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Quantifying the effects of sawdust application on soil chemical and physical properties and corn yield

Huong Mai Tran
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Huong Mai Tran entitled "Quantifying the effects of sawdust application on soil chemical and physical properties and corn yield." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant Sciences.

H. Paul Denton, Major Professor

We have read this thesis and recommend its acceptance:

Richard Buggeln, Neal Eash, Mark Radosevich

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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Anne Mayhew
Vice Chancellor and
Dean of Graduate Studies

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QUANTIFYING THE EFFECTS OF SAWDUST APPLICATION ON SOIL CHEMICAL AND PHYSICAL PROPERTIES AND CORN YIELD

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Huong Mai Tran

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I also would like to thank the staff at the University of Tennessee Tobacco Experiment Station in Greeneville for providing the study site and the field operations for the project.

Abstract

Sawdust is a wood waste containing a very rich carbonaceous component that can be used as soil amendment. However, it is also important to understand the adverse impact that sawdust might have on soil and crops. In this study, sawdust application at varying rates of nitrogen fertilizer was investigated in soils planted with two years of no-till corn and in soils planted in one year tilled and no till corn. Sawdust may be beneficial due to its rich carbonaceous nature, but it may also affect nitrogen availability for the same reason. Data on crop yield, soil physical and chemical properties such as bulk density, pH, P, K, NO_3^-, organic matter, and total soil C and N were analyzed to study the effect of sawdust on corn yield and soil quality. Three experiments were conducted including (1) two-year no-till corn with spring sawdust application (Experiment 1), (2) one-year no till corn with spring and fall sawdust application (Experiment 2), and (3) one-year tilled corn with spring and fall sawdust application (Experiment 3). Results showed no effect of sawdust on soil pH in all treatments, slight to negligible detrimental effect on corn yield which was overcome in most cases by addition of N fertilizer and significant depression on soil nitrate as a result of N immobilization. However, contrary to previous studies, no increase in soil organic matter and soil total carbon occurred. Likewise, soil total N and bulk density of the soil after two years did not differ with sawdust addition. It is probable that the short time frame of the study prevented these effects from being expressed.

Keyword: nitrogen, carbon, nitrate, soil organic matter, pH, N immobilization, sawdust.

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Nomenclature

kg	kilograms
Mg	megagrams
ha	hectares
mm	millimeters
ppm	part per million

Abbreviations

Al	Aluminum
ANOVA	Analysis of Variance
C	Carbon
CO_2	Carbon dioxide
Fe	Iron
K	Potassium
LSD	Least significant difference
N	Nitrogen
NH_4^+	Ammonium
NO_3^-	Nitrate
P	Phosphorus
SD	Sawdust
SOC	Soil organic carbon
SOM	Soil organic matter

1. CHAPTER I: INTRODUCTION

In the United States, the wood processing business has become a big industry due to increasing demand. As a result, an appreciable amount of wood waste has been generated. McKeever (1999) stated that over 160 million tons of "waste wood" were generated in the U.S in 1998. These wastes, which were once put in the landfills, have increasingly been made into usable products. Existing wood waste in the US comes from three major sources: 1) municipal solid waste; 2) construction and demolition waste; and 3) wood residues from primary timber processing mills. The total amount of each source and each type of wood waste is presented in Table 1.1.

In primary timber processing, slightly over one half of the volume of a 14 inch diameter red oak log becomes lumber. The wood wastes generated include: bark (14% of the volume), chippable material such as slabs and edging (16%), and sawdust (19%). According to Schweitzer (1999), approximately 11,740 tons of wood per year are exploited for the wood processing industry in Tennessee. Of the annual wood waste production in this state, 560,107 tons are sawdust from sawmills. In the US as a whole, large quantities of sawdust and other wood wastes accumulate each year, especially in the far West, North Central and Southern States, as shown in Table 1.2.

Sawmill residues that were once considered practically useless and, therefore, often discarded have increased in value due to a demand for these residues as salable products. These residues have been reused in many different ways, including pulp and paper production, nonstructural panels, strand board, domestic and industrial fuel.

Table 1.1. Wood waste generated, recovered, combusted, or not usable, and wood waste available for recovery in the United States, 1998.

Source	Generated (million tons)	Recovered, Combusted Or Not Usable (million tons)	Available For Recovery	
			Amount (million tons)	Total Waste Wood Available (%)
<u>Municipal solid waste</u>				
Waste wood	11.8	6.4	5.4	18
Woody yard trimmings	25.2	18.4	6.8	23
Total	37.0	24.8	12.2	41
<u>Construction and demolition waste</u>				
Construction	8.7	2.1	6.6	22
Demolition	26.4	17.4	9.0	30
Total	35.1	19.5	15.5	52
<u>Primary timber processing residues</u>				
Bark residues	24.5	23.9	0.6	2
Wood residues	65.8	64.5	1.3	4
Total	90.3	88.4	1.9	6
Total waste wood	162.4	132.8	29.6	100

Source: McKeever (1999).

Table 1.2. Annual production of wood waste residues (oven-dry basis) in the 201 counties of the TN Valley.

	Wood waste residues (million tons)			
	Sawdust	Chips	Shavings	Bark
Used	1.07	1.82	0.53	1.23
Unused	0.32	0.40	0.34	0.17
Total	1.40	2.22	0.87	1.41

Source: Pier and Kelly (1997)

Skog and Rosen (1997) reported that wood residue from primary wood processing made up about 41 x 10^6 tons in 1991 in the U.S. The most common recycling use of this residue is as fuel for conservation of fossil fuels.

Despite the remarkable effort that has been made in recycling wood residues, a great amount of these materials are still being unused. For sawdust in particular, dumping in land fills, burning, or simply outdoor storage in piles are common types of waste management. As wood waste generation increases, disposal of this amount of sawdust by land fill requires a fairly large area which is not a wise or recommended solution in the long run. Burning a great amount of this waste will release increasing CO_2 gas and other pollutants into the atmosphere. Piling of sawdust can lead to a number of problems in the environment such as CO_2 emission due to microbial activity and other complex changes derived from successive activities of biochemical, microbiological, and organic chemical reactions. Moreover, sawdust which contains highly degradable organic carbon is a potential source of methane production once stored either in piles or converted to landfills under anaerobic conditions (Pier and Kelly, 1997). Fly ash from burning and windborne dust and dirt, as well as fire hazard have also been encountered in pile areas (Hajny, 1966). All of these practices raise air pollution concerns. Outside piles may also potentially contaminate groundwater through leaching and surface water through runoff. Therefore, it is necessary to search for an environmentally-oriented solution to this problem. To date, several practical ways of utilizing sawdust in an environmentally sound manner are: as mulch, as bedding for livestock, in compost, and by direct application into the soil. Since sawdust is an additional plant residue and a rich carbonaceous substance, it holds promise in supplying humus once applied in soils.

For the purpose of this study, using sawdust as a soil amendment was investigated under two different soils management systems, conventional tillage and no till.

Traditionally, conventional tillage involves mechanical soil manipulation of an entire field by ploughing followed by one or more harrowing. This obviously is a capital and energy intensive activity once applied in large-scale farming. By its nature, great disturbance of soils has resulted, such as increases in soil erosion and changes in soil temperature regime and soil moisture condition. More importantly, conventional tillage has recently been recognized as a source for emission of CO_2 into the atmosphere, which has drawn increasing concern about tillage impact on the environment through global warming. In response to these undesirable effects of tillage, conservation tillage has been developed in recent years in an effort to minimize possible impact to the environment and to conserve and simultaneously improve soil quality. Of the five current conservation tillage practices, which are known as no-tillage, mulch tillage, strip or zonal tillage, ridge till, and reduced or minimized tillage, no-till (NT) management is increasing.

The no-till system consists of a one-pass planting operation in which disturbance of the soil and the surface residues is minimized (Parr et al., 1990). Weed control is generally achieved with herbicides or in some cases with crop rotations. According to Lal (1983), no-tillage systems eliminate all preplant mechanical seedbed preparation except for the opening of a narrow (2-3 cm wide) strip or small hole in the ground for seed placement to ensure adequate seed/soil contact. The entire soil surface is covered by crop residue mulch or killed sod.

By minimizing soil disturbance through NT, CO_2 emissions are reduce thereby increasing soil C through the retention of soil organic matter (SOM). This practice holds promise in improving soil quality through reduced erosion, increased soil structural stability and decreased oxidation of SOM, and in increased improving the efficiency of crop production by soil water storage, lower energy cost per unit of production and higher grain yields. Even though the use of NT is increasing, the adoption is still low. While no-till is used on two-thirds of the area of the major warm season annual crops of corn, soybean and cotton in Tennessee, this practice has been applied on less than 23% of the whole nation's cropland area (Conservation Technology Information Center, 2005).

In an effort to develop a system that obtains the highest yield and not only conserves but also improves soil properties most effectively, sawdust and nitrogen fertilizer were applied in this study at varying rates in NT and conventional till corn.

2. CHAPTER II: LITERATURE REVIEW

2.1 Soil carbon and soil organic matter

Carbon is present in six global carbon reservoirs: atmosphere, world ocean, lithosphere, land biosphere, biosphere of inland waters, and fossil fuel with corresponding amounts in each reservoir presented in Table 2.1. A small but important proportion of the global C is stored in the soil pool, which consists of inorganic and organic C components. C is the chief element present in SOM, comprising from 48 to 58% of the total weight. The soil organic carbon (SOC) includes a "mixture of plant and animal residues at various stages of decomposition, of substances synthesized microbiologically and/or chemically from the breakdown products, and of the bodies of live microorganisms and small animals and their decomposing products" (Schnitzer, 1991). The soil inorganic carbon (SIC) consists of elemental C and primary and secondary carbonate minerals. Primary carbonates are from parent materials and secondary carbonates are formed from the reactions of atmospheric carbonic gas with Ca^{2+} and Mg^{2+} (Lal and Kimble, 2000). Concerns about global warming caused by the presence of high levels of carbon dioxide in the earth's atmosphere have greatly increased recently. Though cultivation of agricultural soils is not an obvious source of greenhouse gases (GHGs) compared with direct fossil fuel combustion, improper agricultural management has led to the reduction in the soil C pool with attendant emission of GHGs (e.g., CO_2, CH_4) into the atmosphere. Numerous strategies have been considered to reduce the net atmospheric CO_2 increase, of which agricultural practices that help increase soil carbon storage, or soil C sequestration, are highly attractive due to

Table 2.1. Global carbon reservoirs.

Reservoir	Amount of carbon (Gt C)
Atmosphere	720
World Ocean	
Total inorganic carbon	37,400
Surface layer	670
Deep layers	36,730
Total organic carbon	1,000
Total Ocean	38,400
Lithosphere	
Carbonate sedimentary rocks	>60,000,000
Kerogens	15,000,000
Total lithosphere	>75,000,000
Land biosphere	
Living biomass	600-1,000
Dead biomass	1,200
Total	2,000
Biosphere of inland waters	1-2
Fossil fuel	
Coal	3,510
Oil	230
Natural gas	140
Other (peat, etc.)	250
Total	4,130

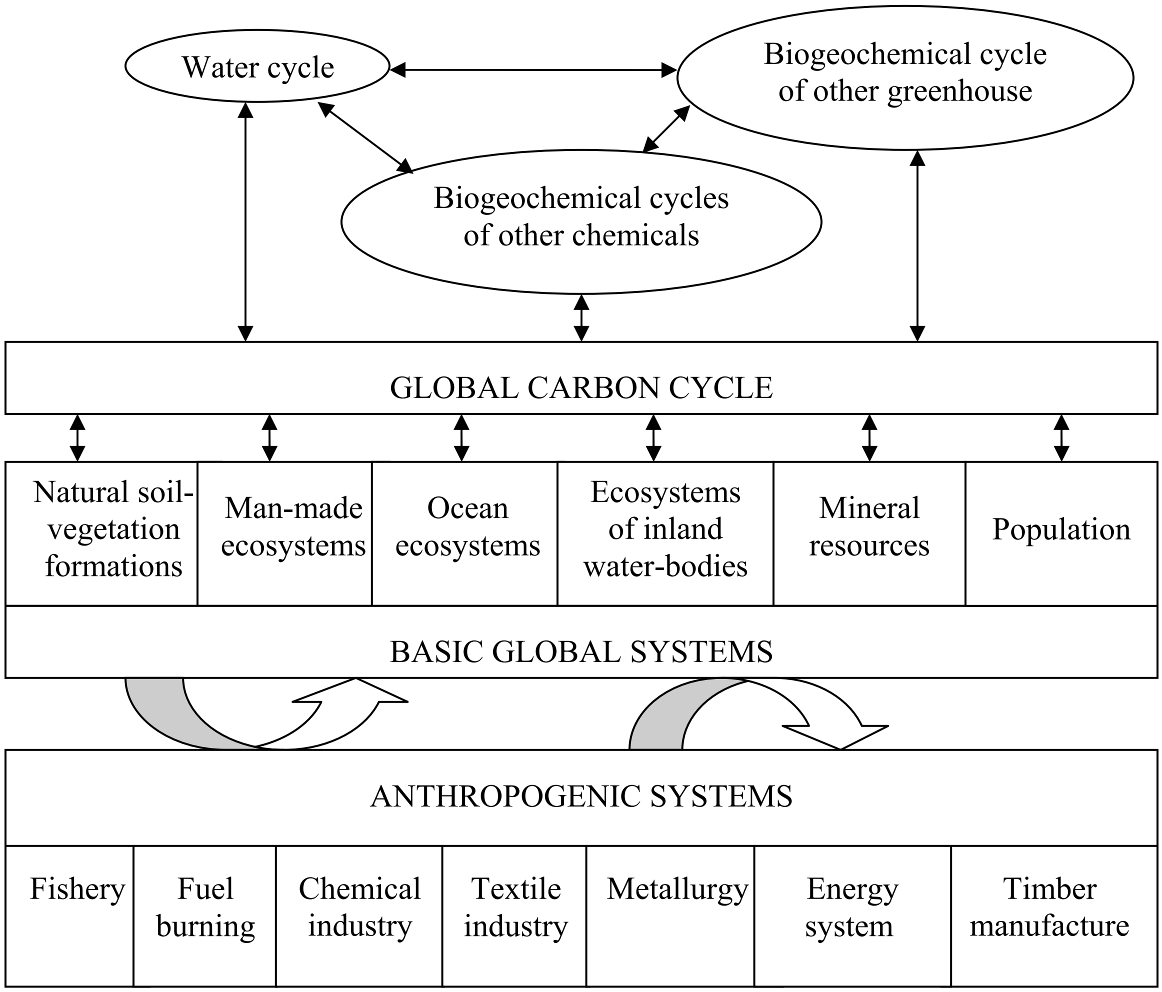
Source: Kondratyev et. al (2003).

their capability to also improve soil quality. SOC affects soil physical quality through changes in soil structure, aggregation, total and macro-porosity, susceptibility to crusting and compaction, and ease of root system development. Soil fertility is improved due to the capacity of SOC to hold and slowly release plant nutrients in the process of decomposition or mineralization. SOC also plays a key role in cycling of essential elements including N, P, S and Zn (Lal, 2002). SOC is the main source of energy that sustains the soil biota which functions in respiration and decomposition. Biological processes depend on the SOC pool and the characteristics of humic substances in soils.

SOM is the most complex and least understood soil component. SOM has been defined as the organic fraction of soil, including plant, animal, and microbial residues (fresh and at all stages of decomposition), and the relatively resistant soil humus (Nelson and Sommers, 1996a). Most arable soils contain only 2 to 4% organic matter by weight. SOM has been long recognized to be a very important component influencing soil properties. It plays a key role in formation and stabilization of soil structure, which in turn produces good tilth and drainage, and resistance to erosion. High SOM content can increase soil porosity, and hence decrease bulk density. Macks et al. (1996) demonstrated that friability (the tendency of soil clods to easily crumble into their constituent natural aggregates) is significantly related to organic carbon, aggregate stability and bulk density. Highly friable soils increase the ease of tillage (Magdoff and Weil, 2004). Capacity of SOM to increase infiltration and retention of water has been long perceived. In the chemical sense, SOM is not only capable of storing and making available nitrogen, sulfur and phosphorus, but also other elements needed for plant growth such as metals to plants. Cation exchange capacity and anion exchange capacity, and adsorption and deactivation of agricultural chemicals are greatly influenced by SOM. Most importantly, SOM acts as a soil pH buffer that helps provide a "healthy" environment for plants and soil biota to function. SOM participates in as a chelating agent for removal of cations in the dissolution of minerals as well as in inhibiting mineral formation and crystallization (Essington, 2002). Though research during the past 50 years has placed much emphasis on the benefit of SOM to soils, its effect on crop productivity has not been well understood due to obstacles in separating factors affecting crop yields. One reason for this difficulty is that SOM levels are usually related to climate, topography, and soil texture (Magdoff and Weil, 2004). Strickling (1975) was successful in isolating the effects of SOM on corn yield and found that SOM levels accounted for 82 to 84% of the variation in corn yield on a Beltsville silt loam (Typic Fragiudults) in Maryland, regardless of level of N fertilizer. The SOM effect on corn yield in Stricking's study was attributed to its capacity in enhancement of water infiltration resulting from improved aggregation. Therefore, maintaining and increasing SOM through employing conservation tillage and effectively utilizing external organic material additions to soils are of importance for a sustainable agricultural management system.

2.2 Sawdust as soil amendment

Sawdust is a carbonaceous organic substance which has a very high carbon to nitrogen ratio (typically C:N in sawdust is 300:1). Table 2.2 and Table 2.3 show the carbonaceous properties and composition of sawdust. Therefore, it holds potential as a contributing carbon source for increasing SOM when soil applied. Carbon cycle was shown in Figure 2-1.



Source: Kondratyev et al. (2003).

Figure 2-1. The carbon cycle in the environment.

Table 2.2. Content of important components of sawdust and their C content.

C in fresh sawdust	Lignin in sawdust	C in lignin	Cellulose/ hemicellulose/ Other organics	C in cellulose/ hemicellulose/ Other organics
% by weight				
51.9	30.8	51.8	69.2	52.0

Source: Pier and Kelly (1997).

Table 2.3. Elemental composition of sawdust.

Composition of Sawdust (%)			
C	H	O	N
48-54	5.8-6.3	39-45	0.1-0.3

Source: Allison and Anderson (1951).

Many studies showing the effect of sawdust on improving soil quality were initially conducted in the 1940's and early 1950's, though little attention was paid then due to farmers' concern about possible toxicity which sawdust might cause to crops and soil. Literature has shown no toxicity of wood to plants when applied to the soil except for wood and bark from red oak (Quercus rubra) (Allison, 1965). In fact, some substances in a few woods and barks such as resins, turpentine, and tannin in large amounts may be harmful to certain plants. These materials, fortunately, are decomposed fairly rapidly in soil. Allison (1965) also indicated that though some exceptions occurred, most wood products do not contain a concentration of toxic compounds high enough to appreciably affect their use in agriculture. The corn plant symptom of yellow leaves that worried farmers in the 1940's and 1950's, was due to nitrogen insufficiency as farmers applied sawdust alone.

Once applied, these carbonaceous substances will provide soil microorganisms with a rich source of energy. However, in order to reproduce, soil microorganisms require not only carbon but other elements, with the second most important one being nitrogen. As the C:N ratio in microorganisms is about 8:1, the application of sawdust, which has high C:N ratio, into the soil will likely limit available nitrogen and cause inorganic soil N to be immobilized (Myrold, 1998). Therefore, in order to be able to function, microorganisms need to obtain nitrogen from other sources, either the soil or nitrogenous materials added to the soil. Where growing crops are present, a competition for nitrogen and possibly other substances occurs between soil microorganisms and the plants, causing nitrogen immobilization. In nitrogen immobilization, ammonia and nitrate are taken up by microbes and are largely immobilized, or made unavailable to plants, depending on the C:N ratios. The relationship between the C:N ratios and net immobilization and nitrification is presented in Table 2.4. Unless supplementary addition of nitrogen is made in the forms of legume green manure or nitrogen fertilizer, the crop will show nitrogen deficiency.

Table 2.4. The relationship between C:N and N mineralization/immobilization.

C:N		
<20	20-30	>30
Net release of NH_4^+ and NO_3^-	Neither release nor immobilization	Net immobilization of NH_4^+ and NO_3^-

Source: Myrold (1998).

Soil-plant N dynamics can be affected within non-leguminous cover crop system due in part to the relatively slow decomposition rates associated with these residues (Wagger, 1989). Since sawdust typically contains an average of 0.1 to 0.2 percent nitrogen, soil microorganisms in soil where it is applied in large quantities will encounter a shortage of nitrogen and may obtain nitrogen from other sources such as a soil pool and addition supplies applied as fertilizer. When no additional nitrogen is provided, nitrogen immobilization sufficient to assure N deficiency in plants will likely to occur when sawdust is applied to the soil. Therefore, raising the nitrogen of sawdust to 1% by addition of other sources has been recommended to give best biological decomposition. Additional unneeded nitrogen was less beneficial because it lowered the pH and increased the salt concentration, which ultimately limits microflora activity (Allison, 1965).

The rate of decomposition of organic matter added to the soil depends largely on the C:N of the materials. Typical C:N in various materials is present in Table 2.5. The type of wood which sawdust originally comes from, such as hardwood and softwood, contributes to the rate of sawdust decomposition. In fresh sawdust, as mentioned earlier, the cellulose and hemicellulose making up close to 70% are easily decomposed by microorganisms compared to lignin and other substances in wood. Allison (1965) indicated that both wood and bark from hardwood decompose more readily than those from softwood, even though a similar C:N ratio was found in both types of wood.. In addition, the decomposition of wood is accelerated by nitrogen fertilizer. The present study uses fresh sawdust from hardwood, particularly oak, as the research material. The total CO_2 release of wood from white oak was the greatest among woods or barks from 9

Table 2.5. C:N ratio in organic materials.

Material	C:N ratio
Humus	10:1
Food scraps	15:1
Alfalfa hay	18:1
Grass clippings	19:1
Rotted manure	20:1
Sandy loam (coarse)	25:1
Vegetable trimmings	25:1
Oak leaves	26:1
Leaves	35:1 to 85:1
Peat moss	58:1
Corn stalks	60:1
Straw	80:1
Pine needles	60:1 to 110:1
Farm manure	90:1
Alder sawdust	134:1
Sawdust weathered 3 years	142:1
Newspaper	170:1
Douglas fir bark	491:1
Sawdust weathered 2 months	625:1

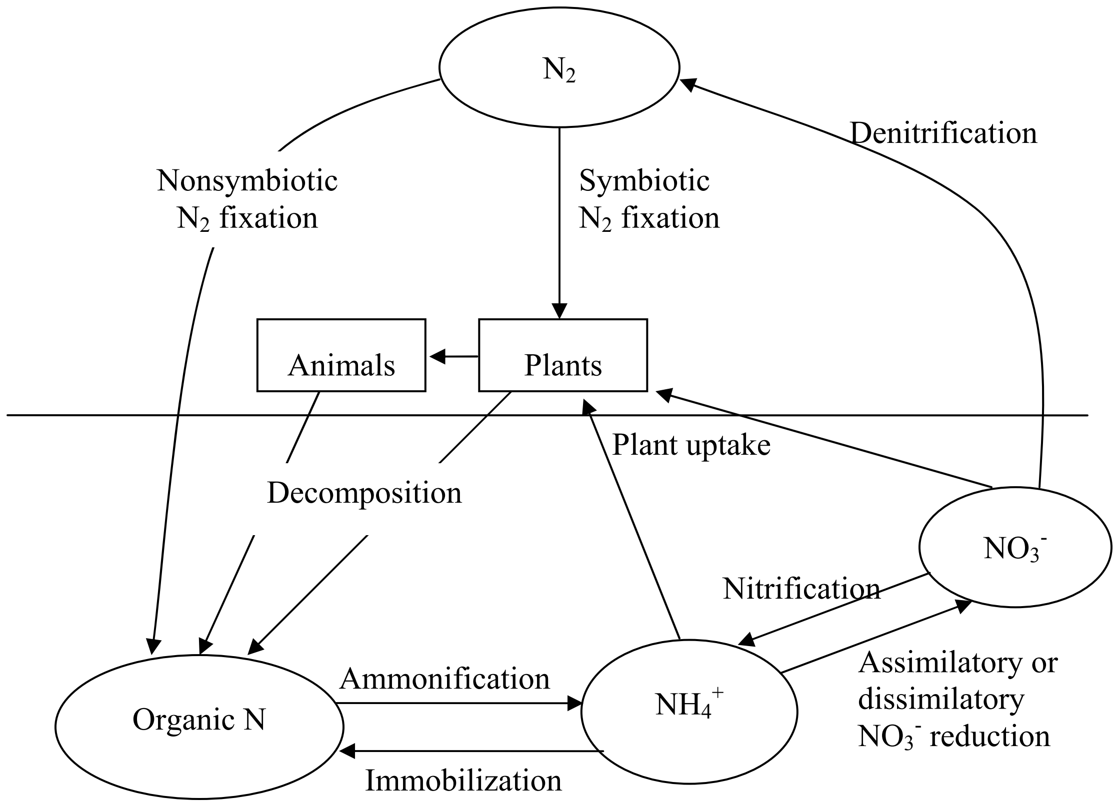
Source: Washington State University Extension (2005).

hardwood species and 19 softwood species in their study (Allison, 1965).

