of runoff and mass of sediment as influenced by tillage treatments, 1989-1991.

Year	Tillage Treatment	Runoff (m^3 ha^{-1})	Sediment (t ha_{-1})
1989[X]	CT	109.8	3.7×10^{-1}
	NT	46.4	5.3×10^{-3}
1990	CT	224.6	7.0×10^{0}
	NT	74.1	9.2×10^{-1}
1991	CT	312.6	5.3×10^{0}
	NT	8.4	7.9×10^{-2}

[X] Plots received approximately one-half as much water in 1989 as they did in 1990 and 1991.

clay dispersion on the surface. The additional cover would also slow surface water movement, allowing more time for infiltration, as well as reduce erosion. In general, less runoff occurred from NT plots than from CT plots. When runoff did occur, sediment concentrations in runoff were considerably greater from CT plots than NT plots. Total sediment losses were often an order of magnitude greater from CT plots than from NT plots.

The decreased quantity of runoff and lower sediment concentrations of the NT system resulted in less total sediment loss (erosion). Therefore, the use of the NT system on the Lonewood soil, which are subject to extreme erosion at slopes greater than 5%, would reduce both runoff and subsequent erosion.

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PART 4: TILLAGE TREATMENTS AND NITROGEN FERTILIZATION RATES FOR TOMATO PRODUCTION. II. EFFECT ON QUALITY OF RUNOFF

CHAPTER I

ABSTRACT

Conservation tillage systems have been found to decrease the quantity of surface runoff. However, there is no consensus as to the effect of conservation tillage systems on the quality of surface runoff. Samples collected from individual runoff events were evaluated for metribuzin, NO_3-N, PO_4-P, and potassium concentration. When runoff did occur, runoff from no tillage (NT) generally carried higher concentrations of metribuzin, NO_3-N, PO_4-P, and potassium than runoff from conventional tillage (CT), especially in the first storm event after agrichemical application. Concentrations were generally higher in runoff from CT later in the growing season. This trend is likely due to the greater zone of mixing in CT soils as well as higher agrichemical concentrations within that zone. Concentrations of these agrichemicals were observed to decrease during simulated rainfall events and decrease progressively with each event following application. Total

losses of metribuzin, NO_3-N, PO_4-P, and potassium in runoff were similar for NT and CT in the first two years of this study. During the third year; however, greater losses were observed from the CT plots than from the NT plots.

CHAPTER II

INTRODUCTION

With ever increasing environmental awareness, new questions are arising in regard to the significance of non-point source pollution. Conservation tillage practices such as NT have been shown to be beneficial to sediment loss problems, but little is known about their effect on chemical migration. Do conservation tillage systems increase or decrease the potential for endangering our surface and subsurface water supplies? Questions like this need to be answered to aid in policy decisions concerning future regulations and agricultural practices.

Chemical concentrations have been found to decrease in surface runoff with time during a storm event (Baker et al., 1978; Baker et al., 1982; Barius et al., 1978). The first 0.5 cm of runoff was found by Martin et al. (1978) to remove as much pesticide as the remaining 3 cm of runoff. Wauchope (1987) reported that in tilted-bed simulations the first 5% of runoff water removed 20% of the water-carried pesticides. Ahuja and Lehman (1983) have explained this phenomenon as a decrease in the chemical concentration of the mixing zone, a region 1-2 cm deep that is the main source of chemicals to the water.

The first storm after application of fertilizer nutrients or pesticides results in the greatest percentage of chemical lost with surface runoff, especially if occurring within two weeks of pesticide application (Wauchope, 1978; Baker, 1980; Baker and Laflen, 1983b). This is due to the chemical source being predominately within the upper few cm of soil where mixing of runoff and infiltrating water occurs. Thus, flushing chemicals into surface water is maximized. Baker and Johnson (1979) stated that time of chemical application prior to first runoff was more important than tillage effects from tillage systems.

Baker et al. (1978) and Baker and Johnson (1979) reported higher pesticide concentrations in runoff water from conservation tillage treatments than from conventional tillage (CT) treatments. Some researchers have found that the cover associated with conservation tillage techniques can intercept the pesticide which in turn becomes a source for pesticide in runoff water (Deuel et al., 1977; Hall et al., 1984; Martin et al., 1978; Trichell et al., 1968). However, others have found mulch and grass cover to remove herbicide from runoff by binding the herbicide and rendering it immobile (Hall et al., 1984; Rhode et al., 1980; Trichell et al., 1968). Baker et al. (1982) found no difference in herbicide loss in runoff water of three herbicides applied above or below mulch applications.

Wauchope (1978) presented a review of pesticide losses in runoff water from agricultural fields, and stated that behavior and fate of pesticides in streams receiving runoff is generally unknown. Unless severe rainfall occurs within one to two weeks after pesticide application, total losses of most pesticides were less than 0.5% of the amount applied.

Metribuzin is an asymmetrical member of the triazine family, with a water solubility of 1220 mg L^{-1} (Anonymous, 1989). Due to the high water solubility of metribuzin, Wauchope et al., (1985) predicted 90% to 100% of metribuzin lost in runoff water will be in the aqueous fraction.

Baker and Laflen (1983) and Wendt and Burwell (1985) predicted the average reduction in nitrogen loss from implementation of conservation tillage systems would be 20 to 25%. Their estimate for reduction of total nitrogen loss is probably accurate, but several experiments have shown substantially higher dissolved nitrogen concentrations from conservation tillage than from CT systems (Alberts et al., 1981; Angle et al., 1984; Baker and Laflen, 1982; Baldwin et al., 1985; Barisas et al., 1978; Johnson et al., 1979; Laflen et al., 1978; Laflen and Colvin, 1981; Laflen and Tabatabai, 1984; McDowell and McGregor, 1980; Romkens et al., 1973; Siemens and Oschwald, 1978). This increase in concentration of dissolved or solution nitrogen has been

attributed to two factors: 1) the surface applications of fertilizer in conservation tillage systems (McDowell and McGregor, 1980; Timmons et al., 1970; Wells, 1984) and 2) increased concentrations of nitrogen at the soil surface of conservation tillage systems due to minimal incorporation (Doran, 1980; House et al., 1984; Powlson and Jenkinson, 1981).

Concentrations of soluble phosphorus have been found to be greater in runoff water from conservation tillage systems than in runoff from CT systems (Baker and Laflen, 1983a; Logan and Adams, 1981; McDowell and McGregor, 1981; Romkens et al., 1973). However, Andraski et al. (1985) found less total phosphorus load from conservation tillage than from CT systems due to less runoff from conservation tillage systems.

The objectives of this portion of the study were: 1) to determine the effect of tillage treatments on the concentration and mass of metribuzin in runoff water and 2) to determine the effect of tillage treatments on the concentration and mass of nutrient fertilizer (NO_3-N, PO_4-P, and potassium) in runoff water.

CHAPTER III

MATERIALS AND METHODS

Metribuzin was applied using a CO_2 backpack sprayer at a rate of 840 g ha^{-1}, 24 h prior to the 7/25/89, 7/18/90, and 6/25/91 simulated runoff events. Fertilizer was broadcast prior to the 7/25/89, 6/27/90, and 6/25/91 simulated rainfall events. Phosphorus and potassium were applied at rates of 49 and 93 kg ha^{-1}, respectively. Nitrogen fertilization consisted of 112 kg ha^{-1} in 1989 and 0, 112, or 336 kg ha^{-1} in 1990 and 1991. All nitrogen was applied in the form of ammonium nitrate. Quantity of runoff water was determined by periodically monitoring the depth of flow from the flumes during each runoff event and used to determine total mass of chemicals moved. Samples were collected manually at discrete times during the runoff event to produce a flow weighted composite sample for determining solute concentrations.

In 1989, metribuzin content of runoff water was determined by EPA Method 507 (Graves, 1989). In 1990, metribuzin content was determined using a modified high performance liquid chromatography (HPLC) version of EPA Method 507 (Wells, personal communication). In 1991, metribuzin concentration was determined using a solid phase

extraction technique (Riemer and Wells, 1992). The NO_3-N and PO_4-P concentrations were determined using ion chromatography chemically suppressed conductivity detection. Potassium concentrations were determined using inductive coupled plasma atomic emissions spectroscopy.

CHAPTER IV

RESULTS AND DISCUSSION

Runoff and subsequent water quality evaluations are presented chronologically, by chemical of interest due to the dynamic characteristics of the processes as tillage systems were established. Differences were also observed between years due to different amounts of water applied (duration of simulated rainfall events), varying amounts of natural rainfall, and other environmental differences.

Metribuzin

Metribuzin was detected only in runoff from the first simulated rainfall event in 1989. The concentration of metribuzin was found to be an order of magnitude greater in runoff from no tillage (NT) plots than in runoff from CT plots (Figure 1). A similar trend was observed in 1990. Metribuzin observed in runoff from the first simulated rainfall event after application (7/18/90) was 245 ug L^{-1} from NT and 107 ug L^{-1} from CT and was negligible in runoff from the second simulated rainfall event after metribuzin application (8/13/90). Although metribuzin was detected at the 8/13/90 date, concentrations were two orders of

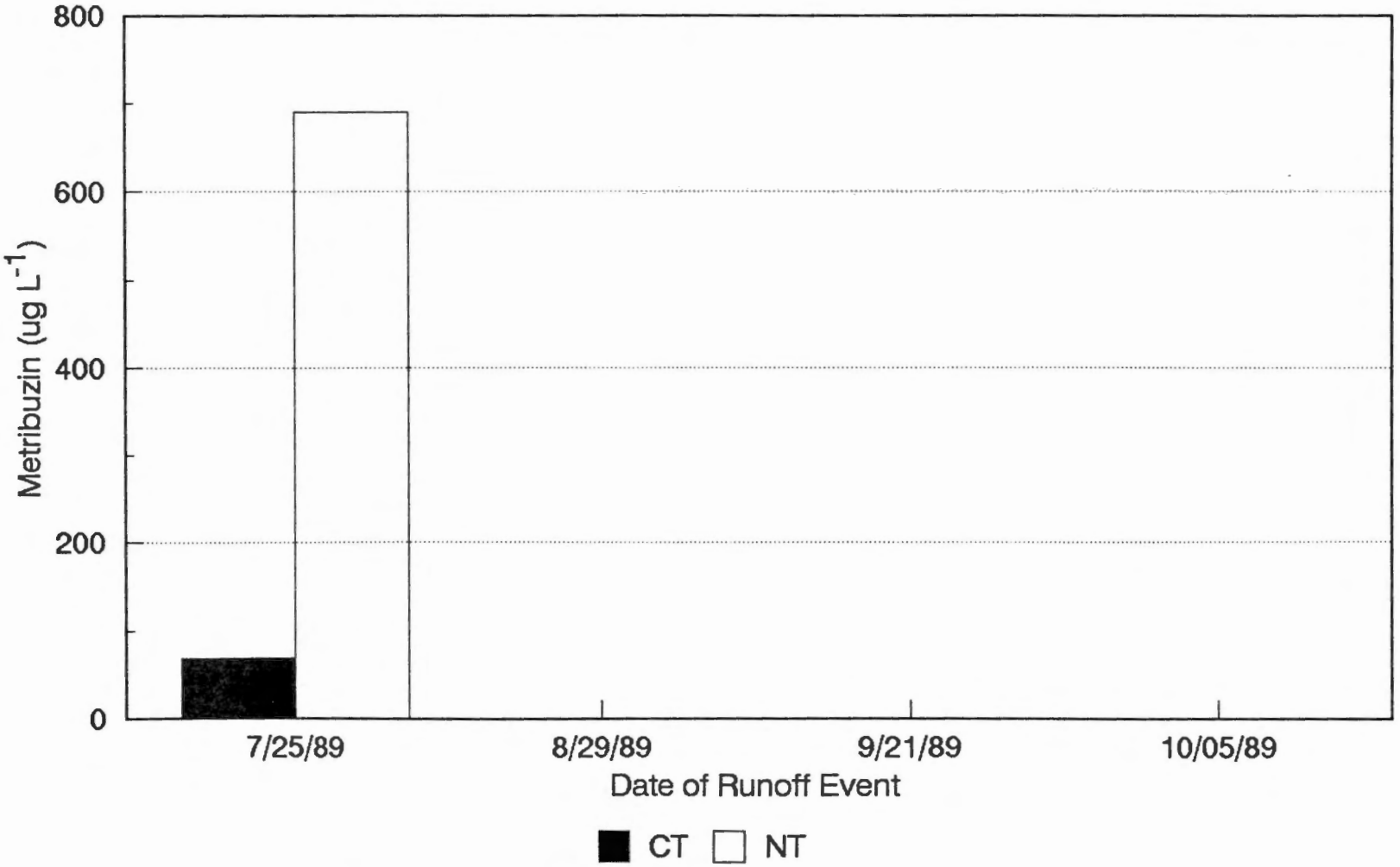

Figure 1. Effect of tillage treatments on metribuzin concentration in runoff water, 1989.

magnitude lower than detected in runoff from the 7/18/90 event (0.3 ug L^{-1} from CT and 1.1 ug L^{-1} from NT). This trend was repeated in 1991 with the highest metribuzin concentrations observed in runoff from the first simulated rainfall event after metribuzin application (6/25/91). The concentration of metribuzin in runoff for this event from NT was more than twice that observed in runoff from CT (312 vs. 121 ug L^{-1}). The tillage effect was reversed for subsequent events with runoff from CT plots containing higher concentrations (10.8 and 1.8 ug L^{-1}) of metribuzin than did runoff from NT plots (4.1 and 0.3 ug L^{-1}). These differences observed for the latter events are likely due to the greatest loss from NT in the initial event resulting in a lower metribuzin source in the mixing zone. Ninety five percent of the total loss (19.4 g ha^{-1}) of metribuzin in runoff occurred in the first runoff event, with only 1.0 g ha^{-1} being lost in the latter two events.