Soil-plant dynamics can be affected within non-leguminous cover crop system due in part to the relatively slow decomposition rates associated with these residues (Wagger, 1989). Since sawdust typically contains an average of 0.1 to 0.2 percent nitrogen, soil microorganisms in soil where it is applied in large quantities will encounter a shortage of nitrogen and may obtain nitrogen from other sources such as a soil pool and additional supplies applied as fertilizer. When no additional nitrogen is provided, nitrogen immobilization sufficient to assure N deficiency in plants is likely to occur when sawdust is applied to the soil. Therefore, adding 1% nitrogen to applied sawdust has been recommended to give best biological decomposition. Additional unneeded nitrogen was less beneficial because it lowered the pH and increased the salt concentration, which ultimately limits microflora activity (Allison, 1965).

2.3 Nitrogen cycle

N cycle is illustrated in Figure 2-2. Nitrogen plays a vital role for the plant growth. Even though elemental N_2 gas nitrogen makes up 78 percent of the atmosphere, the element is too stable to transform easily into a reactive form that plants can take up. Lightning is known to be capable of cleaving these strongly bonded molecules; however it happens neither on a regular nor frequent basis enough to provide sufficient supplies of available nitrogen. The most natural nitrogen "fixation", in which the splitting of paired nitrogen molecules and subsequent incorporation of the element into the chemically reactive compound ammonia occur, is done by bacteria. The most well known N-fixing bacteria are of the genus Rhizobium, symbionts that create nodules on the roots of



Source: Myrold (1998).

Figure 2-2. Nitrogen cycle.

leguminous plants, such as beans or acacia trees. Cyanobacteria that live either freely or in association with certain plants are capable of fixing nitrogen as well. Traditionally, farmers replaced the loss of nitrogen by enriching their fields with human or animal waste. But these materials contain low concentration of available nitrogen. In some parts of the world such as Asia, legumes, such as a so called green manure Azolla fern, which harbor nitrogen-fixing cyanobacteria have been grown and incorporated into the soil without being harvested for food. With the real breakthrough invention of ammonia synthesis from nitrogen and hydrogen by Haber in 1913, the whole world has benefited from synthetic nitrogen fertilizer that provides about one third of the protein in human (Smil, 1997).

2.4 Effects of organic material addition on crop yields and soil properties

2.4.1 Crop yields

There have been many studies on soil amendment using different materials such as those shown in Table 2.5. Observations on crop yields have varied widely among studies, including increasing, decreasing, or having no effect on the yield of crop planted into rye (Secale cereale L.), depending on soil, climatic, and management condition (Ebelhar et al., 1984; Eckert, 1988; Mitchell and Teel, 1977; Moschler et al., 1967; Wagger, 1989). Rye, wheat (Triticum aestivum), and hairy vetch (Vicia villosa Roth.) are widely used cover crops because of the potential of rye and wheat for weed suppression and erosion control and the N contribution of vetch to soil. Burgos and Talbert (1996) found that sweet corn yield was less from plots with rye cover crop compared to check plots in the first year but was not affected in the second year. Without applied N, grain yields in the rye cover were depressed, presumably due to N immobilization (Wagger, 1989; Eckert, 1991). Residue from a rye cover crop commonly has C:N ranging from 25:1 to 50:1, significantly inhibits emergence and growth of weeds (Burgos and Talbert, 1996; Regnier and Jahnke, 1990), and reduces corn whole-plant yields if late killed (just prior to planting) (Raimbault et al., 1991). Yield reduction of corn when planted directly following a winter rye crop relative to planting after corn silage without a rye cover crop was indicated by Raimbault et al. (1990). The use of cover crops such as rye and bigflower vetch (Vicia grandiflora var. kitaibeliana) in conservation tillage has been reported to increase soil organic matter (DeGregorio et al., 1995). However, corn yield response to applied N was greatest in a rye cover crop system compared to fallow, crimson clover (Trifolium incarnatum L.), or hairy vetch (Wagger, 1989; Eckert, 1991).

It has been widely accepted that sawdust when applied either as a mulch or by incorporation in the soil can be beneficial to plant growth and to the soil in that it improves soil organic matter content and related biological, physical and chemical properties. Early studies under field conditions mostly employed conventional tillage with sawdust application either as mulch or by incorporation into the soils, with and without nitrogen fertilizer supplement (Johnson, 1944; Lunt, 1955).

Many studies of the effect of sawdust on crop yields have been conducted during the last 60 years. In a study by Johnson (1944), tomato yield was greater in plots where sawdust was applied as a surface mulch than in sawdust incorporated plots in the first year. The results were reversed after two years. When nitrogen fertilizer was added, greater yield was obtained in sawdust-incorporated treatments than in those without sawdust. The depressive effect of the incorporated sawdust was shown only in the first growing season. After this period, the yields with sawdust exceeded those of the check plots. In this study, the length of time that sawdust has been applied to the soil was an important factor accounting for the effect of sawdust on crop yield. Sawdust application alone showed a detrimental effect on crop growth and yield (Turk, 1943). However, this effect was only temporary due to the recovery of soil nitrates. Sawdust was found not to prohibit nitrate formation by nitrification but rather to decrease the accumulation of nitrate because of microbial assimilation. Results from the most recent study, however, reflect a negative effect of sawdust on growth of highbush blueberry relative to unamended soil, regardless of N treatment (Yang et al., 2002).

In combinations of carbonaceous materials with fertilizer, however, a positive response of crop yield was observed (Roberts, 1948; Lunt, 1955). Obiefuna (1986) found that application of sawdust mulch as organic manure combined with fertilizer effectively increased yield of False Horn Plantains. Corn grain yield response to applied N was greatest in a rye cover crop system compared to that obtained with crimson clover and hairy vetch (Wagger, 1989).

2.4.2 Soil properties

A recent study on the effects of sawdust and wood chip on forest soil properties by Bulmer (2000) indicated benefits from sawdust application such as trees with more volume and soil with higher organic matter level and more moisture retention relative to untreated soil. Johnson (1944) also found that more moisture was present in soil treated with sawdust than was present in the soil without sawdust. Sawdust mulch was also found to increase soil oxygen diffusion rate, maintain a more uniform soil temperature, reduce the surface crusting and soil bulk density, and increase the aeration porosity and soil moisture (Johnson, 1944; Khan et al., 2000; Lareau, 1989). In a greenhouse experiment on the effect of wood chips on properties of soil, Lunt (1955) concluded that bulk density decreased, moisture increased, pH remained constant, total pore space increased, and total nitrogen and organic carbon increased in all treatments amended with chips as compared to check plots. Similar conclusions were made by Turk (1943) in studies under both laboratory and field condition.

An important principle in agricultural management is to maintain a neutral to slightly basic acid soil pH range because of its close relation with soil fertility and plant growth. Both extremely high and low soil pH hinders the efficient functioning of most soil microorganisms and plants. Nutrient availability is commonly greatest between pH 6 and 7. For example, in this range, nitrogen mineralization is maximum, and the availability of P is not limited by precipitation and adsorption by Fe and Al as at lower pH (Magdoff and Weil, 2004). The presence of other elements that are toxic to plant, such as Al^{3+} and Mn^{2+} is also restricted in a near neutral soil compared to acid soils. Therefore, a look at the possible effect of SD on soil pH is of great concern in this study. Early studies have disagreed about the effect of SD on soil acidity. While Allison and Anderson (1951) reported that SD decomposition contributed a slight to negligible temporary increase in acidity, Kwasna et al. (2000) showed that soil pH decreased 2 years after sawdust treatment in the plots that had been left fallow for 6 years before sawdust addtion but increased in plots that had been left for 3 years. A four-year study by Eckert (1991) concluded that there was little major effect of rye cover crops in no-till cropping systems on two Ohio sols in terms of soil fertility. He also suggested there should not be any concerns about an adverse impact of a rye cover crop on pH distribution by depth in the soil.

2.5 Objectives

It is apparent that little attention has been paid in exhaustively examining and quantifying the effect of sawdust on plant growth and soil physical/chemical properties, especially in combination with different modern farming practices such as no-till and high rates of N fertilizer. With the current need to dispose of sawdust by land application and adoption of the no-till system, more research is needed on soil amendment with sawdust in order to maximize soil conservation and crop yield simultaneously. Therefore, the objectives of this study are to:

- (1) Quantify the effects of sawdust application and the rates of sawdust and nitrogen fertilizer that will produce maximum yield for corn in no-till and conventional tillage.
- (2) Document soil chemical and physical changes.

The specific research objectives are:

Evaluate and compare the effect of sawdust application and nitrogen fertilizer rates on crop yield and soil properties in 3 experiments:

* Experiment 1: Two consecutive seasons of NT corn with spring SD application.
* Experiment 2: One season of fall vs. spring SD application on NT corn.
* Experiment 3: One season of fall vs. spring SD application on conventional tillage corn.

3. CHAPTER III: MATERIALS AND METHODS

3.1 Experimental site and soil characterization

Three field experiments investigating the effects of land application of sawdust in corn production were conducted during 2003 and 2004 at the University of Tennessee Tobacco Experiment Station in Greeneville, Tennessee. The exact location of the station is N 36^o 04’ and W 82^o 50’. The elevation is approximately 400 m. Greeneville is located in Greene County which is in the northern portion of the Great Valley of East Tennessee.

As a result of proximity to the western slopes of the Appalachian Mountains, the Station’s mean annual precipitation is 1074 mm which is rather higher compared to the statewide lowest annual precipitation of about 965 mm, which occurs in parts of the Great Valley which have a “rain shadow” effect from the Cumberland Mountains to the west. Mean annual air temperature is 13.7 degree C.

Climatological information for the site is summarized in Table 3.1 and Table 3.2.

Prior to this study, the experiment site was in four-year fescue grass. Over time, the site has been in a rotation of tobacco with 2 to 4 years of grass.

The soil type was a Nolichucky loam (fine-loamy, siliceous, thermic Typic Paleudult) for experiment 1 in 2003 and 2004 and a mixture of Nolichucky loam and Waynesboro loam (fine, kaolinitic, thermic Typic Paleudult) for Experiments 2 and 3 in 2004. Experiment 1 was a two consecutive season experiment with no till corn. The second and the third experiments were one season of no till and tilled corn, respectively. Both the Nolichucky soil series and the Waynesboro series are derived from alluvial parent material on high terraces, and are typical upland/high terrace soils in the limestone

Table 3.1. Temperature summary in Greeneville during the period from 1971-2000 (^{o}C).

Month	Temperature (^{o}C)								
	Means			Extremes		Mean number of days			
						Max		Min	
	Daily max	Daily min	Mean	Highest month mean	Lowest month mean	>= 32	<= 0	<= 0	<= -17
Jan	8.0	-6.4	0.8	6.8	-6.4	0.0	3.7	23.6	0.9
Feb	10.6	-5.3	2.7	6.5	-3.2	0.0	2.3	20.6	0.5
Mar	15.5	-1.7	6.9	9.7	3.7	0.0	0.3	15.9	0.1
Apr	20.3	2.0	11.2	14.3	8.3	0.1	0.0	7.5	0.0
May	24.8	7.4	16.2	19.3	13.9	0.1	0.0	0.7	0.0
June	28.7	12.7	20.7	22.8	18.1	3.8	0.0	0.0	0.0
July	30.6	15.5	23.1	25.1	21.1	10.2	0.0	0.0	0.0
Aug	30.1	14.3	22.2	24.4	20.5	7.6	0.0	0.0	0.0
Sep	27.2	10.2	18.7	21.7	16.4	2.7	0.0	0.2	0.0
Oct	21.4	2.6	12.1	16.1	8.6	0.0	0.0	6.0	0.0
Nov	15.6	-1.9	6.9	12.1	1.4	0.0	0.1	16.0	0.0
Dec	10.2	-5.4	2.4	6.3	-3.1	0.0	2.0	22.8	0.2
Ann	20.3	3.7	12.0	25.1	-6.4	24.5	8.4	113.3	1.7

Source: USDOC-NOAA (2004).

Table 3.2. Summary of precipitation totals in Greeneville from 1971 to 2000 (mm).

Month	Precipitation totals (mm)							
	Mean	Greatest monthly	Greatest daily	Snow		Mean number of days		
				Mean	Max monthly	>= 2.54	>= 12.7	>= 25.4
Jan	89.7	156.0	56.9	76.2	292.1	8.0	2.6	0.5
Feb	88.4	167.6	61.2	53.3	350.5	7.4	2.3	0.6
Mar	109.5	226.3	100.6	22.9	330.2	8.6	2.6	0.7
Apr	94.5	216.9	60.7	5.1	127.0	7.5	2.6	0.7
May	113.5	234.2	127.8	0.0	0.0	8.6	3.0	0.9
Jun	107.2	220.2	72.1	0.0	0.0	8.0	3.0	1.2
Jul	120.1	267.7	80.0	0.0	0.0	8.0	3.5	1.3
Aug	96.5	181.6	71.6	0.0	0.0	7.1	2.5	1.0
Sep	82.6	140.2	62.2	0.0	0.0	6.1	2.3	0.8
Oct	59.7	160.8	84.8	0.0	25.4	5.1	1.6	0.4
Nov	76.2	131.1	56.9	0.0	25.4	6.6	1.8	0.7
Dec	86.9	191.5	58.9	25.4	198.1	7.2	2.1	0.5
Year	1124.7	267.7	127.8	182.9	350.5	88.2	29.9	9.3

Source: USDOC-NOAA (2004).

valleys of East Tennessee. Slope of these soils typically ranges from 2 to 30 percent and solum thickness may exceed 15 m. For the experimental area, slopes ranged from 1 to 3%.

A typical pedon description of Nolichucky soil is presented in Table 3.3 (USDA – NRCS. 2005). Nolichucky soils were formed in moderately fine textured alluvium from watersheds dominated by sandstone, quartzite, limestone and shale. This soil is well drained. Runoff is medium on gentle slope and permeability is moderate.

Waynesboro soils were formed in old alluvium or unconsolidated material of sandstone, shale, and limestone origin 1.2 to 6 m in thickness. A typical pedon description is presented in Table 3.4.

3.2 Experiment 1 - Two-year NT corn

With respect to the first experiment, the experimental design was a split plot consisting of sawdust and nitrogen fertilizer rates. Main plots were fresh mixed sawdust, predominantly oak (quercus species) and hickory (carya species), treatments of 0, 9, and 18 Mg ha^{-1}. Sawdusts used in Fall 2003 and Spring 2004 were oven – dried at 65^{o}C for 24 hours after storage in sealed plastic bags for a few months to determine water content. Water content in these sawdusts was approximately 10%. Water content in sawdust used in Spring 2003 was estimated to be close to those applied the second year but was not measured. The split plot treatments were N fertilizer rates of 170, 200 and 235 kg ha^{-1}. A total of 9 treatments with four replicates made up 36 plots. Main plots were in a randomized complete block design. Plot dimensions were 3.6 x 6.1 m and were

Table 3.3. Typical pedon description of Nolichucky soil (USDA – NRCS. 2005).

Horizon	Depth (cm)	Boundary	Texture	Color	Structure	Consistence	Other description
Ap	0-18	Clear smooth	Loam	Yellowish brown 10YR 5/4	Weak medium granular	Very friable	Many fine roots, slightly acid
BA	18-38	Clear smooth	Loam	Strong brown 7.5YR 5/8	Weak medium subangular blocky	Friable	Common fine roots, few small quartzite pebbles, medium acid
Bt1	38-53	Clear smooth	Clay loam	Yellowish red 5YR 5/8	Weak medium subangular blocky	Friable	Few fine roots, few faint clay films on faces of peds, few small quartzite pebbles, strongly acid
Bt2	53-81	Gradual smooth	Clay loam	Red 2.5YR 4/8	Moderate medium subangular and angular blocky	Friable	Few fine and medium faint strong brown (7.5 YR 5/6) and yellowish red (5YR 4/6) mottles on edges of peds, common distinct clay films on faces of peds, strongly acid.
Bt3	81- 142	Gradual smooth	Clay loam	Red 2.5YR 4/6	Moderate medium angular blocky	Friable	Many distinct clay films on faces of peds, strongly acid.
Bt4	142-191		Clay	Red 2.5 YR 4/6	Weak coarse subangular blocky	Friable	Few medium and fine distinct yellowish brown (10YR 5/6) and strong brown (7.5YR 5/6) mottles, many distinct clay films on faces of peds, very strongly acid.

Table 3.4. Typical pedon description of Waynesboro soil (USDA – NRCS. 2005).

Horizon	Depth (cm)	Boundary	Texture	Color	Structure	Consistence	Other description
A	0- 5	Abrupt smooth	Loam	Black 10YR 2/1	Moderate fine granular	Very friable	Many roots, strongly acid
E	5- 15	Clear smooth	Loam	Brown 10YR 5/3	Weak medium granular	Very friable	Many roots, strongly acid
BA	15– 25	Clear smooth	Loam	Strong brown 7.5YR 5/6	Weak fine and medium subangular blocky	Very friable	Common roots, strongly acid
Bt1	25– 41	Gradual smooth	Clay loam	Yellowish red 5YR 4/6	Weak fine and medium subangular blocky	Friable	Common roots, few faint clay films on faces of peds, strongly acid
Bt2	41- 56	Gradual smooth	Clay	Red 2.5YR 4/6	Weak fine subangular blocky	Friable	Common roots, common distinct clay films on faces of peds, strongly acid.
Bt3	56 – 120	Gradual smooth	Clay	Dark red 2.5YR 3/6	Moderate medium and fine angular blocky	Friable	Few roots, many distinct clay films on faces of peds; 3 percent pebbles, strongly acid.
Bt4	120 – 152		Clay	Dark red 2.5YR 3/6	Weak medium angular blocky	Friable	Common fine and medium prominent strong brown (7.5YR 5/6) mottles; 3 percent pebbles, common distinct clay films on faces of peds, strongly acid.

designed for four 0.9 m rows. The plot alley between replications was 3 m wide. N fertilizer used was ammonium nitrate (NH_4NO_3). In 2003, just prior to sawdust application and planting, 112 kg ha^{-1} of N was surface broadcast uniformly across all plots. The remainder of the N was banded beside the row three weeks later. Immediately prior to corn planting and sawdust and nitrogen fertilizer application on May 20th 2003, the first preliminary soil samples were randomly collected from Experiment 1 from the 0 to 15 cm depth within each plot for determining soil test phosphorous, soil test potassium, soil pH, soil organic matter (SOM) and total soil nitrogen and total soil carbon. Samples were composites of nine randomly collected cores per plot. On the same day, corn (Pioneer 33J57) was planted at a seeding rate of approximately 69,200 kernels ha^{-1}, using a no-tillage (NT) planter consisting of a fluted coulter arrangement with a double disk opener planting assembly. The experimental area was sprayed to control weeds with 1.26 L ha^{-1} glyphosate (for burndown) [*N*-(phosphonomethyl)glycine] and 2.30L ha^{-1} atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] plus 1.33 kg ha^{-1} metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide] (for residual control). Fresh sawdust derived from hardwood processing was applied by hand in main plots on the same day prior to planting.

Tables 3.5, 3.6 present the plot layout for the three experiments.

3.2.1 Soil sampling

For all soil samples throughout the study, undecomposed organic matter, including applied sawdust, was brushed from the soil surface before obtaining the samples, using a standard soil test probe. As noted above, preliminary samples were taken prior to the application of treatments. Surface soil was sampled at the depth of 0 to

Table 3.5. Plot plan for Experiment 1.

Block 4									
SD (Mg ha^{-1})	0	0	0	9	9	9	18	18	18
N rate (kg ha^{-1})	170	200	235	170	200	235	170	200	235
Plot	401	402	403	404	405	406	407	408	409
Block 3									
SD (Mg ha^{-1})	9	9	9	18	18	18	0	0	0
N rate (kg ha^{-1})	235	170	200	170	235	200	235	200	170
Plot	301	302	303	304	305	306	307	308	309
Block 2									
SD (Mg ha^{-1})	18	18	18	0	0	0	9	9	9
N rate (kg ha^{-1})	170	200	235	200	170	235	235	170	200
Plot	201	202	203	204	205	206	207	208	209
Block 1									
SD (Mg ha^{-1})	0	0	0	9	9	9	18	18	18
N rate (kg ha^{-1})	170	235	200	235	200	170	200	170	235
Plot	101	102	103	104	105	106	107	108	109

Table 3.6. Plot plan for Experiments 2 and 3.

Block 4	*Experiment 3*						*Experiment 2*					
Season SD applied	*Spring 2004*			*Fall 2003*			*Spring 2004*			*Fall 2003*		
SD (Mg ha^{-1})	18	18	18	18	18	18	18	18	18	18	18	18
N rate (kg ha^{-1})	170	200	235	170	200	235	170	200	235	170	200	235
Plot	407	408	409	410	411	412	419	420	421	422	423	424
Season SD applied	*Spring 2004*						*Spring 2004*					
SD (Mg ha^{-1})	0	0	0	9	9	9	0	0	0	9	9	9
N rate (kg ha^{-1})	170	200	235	170	200	235	170	200	235	170	200	235
Plot	401	402	403	404	405	406	413	414	415	416	417	418
Block 3												
Season SD applied	*Spring 2004*						*Spring 2004*					
SD (Mg ha^{-1})	0	0	0	9	9	9	0	0	0	9	9	9
N rate (kg ha^{-1})	235	200	170	235	170	200	235	200	170	235	170	200
Plot	307	308	309	310	311	312	319	320	321	322	323	324
Season SD applied	*Fall 2003*			*Spring 2004*			*Fall 2003*			*Spring 2004*		
SD (Mg ha^{-1})	18	18	18	18	18	18	18	18	18	18	18	18
N rate (kg ha^{-1})	235	170	200	170	235	200	235	170	200	170	235	200
Plot	301	302	303	304	305	306	313	314	315	316	317	318

Table 3.6. Continued.