Nitrate

In 1989, the concentration of NO_3-N in runoff from the first simulated rainfall event following fertilization was observed to be nearly three times greater from NT plots (1.5 mg L^{-1}) than from CT plots (0.6 mg L^{-1}). Concentrations were very similar at the other three simulated rainfall

events in 1989 (Figure 2). In 1990, NO_3-N concentrations in runoff were generally quite low (1.1 mg L^{-1} or less) from all tillage treatments and nitrogen fertilization rates. The exception was the NT plots that received 336 kg ha^{-1} of nitrogen fertilization which exhibited runoff NO_3-N concentrations from 2.3 to 3.3 mg L^{-1} for the 7/18/90 to the 9/05/90 simulated rainfall events (Figure 3).

Concentrations of NO_3-N were considerably higher in runoff from plots receiving N fertilization in 1991. At the 6/25/91 simulated rainfall event, the concentration of NO_3-N in runoff from the NT plots receiving 112 kg ha^{-1} of nitrogen fertilization was considerably greater than the 10 mg L^{-1} level established by EPA for drinking water (EPA, 1990) (Figure 4). No runoff was measured from the three NT plots receiving 336 kg ha^{-1} of nitrogen fertilization in 1991. Therefore, the treatment was omitted in Figure 4. Concentrations of NO_3-N were greater in runoff of CT plots in 1991 than in runoff from CT plots in the previous two years due to a lack of fertilizer incorporation in 1991.

Phosphate

Phosphate-P concentrations observed in runoff were small in 1989 (less than 0.4 ug L^{-1}). Concentrations were 4 times higher in runoff from NT (average of 0.22 mg L^{-1})

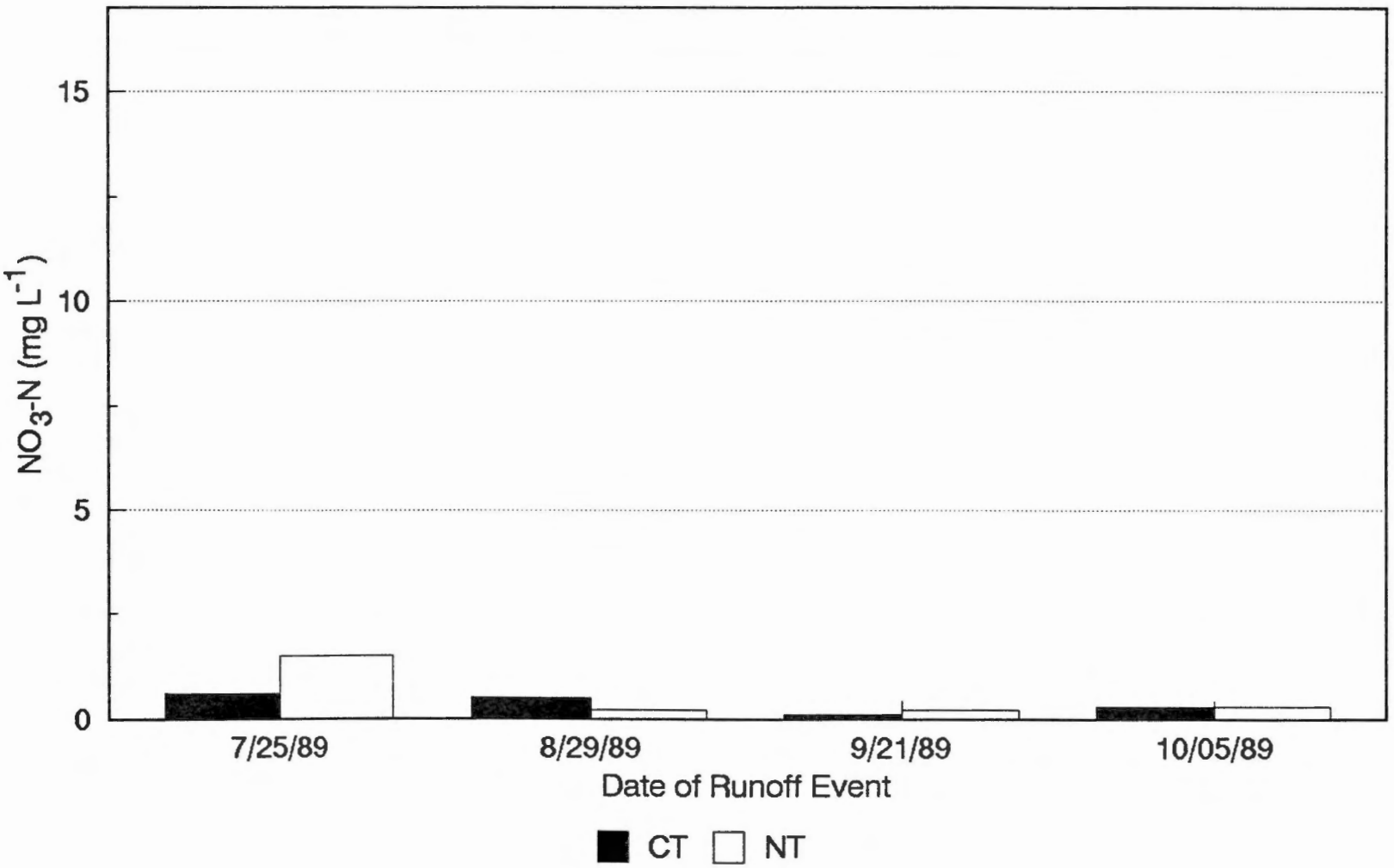

Figure 2. Effect of tillage treatments on NO_3-N concentration in runoff water, 1989.

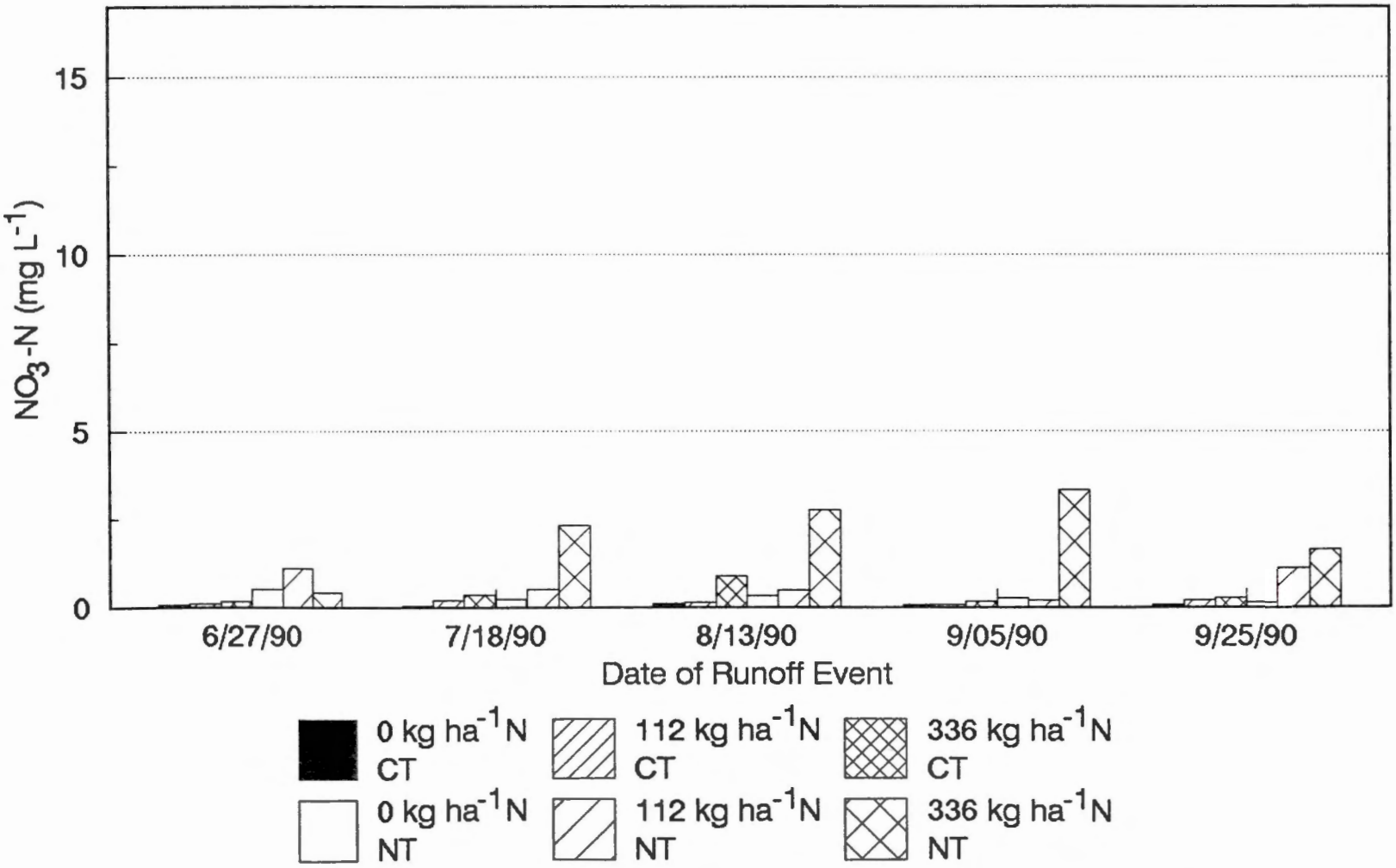

Figure 3. Effect of tillage treatments on NO_3-N concentration in runoff water, 1990.

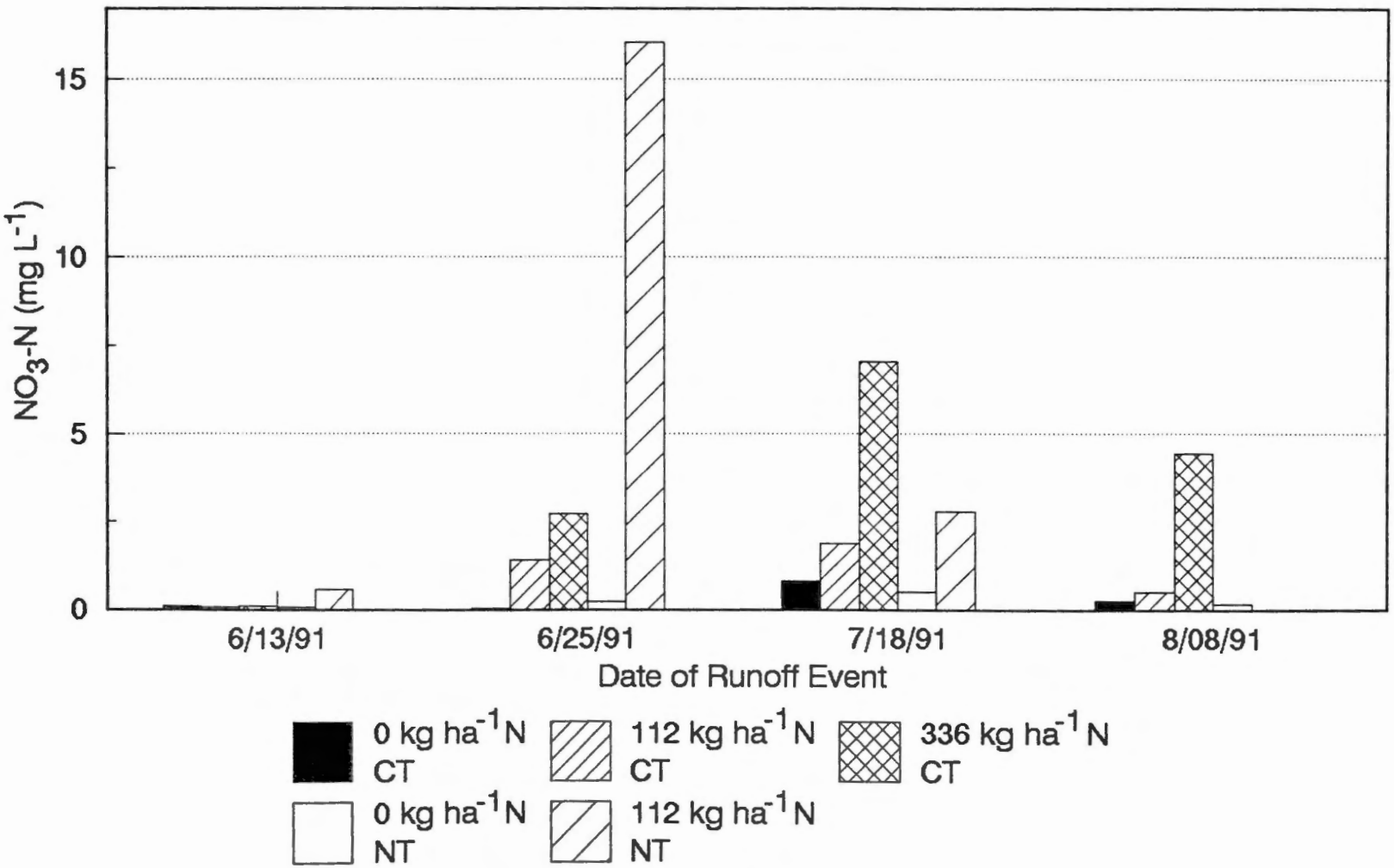

Figure 4. Effect of tillage treatments on NO_3-N concentration in runoff water, 1991.

than runoff from CT (average of 0.05 mg L^{-1}). Phosphate-P concentration tended to decrease with each simulated rainfall event in 1989. In 1990, the concentration of PO_4-P in runoff from NT treatments was consistently higher at all simulated rainfall events (Figure 5). High concentrations of PO_4-P in runoff from both CT and NT were observed for the 6/25/91 simulated rainfall event (Figure 6). These concentrations are more than an order of magnitude greater than concentrations observed in all other rainfall events. Contributing to this difference in the CT plots is the lack of fertilizer incorporation. However, fertilizer was not incorporated on NT plots any year. Build up of P levels at the surface of the NT plots may have contributed to this response. Phosphate-P concentrations decreased during the 7/18/91 and 8/08/91 simulated rainfall event; although, concentrations were greater in runoff from NT plots than in runoff from CT plots during those events.

Potassium

Potassium concentrations in runoff water were consistently higher in runoff from NT plots than in runoff from CT plots for this three year study. In 1989, potassium concentrations averaged 6.2 mg L^{-1} in runoff from NT plots

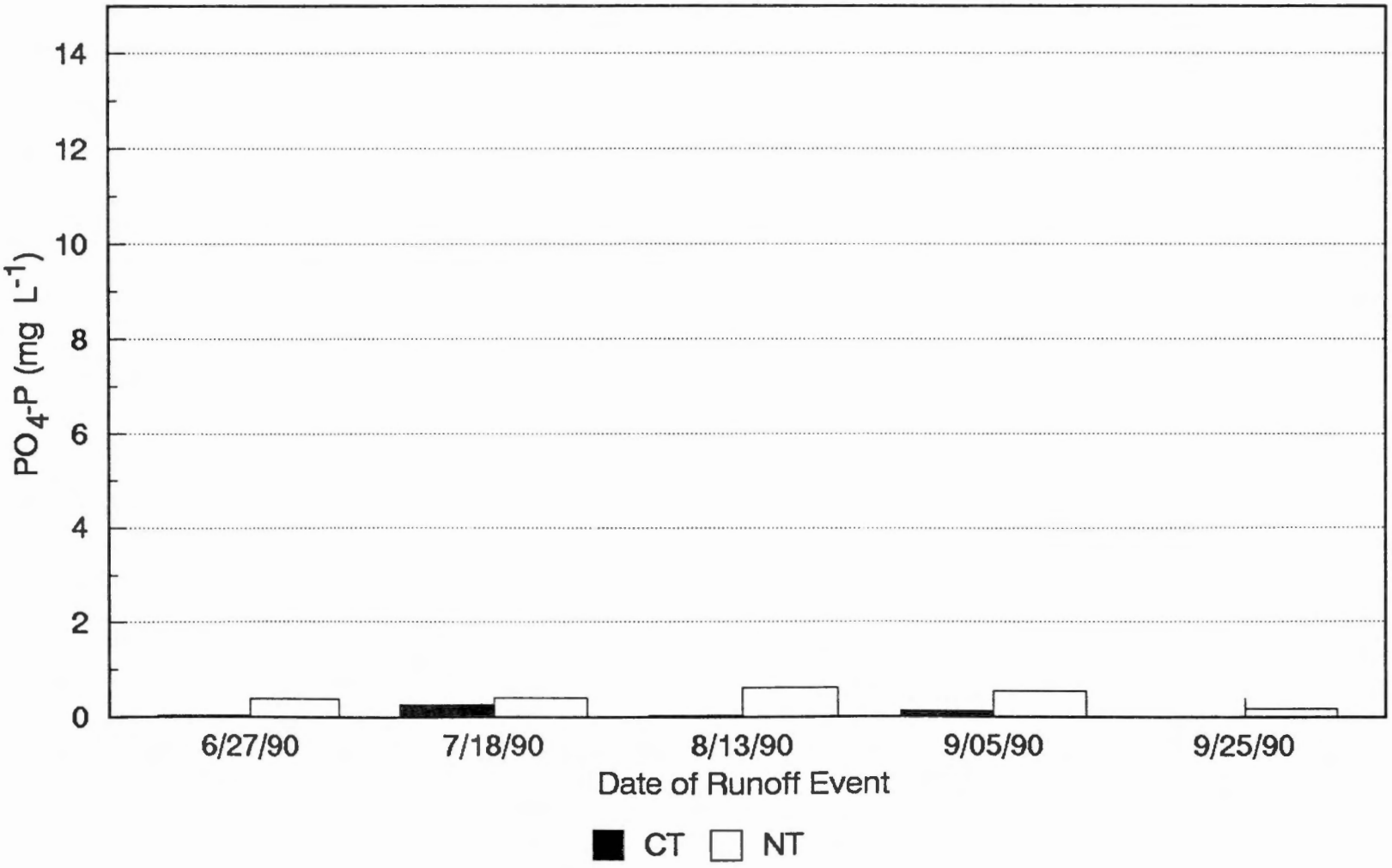

Figure 5. Effect of tillage treatments on PO_4-P concentration in runoff water, 1990.

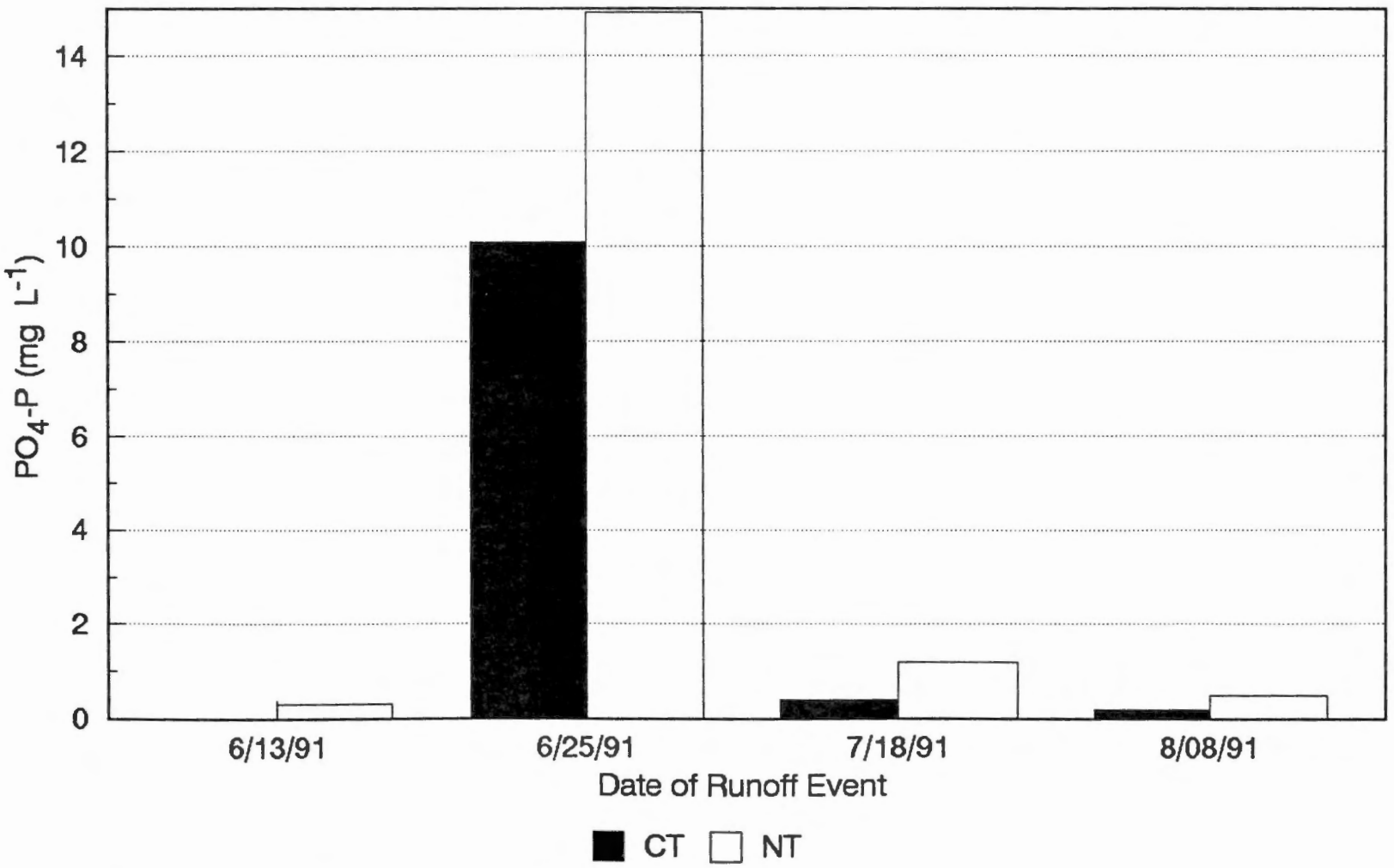

Figure 6. Effect of tillage treatments on PO_4-P concentration in runoff water, 1991.

as compared to 3.8 mg L^{-1} in runoff from CT plots. In 1990, the average concentration of potassium observed in runoff was 2.8 mg L^{-1} for CT as compared to 10.7 mg L^{-1} for NT (Figure 7). Potassium concentrations were observed to be greater in runoff from NT plots than in runoff from CT plots at the first three events in 1991. However, at the 6/25/91 event potassium concentrations were more than five times greater in runoff from NT (43.6 mg L^{-1}) than in runoff from CT (7.8 mg L^{-1}), indicating a significant loss of surface applied potassium (Figure 8).