Block 2	*Experiment 3*						*Experiment 2*					
Season SD applied	*Spring 2004*						*Spring 2004*					
SD (Mg ha^{-1})	9	9	9	0	0	0	9	9	9	0	0	0
N rate (kg ha^{-1})	235	170	200	200	170	235	235	170	200	200	170	235
Plot	207	208	209	235	211	212	219	220	221	222	223	224
Season SD applied	*Spring 2004*			*Fall 2003*			*Spring 2004*			*Fall 2003*		
SD (Mg ha^{-1})	18	18	18	18	18	18	18	18	18	18	18	18
N rate (kg ha^{-1})	170	200	235	200	235	170	170	200	235	200	235	170
Plot	201	202	203	204	205	206	213	214	215	216	217	218
Block 1												
Season SD applied	*Fall 2003*			*Spring 2004*			*Fall 2003*			*Spring 2004*		
SD (Mg ha^{-1})	18	18	18	18	18	18	18	18	18	18	18	18
N rate (kg ha^{-1})	170	235	200	200	170	235	170	235	200	200	170	235
Plot	107	108	109	110	111	112	119	120	121	122	123	124
Season SD applied	*Spring 2004*						*Spring 2004*					
SD (Mg ha^{-1})	0	0	0	9	9	9	0	0	0	9	9	9
N rate (kg ha^{-1})	170	235	200	235	200	170	170	235	200	235	200	170
Plot	101	102	103	104	105	106	113	114	115	116	117	118

15 cm 60 days after corn planting for determination of soil nitrate-N. Another set of surface soil samples was taken at the same depth on November 2003 to determine total N, total C, soil pH, and SOM. Because the supplemental nitrogen had been banded rather than broadcast, samples were taken in a stratified design, with three cores taken randomly from within the row area, three taken randomly form the area 20 to 25 cm from the row, and three taken randomly from the area 40 to 45 cm form the row. This pattern was followed to properly weight all row positions and avoid variability due to the banded application of part of the nitrogen. Samples were taken between row 1 and row 4. Areas outside rows 1 and 4 were considered t o be border areas. All samples form all sampling dates were composited, air dried, ground to pass through a 2 mm sieve, and stored at room temperature. Soil nitrate-N was analyzed using a specific-ion electrode procedure described by Johnson (1992) with the use of aluminum sulfate as extracting solution rather than calcium sulfate. Soil pH was determined by H^+-sensing electrode (McLean, 1982), and soil organic matter by Walkey-Black procedure (Nelson and Sommers, 1996(a)). Phosphorus and potassium were both determined by Mehlich I (0.05N HCl and 0.025N H_2SO_4) extractant (Isaac et al., 1983a, Isaac et al., 1983b). To analyze total soil C and total soil N, dry combustion of 50 mg of representative ground soil for each sample were employed using Flash EA® 1112 Elemental Analyzer. The dry combustion method is described by Nelson and Sommers (1996b).

3.2.2 Plant leaf sampling

Eight uppermost fully extended corn leaves per plot were collected from each plot on July 10th 2003, when the corn was in the late vegetative stage. Samples were air dried at room temperature, followed by oven drying at 65^0C for 24 hours. Dry leaves were finely ground using a Wiley mill. A 3 mg representative subsample was taken from each sample for total N determination using a Flash EA® 1112 Elemental Analyzer.

3.2.3 *Corn harvest*

Plots were harvested on October 7th 2003. Corn grain yield was determined by hand-harvesting from the center two rows of each plot. Grain yield was adjusted to a 155 g kg^{-1} moisture basis. The corn grain yield (Mg ha^{-1}) was calculated according to the following formula:

$$Y = [W_1 \text{ (lbs)} * W_2 \text{ (lbs)} / W_3 \text{ (lbs)} * 0.454 \text{ kg/lb} * 10{,}000 \text{ m}^2 \text{ ha}^{-1} / (L_1 \text{ m} * L_2 \text{ m})] / 1000 \text{ kg Mg}^{-1}$$

Where:

Y:	Corn grain yield (Mg ha^{-1})
W_1:	Plot weight (lbs)
W_2:	Weight of shelled corn (lbs)
W_3:	Weight of ear corn (lbs)
L_1:	Plot width (m)
L_2:	Plot length (m)

Yield was adjusted based on assumption of 155 g kg^{-1} moisture.

Yield (155g/kg moisture) = (1.0 – field moisture %)/0.845 x Yield (field moisture)

3.2.4 *Sawdust*

Fresh sawdust was partly air dried at room temperature and then oven dried at 65^0C for 24 hours. Weight of partially air drying sawdust was obtained before and after being oven – dried to determine water content. In all sawdusts used in this study, water content in sawdust was approximately 10%. Both air-dried and oven-dried sawdust were finely ground using the same grinder as for plant leaves. A 5 mg subsample of sawdust was taken for total C and total N analysis using the same method as described for soil.

In the second season, surface soils were sampled prior to planting corn on April 22, 2004 from 0 to 15 cm to analyze for pH, SOM, total soil N and total soil C. The variety used in the second year was FFR 943. Details of planting and weed control were the same as in 2003. In 2004, all N was broadcast by hand prior to planting and sawdust application, as NH_4NO_3. Surface soil samples from 0 to 7.5 cm were taken on May 4, 2004 to analyze for SOM, total soil N and total soil C. The purpose of this additional sampling was to examine near surface changes in SOM. Prior studies in no-till have shown that most changes in soil organic matter occur near the soil surface. Another set of surface soils (0-15cm) was taken on June 2, 2004 and June 27, 2004 (30 days and 55 days after corn planting, respectively) to determine soil NO_3-N. Final soil surface samples at 0-15 cm and 0-7.5 cm as described above were taken on October 24, 2004 to examine soil pH, SOM, total soil C, and total soil N. In all cases, eight soil cores were taken per plot and composited to form the sample. Since all N was broadcast in 2004, samples were taken randomly between rows 1 and 4. The area outside row 1 and 4 was considered border area and was not sampled.

Corn leaves were taken on June 27, 2004 - 60 days after planting. Similar procedures of taking, preserving and analyzing samples to those in the first season were used.

Corn grain yield was harvested and calculated in the same manner as described for corn yield in the first year.

3.2.5 Bulk density

Samples were taken for analyzing bulk density on December 17, 2004, using the short core method (Grossman and Reinsch, 2002). The cylindrical core was 75 mm in diameter, and the height was same as the diameter. The cylinder wall was 0.5 mm. The cylinder was inserted with force supplied with a sliding hammer on the handle. Bulk density samples were taken following the procedures described by Grossman and Reinsch (2002). Two bulk density samples were taken per plot in a location that was 5 cm away from the corn row to avoid the area in the row that might be affected by the planter and the interior areas affected by wheel tracks. Once the inner cylinder was filled with soil, it was removed and the bottom ends were trimmed flush to assure that the exact volume of undisturbed soil of interest was completely within the core before the soil was removed from this ring and placed into a bag for transportation back to the laboratory. Care was taken to avoid compacting the soil within the cylinder during and after obtaining the core. Samples were oven dried at 105^0C for 24 hours and weighed.

Bulk density of soils was calculated according to the following formula:

BD =Mass of oven dry soil (gms) ÷ total volume of soil (cm^3)

3.3 Experiment 2 (NT one season corn)

In each of the single-season experiments (Experiment 2 and 3), the same design was employed. Main plots were fresh sawdust treatments of 0, 9, and 18 Mg ha^{-1} in spring 2004 and 18 Mg ha^{-1} in fall 2003. The split plot treatments were N fertilizer rates of 170, 200 and 235 kg ha^{-1}. A total of 12 treatments with four replicates made 48 plots in each experiment. Main plots were arranged in a randomized complete block design.

3.3.1 Sawdust application and analysis

Sawdust was applied by hand on appropriate treatments on December 8th 2003 and April 28 2004 as fall vs. spring applications. Sawdust samples were oven dried at 65°C for 24 hours and analyzed for total C and total N using the same procedure as described for sawdust used in the two-year experiment. One concern was that the sawdust applied in the fall of 2003, while from the same mill as the spring 2003 and spring 2004, had been stockpiled for some time. It was noticeably more weathered than the very fresh sawdust used in the spring of both years. The C:N of sawdust applied in each experiment is presented in Table 3.7. The fact that the fall 2003 sawdust had been stockpiled for some time is clearly reflected in the lower C:N ratio.

Table 3.7. C:N of sawdust applied in three experiments.

Sawdust	C	N	C:N	Exp. applied
SD applied in the Spring 2003	47.08	0.086	546.6	1
Air dry SD applied in the Fall 2003	46.11	0.29	158.3	2, 3
Oven dry SD applied in the Fall 2003	45.44	0.38	119.16	2, 3
Air dry SD applied in the Spring 2004	49.38	0.077	669	1, 2, 3
Oven dry SD applied in the Spring 2004	48.17	0.07	665.5	1, 2, 3

3.3.2 Pesticide/herbicide and fertilizer applications and corn plantation

The same preemergence of herbicides with the same rate as in Experiment 1 were sprayed on April 20, 2004. Johnson grass was controlled by spraying 31 g ha^{-1} Nicosulfuron [2-[[(4,6-dimethoxypyrimidin – 2 – yl) aminocarbonyl]aminosulfonyl] - N, N-dimethy-3-pyridine carboxamide] during the early growing season. Nitrogen fertilizer was broadcast applied on April 27, 2004. Corn (FFR 943) was planted on April 30, at the same population used in Experiment 1.

3.3.3 Soil sampling

Surface soil samples were randomly collected from nine locations within each plot from the 0 to 15 cm depth on December 3, 2003 to determine soil pH, phosphorous (P), potassium (K), total C, total N and SOM. Similar criteria except for P and K were determined for surface soils taken at the same depth on April 22, 2004. The reason for two sampling dates is to investigate the possible change in soil properties due to the decomposition of sawdust applied to some treatments in the fall of 2003. SOM in NT is believed to accumulate mostly in the top 7.5 cm. Therefore additional soil samples at this depth were taken to test for SOM, total N, and total C immediately prior to spring sawdust application, corn planting and nitrogen fertilizer application. Two sets of mid-season surface soil samples were taken from 0 to 15 cm to determine soil NO_3-N on June 2, and June 27, 2004. The last two sets of soil samples were taken on December 17, 2004 from 0 to 15 cm to analyze for soil pH, SOM, total soil C, and total soil N and from 0 to 7.5 cm for SOM, total soil C, and total soil N. However, these samples were eventually analyzed only for soil pH and SOM for those taken at 0-15cm and for SOM for those at

0-7.5 cm. This decision was made to save analysis costs after examination at the data from Experiment 1 which showed no measurable change in soil C and N in only one year.

3.3.3 Plant leaf sampling

Plant leaves were collected on June 27, 2004, using the procedure described for Experiment 1 above.

3.3.4 Corn harvest

Because of poor stands of corn in Experiment 2, possibly resulting from uneven distribution of seeds during planting, corn grain yield was harvested on October 2004 by hand-harvesting two mid rows or border rows depending on which had a higher population. Calculation of corn yield was similar to that in the two year experiment. Two plots had inadequate population in all rows, and no yields data was obtained from them.

3.4 Experiment 3 (Conventional tillage)

With respect to the tilled experiment (Experiment 3), similar procedures to Experiment 2 were followed except that surface soils were sampled at the depth of 0-15 cm only and nutsedge was controlled during the early growing season by spraying 1.12 kg ha^{-1} betazon [(3-(1-methylethyl)-1 H-2) 1,3-bezothiadiazin-4(3-one 2,2-dioxide)].

The treatment designs were complete factorial arrangement with regard to sawdust rate and nitrogen fertilizer rate combinations, arranged in a split plot design with sawdust rate as the main plot. Main plots were arranged in a randomized complete block design.

3.5 Statistical analysis

Statistical analysis of the data was conducted using standard analysis of variance procedures for split plot analysis (SAS Institute. 2002). When a main effect of N, sawdust rate or the interaction was significant at $P \leq 0.1$, means were compared using the least significant difference and linear contrasts. A probability level of $P \leq 0.1$ was chosen because this work is of an applied nature and a probability of 90% for a real difference between treatment means was considered to be adequate for relatively low cost practices such as sawdust application and N fertilization. In addition, linear contrasts are a relatively conservative mean comparison technique, which further justified the use of a 10% probability level.

RBD (Randomized Complete Block Design) with covariate was run to investigate the relationship between plant population and corn yield in Experiment 2.

For any significant difference found in the analysis, sum of squares for linear contrasts were calculated based on pre-chosen questions as shown in Tables 3.8 and 3.9.

Table 3.8. Coefficients for linear contrasts for significant differences in Experiment 1.

	Treatment contrast	Nitrogen rates (kg ha^{-1})		
		170	200	235
N1	170 vs. mean of 200 & 235	2	-1	-1
N2	200 vs. 235	0	1	-1

		Sawdust rates (Mg ha^{-1})		
		0	9	18
SD1	0 vs. 9	1	-1	0
SD2	9 vs. 18	0	1	-1

Table 3.9. Coefficients for linear contrasts for significant differences in Experiment 2 and 3.

	Treatment contrast	Nitrogen rates (kg ha^{-1})		
		170	200	235
N1	170 vs. mean of 200 & 235	2	-1	-1
N2	200 vs. 235	0	1	-1

		Sawdust rates (Mg ha^{-1})			
		0	9	18	18F
SD1	0 vs. mean of 9 & 18 & 18F*	3	-1	-1	-1
SD2	Mean of 9 & 18 vs. 18F	0	1	1	-2
SD3	18 vs. 18F	0	0	1	-1

18F*: 18 Mg ha^{-1} SD applied in fall 2003.

4. CHAPTER IV RESULTS AND DISCUSSION

4.1 Experiment 1, 2003 (1st year of the 2-year NT corn)

4.1.1 P and K

Preliminary samples taken before the treatments were applied were analyzed for soil pH, plant available phosphorous (P), plant available potassium (K), SOM, total soil C and total soil N.

Plant available P and K were determined in the University of Tennessee Soil Test Laboratory using the Melich I extractant (Isaac et al., 1983(a); Isaac et al., 1983(b)), for the purpose of assessing the need for fertilization. P ranged from 63 to 94 ppm, which is very high, and K ranged from 269 to 307 ppm, which is very high according to the University of Tennessee soil test interpretations (Table 4.1). Low P ranges from 0 to 9 ppm, medium from 10-15, high from 16-60, and very high over 60. Low K ranges from 0 to 45 ppm, medium 48-80, high 81-160, and very high over 160. This is due to heavy fertilization as part of a long term rotation with tobacco, which has increased soil reserves of these nutrients to very high levels. At these soil test levels, no additional P and K fertilizer is necessary for optimum corn yield.

4.1.2 Soil pH

Soil pH prior to the experiment was not different between treatments, and after one season cropping with corn it was not affected by any treatments. Soil pH was initially around 7 and slightly increased to 7.2 to 7.25 by the end of the growing season (Table 4.1), though the change was not statistically different. Bendfeldt et al. (2001) reported that soil pH was significantly lower in mine soil treated with SD and isobutyl di-urea

Table 4.1. Average soil P, K, and pH by treatment in Experiment 1 (1st year).

Treatment		P	K	pH		
SD (Mg ha^{-1})	N (kg ha^{-1})	(ppm)	(ppm)	May	Dec	Std.dev
0	170	63	277	7.0	7.2	-0.23
0	200	89	301	7.0	7.3	-0.28
0	235	94	307	7.0	7.2	-0.25
9	170	76	287	7.0	7.3	-0.30
9	200	89	291	6.9	7.3	-0.35
9	235	74	284	7.0	7.3	-0.23
18	170	66	269	7.0	7.3	-0.25
18	200	93	302	7.0	7.3	-0.25
18	235	80	288	7.0	7.2	-0.23

(slow release N source) than in check and sludge treated plots after initial amendment. He stated that the difference was due to the higher level of H_2CO_3 in the soil solution compared to others. However, the amounts of hardwood SD and N fertilizer that Bendfeldt applied to the soil were 112 Mg ha^{-1} and 336 kg ha^{-1}, respectively. Lower pH in his study might have been due to the high N rate. Contrary to the common concepts, the soil pH result supports our hypothesis that sawdust application had no negative impact on soil pH.

4.1.3 Total soil carbon

Both preliminary and after-season soil total C were not significantly different between treatments in 2003 (Table 4.2, and Figure 4-1). Unexplainably high total C content after the growing season occurred in treatments with the highest N fertilizer rate (235 kg ha^{-1} N) with no sawdust added and with 18 Mg SD ha^{-1} (Table 4.3). This resulted from only one extremely high soil total C value in one replicate of each of these

Table 4.2. Analysis of variance for treatment effects on soil pH, SOM, soil NO_3-N, corn yield, plant nitrogen, soil total C, and total N for Experiment 1 in 2003 (1st year).

Sampling date	Source of variance	Degree of freedom	Soil pH	Soil OM	NO_3 -N	Corn yield	Corn leaf N	Total C		Total N	
								Before dropping[1]	After dropping[2]	Before dropping	After dropping
May, 2003	SD	2	NS	NS				NS	NS	NS	NS
	N	2	NS	*				NS	NS	NS	NS
	SD*N	4	NS	*				NS	NS	NS	NS
July, 2003	SD	2			NS		NS				
	N	2			*		NS				
	SD*N	4			NS		NS				
Oct, 2003	SD	2				*					
	N	2				*					
	SD*N	4				NS					
Nov, 2003	SD	2	NS	NS				NS	NS	NS	NS
	N	2	NS	NS				NS	NS	NS	NS
	SD*N	4	NS	NS				NS	NS	NS	NS

* Significant at 0.1 probability level.

[1] Data were analyzed before dropping two unusual observations.
[2] Data were rerun after dropping two unusual observations.

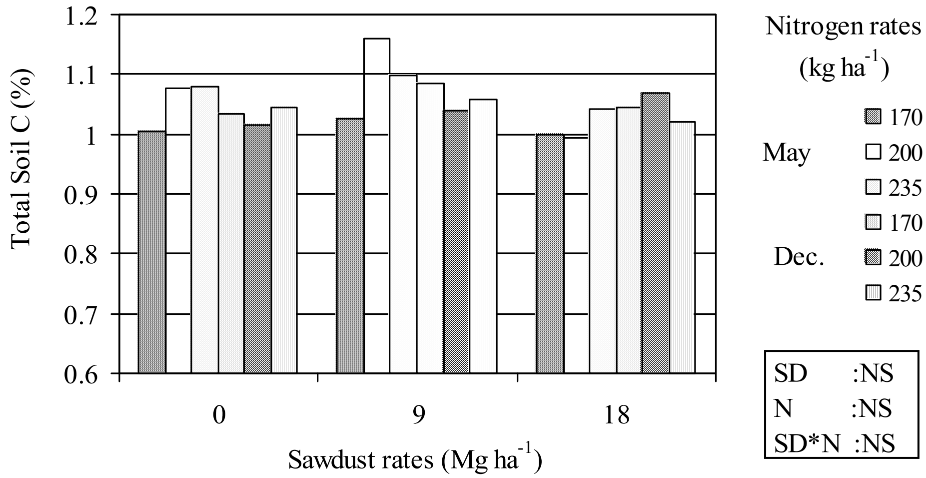


Figure 4-1. Total soil carbon in Experiment 1 in 2003.

Table 4.3. Average soil $N0_3$-N, corn yield, SOM, total soil N, and total soil C in Experiment 1 in 2003 (1st year).

Treatment		NO_3-N	Yield	SOM (%)		Total N (%)		Total C (%)	
SD (Mg ha^{-1})	N (kg ha^{-1})	(kg ha^{-1})	(Mg ha^{-1})	May	Dec.	May	Dec.	May	Dec.
0	170	35.87	14.63	1.43	1.68	0.09	0.09	1.0	1.03
0	200	59.92	14.38	1.95	1.5	0.09	0.09	1.08	1.02
0	235	110.3	16.14	1.7	1.48	0.09	0.13*	1.08	1.64*
9	170	43.55	13.97	1.68	1.55	0.09	0.09	1.03	1.08
9	200	51.29	15.14	1.85	1.75	0.1	0.08	1.16	1.04
9	235	108.6	15.55	1.55	1.63	0.1	0.09	1.1	1.06
18	170	26.1	12.97	1.45	1.53	0.08	0.09	1.0	1.04
18	200	32.93	13.38	1.48	1.73	0.09	0.08	1.0	1.07
18	235	102.7	14.55	1.73	1.63	0.09	0.12*	1.04	1.54*

* Unusually high values

treatments. It is probable that this was not due to treatments. When these two plots were dropped from the analysis, there was still no significant difference. No overall significant change in soil total C observed after only one year was not surprising, and encouraged continuing investigation for another year. Paustian et al. (1992) reported that the addition of sawdust, as opposed to wheat straw, yielded 13% higher total soil C content, irrespective of fertilizer addition. Larson et al. (1972) reported increase in soil C due to additions of plant residues, but reported no further increase in soil C content after 11 yr of addition of 8 t/ha/yr of alfalfa (Medicago sativa L.), corn (Zea mays L.) stalks, oat (Avena sativa L.) straw, brome grass (Bromus inermis Leys.) and sawdust. Even though both studies indicated an increase in soil total C during the first 10 years after cropping and no further increase in soil total C thereafter, results after one year cropping in our experiment indicated that this time period may be too short to see a change. Moreover, fresh sawdust applied on the surface under no-till practice was still found on the surface of sawdust treated plots at the end of the season indicating that sawdust did not totally decompose.

4.1.4 Total soil nitrogen

Initially, total soil N did not differ between treatments. Soil total N content after one year showed similarities to total soil C, in that neither was significantly affected by treatments (Table 4.2, Table 4.3, and Figure 4-2). This result agreed with other studies which commonly showed constant or increasing total N in plots where external organic materials such as sawdust, straw and green manure were added together with N fertilizer (Moss et al., 1989, and Paustian et al., 1992). However, while Paustian et al. (1992)

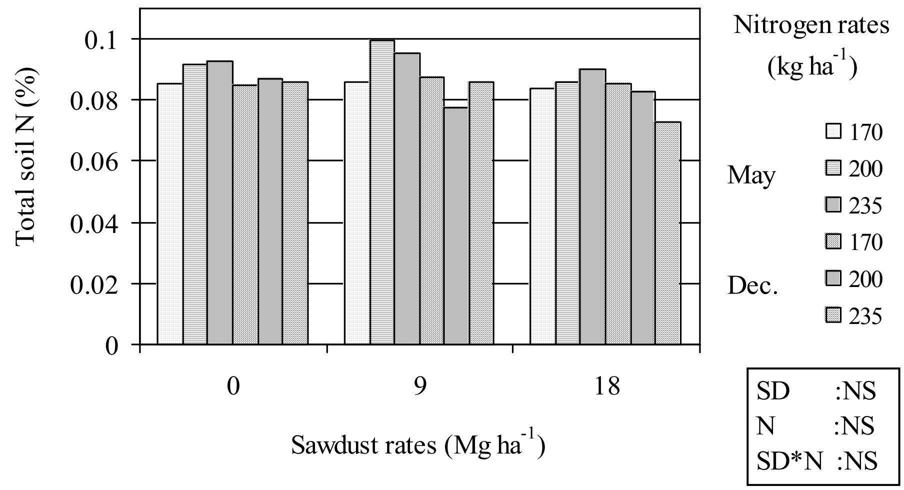


Figure 4-2. Total soil nitrogen in Experiment 1 in 2003.

reported a N decline in the treatments receiving no organic amendments, total soil N in this study remains almost the same in all treatments without sawdust. Similarly to the unusually high values in total C mentioned earlier, higher values of total N at 235 kg N ha^{-1} for 0 and 18 Mg SD ha^{-1} occurred as individual observations that might be due to unexplainable variation rather than to the treatments.