Solute Concentration Dynamics within Events

Concentrations of metribuzin were observed to be considerably higher in runoff from NT than from CT plots throughout the 6/25/91 runoff hydrograph (Figure 9). Concentrations were much lower throughout the latter events. During the early stages of the 7/18/91 hydrograph, runoff from CT plots contained a higher concentration of metribuzin than runoff from NT plots. However, as runoff continued, the concentration from CT decreased and was nearly equal to runoff from NT. This higher concentration for CT than NT observed at the second date is most likely attributed to a greater zone of mixing and the greater amount of metribuzin remaining following the first event. This resulted in

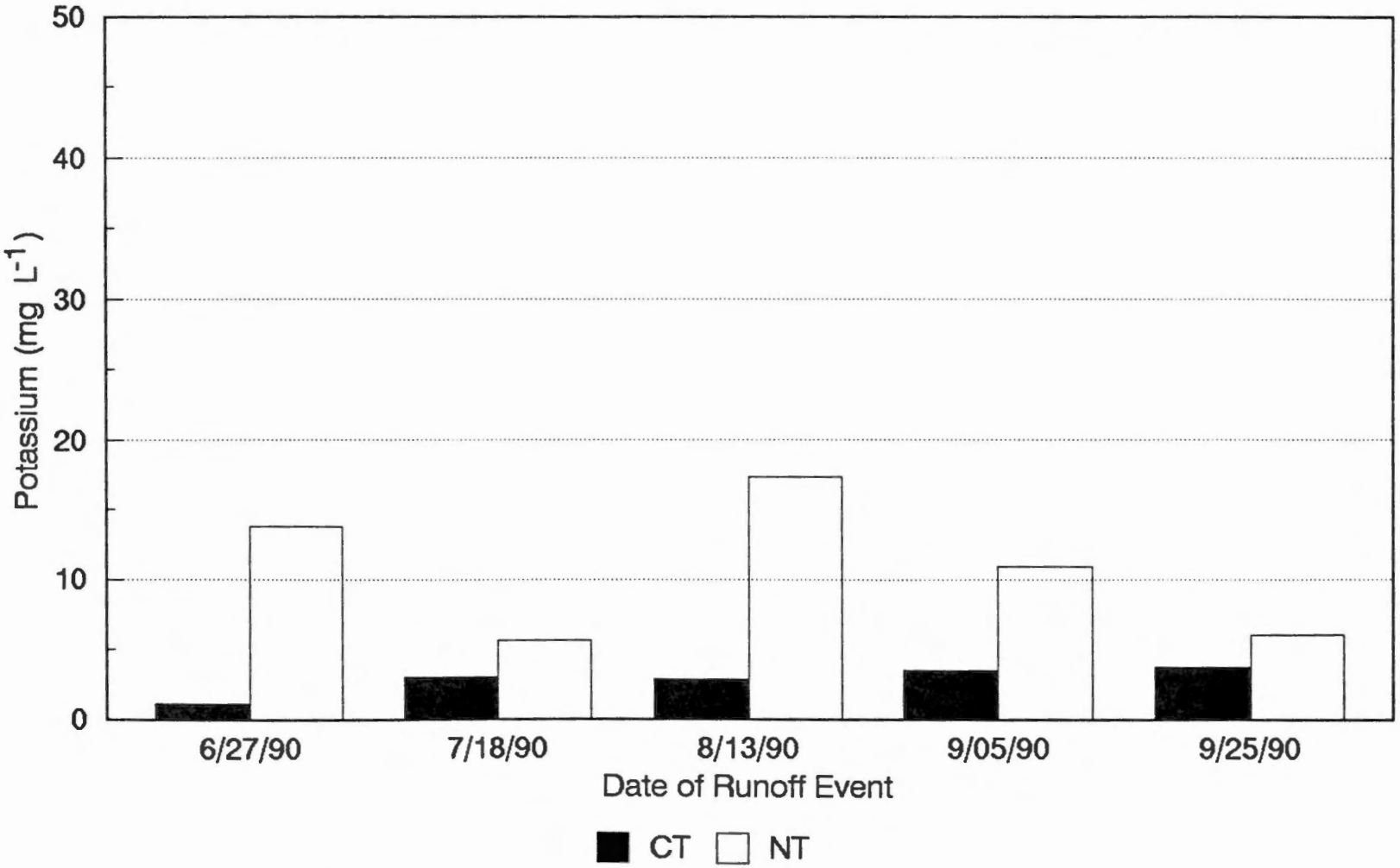

Figure 7. Effect of tillage treatments on potassium concentration in runoff water, 1990.

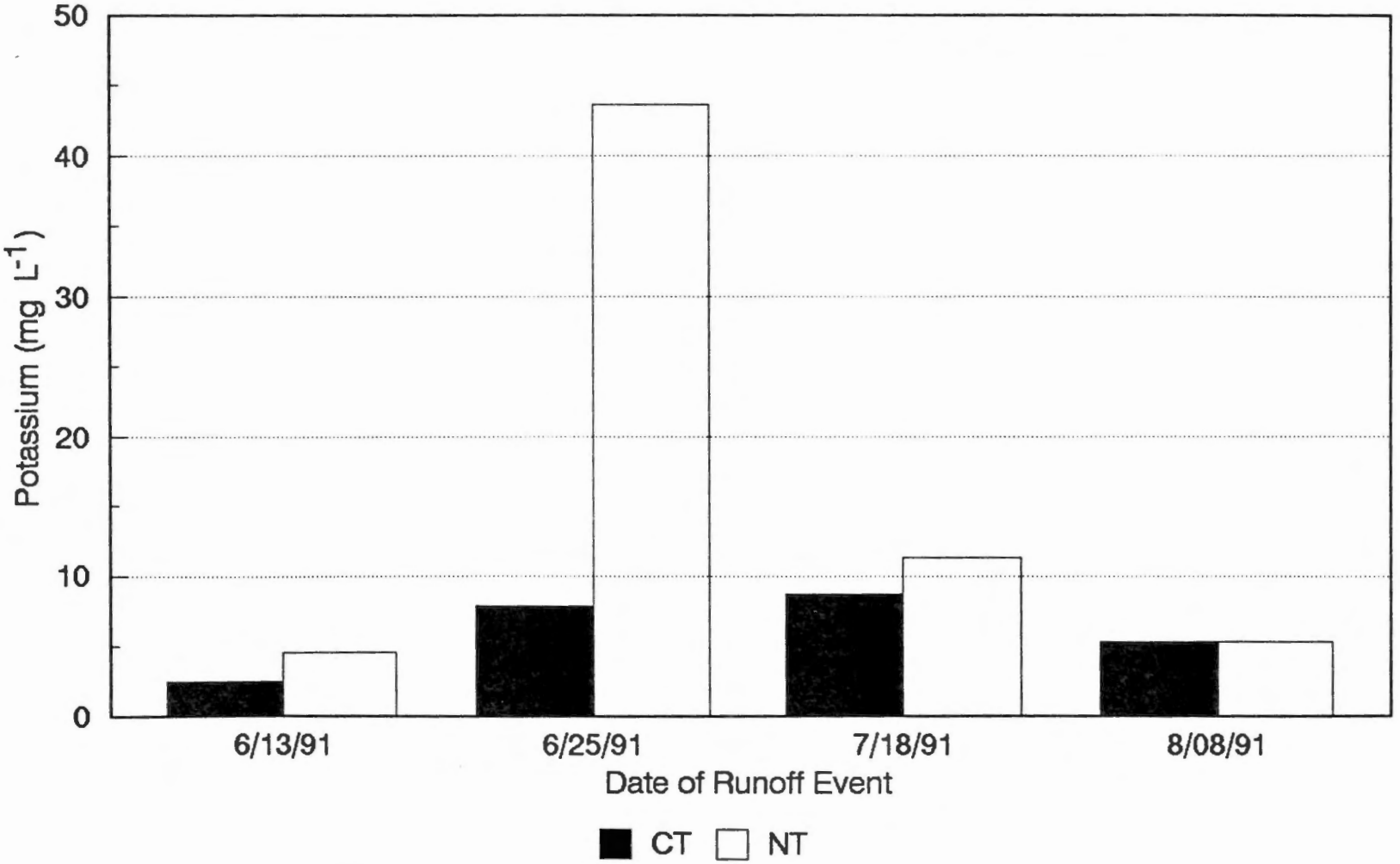

Figure 8. Effect of tillage treatments on potassium concentration in runoff water, 1991.

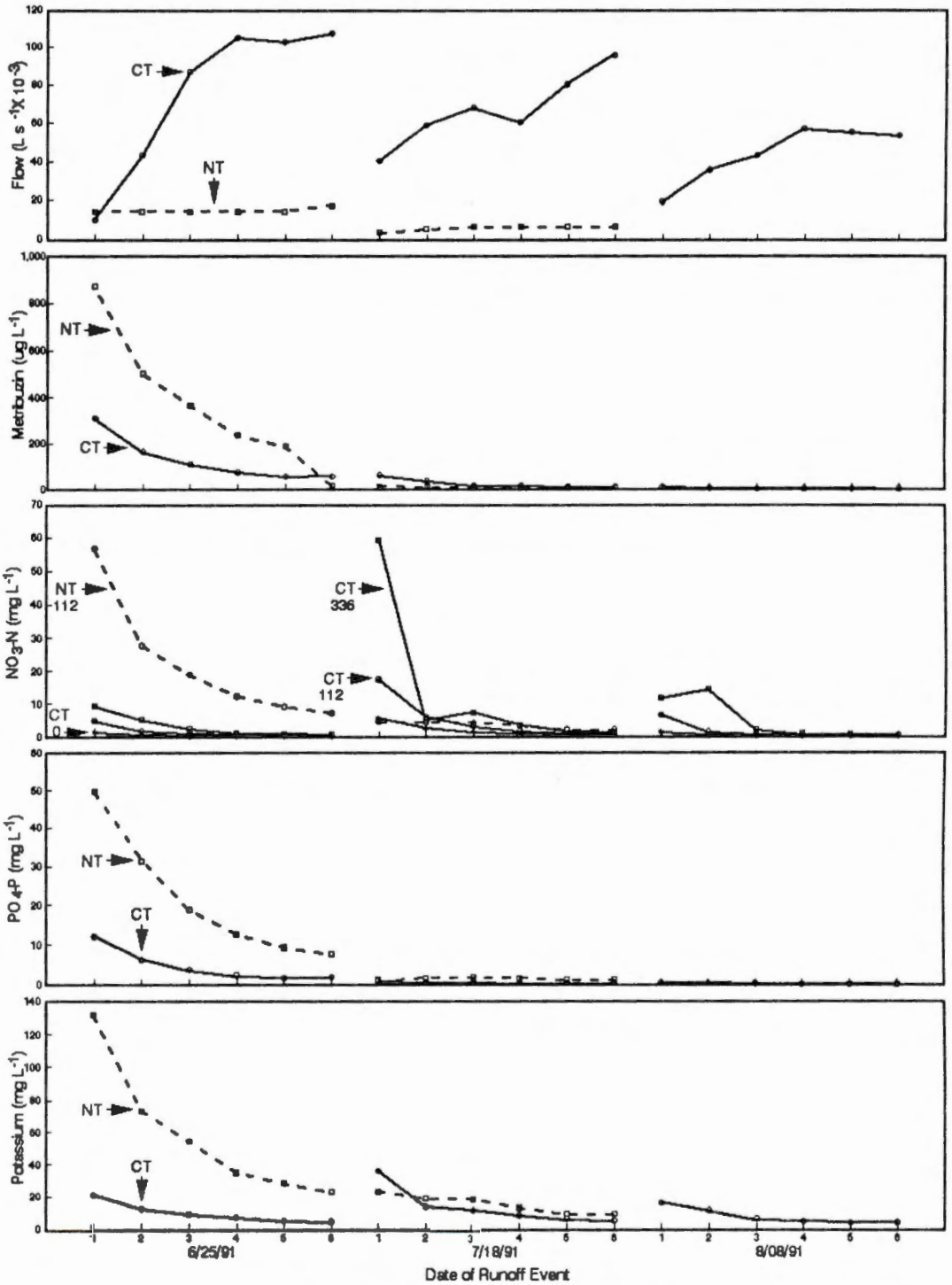

Figure 9. Effect of tillage treatments on quantity of flow and concentration of metribuzin, NO_3-N, PO_4-P, and potassium during runoff, 1991.

higher concentrations of metribuzin present at the soil surface in the CT plots (107.6 ug kg^{-1} for CT vs. 62.8 ug kg^{-1} for NT).

The NO_3-N concentration in runoff from the NT plot receiving 112 kg ha^{-1} was considerably higher than the concentration in any other nitrogen treatment that exhibited runoff during the 6/25/91 event (Figure 9). The concentrations remained above the 10 mg L^{-1} threshold for nearly two-thirds of the event. It is speculated that if the NT plots receiving 336 kg ha^{-1} of nitrogen fertilization had exhibited runoff, the nitrogen concentrations would have far exceeded those observed from the NT plots receiving 112 kg ha^{-1} of nitrogen fertilization. Comparing the CT treatments during the 6/25/91 event, NO_3-N concentrations increased as N fertilization rate increased. However, as the event continued, NO_3-N concentrations became smaller as did differences between N fertilization rates. This rate response was also observed in the latter two runoff events. However, at the beginning of each of these events, the NO_3-N concentration was higher than the concentration at the end of the previous event, suggesting mineralization processes occurring.

The concentration of PO_4-P in runoff from NT plots was consistently higher than the concentration from CT plots throughout the 6/25/91 hydrograph (Figure 9).

Concentrations were very similar between tillage systems during the subsequent two events.

During the 6/25/91 simulated rainfall event, potassium concentrations were considerably higher in runoff from NT plots than from CT plots (Figure 9). The potassium concentration decreased during each runoff hydrograph from both tillage treatments. As was observed with NO3-N, potassium concentrations were greater at the start of the second and third events than at the end of the previous event for CT hydrographs.

Concentrations of all agrichemicals were negatively correlated to flow rate. Potassium concentration was most affected by flow rate ($r=-0.42$), while metribuzin concentration was least affected by flow rate ($r=-0.29$). Regression analysis revealed that most rate responses were linear or linear and quadratic. However, the flow rate remained low and constant from NT plots resulting in a poor flow rate response. Therefore, cumulative flow was used in the regression model and generated acceptable models (r^2 = 0.90 to 0.98) for concentrations of agrichemical in runoff from both CT and NT plots. Analysis of the first runoff event after chemical application revealed a higher intercept for models generated for NT plots as compared to CT plots. In the case of metribuzin, the intercept for the NT plots was 883.25 as compared to 281.90 for the CT plots. This

would indicate a more readily available source of pesticide from the NT plots, likely in the form of metribuzin being washed off of the residue present on the surface. The slope was also observed to be steeper from the NT plots (-26.22) than from the CT plots (-3.14), suggesting wash off from the NT plots and the mixing zone phenomenon from CT plots. At the second runoff event after metribuzin application, the intercepts reverse (8.99 for NT vs. 60.16 for CT) as do the slopes. However, the slopes were much more gradual and more comparable (-0.50 for CT vs. -0.17 for NT) than the slopes observed from the first runoff event. These results are likely attributed to the zone of mixing phenomenon.