4.1.5 Soil organic matter

In 2003, statistical analysis showed significant differences in initial SOM between treatments, indicating pre-existing variability. SOM was higher in plots with 200 and 235 kg N ha^{-1} compared to that in plots receiving 170 kg N ha^{-1} irrespective of SD. There was also a significant interaction between SD and N. Because of irregular variation among plots and, more importantly, Because initial SOM was determined on samples collected prior to applying treatments, the reason for variation in initial SOM can not be due to treatment effect but rather to pre-existing variability. A likely explanation may lie in the history of the experimental site, which had been maintained in continuous grass for four years before the experiment was set up. At the end of the season, however, no effects of SD, N, and interaction on SOM were found (Table 4.2, Table 4.3, and Figure 4-3). It is commonly believed that the rate of C addition is the single most important factor determining organic matter levels, and some previous studies have found (e.g., Rasmussen et al., 1980) that annual organic matter changes are roughly linear with respect to annual C-input rate. Bendfeldt et al. (2001) found that after 5 growing seasons, sawdust addition on a mine soil increased organic matter content. In Bendfeldt's study, SOM was highest in the 14 Mg ha^{-1} sawdust treated plots in 1982, one year after the treatments were applied. By using both model prediction and field measurement, Paustian et al. (1992) reported an increase in SOM contents during the first ten years in all treatments receiving external additions of OM, and highest SOM accumulation in the

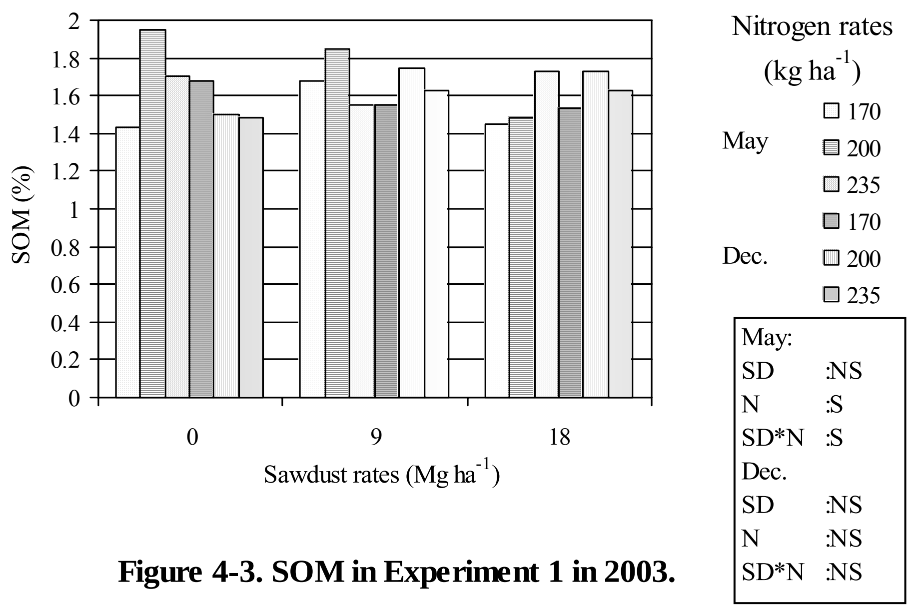


Figure 4-3. SOM in Experiment 1 in 2003.

sawdust treatment with N addition compared to other materials such as green manure, farm manure, straw and check. Despite no significant change in SOM in this study, slight visual indications of increase in SOM were noticed in treatments where SD was applied. The addition of sawdust and decomposition of previously existing vegetation may have helped even the SOM content between plots. This resulted in no statistically significant differences between plots, whereas there were prior to the experiment. In the treatments receiving no SD combined with 200 and 235 kg N ha^{-1}, which showed fairly high initial SOM (1.95% and 1.7%), SOM at the end of the season decreased to 1.5% and 1.48%, respectively, probably due to the biological decomposition of existing SOM prior to the experiment and sampling variability. Because of the linear relationship between SD rates and SOM, another possible explanation for slight change in SOM may be due to the quality of the SD. The fresh SD used in this study was largely hardwood SD from oak and hickory, which is composed in part of highly recalcitrant components such as lignin. This source has a potential to provide higher accumulations per unit C input than low-lignin amendments such as straw and green manure. However, it is likely to require longer time to decompose. In this study, undecomposed SD was visible on the soil surface one year after application.

4.1.6 Soil NO_3-N

The surface soil was sampled for nitrate content at 60 days after planting, to examine the effect of sawdust on nitrogen availability to the crop. Soil nitrate content followed a logical pattern, generally increasing with N rate. At the 170 and 200 kg ha^{-1} rates, soil nitrate appeared to be reduced by 18 Mg ha^{-1} of sawdust. The numbers at 0 and

9 Mg SD were somewhat variable, and were not different. At 235 kg N per hectare, there appeared to be no difference between SD rates in soil nitrate. However, statistical analysis indicated that soil NO_3-N was affected by N fertilizer rate but not affected by SD or by the interaction (Table 4.2 and 4.3, and Figure 4-4). Mean separation using the least significant difference (LSD) method showed high available nitrogen at 235 kg N ha^{-1} relative to that at lower rates, NO_3-N was 107, 48, and 35 kg ha^{-1} at 235, 200 and 170 kg N ha^{-1}, respectively (Table 4.5). Because NO_3-N was affected by N rates, contrasts were run as discussed in chapter 3 to answer the question of whether soil NO_3-N responded to: (1) 170 versus the average of 200 and 235 kg N ha^{-1} and (2) 200 versus 235 kg N ha^{-1}. Results revealed that Soil NO_3-N was significantly increased by higher N fertilizer rates up to 235 kg N ha^{-1} (Table 4.4).

N immobilization was expected to occur in this study due to high carbonaceous material addition, but our statistical analysis did not confirm this effect. Immobilization is the reverse process of mineralization. In the immobilization process, inorganic nitrogen in the form of NO_3-N is converted to organic forms of nitrogen by biological activities. Soil microorganisms acquire this source of inorganic nitrogen to build their tissue during the decomposition process. As sawdust used in this experiment had a C:N ratio of approximately 546:1 whereas that of microbial tissue is from 6:1 to 10:1, a competition for nitrogen source may have been occurred where sawdust was added even with 170 and 200 kg N fertilizer ha^{-1}. However, it appeared that the extra 65 kg of N at the 235 kg ha^{-1} rate had increased available N in all treatments by about the same magnitude. Our results did not agree well with early studies (Johnson, 1944, and Samater et al., 1998). For example, Motavalli and Diambra (1997) indicated that N immobilization resulting from

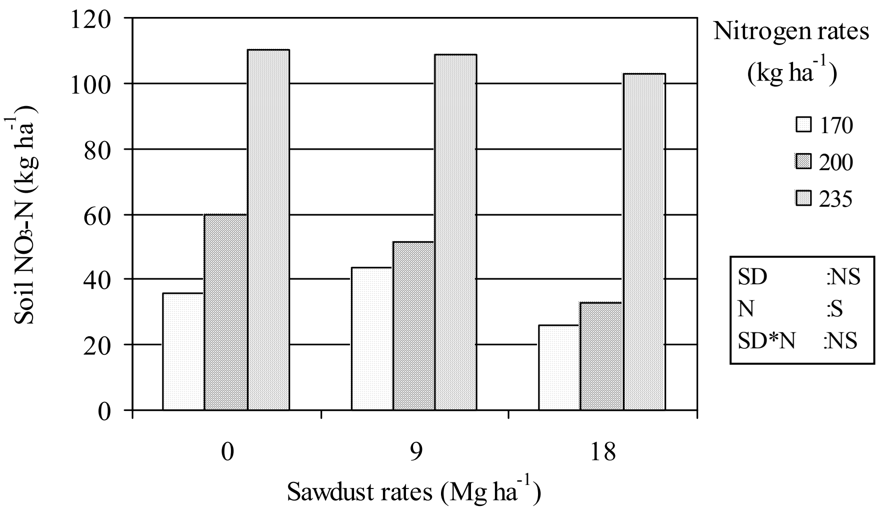


Figure 4-4. Soil NO_3-N after 2 months planting in Experiment 1 in 2003.

Table 4.4. Results of linear contrasts in Experiment 1 in 2003 (1st year).

Treatment	Contrast	NO_3-N	Corn yield
N rates	N1	*	*
	N2	*	*
SD rates	SD1	-	NS
	SD2	-	*
Interaction	SD1*N1	-	-
	SD1*N2	-	-
	SD2*N1	-	-
	SD2*N2	-	-

* : Significant at 0.1 probability level.
NS : Not significant at 0.1 probability level
\- : No contrast was run due to insignificant main effect

Table 4.5. Mean separation using LSD for soil NO_3-N and corn yield in Experiment 1 in the 1st year in 2003.

Treatment		NO_3-N	Corn yield
SD ($Mg\ ha^{-1}$)	N ($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($Mg\ ha^{-1}$)
0		68.68a*	15.06a
9		67.8a	14.88a
18		53.93a	13.64b
	170	35.18b	13.86b
	200	48.05b	14.3ab
	235	107.19a	15.42a
0	170	35.87bc	14.64abcd
0	200	59.92b	14.39abcd
0	235	110.25a	16.14a
9	170	43.55bc	13.97bcd
9	200	51.29bc	15.13abc
9	235	108.57a	15.56ab
18	170	26.11c	12.97d
18	200	32.93bc	13.38cd
18	235	102.74a	14.56abcd

* Means followed by the same letter are not significantly different at P>0.10.

paper applications was observed in soil total inorganic N levels. Total inorganic N content of soil sampled 17 d after treatments were applied was significantly lower in paper-treated plots compared to untreated plots at 1, 50, and 100 kg N ha^{-1} fertilizer treatments. However, total inorganic N levels at the 400 kg N ha^{-1} treatment were higher in the paper-treated plots after 73 and 91 d. These results suggested that at the 400 kg N ha^{-1} fertilizer rate, the N that was immobilized early in the growing season was subsequently mineralized and available for crop uptake. A similar effect may have occurred in this study, since substantial N was added to all plots. This indicated that perhaps 60 d after SD addition was too late to see the effect, and earlier immobilization might have occurred. To some extent, early N immobilization may be beneficial as it protects soil NO_3-N from leaching out the rooting zone, especially in high rainfall climate regions.

4.1.7 Corn yield

SD and N rates significantly affected corn yield whereas no interaction effect on corn yield was found (Table 4.2 and 4.3, and Figure 4-5). Mean separation comparison showed significantly higher corn yield in 0 and 9 Mg ha^{-1} SD compared to 18 Mg ha^{-1} and significantly higher corn yield at 235 kg N ha^{-1} compared to 170, with the 200 rate giving intermediate yields (Table 4.5). Contrasts were run within the SD and N effects. Similar to the mean separation results, contrast showed a significance between 170 and the average of 200 and 235 kg N ha^{-1}, and a difference between 200 and 235 kg N ha^{-1}, indicating increased corn yield up to 235 kg N ha^{-1} (Table 4.4). Contrasts for SD rates also showed that up to 9 Mg ha^{-1} SD, corn yield was not suppressed. The detrimental

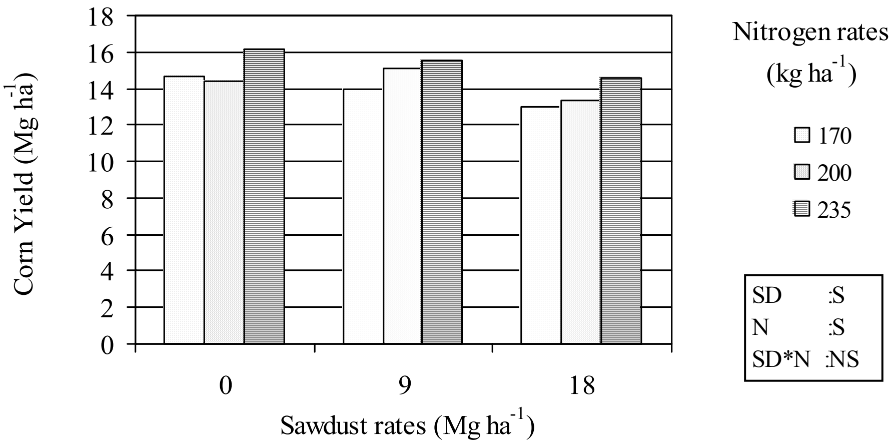


Figure 4-5. Corn yield in Experiment 1 in 2003.

effect occurred when SD was increased from 9 to 18 Mg ha^{-1}. The highest N rate significantly increased corn yield in all treatments. Data for soil NO_3–N did not indicate significant immobilization by SD; however, it is apparently that SD did limit yield because of nitrogen immobilization, but the effect may have occurred earlier in the season, from just after planting until 30-45 days after planting. By 60 days after planting, there had been enough decomposition of SD to release some of the immobilized nitrogen back to the soil (which is called remineralization), and this resulted in no difference between SD rates in soil NO_3 at that time. In this case, we speculated that the early season nitrogen deficiency limited yield where SD was applied, and the increased availability later in the season was too late to completely overcome this. For this reason, beside the samples taken 60 days after planting, additional surface soil samples were taken 30 days after planting in the second year to examine soil nitrate. Overall, corn yield harvested in the 1st year of the experiment was tremendously high, ranging from 13 to over 16 Mg ha^{-1} whereas longer term average corn yield in this area is reported to be 7 to

10 Mg ha^{-1}. It is possibly due to the appreciable amount of rainfall of 1292.1 mm occurring in 2003, especially during July (122.68 mm) when corn was entering the critical pollination stage, which helped ensure soil moisture availability and accelerate corn growth (Table 4.6). Most of earlier studies have showed a positive effect of high-organic materials on crop yields when applied with nitrogen fertilizer. For example, Johnson (1944) stated that when SD was applied as surface mulch in combination with nitrogen, yields of tomatoes and fall potatoes were greater the first year than the yields from the plots in which SD was incorporated. Motavalli and Diambra (1997) indicated that sweet corn ear and total biomass yields and N uptake were significantly lower in the paper-treated plots compared to the untreated plots without nitrogen fertilizer. When 400

Table 4.6. Average precipitation and soil temperature in the University of Tennessee Tobacco Experiment Station in Greeneville in 2003.

Month	Soil temperature (^oC)		Precipitation
	Max	Min	(mm)
January	11.11	1.11	46.99
February	6.11	3.33	159.26
March	12.78	8.89	68.58
April	17.22	12.22	115.06
May	22.23	18.30	147.57
June	25.56	21.67	70.36
July	28.33	24.44	122.68
August	29.44	25.00	224.28
September	26.11	21.11	81.53
October	18.33	15.00	27.94
November	13.89	10.56	149.86
December	5.56	3.33	77.98
Total			1292.1

Source: UT Tobacco Experiment Station in Greeneville-TN (2003) (personal communication).

kg N ha^{-1} was applied to the paper-treated plots, however, no significant increases in yields or N uptake were observed.

4.1.8 Corn leaf nitrogen

Even though corn leaf N was not affected by SD, N fertilizer or the interaction, rather high N concentration was obtained overall, ranging from 2.5 to over 3% (Table 4.2 and 4.3, and Figure 4-6). Highest corn leaf nitrogen was present at 9 Mg ha^{-1} of SD and 200 kg ha^{-1} N fertilizer. Overall, no trend of N uptake correlated to SD treatments and N fertilizer was observed. Common concepts would lead to expectations of lower uptake of N where sawdust was added at low N rates, and possibly higher in SD + high N treatments compared to check plots (Paustian et al., 1992). This is due to the small or negligible net contribution of N to the crop from sawdust which has a relatively high C:N ratio (Hyvonen et al., 1996).

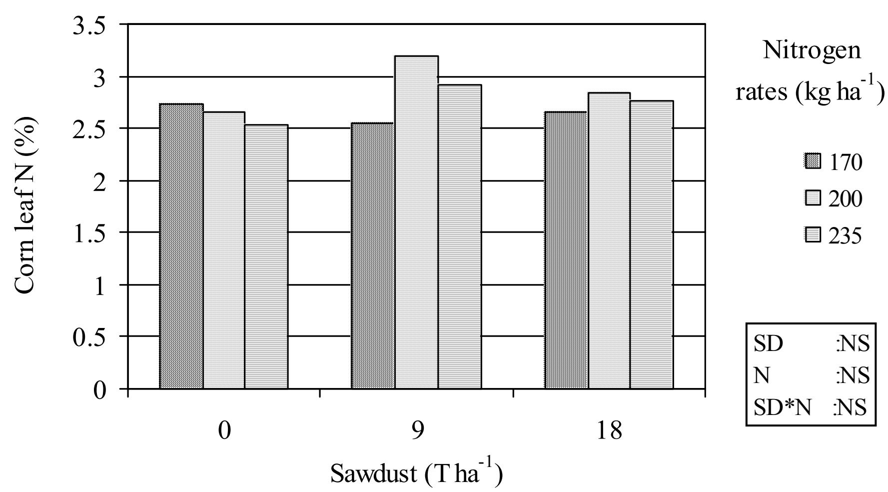


Figure 4-6. Corn leaf N concentration in Experiment 1 in 2003.

4.1.9 *Summary from year 1 of Experiment 1*

In general, after the first year, results in this study showed no change in total soil C, total soil N, and SOM, and no effect of treatments on pH, but indicated that corn yield decreased as SD increased from 9 to 18 Mg ha^{-1}, and increased as N fertilizer increased with maximum values at zero SD and 235 kg N ha^{-1} and 9 Mg ha^{-1} SD with 235 kg N ha^{-1}. However, no interaction between SD and N fertilizer on corn yield was found. A sawdust rate of 9 Mg ha^{-1} had no effect on corn yield.

4.2 *Experiment 1, 2004 (2^{nd} year of the 2-year NT corn)*

In the second year of Experiment 1, a similar investigation was conducted except that additional soil samples were taken at a shallower depth (0-7.5 cm) to examine soil total C, soil total N, and SOM as we speculated to be more likely to detect change in SOM in this depth compared to a deeper depth, and soil NO_3-N was taken two times, 30 d and 55 d after planting corn, as discussed earlier in the discussion about NO_3-N in the first year. Time and labor limitation only allowed us to investigate soil bulk density at the end of 2004 as the only soil physical property in this study.

4.2.1 *Soil pH*

Neither early nor after season soil pH was affected by treatments (Table 4.7). Initial soil pH in Experiment 1 in the second year had a similar range in soil pH as at the end of the first year (from 7.2 to 7.32). Similar results were found in a study by Roberts (1948), and Lareau (1989). By the end of the season, soil pH slightly decreased to the values close to that prior to the study (Table 4.8). Because no effect of SD on soil pH was found after two-year study, the slight change in soil pH may be due to seasonal

Table 4.7. ANOVA table for pH, SOM, soil NO_3-N, corn yield and corn leaf N in Experiment 1 in the 2nd year (2004).

Sampling date	Source of variance	Degree of freedom	Soil pH	SOM (0-15 cm)	SOM (0-7.5cm)		Soil NO_3-N	Corn yield	Corn leaf N
					Before dropping	After dropping			
Apr., 2004	SD	2	NS	NS					
	N	2	NS	NS					
	SD*N	4	NS	NS					
May, 2004	SD	2			NS	NS			
	N	2			NS	*			
	SD*N	4			NS	NS			
Jun, 2nd, 2004	SD	2					*		
	N	2					NS		
	SD*N	4					NS		
Jun, 27th 2004	SD	2					*		NS
	N	2					NS		NS
	SD*N	4					NS		NS
Oct., 2004	SD	2	NS	NS	NS			NS	
	N	2	NS	NS	NS			*	
	SD*N	4	NS	NS	NS			*	
Dec., 2004	SD	2							
	N	2							
	SD*N	4							

* Significant at 0.1 probability level.

Table 4.8. Average soil pH, soil bulk density and total C (0-15cm) in Experiment 1 (2nd year) in 2004.

Treatment		pH			Bulk density	Total C (%) (0-15cm)	
SD ($Mg\ ha^{-1}$)	N ($kg\ ha^{-1}$)	Apr04	Oct04	Change	($g\ cm^{-3}$)	Apr04	Oct04
0	170	7.23	7.00	0.23	1.61	0.93	1.06
0	200	7.28	7.08	0.2	1.61	0.95	1.14
0	235	7.25	6.98	0.27	1.57	0.89	1.13
9	170	7.30	7.00	0.3	1.57	0.95	1.24
9	200	7.25	7.00	0.25	1.54	1.05	1.22
9	235	7.23	7.03	0.2	1.56	1.02	1.21
18	170	7.33	7.10	0.23	1.59	0.94	1.14
18	200	7.30	7.08	0.22	1.54	0.95	1.15
18	235	7.20	7.05	0.15	1.56	0.98	1.20

variability. Our study showed opposite results to Obiefura (1991) and Kwasna et al. (2000) whose soil pH decreased as a result of SD application. This suggests that SD at moderate rates with attendant application of N fertilizer is not harmful in terms of soil pH.

4.2.2 Bulk density

Soil bulk density at 1-8.5 cm depth was not significantly different by treatments (Table 4.9). Though bulk density decreased slightly numerically in plots treated with sawdust at 9 and 18 Mg ha^{-1} (Table 4.8 and Figure 4-7), the effect was not significant. Lunt (1955) found similar results after one year applying oak-hickory chips at 11, 23, 45, and 90 Mg ha^{-1} to Cheshire loam soil in Connecticut. Motavalli and Diambra (1997) also found no difference in bulk density between paper and untreated plots. However, it is

Table 4.9. ANOVA table for total C and total N and bulk density in Experiment 1 in the 2nd year (2004).

Sampling date	Source of variance	Degree of freedom	Total C (0-15cm)	Total C (0-7.5cm)	Total N (0-15cm)	Total N (0-7.5cm)	Bulk Density
Apr., 2004	SD	2	NS		NS		
	N	2	NS		NS		
	SD*N	4	NS		NS		
May, 2004	SD	2		NS		NS	
	N	2		NS		NS	
	SD*N	4		NS		NS	
Oct., 2004	SD	2	NS	NS	NS	NS	
	N	2	NS	NS	NS	NS	
	SD*N	4	NS	NS	NS	NS	
Dec., 2004	SD	2					NS
	N	2					NS
	SD*N	4					NS

* Significant at 0.1 probability level.

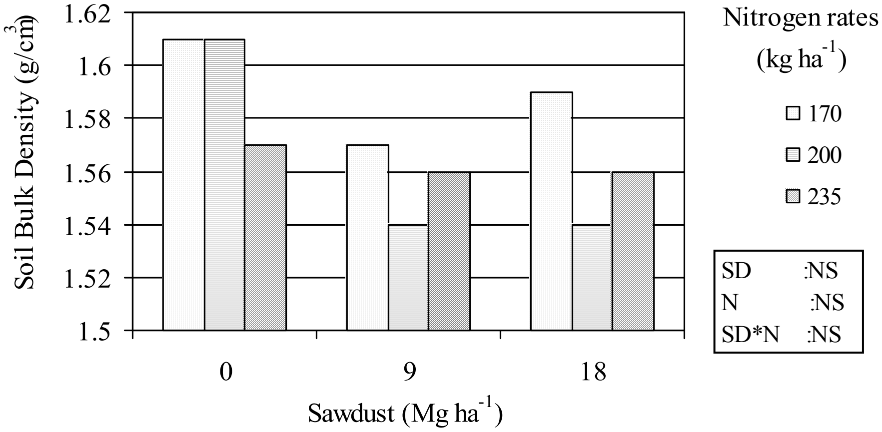


Figure 4-7. Soil bulk density (1-8.5 cm) in Experiment 1 in 2004.

commonly agreed that bulk density decreases where soil is either surface covered or mixed with soil amendment materials such as paper, sawdust and other organic materials for soil bulk density is inversely correlated to OM content; as OM is added and accumulated in mine soils, bulk density corresponding decreases. (Bendfeldt et al. 2001) illustrated a significantly higher Db of the native soil treatment than the control, SD, and sludge-amended treatments at 1.38 Mg m^{-3}, which is compatible to values for local agricultural soils of the region. Obiefura (1991) showed a lower bulk density in soil mulched with SD. No effect of sawdust on soil bulk density in our study indicates that a two-year experiment is a fairly short time for the effects of organic matter addition to the soil structure to be fully expressed.