Mass of Agrichemical Loss

The mass of metribuzin lost was quite low from CT in 1989 (Table 1). Each year greater losses were observed from CT plots with over 2% of the applied metribuzin being lost during the four simulated rainfall events in 1991. Metribuzin losses in runoff from NT were variable among years and less than losses in runoff from CT in the last two years despite runoff of NT containing substantially higher concentrations. Total loss of NO_3-N was observed to be very small despite high NO_3-N concentrations that were occasionally above the maximum contaminant level (MCL).

Table 1. Effect of tillage treatments on total loss of metribuzin, NO_3-N, PO_4-P, and potassium, with runoff water, 1989-1991.

Year	Tillage Treatment	Metribuzin[X] g ha^{-1}	NO_3-N kg ha^{-1}	PO_4-P kg ha^{-1}	Potassium kg ha^{-1}
1989	CT	0.6	0.04	0.002	0.45
	NT	5.0	0.02	0.008	0.28
1990	CT	1.8	0.05	0.010	0.81
	NT	0.2	0.17	0.041	1.01
1991	CT	19.4	0.44	1.443	2.14
	NT	7.1	0.24	0.329	1.10

[X] Total application consisted of each; metribuzin = 840 g ha^{-1}, N = 112 kg ha^{-1}, P = 49 kg ha^{-1}, and K= 93 kg ha^{-1}.

Losses were extremely low from both tillage systems in 1989. Nitrate-N losses increased slightly each year with CT losses increasing more rapidly than NT losses. As a result, NO_3-N loss in runoff from CT was slightly more than the loss observed in runoff from NT in 1991. The pattern for total mass of PO_4-P lost in runoff was very similar to the NO_3-N pattern. Loss was relatively low the first year with less losses from the CT system in 1989 and 1990. However, total losses increased each year with CT losses increasing faster than NT losses. By 1991, losses were considerable with CT losing more than NT. Potassium losses also followed this pattern of increase each year and potassium losses in runoff from CT being more than twice that observed in runoff from NT by 1991. This faster increase in total mass losses of agrichemicals from CT is likely attributed to increased runoff and/or increased soil concentrations.

CHAPTER V

SUMMARY AND CONCLUSIONS

In summary, when runoff occurred, runoff from NT was observed to carry higher concentrations of metribuzin, NO_3-N, PO_4-P, and potassium than runoff from CT. Concentrations were highest for the first storm event after agrichemical application and decreased dramatically with subsequent events. Concentrations may be higher in runoff from CT than NT later in the growing season due to the greater source remaining in the soil surface. Total losses of metribuzin, NO_3-N, PO_4-P, and potassium in runoff were comparable between the tillage treatments in the first two years of this study. However, losses of the agrichemicals increased more rapidly under CT than NT, with the exception of metribuzin, and by the third year greater losses were observed from the CT than from the NT plots.

Even though the concentration of agrichemicals was greater in runoff from NT during the first simulated rainfall event after agrichemical application, the use of the NT system should improve water quality. This improvement is based on less total agrichemical loading into surface water supplies.

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PART 5: TILLAGE TREATMENTS AND NITROGEN FERTILIZATION RATES FOR TOMATO PRODUCTION. III. EFFECT ON SUBSURFACE WATER MOVEMENT AND QUALITY

CHAPTER I

ABSTRACT

Conservation tillage systems reduce erosion and may reduce runoff. Increased infiltration is often observed with conservation tillage systems. If increased infiltration does occur with conservation tillage practices then such practices may have a detrimental impact on groundwater. Pan lysimeters were installed to evaluate the effect of tillage treatment on water and agrichemical movement through the soil profile. Greater movement of water, NO_3-N, and metribuzin out of the root zone was observed under no tillage (NT) soil than under conventional tillage (CT) soil. This was reasoned to be the result of macropores under the NT system causing faster movement of water and less reactivity of fertilizer and pesticides with soil. Macropore flow processes were also considered influential in lower resident agrichemical concentrations in NT soils than in CT soils. Due to the channelization of the subsurface soil, the small pans (12.7 cm X 30.5 cm)

collected flow from an area considerably larger than its size. The two larger pans (45.7 cm X 35.6 cm or 61 cm X 76.2 cm) proved to produce more representative flow measurements. Soil water content was observed to be slightly higher under NT soil in the top 15 cm and below 60 cm. However, soil water contents of CT soil were as great or greater between 15 and 60 cm. Residual NO_3-N and metribuzin concentrations were generally higher (at least in the top 15 cm) in CT soil than in NT soil. These differences were most likely a result of the water moving through the macropores by-passing micro and mesopores in the NT soils. Under CT, water movement was considered to occur through the soil matrix pores, thereby resulting in a greater volume of infiltration that was physically immobilized between events.

CHAPTER II

INTRODUCTION

With the recent increase in environmental awareness, much concern has been voiced as to the quality of drinking water. Attention has been focused on agrichemicals and agriculture practices in general. It is generally agreed and our data (Straw et al., 1992) support the conclusion that conservation tillage systems reduce erosion. It is often observed (Straw et al., 1992) that conservation tillage also reduces runoff volume. If runoff is reduced using conservation tillage systems, then where do the water and agrichemicals go? Are they going into the ground water and contaminating drinking water supplies? According to a national EPA survey (EPA, 1990), only 1.2 percent of commercial and 2.4 percent of rural wells had NO_3-N concentrations greater than the 10 mg L^{-1} maximum contaminant level (MCL). Greater than 50 percent of all wells sampled had detectable levels of nitrate; however, no correlation was made between NO_3-N concentration and cultural practice.

Chemicals have been observed to accumulate in the top 5 to 10 cm of no tillage (NT) systems, while at greater depths in the profile there is a reversal of this trend. No

tillage systems generally have lower chemical concentrations below the surface (10 cm) than conventional tillage (CT) treatments (Hendrix et al., 1986). Several tillage studies have reported greater available phosphorus levels in the top 5 to 10 cm of soil from conservation tillage systems than from CT systems (Dick et al., 1986a; Eckert and Johnson, 1985; Fink and Wesley, 1974; Moschler et al., 1972; Triplett and Van Doren, 1969). Other studies have reported a stratification of potassium, calcium, magnesium, manganese, iron, copper, and zinc in conservation tillage systems, with concentrations decreasing as depth through the profile increased (Blevins et al., 1983; Chandhi and Takkar, 1982; Hargrove et al., 1982; Hendrix et al., 1986; Lal, 1976; Shuman and Hargrove, 1985).

Nitrate concentrations have been observed to be greater in CT soil in the fall after plowing than in NT soils; although, by spring no differences in nitrate concentrations were observed (Carter and Rennie, 1984; Dowdell et al., 1983; Linn and Doran, 1984; Rice and Smith, 1983.

Time after establishment of tillage practices influences nitrogen levels in the soil. Thomas et al. (1973) found higher nitrate concentrations in CT soils than in NT soils during the first year tillage treatments were imposed. Several other studies evaluated soon after the implementation of tillage practices showed similar results

(Dowdell and Cannell, 1975; House et al., 1984; NaNagara et al., 1976). Lamb et al. (1985) reported increased inorganic nitrogen concentrations from plowed wheat-fallow systems early in the experiment; however, after two to six years no significant differences in nitrogen concentrations were observed due to tillage treatments. Rice et al. (1986) found soil nitrogen levels reached a steady state approximately five years after initiation of tillage treatments. After 12 years no differences in ammonium or nitrate were measured between soils of NT and CT treatments.

Recently, atrazine and metolachlor were detected in corn fields in Connecticut to a depth of 2.25 m (Huang, 1989). In a sandy soil, 900 ug L^{-1} atrazine and 846 ug L^{-1} metolachlor were detected at a soil depth of 0 to 27 cm. Concentrations at 1.77 to 2.25 m were 9.3 and 5.8 ug L^{-1} for atrazine and metolachlor, respectively. This study has far reaching implications in that pesticide residues are present below the root zone and impose a threat to ground water. Numerous studies have shown that microbial degradation is slower in subsoils (Cohen et al., 1984), which suggests herbicide residues found in the subsoil could leach into the groundwater before they are degraded. Atrazine and metolachlor levels remaining in the soil profile were extrapolated to equal 3.9 and 3.6 kg ai ha^{-1}, respectively (Huang, 1989).

Hall et al. (1989) compared leaching and distribution of atrazine and metolachlor in CT and NT soil. They found atrazine residues consistently at all soil depths to 122 cm beneath the soil surface. When analyzing pan lysimeter percolates, they found greater herbicide leachates from NT soil than from CT soil.

Brown et al. (1985) examined the effect of tillage and crop management on downward movement of metribuzin during growth of winter wheat in Washington. Analysis of multiple core samples at 0 to 7 or 0 to 15 cm showed that NT resulted in lower herbicide residues than CT indicating metribuzin movement deeper in the profile. Moorman and Harper (1988) reported longer persistence of metribuzin at a soil depth of 10 to 20 cm than at a soil depth of 0 to 10 cm, which could result in greater opportunity for further movement of metribuzin once it enters the subsoil. Metribuzin was found to move more through the soil than was alachlor (Jones et al., 1990). Metribuzin was also found to move faster under NT conditions than under CT. The addition of 2800 kg ha^{-1} of straw was also found to increase metribuzin movement. Metribuzin dissipated faster at a depth of 8 cm than at a depth of 58 cm.

Tyler and Thomas (1977) found greater nitrate leaching (increased movement and movement was faster) under NT conditions than under CT conditions in the early spring when

nitrogen was added to the soil. Similar results were reported by Thomas et al., 1973 and 1981. They explained their results by hypothesizing that water carries surface applied nitrogen through the macropores, by-passing soil matrix pores that would have otherwise immobilized the nitrogen physically. Studies by Wild (1972) and Kanwar et al. (1985) contradicted these results by finding less nitrate movement under NT than CT. They reasoned that infiltrating water moved through the macropores; thereby, by-passing the nitrate present within the soil matrix. The critical question as to whether macropores increase leaching is how available is the nitrogen source to infiltrating water. The transfer between immobilized water containing the nitrogen and mobile water moving through macropores is highly dependent upon the timing of the rainfall event relative to fertilizer application and hydrologic conditions. Gold and Loudon (1982) observed higher NO_3-N concentrations from tile drainage of conservation tillage systems than from drainage of CT systems, whereas Kitur et al. (1984) found no difference between tillage systems.

Schuman et al. (1975) documented nitrate leaching under conservation tillage systems and found it to be influenced by the amount of nitrogen fertilizer applied. Work done in Nebraska revealed that groundwater NO_3-N concentrations were positively correlated with nitrogen fertilizer usage,

irrigation well density, and livestock density. Significant negative correlations were found with percentage clay, irrigation well depth, and water pH.

The objectives of this portion of the experiment were: 1) to evaluate the quality and quantity of water moving through the soil profile toward ground water supplies and 2) to determine the residual quantity of water, NO_3-N, and metribuzin in the soil profile.

CHAPTER III

MATERIALS AND METHODS

In April of 1990, pan lysimeters (45.7 cm X 35.6 cm) were installed at a depth of 90 cm under one plot of each tillage-nitrogen combination. The 90 cm depth was chosen to represent movement of water and agrichemicals out of the root zone. Observation at the 90 cm depth does not necessarily reveal anything specific about movement of agrichemicals into ground water supplies. A large pan lysimeter (61 cm X 76.2 cm) and four connected small pan lysimeters (12.7 cm X 30.5 cm per compartment) were installed under one plot of each CT and NT plot receiving the recommended 112 kg ha^{-1} of nitrogen fertilization. All lysimeters were connected to carboys, buried at a depth below the pan to allow gravity flow from the pans. Carboys were emptied one to two days following all natural or simulated rainfall events after installation. The volume of leachate was recorded and samples were collected for metribuzin and NO_3-N analysis.

In 1990, metribuzin concentration was determined using a modified high performance liquid chromatography version (HPLC) of EPA Method 507 (Wells, personal communication). In 1991, metribuzin concentration was determined using a

solid phase extraction technique (Riemer and Wells, 1992). The NO_3-N concentration was determined using ion chromatography chemically suppressed conductivity detection.