4.2.3 Total soil carbon

Surface soil samples were taken on April 22nd 2004 at the depth of 0-15 cm prior to planting corn and N fertilizer application and on May 4th 2004 at the depth of 0-7.5 cm immediately after the treatments were applied (April 30th 2004). Soil total C prior to and after the second season (October, 2004) was not affected by any treatment at both depths of 0-7.5 and 0-15 cm (Table 4.9). Higher total C was found at the 0-7.5 cm depth as compared to 0-15 cm, as expected. As already stated, total C did not increase at the end of the first year. However, overall increasing total C was noticed in both depths at the end of the second year regardless of SD addition (Table 4.8, 4.10, and Figure 4-8, 4-9). Lalande et al. (1998) reported a significant increase in total soil C and N in soil receiving 600 m^3 ha^{-1} chipped woods from twigs (CWT) in the second year compared to untreated soil. CWT, however, was incorporated into the soil. The slight increase in total C, though not great enough to be significant, indicates soil C sequestration was occurring but the accumulation was rather small. This is probably due in part to the fresh sawdust used in this experiment which contained a very high C:N ratio of 547:1. Moreover, oak and

Table 4.10. Average total C (0-7.5cm), and total N (0-7.5cm and 0-15cm) in Experiment 1 (2^{nd} year) in 2004.

Treatment		Total C (%)		Total N (%)		Total N (%)	
SD	N	(0-7.5cm)		(0-15cm)		(0-7.5cm)	
(Mg ha^{-1})	(kg ha^{-1})	May04	Oct04	Apr04	Oct04	May04	Oct04
0	170	1.21	1.30	0.08	0.09	0.11	0.11
0	200	1.19	1.31	0.08	0.10	0.11	0.11
0	235	1.20	1.35	0.07	0.10	0.12	0.12
9	170	1.29	1.46	0.08	0.10	0.12	0.12
9	200	1.31	1.51	0.09	0.10	0.11	0.13
9	235	1.31	1.41	0.09	0.10	0.13	0.12
18	170	1.21	1.29	0.08	0.10	0.11	0.11
18	200	1.52	1.38	0.08	0.10	0.14	0.11
18	235	1.24	1.44	0.08	0.10	0.12	0.12

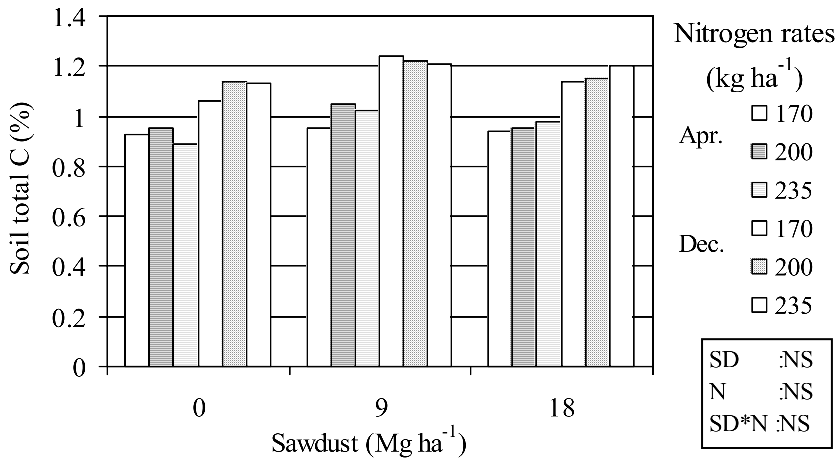


Figure 4-8. Soil total C (0-15cm) in Experiment 1 in 2004.

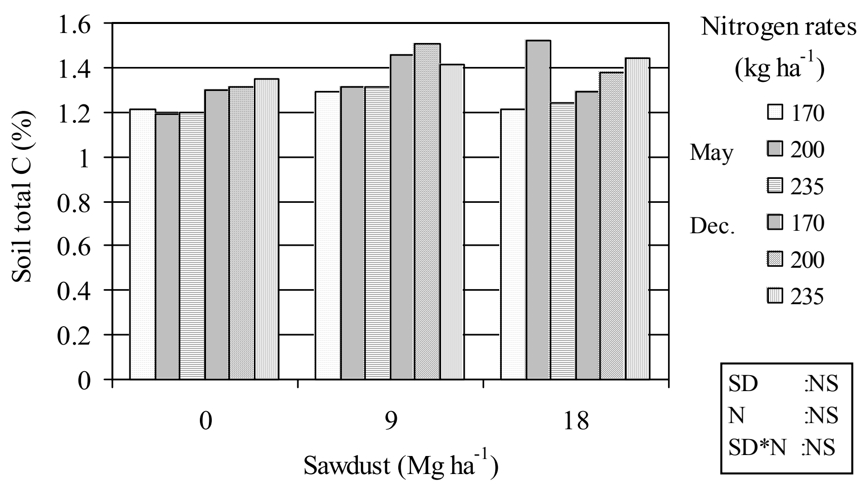


Figure 4-9. Soil total C (0-7.5cm) in Experiment 1 in 2004.

hickory sawdusts are slowly decomposing materials. Being applied on the surface in no-tillage is another possibility for slow SD decomposition as compared to SD incorporation into the soil (Roberts, 1948; Johnson, 1944). The short time frame might have been another reason for the relatively small change in total soil C. Also, the total content of C added was not large relative to that already present in the soil when annual decomposition and loss of C as CO_2 is considered.

4.2.4 Total soil nitrogen

Similarly to soil total C, soil total N both prior to and after the second growing season was not affected by treatments (Table 4.9). Total N at the depth of 0-15 cm after 2 years cropping with corn in sawdust treatments remained constant if not slightly increased, ranging from 0.09 to 0.1% (Table 4.10 and Figure 4-10, 4-11) which fell into the common range of 0.06 to 0.5% of most cultivated soils in the surface layer (Bremner and Mulvaney, 1982). Lunt (1955) indicated no great change in total N in plots treated with oak and hickory chips at different rates. Bendfeldt et al. (2001) reported an increase in total N after 5 years amending mine soil with SD and isobutyl di-urea (slow release N source). However, 16 years after the treatment, he found a decrease in total N in the same treatment. At the end of the first season in our study, corn stalk residues were left on the surface of the field. This was a source of readily mineralizable nitrogen that helped N recycle to the soil. Moreover, some N may have been released from sawdust decomposition applied in the first year. It is commonly believed that agricultural soil has the capacity to supply available N for cropping if supplied with labile or readily decomposable organic matter with a narrow C:N ratio. Though addition of high C:N ratio

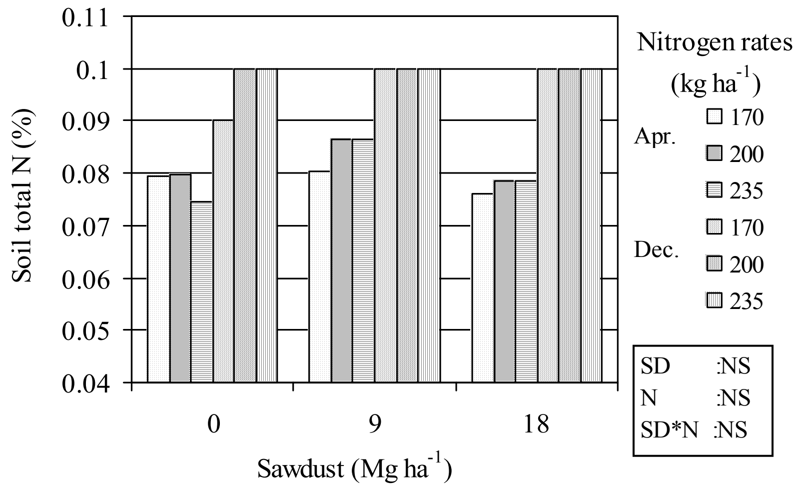


Figure 4-10. Soil total N (0-15cm) in Experiment 1 in 2004.

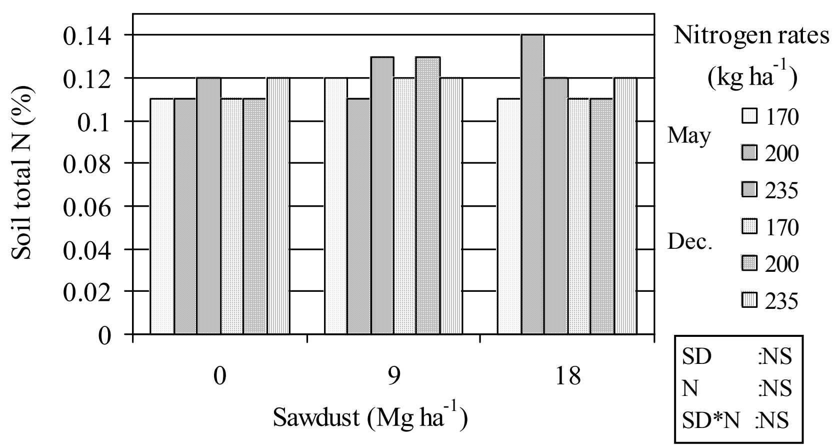


Figure 4-11. Soil total N (0-7.5cm) in Eperiment 1 in 2004.

results in a net fall in the amount of plant-available nitrogen for a period (Vinten and Smith, 1993), its long term effect is greater mineralization. Addition of SD and chemical N fertilizer may have changed the relative proportion of N in various soil pools, but the total N addition was not enough to change soil total N content.

4.2.5 Soil organic matter

In the second year of Experiment 1, besides the surface soil samples taken from the traditional depth (0-15 cm), SOM was examined at the 0-7.5 cm depth. SOM was not affected by treatments at either depth (Table 4.7). As expected, higher SOM was found at shallower depth as compared to 0-15 cm (Table 4.11 and Figures 4-12, 4-13). One unusually high and two low values of SOM at the 0-7.5 cm prior to the second growing season were found, encouraging us to believe they were derived from sampling variability or experimental error and the statistical analysis needed to be rerun without these plots. After dropping these values, initial SOM at 0-7.5 cm was not significantly affected by SD and interaction, but significant by N rates. However, mean separation comparison indicated that the highest SOM occurred at 200 kg N ha^{-1} regardless of sawdust rates, and an especially high average SOM was found at zero sawdust with 200 kg N ha^{-1}. On the other hand, lower SOM were present at 170 and 235 kg N ha^{-1} and the effect of N rates on SOM was found in early season which was only 6 d after N fertilizer was applied. Therefore, it appeared that the significance of SOM by N rates found after dropping the three odd numbers might have been attributed to the lack of uniformity rather than treatment effect. Many researchers have reported increased SOM as N

Table 4.11. Average SOM (0-7.5cm and 0-15cm) and soil NO_3-N in Experiment 1 (2^{nd} year) in 2004.

Treatment		SOM (%)				NO_3-N		Corn yield	Corn leaf N
		(0-15cm)		(0-7.5cm)		(kg ha^{-1})			
SD (Mg ha^{-1})	N (kg ha^{-1})	May 04	Oct 04	Apr 04	Oct 04	Jun 2^{nd}	Jun 27^{th}	(Mg ha^{-1})	(%)
0	170	1.25	1.58	1.58	1.85	116.6	69.33	13.67	2.42
0	200	1.70	1.68	2.00	1.83	95.85	69.11	12.28	2.54
0	235	1.25	1.70	1.53	1.90	107.1	84.02	13.18	2.46
9	170	1.83	1.88	1.70	2.13	53.81	30.17	11.31	2.28
9	200	1.55	1.88	2.00	2.23	56.05	21.89	12.93	2.32
9	235	1.35	1.70	2.58	1.95	61.09	37.98	13.67	2.38
18	170	1.90	1.75	1.88	2.03	29.71	9.11	11.96	2.35
18	200	1.30	1.80	1.93	2.00	39.80	13.61	11.31	2.58
18	235	1.60	1.83	1.55	2.25	45.96	19.47	13.75	2.68

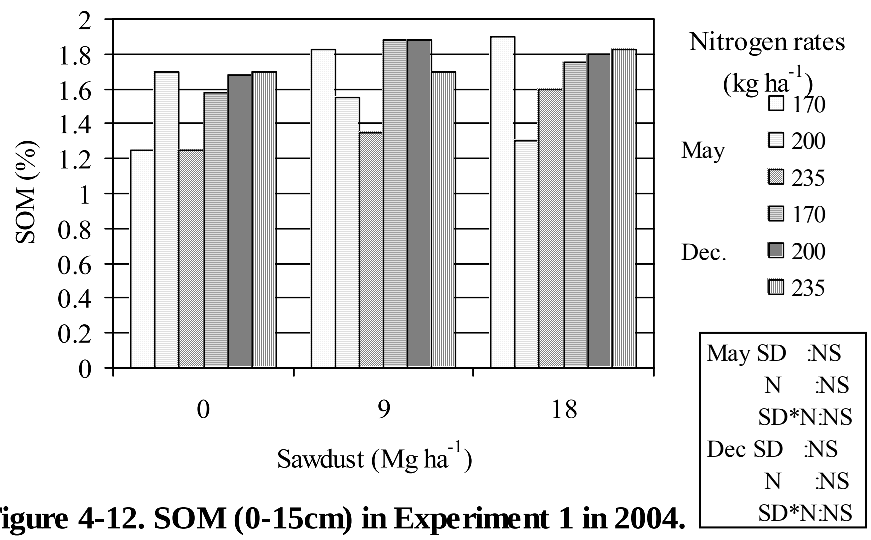


Figure 4-12. SOM (0-15cm) in Experiment 1 in 2004.

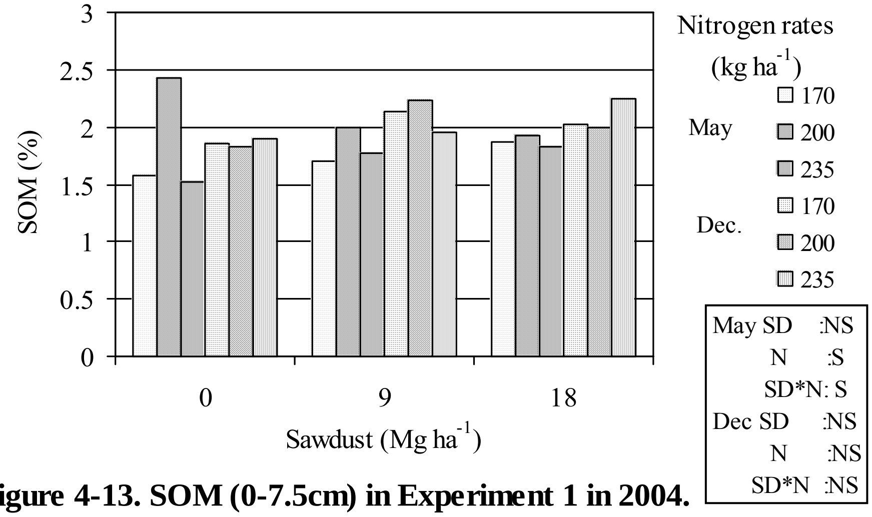


Figure 4-13. SOM (0-7.5cm) in Experiment 1 in 2004.

fertilizer levels increased and the effect of increasing application rate of N fertilizer on increasing soil organic carbon might be most pronounced in the surface layers of soil under no-till management (Rickman et al., 2001). Also, an early study showed that the change in SOM over time is linearly related to the level of C inputs (Paustian et al., 1992). Addition of wood chips has been shown to increase SOM slightly the first year, with greater changes occurring in the second and the third years, due to the relatively show decomposition of wood chips (McCoy et al., 1999). In our study, although sawdust applied every year during the period of two year experiment provided comparatively high C input, no effect on SOM was found at the end of the second season. Fresh sawdust used in both years with high C:N ratio (547:1 and 665:1 in 2003 and 2004, respectively), may mainly account for the slow decomposition of sawdust. However, in a comparison of average SOM at 0-15 cm depth prior to the first growing season to that at the end of the second season, overall SOM increased in all SD treatments whereas in zero SD plots, SOM increased at 170 kg N ha^{-1} but decreased at 200 and 235 kg N ha^{-1} (Table 4.12).

Table 4.12. Average change in SOM (0-15 cm) after two year study in Experiment 1.

Treatment		SOM (%) (0-15cm)	
SD (Mg ha^{-1})	N (kg ha^{-1})	May03	Oct04
0	170	1.43	1.58
0	200	1.95	1.68
0	235	1.70	1.70
9	170	1.68	1.88
9	200	1.85	1.88
9	235	1.55	1.70
18	170	1.45	1.75
18	200	1.48	1.80
18	235	1.73	1.83

Therefore, it is possible that increased SOM after two years was partly due to SD decomposition but the decomposition was not complete enough to result in a significant effect. Moreover, preexisting comparatively high SOM in the study site derived from 5 years of fescue management may have also made it more difficult for us to detect the difference from SD. Tillage management is another factor in the rate of sawdust decomposition. In the no-till system in our study, sawdust remained on the soil surface, which reduced contact with soil organisms that decompose SD. In addition, less oxygen required by many decomposers was added to the soil than would be the case if tilled slowing down their activity. These factors may have resulted in slower decomposition of sawdust. It is popular opinion that no-till with crop residues and other surface mulch low in nitrogen is likely to increase SOM but the effect is a long-term one. Therefore, our results suggest that sawdust did contribute to the slight increase in these properties but the time frame of 2 years might be too short to show a significant effect.

4.2.6 Soil NO_3-N

In the 2nd year, surface soil samples (0-15 cm) were taken to investigate soil nitrate on June 2nd and June 27th 2004 which was 33 d and 58 d after planting corn. As expected, soil NO_3-N 1 month and 2 months after planting was significantly affected by sawdust rates, with the highest rate of SD (18 Mg ha^{-1}) resulting in the lowest nitrate (38kg ha^{-1} and 14kg ha^{-1}, respectively). No effects from nitrogen fertilizer and interaction were indicated (Tables 4.7 and 4.11, and Figure 4-14). Mean separation and contrast tests showed significantly different soil NO_3-N taken on June 2nd 2004 between 0 and 9 Mg ha^{-1} SD but not between 9 and 18 Mg ha^{-1}. However, soil NO_3-N was different at incremental SD rates on June 27th 2004 (Table 4.13 and 4.14). This implied that 30 days after planting, presence of SD at 9 Mg ha^{-1} significantly reduced soil NO_3-N due to immobilization. Higher amount of SD (18 Mg ha^{-1}) also caused a reduction in NO_3-N though it was not different from 9 Mg ha^{-1}. The difference in soil NO_3-N between SD rates on June 27th suggested that longer time allowed more SD to decompose, causing more competition for available N; thus, more NO_3-N was immobilized.

Soil NO_3-N deficiency resulting from the use of sawdust as a mulch material seems to be the principle problem as it has been reported in many studies from very early date to present (Viljoen and Fred, 1924; Turk, 1943; Roberts, 1948; Allison and Anderson, 1951; Allison, 1965; Lareau, 1989, Lalande et al., 1998). Johnson (1944) stated that when SD was applied as surface mulch, nitrates were slightly depressed the first year and were further depressed the second year. In a comparison of the effects of different types of organic material addition on soil properties, Paustian et al. (1992) reported that nitrogen immobilization was greater in sawdust only than in straw. Soil

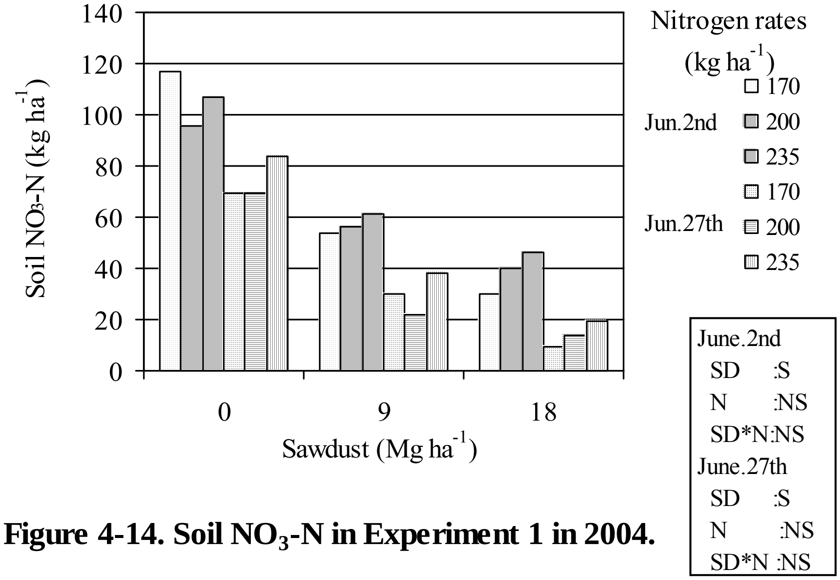


Figure 4-14. Soil NO_3-N in Experiment 1 in 2004.

Table 4.13. Results of linear contrasts for NO_3-N and corn yield in Experiment 1 in the 2nd year in 2004.

Treatment	Contrast	Soil NO_3-N		Corn yield
		June 2nd	June 27th	
N rates	N1	-	-	NS
	N2	-	-	*
SD rates	SD1	*	*	-
	SD2	NS	*	-
Interaction	SD1*N1	-	-	*
	SD1*N2	-	-	NS
	SD2*N1	-	-	NS
	SD2*N2	-	-	NS

* : Significant at 0.1 probability level.
NS : Not significant at 0.1 probability level
\- : No contrast was run due to insignificant main effect

Table 4.14. Mean separation using LSD for soil NO_3-N and corn yield in Experiment 1 in the 2nd year in 2004.

Treatment		NO_3-N ($kg\ ha^{-1}$)		Corn yield ($Mg\ ha^{-1}$)
SD ($Mg\ ha^{-1}$)	N ($kg\ ha^{-1}$)	June 2nd	June 27th	
0		106.5a*	74.15a	13.04a
9		56.98b	30.01b	12.63a
18		38.49b	14.06b	12.34a
	170	66.7a	36.2a	12.31b
	200	63.9a	34.87a	12.17b
	235	71.37a	47.16a	13.53a
0	170	116.58a	69.33a	13.67ab
0	200	95.85ab	69.11a	12.28abc
0	235	107.06a	84.02a	13.18ab
9	170	53.81c	30.17bc	11.31c
9	200	56.05c	21.89bc	12.93abc
9	235	61.09bc	37.98b	13.67ab
18	170	29.71c	9.11c	11.96bc
18	200	39.8c	13.61bc	11.31c
18	235	45.96c	10.28bc	13.75a

* Means followed by the same letter are not significantly different at $P>0.10$.