In 1991, soil samples were taken on 7/10/91 and 8/02/91 to evaluate the amount of water, metribuzin, and NO_3-N remaining in the soil profile. Nitrate-N concentrations from soil samples were determined using EPA Method 300.0 (Pfaff et al., 1989).

CHAPTER IV

RESULTS AND DISCUSSION

Solute Leaching

Water flow out of the root zone was observed to be small during the growing season. However, when large quantities of rainfall were received during the winter, a small increase was observed in the flow of water under CT plots, and a large increase in flow was observed under NT plots (Figure 1). Soil water storage and evapotranspiration are generally small during this period and differences between tillage systems minimal. Thus the greater percolation out of the NT profile was likely due to the greater runoff from CT limiting the quantity of water infiltrating.

Metribuzin was detected in leachate on 7/18/90 and 11/02/90. Concentrations were higher in leachate from CT plots (533.2 ug L^{-1}) than in leachate from NT plots (385.3 ug L^{-1}) at 7/18/90. However, at the 11/02/90 sampling date leachate from NT (219.2 ug L^{-1}) plots was over 5 times greater than leachate from CT plots (41.1 ug L^{-1}). During the 1991 production year, metribuzin was detected in leachate from the 12/10/91, 12/17/91, and 1/07/92 sampling

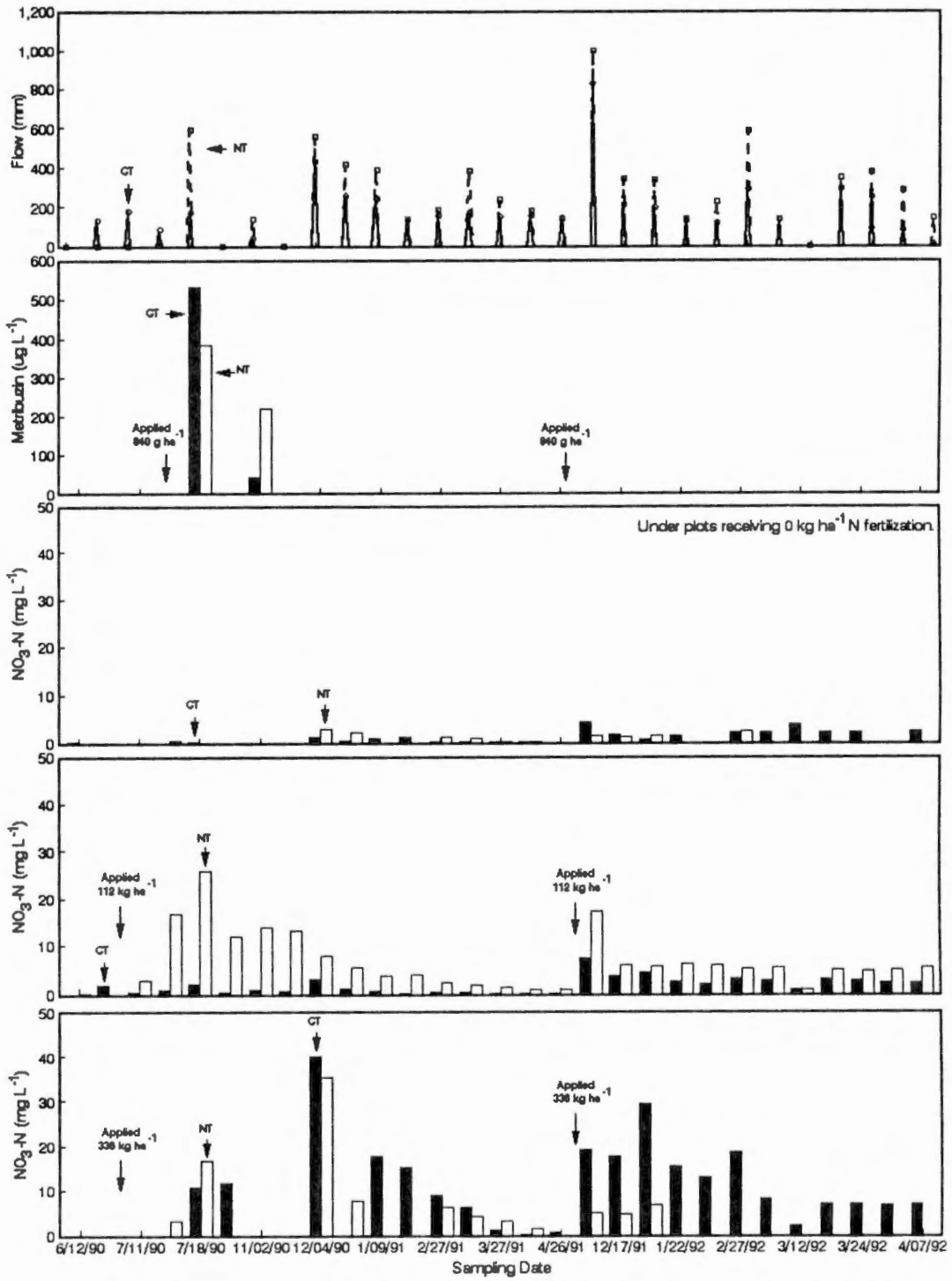

Figure 1. Effect of tillage treatments on water, metribuzin, and NO_3-N movement out of the root zone into pan lysimeters, 1990-1991.

dates. Metribuzin concentrations observed in 1991 were very low (0.4 ug L^{-1} or less) in comparison to those observed in 1990. These lower concentrations were likely attributed to less movement early in the growing season allowing more plant uptake and degradation. Tillage systems had no affect on the concentration of metribuzin in leachate during the 1991 production year.

During the 1990 production season, NO_3-N concentrations in lysimeter leachate were much lower under plots that were not fertilized than plots receiving nitrogen fertilization (Figure 1). In 1991, the plots receiving no fertilization produced very little flow and the flow that did occur had very low NO_3-N concentrations.

Lysimeter leachate from plots receiving 112 kg ha^{-1} of nitrogen fertilization revealed considerably higher NO_3-N concentrations than the plots receiving no nitrogen fertilization, especially under the NT plot during 1990 (Figure 1). Nitrate-N concentrations were above the 10 mg L^{-1} MCL from the 7/17/90 to the 11/15/90 sampling date. Nitrate-N concentrations were observed to decline during the winter and spring of 1990 and 1991. In 1991, NO_3-N concentrations were observed to be consistently higher in leachate from the NT plot than in leachate from the CT plot. The only leachate containing NO_3-N concentrations above the 10 mg L^{-1} threshold was from the NT plot during the initial

flush on 12/10/91. Concentrations of NO_3-N appeared to remain constant throughout the winter and spring.

Lysimeter leachate from plots receiving 336 kg ha^{-1} contained slightly higher NO_3-N concentrations than the plots receiving 112 kg ha^{-1} (Figure 1). Leachate from both the CT and NT plots were above 10 mg L^{-1} from 7/18/90 to 12/04/90. Concentrations of NO_3-N in the winter months were higher from the CT plot than from the NT plot at the 336 kg ha^{-1} rate. This was likely due to higher flows observed under the CT than the NT plots receiving 336 kg ha^{-1}. In 1991, NO_3-N concentrations were again higher from the plot receiving the CT treatment, with observed levels greater than 10 mg L^{-1} from 12/10/91 to 2/27/92.

One notable difference between the two years is when flow was initiated. Some flow was observed in the early summer of 1990. As the evaporation and crop water usage increased, flow terminated. Flow did not initiate again until the crop was removed and heavy precipitation was received in November. In 1991, precipitation was generally light and water use levels high, preventing flow until December.

Movement Variability

The assumption was made that the pan lysimeters would only collect from the area of soil comparable to the size of the pan. However, this did not appear to happen, especially with the small pans. In some instances, flows were 5 to 10 times greater than the amount of water applied (Tables 1 and 2). This increased flow was attributed to channels draining an area considerably larger than the pan area. Therefore, the larger pans showed less flow per area and most likely gave a more accurate estimation of the representative elemental volume for flow.

Total mass of metribuzin and NO_3-N moving out of the root zone was generally estimated higher from small pans than the medium or large pans (Tables 1 and 2). In some instances, predicted NO_3-N losses were 5 to 10 times greater than the amount of nitrogen applied (Table 2). Variability was observed to be high within tillage treatments and nitrogen fertilization rates (Figure 2). The greatest cumulative flow was observed from the small pans under the NT plot. The small and medium pans under the CT plot showed higher flows than those observed from the large pan under CT and the large and medium pan under NT. The highest metribuzin loss was measured by the small pan under the NT plot, while all of the other pans under CT and NT observed

Table 1. Effect of nitrogen fertilization rate, tillage, and pan size on movement of water, NO_3-N, and metribuzin[X], 1990.

Nitrogen kg ha^{-1}	Tillage[Y]	Pan Size[Z]	Applied mm	Flow mm	Estimated Loss NO_3-N kg ha^{-1}	Estimated Loss Metribuzin g ha^{-1}
0	CT	Medium	2317	115	0.6	2.5
0	NT	Medium	2444	514	8.6	0.0
112	CT	Large	2373	1342	27.6	22.4
112	CT	Medium	2373	2654	22.8	21.2
112	CT	Small	2373	977	7.2	0.0
112	CT	Small	2373	5894	59.7	17.4
112	CT	Small	2373	3744	33.8	10.2
112	CT	Small	2373	4243	40.3	10.4
112	NT	Large	2439	791	54.7	9.2
112	NT	Medium	2439	158	12.0	0.0
112	NT	Small	2439	11214	601.6	194.5
112	NT	Small	2439	3687	262.6	39.9
112	NT	Small	2439	6669	468.0	301.6
112	NT	Small	2439	3534	222.5	109.2
336	CT	Medium	2384	868	82.2	0.0
336	NT	Medium	2319	432	29.5	0.0

[X] Metribuzin was applied to all plots at a rate of 840 g ha^{-1}.
[Y] CT = conventional tillage and NT = no tillage.
[Z] Dimensions of pans were small = 12.7 X 30.5 cm, medium = 45.7 X 35.6, and large = 61 X 76.2 cm.

Table 2. Effect of nitrogen fertilization rate, tillage, and pan size on movement of water, NO_3-N, and metribuzin[X], 1991.

Nitrogen kg ha^{-1}	Tillage[Y]	Pan Size[Z]	Applied mm	Flow mm	Estimated Loss NO_3-N kg ha^{-1}	Estimated Loss Metribuzin g ha^{-1}
0	CT	Medium	1771	88	2.8	0.4
0	NT	Medium	1712	188	2.6	0.5
112	CT	Large	1745	738	44.7	0.0
112	CT	Medium	1745	2514	89.0	4.7
112	CT	Small	1745	552	43.6	0.0
112	CT	Small	1745	8140	272.7	1.1
112	CT	Small	1745	3273	107.6	0.0
112	CT	Small	1745	4211	117.1	0.9
112	NT	Large	1730	418	29.1	0.0
112	NT	Medium	1730	233	28.7	0.0
112	NT	Small	1730	10854	948.6	30.3
112	NT	Small	1730	3513	281.6	3.8
112	NT	Small	1730	12792	802.2	8.1
112	NT	Small	1730	3375	387.7	8.0
336	CT	Medium	1738	861	134.1	1.1
336	NT	Medium	1704	140	7.1	0.0

[X] Metribuzin was applied to all plots at a rate of 840 g ha^{-1}.
[Y] CT = conventional tillage and NT = no tillage.
[Z] Dimensions of pans were small = 12.7 X 30.5 cm, medium = 45.7 X 35.6, and large = 61 X 76.2 cm.

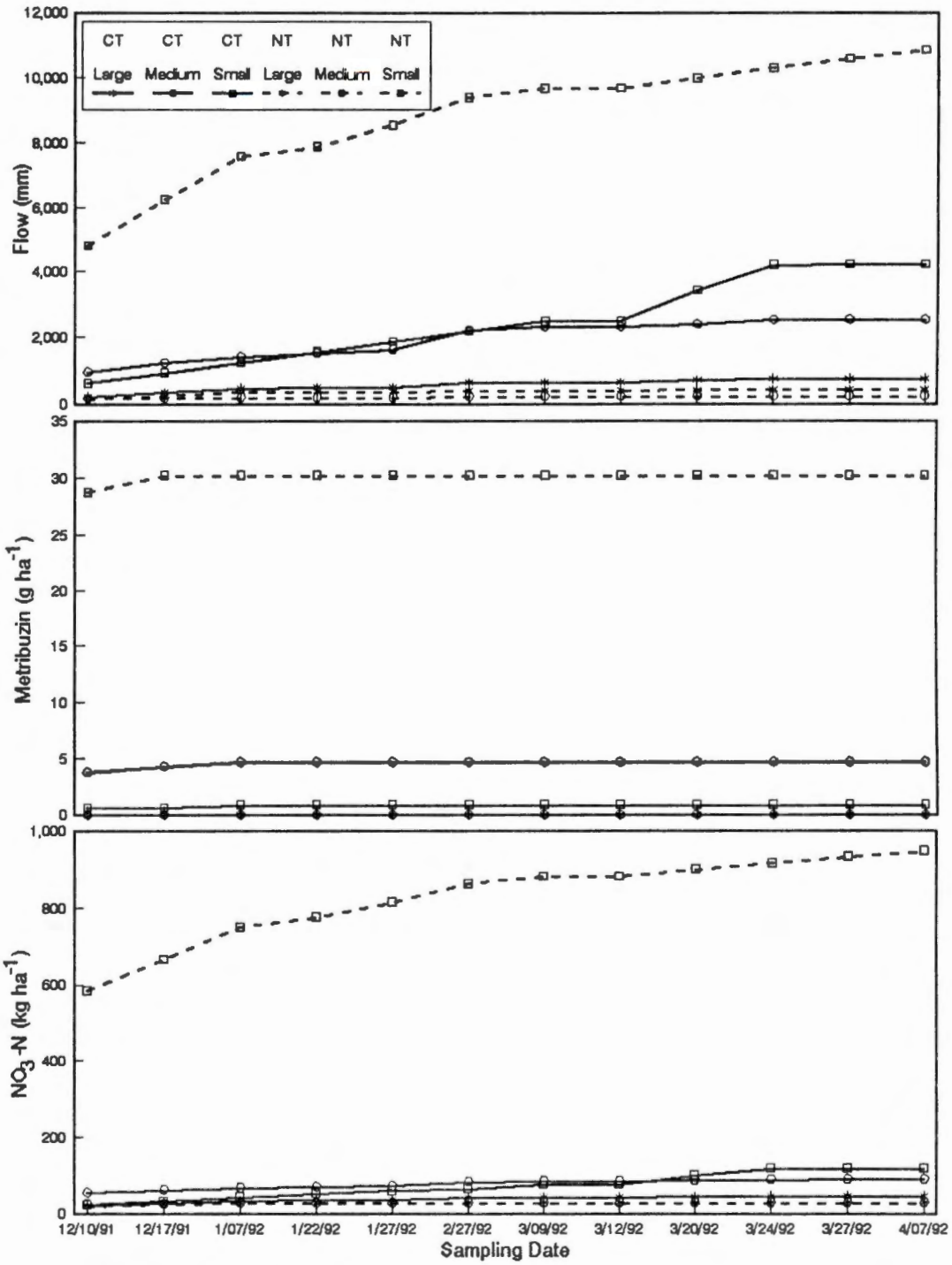

Figure 2. Typical variability of flow, metribuzin, and NO_3-N movement into different sized pans under CT and NT plots receiving 112 kg ha^{-1} of nitrogen fertilization.

little or no metribuzin loss. The same trend was observed for NO_3-N loss.

Soil variability was evident when installing the pan lysimeters. Large, eroded root channels were observed on the edge of one plot. Soil physical characteristics were highly variable within the block (Table 3). Horizons were highly variable in depth, texture, color, structure, and the amount of roots present.

Soil Storage

Gravimetric soil water content appeared to increase slightly from the surface to a depth of 75 cm under CT (Figure 3). No tillage on the other hand appeared to remain constant in soil water content from the surface to 45 cm and then increased slightly to the 75 cm depth. Given the experimental error associated with gravimetric samples, the small differences observed between the tillage treatments were insignificant.

Samples taken 7/10/91 showed slightly higher resident metribuzin concentrations in CT soils than NT soil at the soil surface (Figure 4). Metribuzin was detected in soils to a depth of 75 cm under the CT treatment and to a depth of 60 cm under NT. The effect of tillage systems on the metribuzin concentration in the soil from 15 to 45 cm was

Table 3. Description of soil profile in pits adjacent to plots containing pan lysimeters.

Pit	Horizon	Depth (cm)	Texture	Color	Structure	Roots
1	Ap	0-18	l[x]	10YR4/4	2mgr	common
	Bt1	18-61	cl	10YR4/4	1smbk	common
	Bt2	61-99	scl	10YR5/6	2msbk	few
	Bt3	99-112	scl	10YR5/6	1mcsbk	few
	C	112-122	sl	10YR5/4	massive	none
	Cr	122+	--	---	---	none
2	Ap	0-20	l	10YR4/4	2mgr	common
	Bt1	20-51	l	10YR4/6	1msbk	common
	Bt2	51-71	scl	10YR5/6	2msbk	few
	Bt3	71-122	scl	10YR5/6	2msbk	few
	C	122-152	sl	10YR5/6	massive	none
	Cr	152-163	--	10YR6/2	---	none
	R	163+	--	---	---	none
3	Ap	0-20	l	10YR4/4	1mgr	many
	Bt1	20-53	scl	10YR5/6	1msbk	common
	Bt2	53-89	scl	10YR5/6	2msbk	common
	Bt3	89-119	scl	10YR5/6	2msbk	few
	Bt4	119-142	scl	7.5YR5/6	1mcsbk	few
	C	142-157	sl	mottled	massive	none
	Cr	157+	--	---	---	none
4	Ap	0-18	l	10YR5/4	1fmgr	many
	Bt1	18-43	scl	10YR5/6	1msbk	many
	Bt2	43-66	scl	7.5YR5/6	2msbk	many
	Bt3	66-122	sl	2.5YR4/8	2mvcsbk	few
	C	122-142	sl	10YR6/3	massive	none
	Cr	142+	--	---	---	none

[x] L=loam, s=sandy, and c=clay.

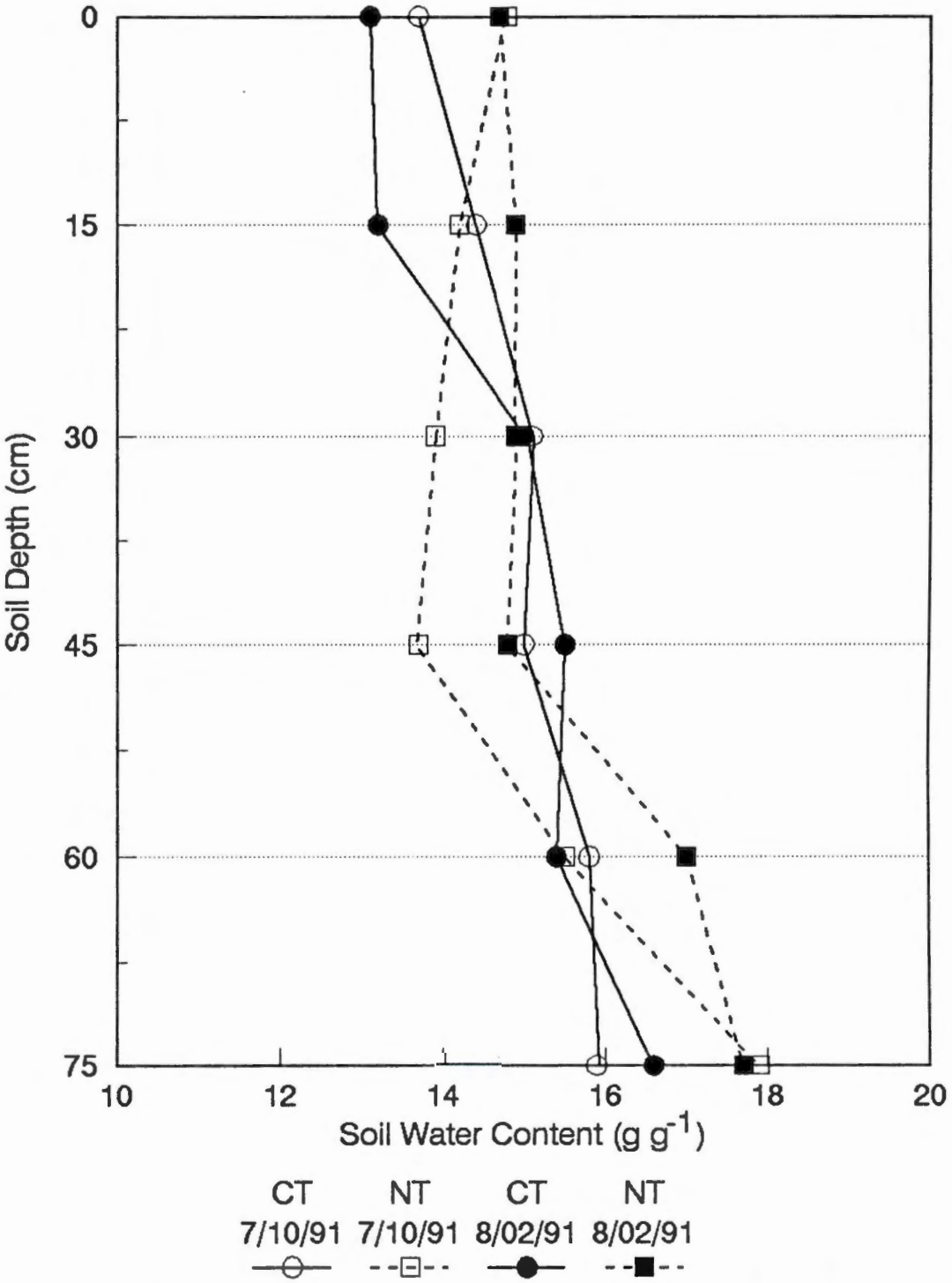

Figure 3. Effect of tillage treatments on soil water content, 1991.

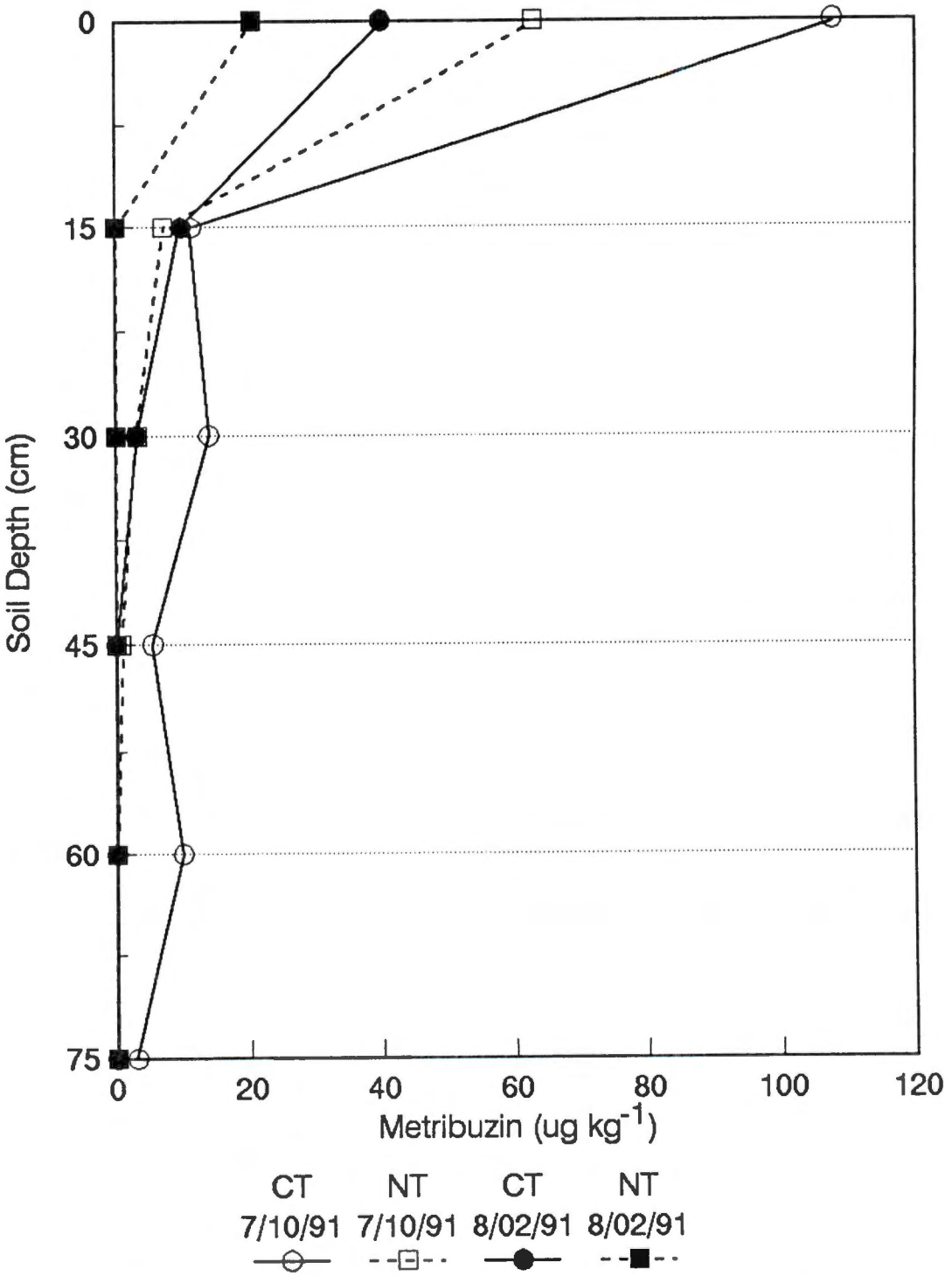

Figure 4. Effect of tillage treatments on metribuzin concentration in the soil, 1991.

negligible. Samples taken on 8/02/91 revealed metribuzin present only in the top 15 cm of NT treatments (Figure 4). The CT soil profile contained higher concentrations at the surface and detectable levels to a depth of 45 cm (Figure 4).