NO_3-N deficiency was an indication of the nitrogen immobilization that was mostly caused by biological assimilation. There was a different trend in nitrate content at two months after planting in the second year as compared to that at the same period of time in the first year. 235 kg N ha^{-1} in the first season was assumed to overcome the immobilization effect of sawdust at 9 and 18 Mg ha^{-1} as noticeable higher NO_3-N was found at this rate relative to lower N rates. On the other hand in 2004, a decreasing trend in NO_3-N after 1 and 2 moths with appreciably greater reduction at the latter date was apparent at all N rates and NO_3-N was significantly reduced at the highest SD rates. Possible explanations for the difference in soil NO_3-N between the two seasons might be the different method of N fertilizer application and higher total C input in the second season relative to the first year. In the first year, N fertilizer used in our study was partially broadcast applied on the surface with the rest banded beside the row. In year 2, all nitrogen was broadcast applied, which supposedly brought a uniform coverage with N across the whole field. Banding is believed to be a more efficient method than broadcast application as it places the fertilizer at concentrations beyond the tolerance of soil microbes, which delays the denitrification process for 2-3 weeks (Heard, 1997). In addition, the relatively high concentration of N in the banded zone may have resulted in much less N immobilization in this area. In contrast, broadcasting all N resulted in more uniform lower NO_3-N concentration, which may have resulted in more immobilization in the second year. Also, in year 1, although stratified sampling relative to row position was used in an attempt to obtain a representative sample, banding should result in greater variability in soil NO_3^- concentration, which probably led to greater sampling variation. Also, the stronger effect on NO_3-N by SD two months after planting in the second year as compared to that on earlier date might have been a result of the cumulative amount of SD in the second year, including residual SD from the first year and SD applied in the second year. Since higher amounts of SD and same N rates were present in the field in the second year, soil microorganisms obtained more C input for their metabolism but the same N, encouraging them to acquire more soil N for their needs. Moreover, residual SD from the first season might have become incorporated into the soil and increased its contact with soil microbes, enhancing the rate of decomposition. Warmer temperature at the end of June as compared to early that month may have contributed to an enhanced rate of biological decomposition, and therefore enhanced immobilization. Despite the occurrence of N immobilization, the effect only occurs temporarily. Nitrate depression was an indication of the rate of SD decomposition. As soon as the C input addition is stopped, the competition for available N will likely cease and more N will be released as a principle part of the N cycling in the soil. The soil by nature appears designed to maintain a low but fairly constant level of available N, rather than a high level of available N during the growing season for the production of high yielding crops (Henry and Ellis, 1997). Therefore, high concentration of soil N is subject to loss by leaching and perhaps denitrification. SD addition caused a temporary shortage of N but at the same time might have protected N from leaching and denitrification in the way that SD was surface applied.

4.2.7 Corn yield

In contrast to the effect of treatments on soil NO_3-N, there was no effect of SD on corn yield in the second year, whereas nitrogen fertilizer rates and the interaction of N and SD did affect corn yield (Table 4.7). Significantly higher corn yield (13.53 Mg ha^{-1}) occurred at 235 kg N ha^{-1} compared to 12.3 and 12.2 Mg ha^{-1} at 170 and 200 kg N ha^{-1}, respectively (Table 4.14). Contrasts for nitrogen rates indicated that corn yield responded significantly higher at 235 kg N ha^{-1} relative to 200 kg ha^{-1} N. Contrasts for interaction indicated a difference in N1*SD1 and not for the rest of the combinations (Table 4.13). As shown in mean separation comparison, higher corn yield was present at 0 SD + 170 N, 0 SD + 235 N, and 9 SD + 235 N compared with 9 SD + 170 N or 18 SD + 200 N (Table 4.14). Essentially, there was no response to additional N above 170 kg ha^{-1} with 0 SD, while at 9 and 18 Mg ha^{-1} there was response up to 235 kg N ha^{-1}. This result suggests that high corn yield could be obtained with sawdust rates of up to 18 Mg ha^{-1} combined with 235 kg N ha^{-1} (Table 4.7 and 4.14, and Figure 4-15), and indicates no clear detrimental effect of SD on corn yield in the second year at the highest N rate. Various conclusions have been made about the effect of SD on crop yields. Under laboratory work by Turk (1943), barley grew well in Fox sandy loam soil treated with

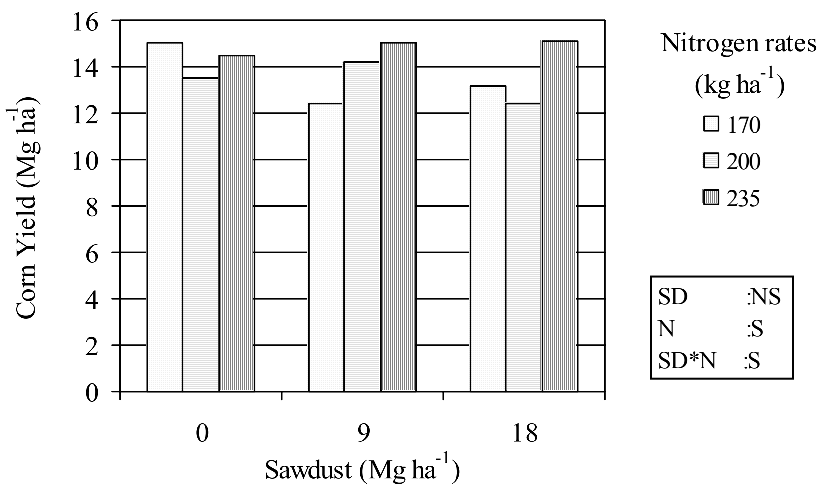


Figure 4-15. Corn yield in Experiment 1 in 2004.

sawdust and nitrogen fertilizer and sawdust mulch had no pronounced depressive effect on the growth of barley in Nappanee silt loam soil. Chemically decomposed poplar sawdust improved yield of ryegrass (Bidegain et al., 2000). Sawdust mulch increased the growth and productivity of highbush blueberries in a study by Lareau (1989). Growth and yield of plantains reported by Obiefura (1986) and Obiefura (1991) were significantly improved by the addition of sawdust mulch and not by the increasing rates of nitrogen fertilizers. Other research workers, however, have shown decreases in plant growth immediately following SD application under both greenhouse and field conditions and argued that the decrease was not due to harmful or toxic effects on either plants or soil but due to temporary depression of nitrates (Viljoen and Fred, 1924; Turk, 1943; Allison, 1965; Apert and Maron, 2000; Yang et al., 2002). Even though no effect of SD on corn yield in the second year was found in our study at the highest N rate, lower corn yield was observed at increasing SD rates at 170 and 200 kg N ha^{-1}. This is supported by the substantial decrease in available N discussed earlier. Corn yield in this experiment in this year was also appreciably high, probably due to abundant rainfall (Table 4.15). Maximum corn yield obtained at 235 kg N ha^{-1} and 18 Mg ha^{-1} coupled with the fact that corn yield in this experiment was still higher than reportedly long-term yield of the region suggest that SD addition concurrent with N fertilizer at 235 kg ha^{-1} can result in high corn yield.

4.2.8 Corn leaf nitrogen

Corn leaf N concentration was not affected by treatments and ranged from 2.3 to 2.7% (Table 4.7, 4.11 and Figure 4-16). Similar to our results, Yang et al. (2002) found

Table 4.15. Monthly average precipitation and soil temperature in the University of Tennessee Tobacco Experiment Station in Greeneville in 2004.

Month	Soil temperature (^oC) Max	Soil temperature (^oC) Min	Precipitation (mm)
January	11.11	1.11	62.23
February	2.78	3.89	85.598
March	12.22	8.33	115.316
April	16.11	11.67	103.124
May	24.44	19.44	153.416
June	26.67	22.78	109.474
July	28.89	24.44	202.184
August	27.78	23.33	57.15
September	25.00	21.11	136.652
October	19.44	16.11	55.626
November	13.89	11.11	80.01
December	6.11	3.89	94.996
Total			1255.776

Source: UT Tobacco Experiment Station in Greeneville (2004) (personal communication).

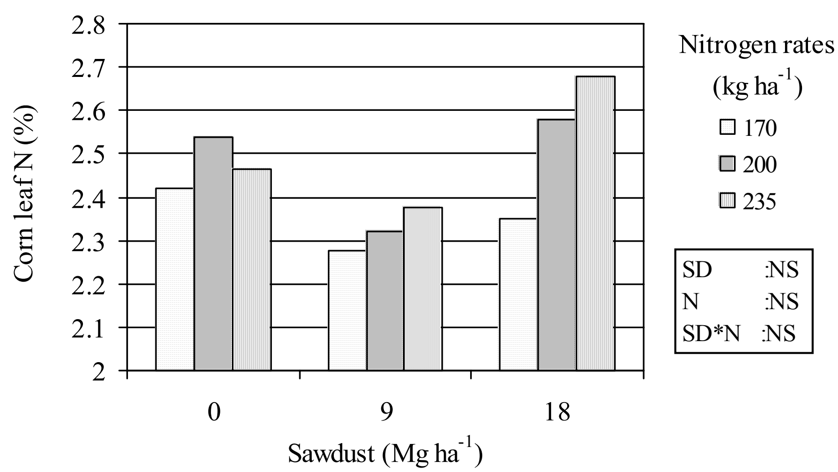


Figure 4-16. Corn leaf N in Experiment 1 in 2004.

no difference in leaf N enrichment between highbush blueberry with rotted SD or no amendment. As our data on NO_3-N indicated a significant effect of SD on reducing available N, it was expected that limited available N would likely have lowered corn leaf N concentration in SD amended plots. No significant effect on corn leaf N concentration by all treatments implied a dilution effect, in that higher yield and biomass in 0 SD and/or 235 kg ha^{-1} N treatments actually did take up more total N, but because there was more biomass in these treatments, the concentration of N was essentially the same as in lower yielding treatments. Yields of 11+ Mg ha^{-1} are not achieved in truly N deficient situation.

4.2.9 Summary of the two-year NT study (Experiment 1)

The two-year no-till study on effect of sawdust addition on soil properties and corn yield showed no effect on soil pH, a slight but statistically insignificant increase in SOM and total C at two depths: 0-15 cm and 0-7.5 cm, and no change in total N at both two depths. Bulk density and corn leaf N concentration were not different among treatments. N immobilization was substantial under the effect of SD after two years. Corn yield was affected by N fertilizer in both years, but was affected by SD in the first year only. There was a significant interaction in the second year. There was no response to N at 0 SD, while there was response to 235 kg N ha^{-1} at 9 and 18 Mg SD ha^{-1}. These results suggest that direct use of fresh SD containing high C:N ratio may have accounted for slow SD decomposition, thus resulting in unclear evidence of effect of SD on soil properties after two years. The effect of SD on N requirement was not clear. In the first year, the N response did not differ by SD rate, while in year 2 it did. Although it appeared that moderate rates of SD with high N did not depress yield, there was no measurable advantage of SD, and it appeared that in the second year SD use would require more N for optimum yield.

4.3 Experiment 2 (NT one season corn)

In this Experiment, SD was applied in the fall of 2003 and spring of 2004 in order to make a comparison between the effect of SD applied several months and applied immediately prior to planting.

4.3.1 P and K

Experiment 2 was located near Experiment 1 on Waynesboro soils that historically received the same liming and fertilization treatment as the Nolichucky soil in Experiment 1. Therefore, investigation of P and K gave similar results to those in Experiment 1, all in very high range (Table 4.16). Surface soils (0-15 cm) were sampled in the fall of 2003 for P, K, pH, soil total C, total N and SOM. Plant available P and K were determined in the University of Tennessee Soil Test Laboratory using Melich I extractant (Isaac et al., 1983a; Isaac et al., 1983b), for the purpose of assessing the need for fertilization. P ranged from 124 to 135 ppm which is very high and K ranged from 318 to 358 ppm which is very high according to the University of Tennessee soil test interpretations. At these soil test levels, no additional P and K fertilizer supply is necessary for optimum corn yield.

4.3.2 Soil pH

Preliminary samples showed significantly lower pH in plots receiving 200 kg N ha^{-1} than in 170 and 235 kg ha^{-1} irrespective to SD; and no different effect by SD and interaction (Table 4.16). Since these samples were taken before the treatments were applied, the

Table 4.16. Average soil P, K, and pH by treatments in Experiment 2 in 2004.

Treatment		P	K	pH		
SD ($Mg\ ha^{-1}$)	N ($kg\ ha^{-1}$)	($mg\ kg^{-1}$)	($mg\ kg^{-1}$)	Dec.03	Apr.04	Dec.04
0	170	124.4	318.1	7.23	7.15	7.05
0	200	132.3	335.2	7.10	7.10	7.03
0	235	134.5	333.5	7.25	7.25	7.08
9	170	124.4	357.9	7.18	7.23	7.10
9	200	125.6	353.7	7.13	7.18	7.08
9	235	132.3	350.0	7.23	7.20	6.98
18	170	126.7	325.9	7.30	7.20	7.08
18	200	134.5	348.6	7.18	7.05	7.03
18	235	126.7	331.3	7.30	7.20	7.10
18F*	170	130.0	338.5	7.18	7.13	7.05
18F	200	127.8	329.3	7.23	7.18	7.10
18F	235	134.5	339.4	7.23	7.18	7.05

*18F: 18 $Mg\ ha^{-1}$ SD applied in fall 2003.

difference was attributed to natural variability existing in the soils. The magnitude of the difference was actually very small, only 0.1 to 0.2 pH unit. Soil pH taken in April 22nd 2004, which was immediately prior to planting, was different by Nrates but not by SD rates and interaction (Table 4.17). Based on the fact that the date these soil samples were taken was prior to N fertilizer application, the difference was not attributed to treatments. At the end of season, soil pH did not differ between treatments (Table 4.17). No effect of SD on soil pH implied that SD did not affect soil acidity in this experiment.

4.3.3 Soil organic matter

SOM at 0-15 cm depth was not different in fall 2003 and spring 2004. At the end of the season, SOM as determined in the laboratory was significantly affected by SD and not by

Table 4.17. ANOVA table for soil pH, SOM (0-15 cm and 0-7.5 cm), NO_3-N, corn yield and corn leaf N in Experiment 2 (2004).

Sampling date	Source of variance	Degree of freedom	Soil pH	SOM (0-15 cm)	SOM (0-7.5cm)		NO_3-N	Corn yield		Corn leaf N
					Before dropping[3]	After dropping[4]		Unadjusted[5]	Adjusted[6]	
Dec, 2003	SD	3	NS	NS						
	N	2	*	NS						
	SD*N	6	NS	NS						
Apr, 2004	SD	3	NS	NS						
	N	2	*	NS						
	SD*N	6	NS	NS						
May, 2004	SD	3			NS	NS				
	N	2			NS	NS				
	SD*N	6			NS	NS				
June, 2nd 2004	SD	3					*			
	N	2					*			
	SD*N	6					NS			
June, 27th 2004	SD	3					NS			NS
	N	2					NS			NS
	SD*N	6					*			NS
Oct., 2004	SD	3						NS	NS	
	N	2						*	NS	
	SD*N	6						*	NS	
Dec., 2004	SD	3	NS	*	NS					
	N	2	NS	NS	NS					
	SD*N	6	NS	NS	NS					

* Significant at 0.1 probability level)

[3] Data were analyzed before dropping unusually high values.
[4] Data were analyzed after dropping unusually high values.
[5] Before adjustment.
[6] After adjustment with plant population as covariate.

nitrogen and interaction (Table 4.17). However, the reported SOM levels were much lower than at the beginning of the season. The measured SOM content for 0-15 cm was less that half of SOM at shallower depth, which is not logically possible. We therefore concluded there was some laboratory or sampling error involved, and decided not to take these data into consideration in interpreting treatment effects (Table 4.18 and Figure 4.17). On the other hand, both initial and after season SOM at shallower depth (0-7.5 cm) showed reasonable values although it was not different by treatments (Table 4.17 and 4.18 and Figure 4-18). Earlier works have shown a constant or increasing SOM when high C input was added to the soil depending on the quality of organic matter added and

Table 4.18. Average SOM (0-15 cm and 0-7.5 cm) and soil NO_3-N in Experiment 2 in 2004.

Treatment		SOM (%)					NO_3-N (kg ha^{-1})	
SD	N	0 – 15 cm			0 – 7.5 cm			
(Mg ha^{-1})	(kg ha^{-1})	Dec. '03	Apr. '04	Dec. '04	May '04	Dec '04	June 2nd '04	June 27th '04
0	170	1.68	1.65	0.80	2.00	2.50	46.24	11.43
0	200	1.78	1.83	0.93	2.15	2.13	39.12	9.18
0	235	1.55	1.70	0.80	2.85	2.25	61.43	18.22
9	170	1.83	1.78	0.98	2.05	2.38	37.27	8.33
9	200	1.93	1.38	1.00	2.90	2.43	37.61	17.49
9	235	1.80	1.73	1.08	2.23	2.45	40.64	6.66
18	170	1.78	1.53	0.95	2.05	2.73	21.97	7.05
18	200	1.83	1.80	1.08	1.90	2.63	33.69	9.00
18	235	1.78	1.58	0.95	1.95	2.45	37.83	12.30
18F*	170	1.63	1.73	1.10	2.35	2.55	30.38	7.05
18F	200	1.68	1.65	1.13	1.95	2.38	22.82	9.47
18F	235	1.83	1.90	1.13	2.18	2.75	36.99	10.52

18F*: 18 Mg ha^{-1} SD applied in fall 2003.

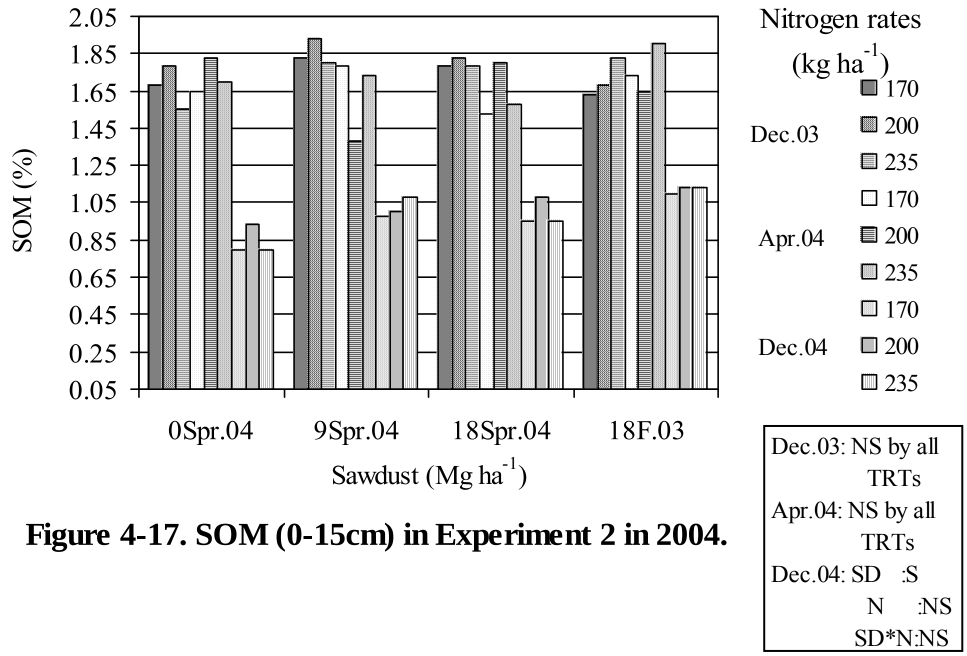


Figure 4-17. SOM (0-15cm) in Experiment 2 in 2004.

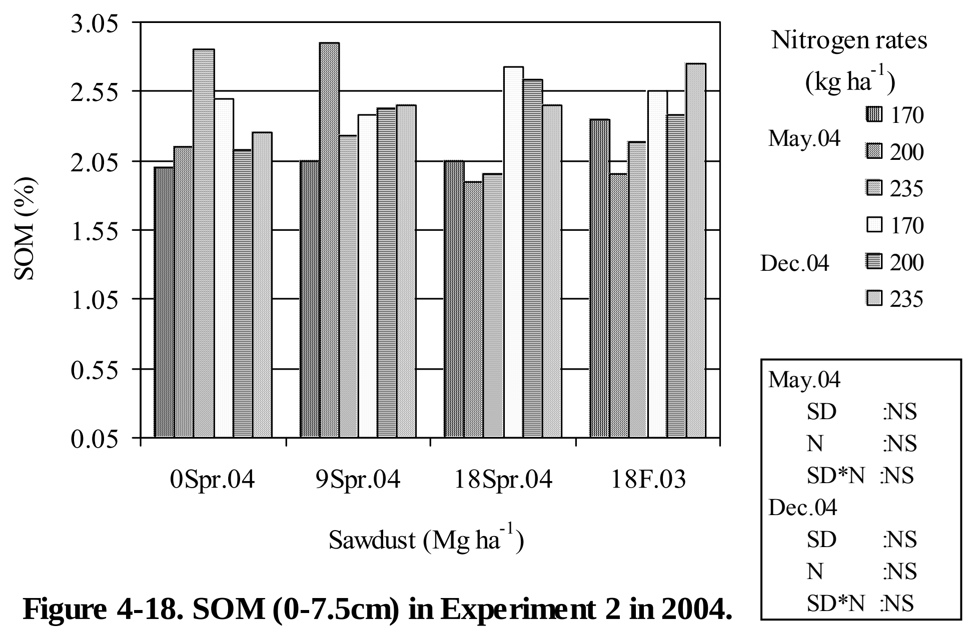


Figure 4-18. SOM (0-7.5cm) in Experiment 2 in 2004.

the amount of N added in organic and inorganic forms(Paustian et al., 1992). Although no effect of treatments was found on SOM at the 0-7.5 cm depth, SOM slightly increased in the whole field at the end of the season. Slightly increasing SOM at 0-7.5 cm even in zero SD plots might have been due to the increasing application rate of N fertilizer and resulting in high corn yield. This agreed with results that increasing N levels lead to SOM increase (Magdoff and Weil, 2004). However, this experiment is far from conclusive in demonstrating the effect. In addition, no apparent effect of SD on SOM at the 0-7.5 cm depth after one year even with the addition of low C:N ratio SD 5 months prior to planting further supported our discussion in Experiment 1 related to the short time frame in our study for measuring SOM changes.

4.3.4 Soil NO_3-N

Soil NO_3-N was taken on June 2nd and June 27th 2004 which were 33 and 58 d after planting. Soil NO_3-N at 33 d after planting was significantly affected by SD and N fertilizer rates but not by interaction. In contrast, NO_3-N at the second date was different by interaction and not by SD and N rates (Table 4.17). With regard to NO_3-N at 33 d after planting, contrast and mean separation comparison for N and SD showed a significantly higher NO_3-N at 235 kg N ha^{-1} compared to lower rates and lower NO_3-N in SD treatments relative to no SD (Table 4.19 and 4.20, and Figure 4.19). Contrast and mean separation for interaction effect on NO_3-N 58 d after planting corn showed a significant difference in SD1*N2, indicating an appreciably lower in NO_3-N where SD was applied even with high N rates (Table 4.19 and 4.20, and Figure 4.19). Immobilization of N when high C:N ratio materials are added to the soil has been well known. This is a biological

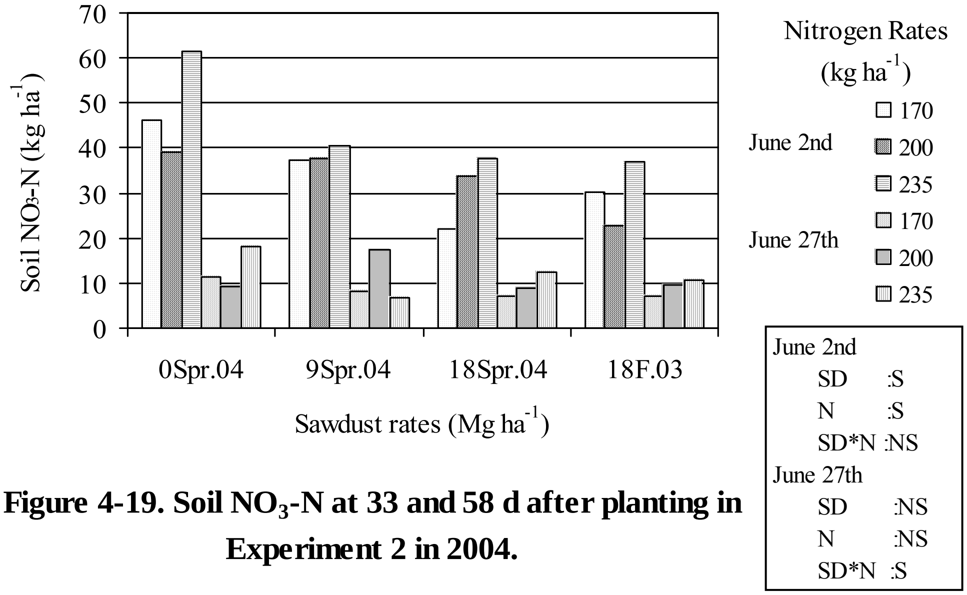


Figure 4-19. Soil NO_3-N at 33 and 58 d after planting in Experiment 2 in 2004.