Nitrate-N concentrations were observed to be higher to a depth of 45 cm in CT soils at the 7/10/91 sampling date (Figure 5). As anticipated concentrations of NO_3-N were also higher in plots receiving nitrogen fertilization, with the 336 kg ha^{-1} nitrogen fertilization rate exhibiting the highest concentrations. Concentrations greater than 90 mg kg^{-1} of NO_3-N were observed in the CT soil receiving 336 kg ha^{-1} nitrogen fertilization.

The NO_3-N concentration at the surface of the CT plot receiving no nitrogen fertilization nearly doubled between the two sampling dates, possibly signifying a release of nitrogen from the decomposition of organic matter provided by the cover crop (Figure 6). Nitrate-N concentrations were observed to be higher in CT than NT soils at the soil surface on 8/02/91 given nitrogen fertilization rates. Concentrations of NO_3-N were higher in plots receiving N fertilization, with the exception of the CT plot receiving 0 kg ha-1 nitrogen fertilization. The plots receiving 336 kg ha^{-1} of nitrogen fertilization had higher NO_3-N

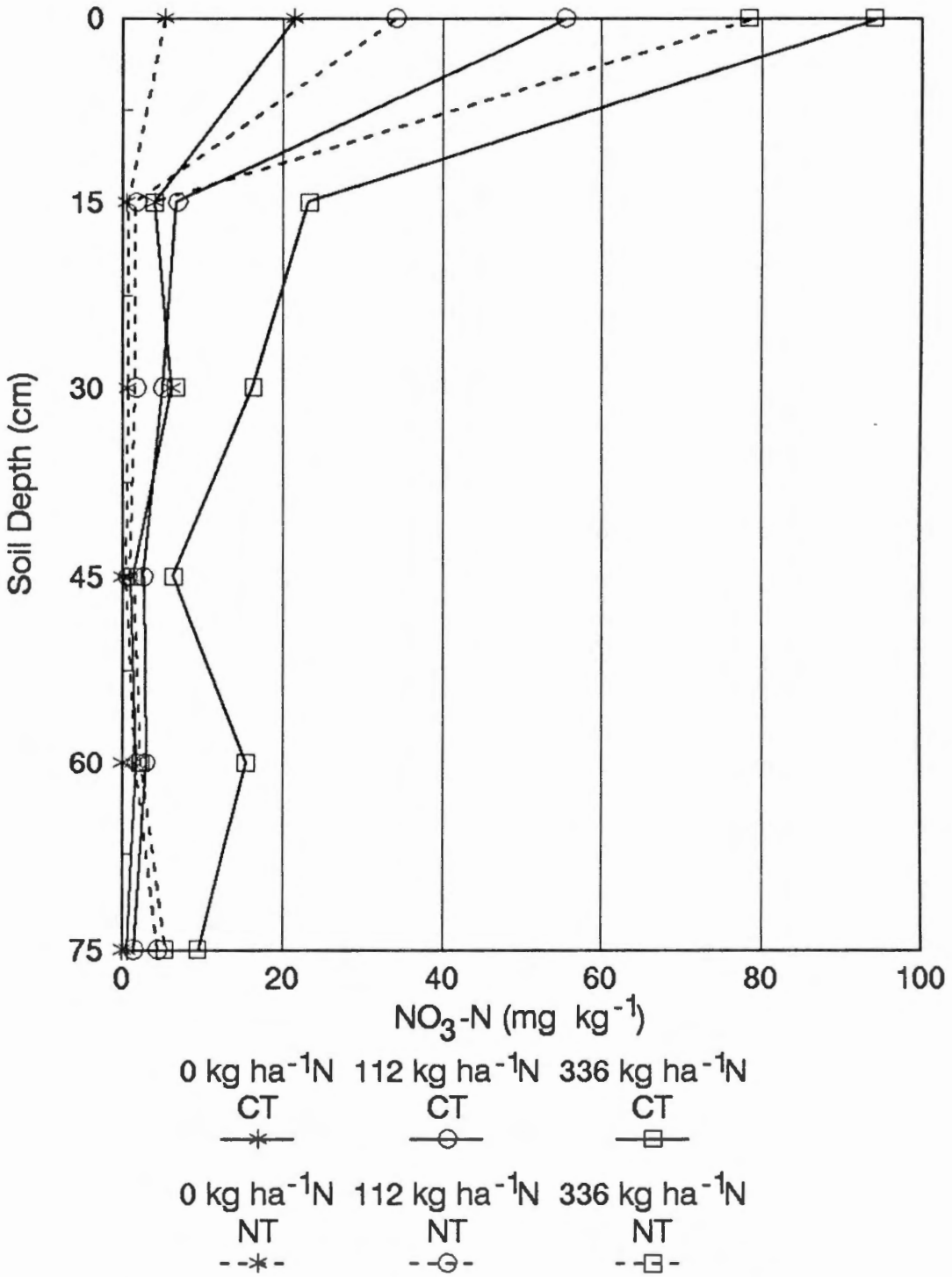

Figure 5. Effect of tillage treatments on NO_3-N concentration in the soil, 7/10/91.

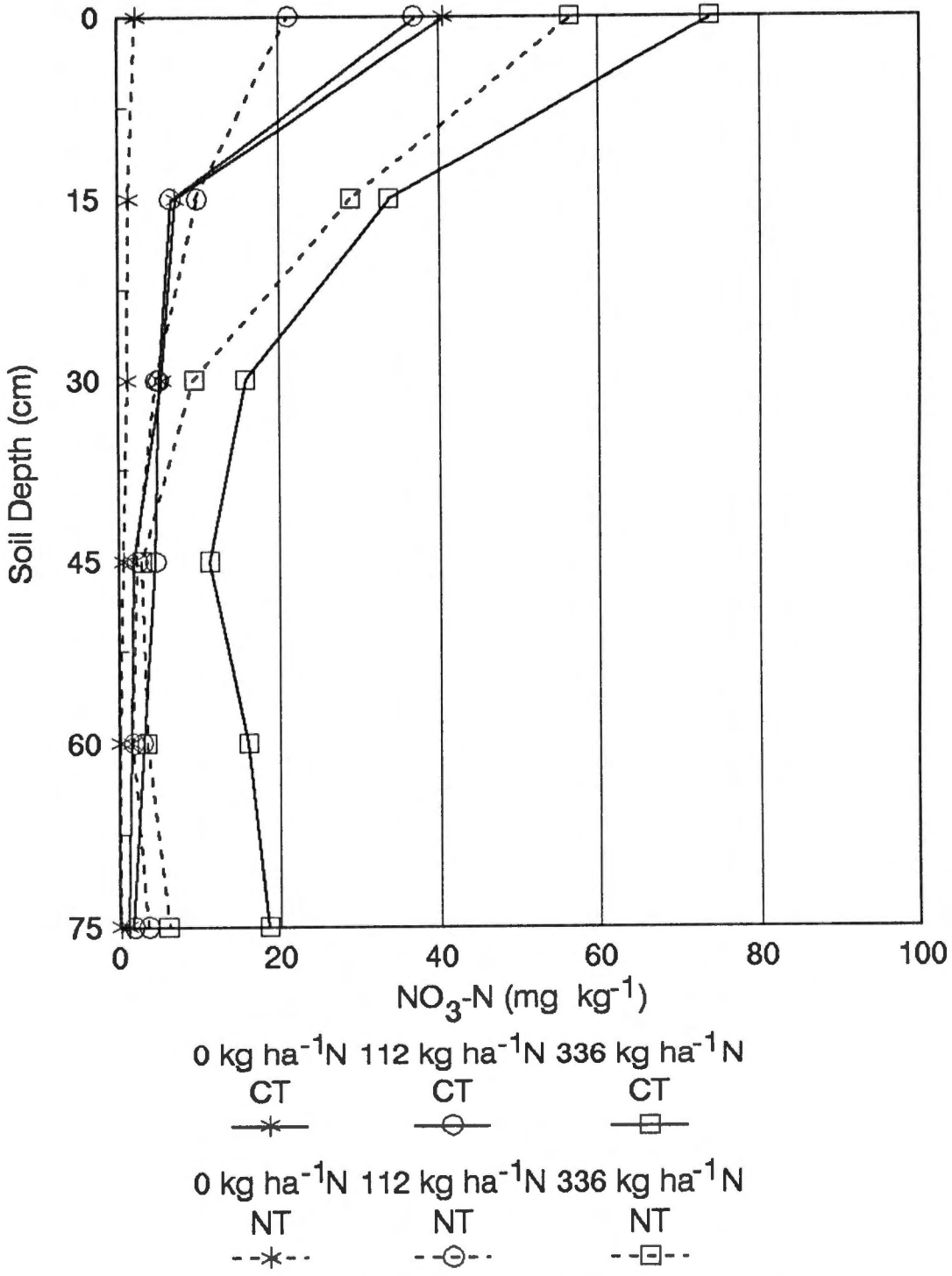

Figure 6. Effect of tillage treatments on NO_3-N concentration in the soil, 8/02/91.

concentrations than the other nitrogen fertilization levels in both tillage systems to the 30 cm depth.

Mass Balance

A mass balance was computed for metribuzin and NO_3-N by adding the runoff losses for the few discrete simulated rainfall events with the continuous measurements of leaching losses. In 1990, a total of 12.3 g of the 840 g of metribuzin applied could be accounted for from CT plots (Table 4). In comparison, 82.0 g of metribuzin was accounted for from the NT plots. In both cases, most of the metribuzin was found in subsurface flow out of the root zone. In 1991, this trend was reversed for CT with more than 90% of the 20.4 grams of metribuzin detected being found in runoff. No tillage plots exhibited a fairly even distribution between runoff and leaching losses of metribuzin in 1991. Metribuzin not accounted for was likely lost in runoff of natural rainfall events, taken up by the plants, or degraded. Evidence of metabolites was observed in latter runoff samples and lysimeter samples. However, metabolites were not quantified. Differences between years were most likely attributed to more degradation, as conditions were drier and more metribuzin would have stayed nearer the surface of the soil in 1991.

Table 4. Total mass of metribuzin and NO_3-N observed in runoff and leachate, 1990-1991.

Year	Tillage Treatment	Metribuzin[X] g ha^{-1}			NO_3-N[Y] kg ha^{-1}		
		Runoff	Leachate	Total	Runoff	Leachate	Total
1990	CT	1.8	10.5	12.3	0.5	31.9	32.4
	NT	0.2	81.8	82.0	0.2	270.2	270.4
1991	CT	19.4	1.0	20.4	0.4	112.5	112.9
	NT	7.1	6.3	13.4	0.2	413.0	413.2

[X] Metribuzin was applied at 840 g ha^{-1}.

[Y] Nitrogen was applied at 112 kg ha^{-1}.

Losses of NO_3-N by runoff were very low from both tillage treatments both years (0.5 kg or less) (Table 4). However, NO_3-N leached out of the root zone under the NT plot receiving the recommended 112 kg ha^{-1} of nitrogen fertilization was very high both years. The total leaching loss was 2.7 and 4.1 times the amount of nitrogen applied in 1990 and 1991, respectively (270.2 kg in 1990 and 413.0 kg in 1991). Leachates from CT plots contained less NO_3-N (31.9 kg in 1990 and 112.5 kg in 1991) than leachate from NT plots, supporting the hypothesis of more leaching under NT.

CHAPTER V

SUMMARY AND CONCLUSIONS

Overall, greater movement of water, NO_3-N, and metribuzin was observed under NT soil than under CT soil. Undisturbed macropores of the NT system were believed to cause faster movement of water and less soil contact of fertilizer and pesticides. This resulted in greater leaching losses under NT and higher resident concentrations in CT soil than in NT soil. Due to the channelization of the subsurface soil, the small pans (12.7 cm X 30.5 cm) collected flow from an area considerably larger than their size and with large variability (C.V. = 145%). The two larger pans were assumed to produce more representative flow measurements. Soil water content was observed to be unaffected by tillage systems. Residual NO_3-N and metribuzin concentrations were generally higher, at least in the top 15 cm, in CT soil than NT soil. These differences were most likely a result of the water moving through the macropores by-passing soil matrix pores in the NT soils, while water movement through CT soils occurred more through the soil matrix.

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