Table 4.19. Results of linear contrasts in Experiment 2 in 2004.

Treatment	Contrast	NO_3-N June 2nd	NO_3-N June 27th
N rates	N1	*	-
	N2	*	-
SD rates	SD1	*	-
	SD2	NS	-
	SD3	NS	-
Interaction	SD1*N1	-	NS
	SD1*N2	-	*
	SD2*N1	-	NS
	SD2*N2	-	NS
	SD3*N1	-	NS
	SD3*N2	-	NS

* : Significant at 0.1 probability level.
NS: Not significant at 0.1 probability level
\- : Contrast was not run due to insignificant main effect

Table 4.20. Mean separation using LSD in Experiment 2 in 2004.

Treatment		pH		NO_3-N (kg ha^{-1})	
SD (Mg ha^{-1})	N (kg ha^{-1})	Apr.'04	Dec.'04	June 2nd	June 27th
0		7.14a*	7.03a	40.23a	12.32a
9		7.2a	7.03a	40.37a	12.28a
18		7.15a	7.05a	37.73ab	9.4a
18F		7.14a	7.06a	27.88b	7.86a
	170	7.16ab	7.05a	33.7b	8.35a
	200	7.12b	7.05a	32.33b	11.29a
	235	7.19a	7.04a	43.63a	11.74a
0	170	7.13abc	7.01ab	37.5abcd	10.31abc
0	200	7.08bd	7.01ab	33.13abcd	9.94abc
0	235	7.2ac	7.08ab	50.1a	16.71ab
9	170	7.2abc	7.1a	42.6abcd	8.87bc
9	200	7.18abc	7.05ab	34.92abcd	17.36a
9	235	7.2abc	6.97b	43.6abc	10.6abc
18	170	7.2ab	7.09ab	29.5bcd	8.03c
18	200	7.06cd	7.03ab	38.47abcd	8.84abc
18	235	7.2ab	7.05ab	45.2ab	11.3abc
18F**	170	7.1abc	7.01ab	25.19cd	6.19c
18F	200	7.17abc	7.11ab	22.8d	9.03abc
18F	235	7.17abc	7.05ab	35.65abcd	8.36abc

* : Means followed by the same letter are not significantly different at P>0.10.

**18F: 18 Mg ha^{-1} SD applied in fall 2003.

process with the involvement of mainly fungi and bacteria whose preferable substrates are wood wastes. These organisms consume the substrate as a C source to build their biomass. Bacteria and fungi have a comparatively short life that varies from a few days, even hours to a few weeks. Nitrogen is released when these microorganisms die but this N will be utilized again and again by other organisms in the further decomposition of SD residues, practically until all of the readily available energy supply (primarily cellulose and pentosan) in these residues has been destroyed. As discussed earlier, the high C:N ratio in SD and low C:N ratio in soil microorganism cells will likely to spur them to obtain the needed N from the soil pool. The competition is especially crucial with the presence of plants, resulting in decreasing available N. Available N also responded to the addition of N fertilizer at 33 d, suggesting that addition of N partially offset the reduction in available N as the effect of SD. Although interaction was not found at 33 d, the significant effect of interaction at 58 d, particularly between SD1 and N2 supported our discussion indicating greater immobilization potential in SD plots. N immobilization occurred in our study in this experiment due to SD addition, in agreement with earlier work.

4.3.5 Corn yield

Unadjusted corn yield in Experiment 2 was affected by N rates and interaction but not by SD (Table 4.17). However, it was noted that plant population was highly variable in Experiment 2 due to the technical problems occurring during planting. A analysis of covariance with plant population as covariate was conducted in order to remove part of the yield variability associated with population difference and give a clearer understanding of the relationship of yield to the experimental variable. As suspected, a significant effect of plant population on corn yield was found (data not shown). After adjusting for population, corn yield was not different by treatments (Table 4.17 and 4.21, and Figure 4-20). Although crop yields have been believed to increase with increasing N rates and effect of SD on crop yields has been arguable, no effect of SD, N and interaction on corn yield was found in this experiment, suggesting that sawdust did not have detrimental effect on corn yield and did not affect response for fertilizer N.

4.3.6 Corn leaf nitrogen

There was no treatment effect on corn leaf N concentration, despite significant effects of treatments on soil nitrate at 33 and 58 d after planting (Table 4.17 and 4.21, and Figure 4-21). Corn leaf N depends on the amount of available nitrogen in the soil. N immobilization would be expected to be the main factor that limits corn N uptake in this study. As indicated, SD addition did cause N immobilization at an early date when corn

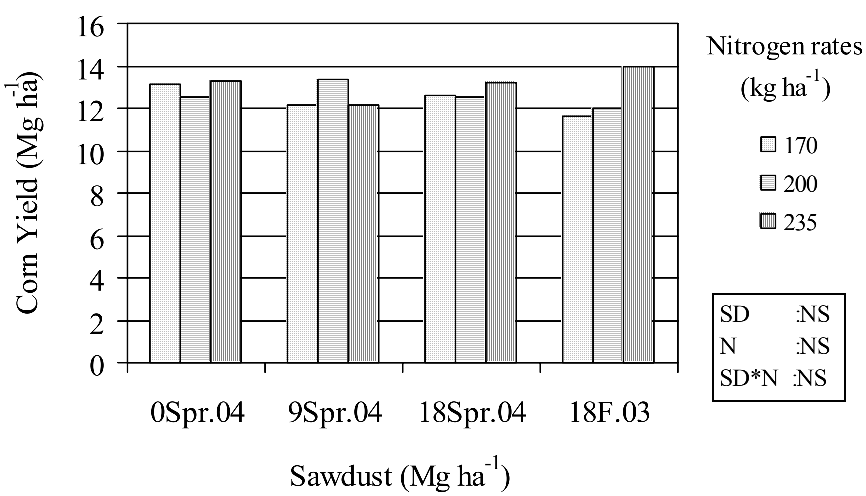


Figure 4-20. Corn yield in Experiment 2 in 2004 after adjusted for population variation.

Table 4.21. Average adjusted corn yield, plant population and corn leaf N concentration in Experiment 2 in 2004.

Treatment		Corn yield	Plant population	Corn leaf N
SD ($Mg\ ha^{-1}$)	N ($kg\ ha^{-1}$)	($Mg\ ha^{-1}$)	($plant\ ha^{-1}$)	(%)
0	170	13.16	61931	3.37
0	200	12.51	59654	2.52
0	235	13.31	59654	2.59
9	170	12.15	50547	2.72
9	200	13.33	55100	2.54
9	235	12.12	55556	2.69
18	170	12.63	56922	3.17
18	200	12.5	48953	2.58
18	235	13.18	61703	2.63
18F*	170	11.62	53052	2.45
18F	200	12.03	54645	2.61
18F	235	13.98	57377	2.49

* 18F: 18 $Mg\ ha^{-1}$ SD applied in fall 2003.

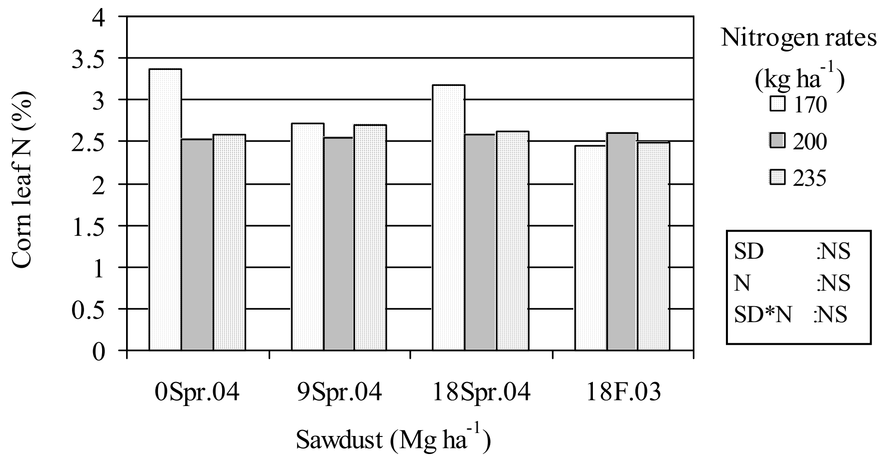


Figure 4-21. Corn leaf N in Experiment 2 in 2004.

required a large amount of available N for growth. However, the addition of N fertilizer was apparently to be sufficient to provide enough available N during the growing period of corn. Although, there was a reduction in available N in the soil at the date of taking corn leaf, the corn apparently had obtained enough N and distributed it to the leaves at that time. This resulted in an insignificant effect on corn leaf N.

4.3.7 Summary of the one-year NT study (Experiment 2)

It appeared likely that the one year study in Experiment 2 did not give a complete picture of the final effect of SD at either application date, implying a need for further study to understand what ultimately happens to soils with the addition of both fresh and weathered SD. In this experiment after one year, however, no detrimental effect of SD on corn yield was observed even though N immobilization occurred, and there was no reduction in pH.

4.4 Experiment 3 (Conventional tillage one season corn)

4.4.1 P and K

Experiment 3 was located next to Experiment 2 on the same Waynesboro soil, that historically received the same liming and fertilization treatment as soil in Experiment 2. Therefore, both P and K values were very high according to standard provided by the University of Tennessee Soil Test Laboratory (Table 4.22), indicating no additional P and K fertilizer supply is necessary for optimum corn yield.

4.4.2 Soil pH

Surface soils (0-15 cm) were sampled for a preliminary investigation on soil pH in the fall 2003 and immediately prior to plant in spring 2004. At the end of season, soil pH was examined to determine the possible change that might occur due to treatments. Soil pH in fall 2003 was different by SD rates and interaction and not by N rates. Because these samples were taken before fall-03 SD was applied, the difference was certainly not due to treatments. pH in spring 2004 and at the end of the season was not different by treatment (Table 4.22). Results of soil pH from all three experiments convinced us that sawdust had no negative effect on soil acidity.

4.4.3 Soil organic matter

SOM taken in fall 2003 was different by N rates and not by SD and interaction. In spring 2004 which was 5 months after fall SD was applied, no effect of treatment was found. SOM at the end of the season was also not affected by treatments. Early season difference was attributed to natural variability because the samples were taken before the treatments were applied. One SOM observation in spring 2004 was found to be abnormal

Table 4.22. Average soil P, K, and pH by treatment in Experiment 3 in 2004.

Treatment		P	K	pH		
SD (Mg ha^{-1})	N (kg ha^{-1})	(mg kg^{-1})	(mg kg^{-1})	Dec.03	Apr.04	Dec.04
0	170	100.89	268.48	7.23	6.95	7.03
0	200	102.01	284.17	7.23	7.08	7.13
0	235	106.50	296.78	7.18	6.98	6.98
9	170	100.89	245.50	7.20	7.03	7.08
9	200	105.37	245.78	7.20	7.13	7.10
9	235	102.01	235.69	7.10	7.05	7.05
18	170	104.25	265.68	7.08	7.08	7.03
18	200	100.89	236.81	7.08	7.00	7.00
18	235	107.62	269.04	7.20	7.15	7.08
18F*	170	91.92	242.70	7.05	7.00	7.03
18F	200	110.98	258.95	7.18	7.10	7.05
18F	235	104.25	242.14	7.15	7.13	7.08

*18F: 18 Mg ha^{-1} SD applied in fall 2003.

as its value was 0.1% whereas the same observation in fall 2003 and fall 2004 showed 0.8 and 1.3%, respectively. Analysis rerun after considering this as a missing value was unchanged (Table 4.23). However, overall SOM slightly increased in spring 2004 relative to fall 2003. The increase was greater at the end of season (Table 4.24 and Figure 4-22). It was surprising that SOM increased even in plots receiving no SD. In a comparison with SOM in Experiment 2 at the same depth (0-15 cm), there was a reverse trend in SOM in the two experiments. Initial SOM in Exp.2 was fairly high, ranging 1.4 to 1.9%, and decreased at the end of the season, ranging from 0.84 to 1.2%. Initial SOM in Exp.3, on the other hand, was low, from 0.95 to 1.5%, and increased at the end of the season, from 1.35 to 1.75%. Clearly, conventional tillage hastened the decomposition of SD compared with no-till. The preexisting high SOM in the experiment site might have been a

Table 4.23. ANOVA table for soil pH, SOM, NO_3-N, corn yield and corn leaf N in Experiment 3 in 2004.

Sampling date	Source of variance	Degree of freedom	Soil pH	SOM (0-15cm) Before dropping[7]	SOM (0-15cm) After dropping[8]	NO_3 -N	Corn yield	Corn leaf N
Dec., 2003	SD	3	*	NS				
	N	2	NS	*				
	SD*N	6	*	NS				
Apr., 2004	SD	3	NS	NS	NS			
	N	2	NS	NS	NS			
	SD*N	6	NS	NS	NS			
June, 2nd 2004	SD	3				NS		
	N	2				NS		
	SD*N	6				NS		
June, 27th 2004	SD	3				*		NS
	N	2				*		NS
	SD*N	6				NS		NS
Oct., 2004	SD	3					NS	
	N	2					NS	
	SD*N	6					NS	
Dec., 2004	SD	3	NS	NS				
	N	2	NS	NS				
	SD*N	6	NS	NS				

* Significant at 0.1 probability level.

[7] Data were analyzed before dropping unusually low values
[8] Data were analyzed after dropping unusually low values

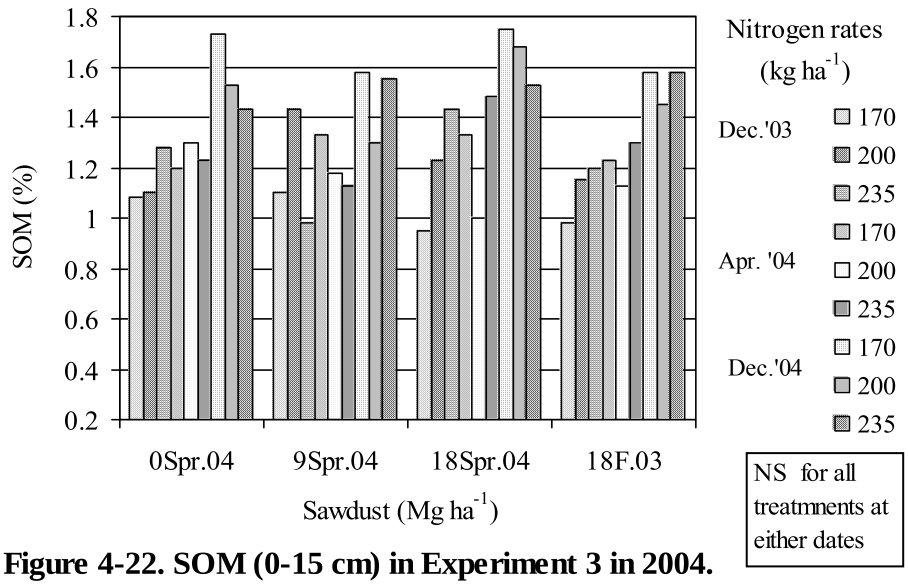


Figure 4-22. SOM (0-15 cm) in Experiment 3 in 2004.

Table 4.24. Average SOM, NO_3-N, corn yield and corn leaf N in Experiment 3 in 2004.

Treatment		SOM (%)			NO_3-N (kg ha^{-1})		Corn yield	Corn
SD (Mg ha^{-1})	N (kg ha^{-1})	Dec. '03	Apr. '04	Dec. '04	June 2nd	June 27th	(Mg ha^{-1})	leaf N (%)
0	170	1.08	1.20	1.73	85.08	35.42	15.28	2.46
0	200	1.10	1.30	1.53	115.01	20.04	16.45	3.15
0	235	1.28	1.23	1.43	97.30	45.79	14.82	2.51
9	170	1.10	1.33	1.58	107.50	10.07	15.64	2.51
9	200	1.43	1.18	1.30	130.93	15.53	15.64	3.00
9	235	0.98	1.13	1.55	117.31	14.21	15.82	2.70
18	170	0.95	1.33	1.75	123.70	9.71	15.19	2.43
18	200	1.23	1.00	1.68	98.09	17.11	14.91	2.47
18	235	1.43	1.48	1.53	127.79	20.96	16.18	3.02
18F*	170	0.98	1.23	1.58	84.75	11.00	15.37	2.60
18F	200	1.15	1.13	1.45	103.36	20.80	16.36	3.30
18F	235	1.20	1.30	1.58	129.87	32.97	15.46	2.53

*18F: 18 Mg ha^{-1} SD applied in fall 2003.

limitation for detection of SOM change during a short period of time in our study. Overall, during the one year period of the experiment, there were no differences in OM due to treatment.

4.4.4 Soil NO_3-N

33 d after planting, soil NO_3-N was not affected by treatments. NO_3-N at 58 d after planting, on the other hand, significantly decreased in SD treatments and different by N rates but there was no significant interaction (Table 4.23). Contrasts for SD rates indicated a significant difference between 0 SD and SD treatments. Contrasts for N rates showed the difference between 200 and 235 kg N ha^{-1} (Table 4.25). Mean separation explained a higher NO_3-N at 0 SD compared to the rest and higher NO_3-N at 235 kg N ha^{-1} relative to other rates (Table 4.26 and Figure 4-23). The greatest reduction of NO_3-N occurred at 18 Mg ha^{-1} SD applied in spring 2004 which followed a logical pattern (Table 4.24). This result was somewhat opposite to that in Experiment 2 where NO_3-N was affected by SD and N rates at 33 d and not at 58 d. The difference might have been due to different tillage management employed in the two experiments. In this conventional tillage experiment, although SD mixed with the soil hastened the decomposition as compared to surface SD application, the tillage also helped distribute N fertilizer more evenly to the lower depth relative to no-till wherein more N was susceptible to immobilization through direct contact with crop residues and sawdust at the soil surface. This might be the reason why we observed appreciably higher available N in Experiment 3 relative to Experiment 2 at 33 d after planting. In contrast, at the later date, NO_3-N reduced greatly and the differences occurred between SD receiving plots versus 0 SD and

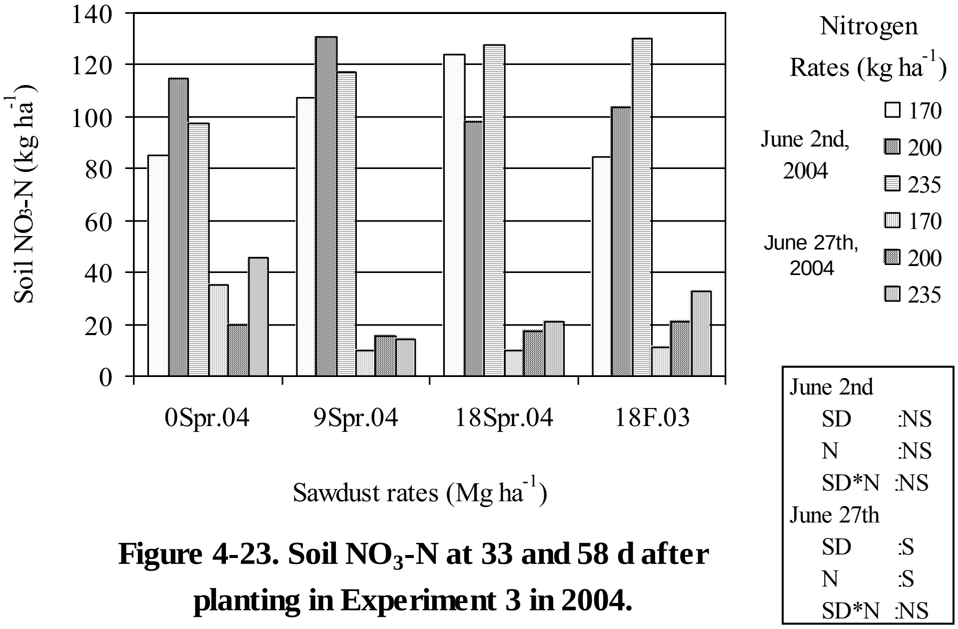


Figure 4-23. Soil NO_3-N at 33 and 58 d after planting in Experiment 3 in 2004.

Table 4.25. Results of linear contrasts for soil NO_3-N in Experiment 3 in 2004.

Treatment	Contrast	NO_3-N (June 27th)
N rates	N1	NS
	N2	*
SD rates	SD1	*
	SD2	NS
	SD3	NS
Interaction	SD1*N1	-
	SD1*N2	-
	SD2*N1	-
	SD2*N2	-
	SD3*N1	-
	SD3*N2	-

* : Significant at 0.1 probability level.
NS: Not significant at 0.1 probability level
\- : Contrast was not run due to insignificant main effect

Table 4.26. Mean separation using LSD for NO_3-N in Experiment 3 in 2004.

Treatment		NO_3-N (kg ha^{-1})
SD (Mg ha^{-1})	N (kg ha^{-1})	June 27th '04
0		33.75a*
9		13.27b
18		15.93b
18F		21.59ab
	170	16.55b
	200	18.37ab
	235	28.48a
0	170	35.42ab
0	200	20.04bcd
0	235	45.79a
9	170	10.07d
9	200	15.53bcd
9	235	14.21bcd
18	170	9.71d
18	200	17.11bcd
18	235	20.96bcd
18F**	170	11.0cd
18F	200	20.8bcd
18F	235	32.97abc

* Means followed by the same letter are not significantly different at $P>0.10$.

**18F: 18 Mg ha^{-1} SD applied in fall 2003.

between 200 versus 235 kg N ha^{-1}. Apparently SD decomposition at that time caused N immobilization. In addition, the tillage method might have partially contributed to differences in that tilling the soil move N fertilizer quickly to a 10 to 15 cm depth, and may have enhanced NO_3-N leaching to lower depth. Although there was a higher mean available N 58 d after planting in fall-03 SD plots relative to spring-04 SD plots, the difference was not statistically significant. This might also be due to the leaching of available N to the lower depth in the whole field as discussed earlier. In general, our finding agreed well with early work by Johnson (1944). Johnson stated that when sawdust was incorporated with the soil, nitrate was greatly depressed the first 18 months. Results of NO_3-N in all three experiments indicated the likely occurrence of N immobilization when SD was either surface applied or incorporated into the soil.

4.4.5 Corn yield

In spite of significant effect of SD on available N, no detrimental influence of SD was found on corn yield. Corn yield was not different by treatments (Table 4.23). Yield remained constant in all treatments and was as extraordinarily high as yield in Experiment 1 in the first year (Table 4.24 and Figure 4-24). Favorably natural conditions during the cropping season played an important role in producing high corn yield. The field received abundant rainfall especially in July when the corn entered the critical pollination stage (Table 4.15). Various conclusions have been made about effect of SD on crop yields but generally it has been stated that sawdust with its high C:N ratio stimulates N immobilization by microorganisms and, therefore, may be detrimental to the developing crop following incorporation (Sommerfeldt and MacKay, 1987). However,

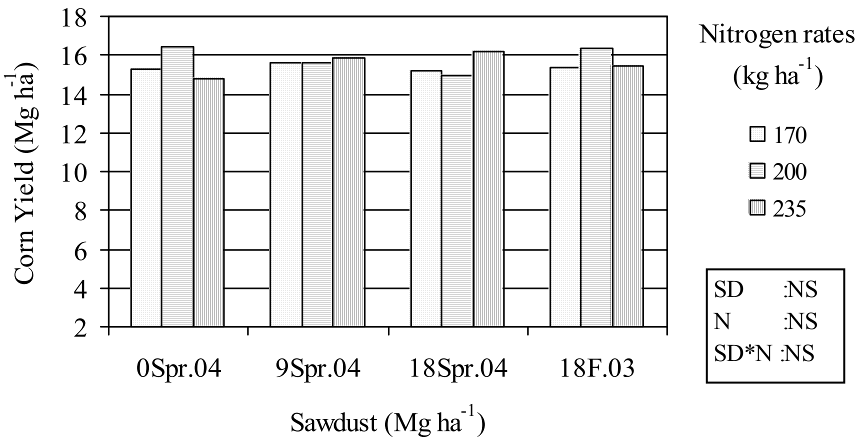


Figure 4-24. Corn yield in Experiment 3 in 2004.

early work by Johnson (1944) indicated that when sawdust was incorporated with the soil, the yields were less for tomatoes and higher for fall potatoes than yield for the check, which received an equivalent application of nitrogen. A detrimental influence of SD on corn yield at higher N rates was found only in the first year in Experiment 1. It is apparent that SD had little damaging effect on corn yield when combined with adequate N fertilizer.

4.4.6 Corn leaf nitrogen

Corn leaf N concentration was not different among treatments (Table 4.23 and 4.24, and Figure 4-25). Despite rather low soil NO_3^- on the date leaf samples were taken, leaf N levels were all adequate for optimum yield. Possibly NO_3^- had leached below the15 cm depth, and was still available to the plant. Also, by 60 d days after planting, the corn was in the late vegetative stage, and had already taken up much of the total N needed to produce grain.

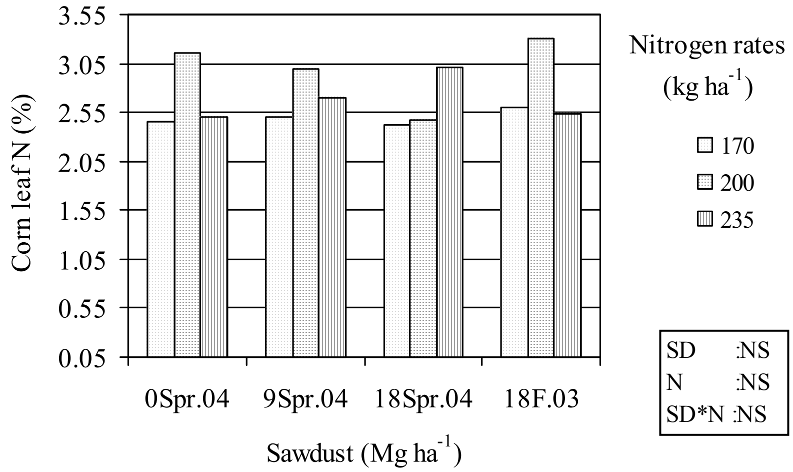


Figure 4-25. Corn leaf N in Experiment 3 in 2004.

4.4.7 Summary of the one-year till study (Experiment 3)

One year till study showed no change in soil acidity, SOM, as well as corn leaf N. Corn yield was not affected by SD, N and interaction. Available N deficiency occurred 58 d after planting as results of immobilization due to SD addition and loss through leaching.

5. CHAPTER V: SUMMARY AND CONCLUSIONS

Using sawdust as a soil amendment has drawn the attention of researchers since the early 1900's. It has been agreed that sawdust provides a rich C source that potentially increases soil organic matter. Influence of SD on other soil physical properties was also proven including lower bulk density, more uniform soil temperature, higher soil moisture (especially when SD was used as a mulch), increasing pore space, improving infiltration rate of soils and increasing water holding capacity of the soil. Likewise, nitrogen immobilization occurrence has been well documented when SD is either surface mulched or mixed with the soil due to its high C:N ratio. However, it has been argued whether or not SD has negative effect on soil acidity and crop yields. Lower crop yield was reported when SD was applied alone without N fertilizer. Response of crop growth to SD addition concurrently with N fertilizer, on the other hand, varied from study to study. Also, investigation of SD influence in soil acidity has been conducted in a few situations, but the true effect of SD has been unknown. This study was to determine the effects of sawdust application and the rates of sawdust and nitrogen fertilizer on soil chemical and physical changes and corn yield in no-till and conventional tillage situations.

Results from three experiments showed no effect of SD on soil acidity. Soil pH remained constant after both one-year and two-year SD addition. Corn yield was slightly decreased due to SD at all N rates only in the first year of the two-year experiment. No detrimental influence of SD was found in the second year of Experiment 1 with adequate N but yields were reduced by SD at lower N rates. Also, there was no negative effect of SD on corn yield in Experiment 2 and 3. No N immobilization due to SD addition was found in year 1 of the Experiment 1, probably because the time when samples were taken

(60 d after planting) was too late and earlier immobilization might have occurred. 235 kg N ha^{-1} significantly increased available N in year 1 of Experiment 1 relative to lower rates. As expected, N immobilization due to SD occurred in year 2 of Experiment 1 and in Experiment 2 and 3. N immobilization caused by SD in year 2 in Experiment 1 was probably due to the accumulation of SD including residual SD from the first year and SD addition in the second year which led to the stronger competition of soil microorganisms for available N for increasing microbial biomass. In this case, N immobilization was reflected in lower yields at lower N rates in SD amended treatments. Therefore, increasing N rates in the case of C input accumulation should be taken into consideration in order to counter the effect of SD on N immobilization. In Experiment 2, soil NO_3^- was reduced by SD addition at 33 d after planting, but not at 58. In contrast, in Experiment 3, soil NO_3^- was reduced by SD addition at 58 d after planting, but not at 33. In both experiments, when there was immobilization by SD, soil NO_3^- was increased by nitrogen, but there was no interaction with sawdust rates or timing. Fall sawdust application that was 5 months prior to planting did not result in higher available N than the spring SD receiving treatments in Experiment 2 or 3, even though there was a major difference in C:N ratio. Spring SD was fresh and had high C:N (approximately 550:1 and 670:1 in Experiment 1 in the first year and 2nd year in all three experiments, respectively), whereas fall SD applied in Experiment 2 and 3 was stock-piled and had a fairly low C:N ratio (119:1). Although it would seem that the use of composted or weathered SD as soil amendment should be favorable due to its less depressing effect on available N, our study did not confirm this. It should also be noted that fall applied sawdust had more time to decompose. The differences between Experiments 2 and 3 in soil NO_3^- at 58 d after

planting were primarily due to odd results in the 9 Mg ha^{-1} SD treatments in Experiment 2. in the 9 Mg ha^{-1} SD treatment, soil NO_3^- was abnormally high in the 200 kg ha^{-1} N treatment, and abnormally low in the 235 kg ha^{-1} treatment. For all other SD rates, the soil NO_3^- data for Experiment 2 and 3 and 58 d after planting were similar. We had no explanation for this results.

Previous studies have recorded a linear relationship between C input and soil organic matter in that SOM increases as the C input increases. However, SOM in three experiments in our study did not significantly increase, suggesting that the time period of 1 or 2 years was not long enough for SD to completely decompose and a longer observation period may be needed to visualize the true effect of SD. Similarly, no soil total C and total N was found in after two years in Experiment 1, confirming our discussion about the time frame. Furthermore, preexisting relatively high SOM in our experiment site was a limitation for detecting an increase in SOM as well as total C in a short period of time. If it is assumed that 80% of the added C will be lost to the atmosphere by conversion to CO_2, then the total residual C added to the soil per Mg of SD is about 90 kg ha^{-1}. For 18 Mg ha^{-1} SD over 2 years, this is equal to about 3200 kg ha-1 additional C. The original C content of the soil was approximately 1% in the upper 15 cm, which means that there was about 21,000 kg ha^{-1} of C in the soil initially in the upper 15 cm. The addition from 2 years of SD at 18 Mg ha^{-1} would only be equal to about 15% of the original amount. Given natural variability, it is difficult to detect a change this small statistically.

Corn leaf N concentration was not affected by treatments in all experiments due to the substantially high N fertilizer applied. As a look at soil physical change as affected by SD, bulk density was determined in Experiment 2 in the second year and showed no difference due to treatment.

This study revealed no major detrimental effects on the two very important factors concerning many researchers: soil pH and corn yield. However, in Experiment 1 more N fertilizer was required when SD was added. 18 Mg ha^{-1} SD combined with 235 kg N ha^{-1} appeared to result in comparatively high yield in all experiments even when there was a reduction in available soil N compared to 0 SD. In Experiment 2 and 3, 170 kg N ha^{-1} was adequate even with 18 Mg ha^{-1} SD. Results for other soil properties, such as SOM, total C, total N, corn leaf N, and bulk density implied that a longer term study would be needed to make further interpretation. From the results obtained in this study, using SD as a soil amendment not only helps waste management but also possibly benefits the soil quality in the long run. However, in the short run no advantage of SD addition was identified, and additional N was sometimes required. Other factors which should be taken into consideration for future investigation of the best use of SD include: (1) SD amendment used on less fertile soils is more likely to yield measurable changes in soil properties, (2) careful maintenances of technical procedures is needed throughout the study, (3) and conducting study over a longer period of time than 2 years will help develop more comprehensive conclusions.

LIST OF REFERENCES

Allison, F.E., and M.S. Anderson. 1951. The use of sawdust for mulches and soil improvement. USDA Cir. 891: 1-19.

Allison, F.E. 1965. Decomposition of wood and bark sawdusts in soil, nitrogen requirements, and effects on plants. USDA Cir. 1332:1-56.

Apert, P., and J.L. Maron. 2000. Carbon addition as a countermeasure against biological invasion by plants. Biological Invasions. 2(1): 33-40.

Bendfeldt, E.S., Burger J.A., and W.L. Daniels. 2001. Quality of amended mine soils after sixteen years. Soil Sci. Soc. Am. J. 65: 1736-1744.

Bidegain, R.A., Kaemmerer M., Guiresse M., Hafidi M., Rey F., Morard P., and J. C. Revel. 2000. Effects of humic substances from composted chemically decomposed poplar sawdust on mineral nutrition of ryegrass. J.Agric. Sci., Cambridge. 134: 259-267.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen total. p. 595-609. *In* A. L Page, R. H. Miller, and D. R. Keeney (ed.). Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Bulmer, C. 2000. Reclamation of forest soils with excavator tillage and organic amendments. For. Ecol. Manage. 133: 157-163.

Burgos, N.R., and R.E. Talbert. 1996. Weed control and sweet corn (Zea mays var. rugosa) response in a no-till system with cover crops. Weed Sci. 44: 355-361.

Conservation Technology Information Center. 2005. National crop residue management survey conservation tillage data – National tillage trends (1990-2004). [Online] Available at www.ctic.purdue.edu/ctic/CRM2004/1990-2004data.pdf. (Accessed April 12, 2005). CTIC, West Lafayette, IN.

Davidson, E.A., S.C. Hart, and M.K. Firestone. 1992. Internal cycling of nitrate in soils of a mature coniferous forest. Ecology 73: 1148-1156.

DeGregorio, R., M.W. Schonbeck, J. Levine, G. Iranzo-Berrocal, and H. Hopkins. 1995. Bigflower vetch and rye vs. rye alone as a cover crop for no-till sweet corn. J. Sustain. Agric. 5(4):7-18.

Ebelhar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from legume cover crops for no-tillage corn. Agron. J. 76: 51-55.

Eckert, D.J. 1988. Rye cover crops for no-tillage corn and soybean production. J. Prod. Agric. I: 207-210.

Eckert, D.J. 1991. Chemical attributes of soils subjected to no-till cropping with rye cover crops. Soil Sci. Soc. Am. J. 55: 405-409.

Essington, M.E. 2002. Water and soil chemistry: An integrative approach. CRC Press, Boca Raton. Fl.

Grossman, R.B., and T.G Reinsch. 2002. The soil phase – Bulk density and linear extensibility. p. 207-209. *In* J.H. Dane and G.C. Topp (ed.). Methods of Soil Analysis- Physical Methods. Part 4. Agron. Monogr. 5. SSSA, Madison, WI.

Hajny, G.J. 1966. Outside storage of pulpwood chips – A review and bibliography. Tech. Assoc. Pulp Paper Industry Mtg. 49 (10): 97A-105A.

Heard, J. 1997. Fall application of fertilizer. Manitoba Agriculture, Food and Rural Initiatives. News and Forecasts. [Online] Available at www.gov.mb.ca/agriculture/news/topics/daa03d01.html (Accessed April 12, 2005).

Henry, D.F., and B.G. Ellis. 1997. Soil Fertility. 2nd ed. Lewis Publishers. Boca Raton. Fl.

Hyvonen, R., G.I. Agren, and O. Andren. 1996. Modeling long-term effects: Carbon and nitrogen dynamics in an arable soil receiving organic matter. Ecol. Applic. 6(4): 1345-1354.

Isaac, R.A., S.J. Donohue, R.H. Brupbacher, J.D. Lancaster, A. Mehlich, D.D. Scott, M.R. Tucker, and J.R. Woodruff. 1983a. Determination of phosphorous by Mehlich I (0.05N HCl in 0.025N H_2SO_4) extraction. Reference soil test methods for the southern region of the United States. South. Coop. Ser. Bull. 289:15-19.

Isaac, R.A., Donohue, S.J., R.H. Brupbacher, J.D. Lancaster, A. Mehlich, D.D. Scott, M.R. Tucker, J.R. Woodruff. 1983b. Determination of potassium, calcium, magnesium, and sodium by Mehlich I (0.05N HCl in 0.024N H_2SO_4) extraction. Reference soil test methods for the southern region of the United States. South. Coop. Ser. Bull. 289:25-29.

Johnson, G.V. 1992. Soil and media diagnostic procedures for the southern region of the United States. South. Coop. Ser. Bull.: 25-27.

Johnson, W.A. 1944. The effect of sawdust on the production tomatoes and fall potatoes and on certain soil factors affecting plant growth. Amer. Soc. Hort. Sci. 44: 407-412.

Khan, A.R., D.Chandra, S.Quraishi, and R. K. Sinha. 2000. Soil aeration under different soil surface conditions. J. Agron. Crop Sci. 185: 105-112.

Kondratyev, K.Y., V.F. Krapivin, and C.A. Varotsos. 2003. Global carbon cycle and climate change. Praxis Publishing, Chichester, UK.

Kwasna H., Z. Sierota, and G.L. Bateman. 2000. Fungal communities in fallow soil before and after amending with pine sawdust. Appl. Soil Ecol. 14: 177-182.

Lal, R. 1983. No-till farming: Soil and water conservation and management in the humid and sub-humid tropics. IITA Monograph No. 2, Ibadan, Nigeria.

Lal, R., J.M. Kimble, and B.A. Stewart. 2000. Global Climate Change and Pedogenic Carbonates, CRC/Lewis Publisher, Boca Raton, FL.

Lal, R. 2002. Why Carbon Sequestration in Agricultural Soils. p. 21-30. *In* R. Lal, J.M. Kimble, R.F. Follett (ed.). *In* Agricultural Practices and Policies for Carbon Sequestration in Soil. CRC/Lewis Publisher, Boca Raton, Fl.

Lalande, R., V. Furlan, D.A. Angers, and G. Lemieux. 1998. Soil improvement following addition of chipped wood from twigs. Am. J. Altern. Agric. 13 (3):132-137.

Lareau, M.J. 1989. Growth and productivity of highbush blueberries as affected by soil amendments, nitrogen fertilization and irrigation. Acta Horticulturae. 241:126-131.

Larson, W.E., C.E. Clapp, W.H. Pierre, and Y.B. Morachan. 1972. Effects of increasing amounts of organic residues on continuous corn: II. Organic carbon, nitrogen, phosphorus, and sulfur. Agron. J. 64, 204-208.

Lunt, H.A. 1955. The use of woodchips and other wood fragments as soil amendments. Connecticut Agric. Exper. Sta. Bull. 593: 6-46.

Macks, S.P., B.W. Murphy, H.P. Cresswell, and T.B. Koen. 1996. Soil friability in relation to management history and suitability for direct drilling. Aust. J. Soil. Res. 34:343-360.

Magdoff, F., and R.R. Weil. 2004. SOM influences on SQ indicator properties and functions. p. 10-43. *In* F. Magdoff and R.R. Weil (ed.). Soil Organic Matter in Sustainable Agriculture, CRC/Lewis Publisher, Boca Raton, FL.

McCoy, S., J. Greenwade, H. Sanchez, and M. Freeman. 1999. Appendix A: Case study-land applying composted materials and uncomposted yard trimmings on highly erodible land. *In* M. Dougherty (ed). Field guide to on-farm composting. Natural Resource, Agriculture, and Engineering Service NRAES-114. Ithaca, NewYork: 98-104.

McKeever, D.B. 1999. How woody residuals are recycled in the United States. Biocycle. Dec. 1999. p. 33-44.

McLean, E.O. 1982. Soil pH and Lime Requirement. *In* A.L. Page, R.H. Miller and D.R. Keeney (ed). Methods of Soil Analysis – Chemical and Microbiological Properties. Part 2. 2nd ed. Agron. Monogr. 9: 199-209.

Mitchell, W.H., and M.R. Teel. 1977. Winter-annual cover crops for no-tillage corn production. Agron. J. 69: 569-673.

Morghan, K.J.R, and T.R. Seastedt. 1999. Effect of soil nitrogen reduction on nonnative plants in restored grasslands. Restoration Ecology 7(1): 51-55.

Moschler, W.W., G.M. Shear, D.L. Hallock, R.D. Sears, and G.D. Jones. 1967. Winter cover crops for sod-planted corn: their selection and management. Agron. J. 59: 547-551.

Moss, S.A., J.A. Burger, and W.L. Daniels. 1989. Pitch x loblolly pine growth in organically amended minesoils. J. Environ. Qual. 18: 110-115.

Motavalli, P.P., and O.H. Diambra. 1997. Management of nitrogen immobilization from waste office paper applications to tropical pacific island soils. Compost Sci. Utilization. 5(3): 71-80.

Myrold, D.D. 1998. Transformations of nitrogen. p. 259-294. *In* Sylvia D.M., J.J. Fuhrmann, P.G. Hartel, and D.A.Zuberer (ed.). Principles and applications of soil microbiology. Prentice Hall Inc., NJ.

Nelson, D.W., and L.E. Sommers. 1996a. Total carbon, organic carbon, and organic matter. p. 1001-1007. *In* D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnson, and M.E. Sumner (ed.). Methods of Soil Analysis-Chemical Methods. Part 3. Agron. Monogr. 5. ASA and SSSA, Madison, WI.

Nelson, D.W., and L.E. Sommers. 1996b. Total carbon, organic carbon, and organic matter. p. 965-974. *In* D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnson, and M.E. Sumner (ed.). Methods of Soil Analysis-Chemical Methods. Part 3. Agron. Monogr. 5. ASA and SSSA, Madison, WI.

Obiefura, J.C. 1986. The effect of sawdust mulch and increasing levels of nitrogen on the weed growth and yield of false horn plantains (Musa ABB). Biol. Agric. Hort. 3: 353-359.

Obiefura, J C. 1991. The effect of crop residue mulches on the yield and production pattern of plantain (Musa-AAB). Biol. Agric. Hort. 8(1):71-80.

Parr, J.F., R.I. Papendick, S.B. Hornick, and R.E. Meyer. 1990. The use of cover crops, mulches and tillage for soil water conservation and weed control. p. 246-261. *In* Organic-matter Management and Tillage in Humid and Sub-humid Africa. IBSRAM Proceedings No.10. Bangkok: IBSRAM.

Paustian, K., W.J. Parton, and J. Pesson. 1992. Modeling Soil organic matter in organic-amended and nitrogen-fertilized long-term plots. Soil Sci. Soc. Am. J. 56: 476-488.

Pier, P. A., and J.M. Kelly. 1997. Measured and estimated methane and carbon dioxide emmisions from sawdust waste in the Tennessee Valley under alternative management strategies. Bioresource Technology 61: 213-220.

Raimbault, B.A., R.J. Vyn, and M. Tollenaar. 1990. Corn response to rye cover crop management and spring tillage systems. Agron. J. 82: 1088-1093.

Raimbault, B.A., R.J. Vyn, and M. Tollenaar. 1991. Corn response to rye cover crop, tillage methods, and planter options. Agron. J. 83: 287-290.

Rasmussen, P.E., R.R. Allmaras, C.R. Rohde, and N.C. Roager Jr. 1980. Crop residue influence on soil carbon and nitrogen in a wheat-fallow system. Soil Sci. Am. J. 44: 596-600.

Regnier, E.E., and Jahnke. 1990. Evolving strategies for managing weeds. p. 174-202. *In* C.A. Edwards et al. (ed.) *In* Sustainable agricultural systems. Soil and Water Conservation Society. Ankeny, IA.

Rickman, R.W., C.L. Douglas Jr., S.L. Albrecht, L.G. Bundy, and J.L. Berc. 2001. CQESTR: A model to estimate carbon sequestration in agricultural soils. J. Soil Water Conserv. 56:237-242.

Roberts, A.N. 1948. Sawdust and other wood waste as mulches for horticultural crops. Oregon State Hort. Soc. 40: 29-34.

Samater, A.H., O.V. Cleepput, and R. Ertebo. 1998. Influence of the presence of nitrite and nitrate in soil on maize biomass production, nitrogen immobilization and nitrogen recovery. Biol. Fertil. Soils. 27: 211-218.

SAS Institute. 2002. The SAS system for Windows. Version 9. Proc Mixed. SAS Inst, Cary. NC.

Schnitzer, M. 1991. Soil organic matter-the next 75 years. Soil Sci. 151:44-58.

Skog, K.E., and H.N. Rosen. 1997. United States wood biomass for energy and chemicals: possible changes in supply, end uses, and environmental impacts. Forest Products J. 47(2): 63-69.

Smil, V. 1997. Global population and the nitrogen cycle. Scientific American: 76-81.

Sommerfeldt, T.G., and D.C. Mackay. 1987. Utilization of cattle manure containing wood shavings: Effect on soil and crop. Can. J. Soil Sci. 67:309-316.

Strickling, E. 1975. Crop sequences and tillage in effective crop production. p. 20-29. *In* North East Branch American Society of Agronomy Abstracts. Agronomy Society of America, Madison, WI.

Schweitzer, C.J. 2000. Forest Statistics for Tennessee, 1999. United States Department of Agriculture. Forest Service. Southern Research Station. Resource Bulletin SRS-52.

Turk, L.M. 1943. The effect of sawdust on plant growth. Michigan Quart. Bull. 26(1): 10-22.

USDA – NRCS. 2005. Official soil series description. [Online] Available at www.soils.usda.gov/technical/classification/osd/index.html. Accessed March 12, 2005.

USDOC. 2004. Climatology of the United States no.20 1971-2000. Station: Greeneville Exp. Stn., TN. [Online] Available at www5.ncdc.noaa.gov/climatenormals/clim20/tn/403679.pdf. Accessed April 14, 2005.

VilJoen, J.A., and E.B. Fred. 1924. The effect of different kinds of wood and of wood pulp cellulose on plant growth. J. Soil Sci. 17: 199-208.

Vinten, A.J.A., and K.A. Smith. 1993. Nitrogen cycling in agricultural soils. p .39-73. *In* T.P. Butt, A.L. Heathwaite, S.T. Trudgill (ed.). Nitrate: Processes, Patterns, and Management. Wiley Publishers, Chichester, UK.

Wagger, M.G. 1989. Cover crop management and nitrogen rate in relation to growth and yield of no-till corn. Agron. J. 81: 533-538.

Washington State University Extension. 2005. Compost fundamentals. [Online]. Available at whatcom.wsu.edu/ag/compost/fundamentals/needs_carbon_nitrogen.htm. Accesses April 12, 2005.

Yang, W.Q., B.L. Goulart, K. Demchak, and Y. Li. 2002. Interactive effects of mycorrhizal inoculation and organic soil amendments on nitrogen acquisition and growth of highbush blueberry. J. Amer. Soc. Hort. Sci. 127(5):742-748.

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