1997

Nutrient accumulation and release in soil under cover crop systems /

Yinliang Liu
University of Massachusetts Amherst

NUTRIENT ACCUMULATION AND RELEASE IN SOIL UNDER COVER CROP SYSTEMS

A Thesis Presented

by

YINLIANG LIU

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER of SCIENCE

May 1997

Department of Plant and Soil Sciences

NUTRIENT ACCUMULATION AND RELEASE IN SOIL UNDER COVER CROP SYSTEMS

A Thesis Presented

by

YINLIANG LIU

Approved as to style and content by :

Stephen J. Herbert, Chair

Allen V. Barker, Member

Jayaram Daliparthy, Member

William Bramlage, Head
Department of Plant and Soil Sciences

ACKNOWLEDGMENTS

I would like to thank my major advisor, Dr. Stephen J. Herbert, for his constant support, encouragement and guidance throughout this research.

I would like to thank Dr. Allen V. Barker, Dr. Jayaram Daliparthy for their assistance and encouragement.

A very special thanks to all who worked with me in Bowditch Hall over the years. Special thanks to Betsy O'Toole, and to Guohua Liu, Ziliang Pan, and Jacob Wheeler for their help and assistance in lab work and field work during this research.

Special thanks are extended to my dear wife Fu Min and family, and my Institute Director in the People's Republic of China (Pro. Yan He), whose support and encouragement have enabled me to finish this study in the United States.

ABSTRACT

NUTRIENT ACCUMULATION AND RELEASE IN SOIL UNDER

COVER CROP SYSTEMS

May 1997

YINLIANG LIU, B.A., NORTHWEST AGRICULTURAL UNIVERSITY/CHINA

M.S., UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Stephen J. Herbert

Cover crops have long been recognized to play an important role in sustainable agriculture due to their roles in preventing soil erosion, improving soil productivity, contributing nutrients to succeeding crops, and suppressing weeds. The uncertainty of cover crop residue mineralization and the quantity of nutrients released from cover crop incorporation is still a major concern in cover crop management. A field experiment was conducted in 1994 and 1995 at University of Massachusetts Agronomy Research Farm in South Deerfield to determine cover crop biomass and nutrient accumulation, cover crop residue decomposition and nutrient release after incorporation. Hairy vetch (*Vicia villosa*, 45 $kg.ha^{-1}$) and rye (*Secale cereale* L.,98 $kg.ha^{-1}$) were seeded in early September 1994 and biomass samples were taken weekly in spring 1995. At time of cover crop incorporation, fine mesh nylon bags (7 x 18 cm) containing fresh cover crops were placed in soil at 7.5 and 22.5 cm depths to determine the decomposition and nutrient release of

cover crops under field conditions. Vetch and rye cover crops could accumulate similar amount of biomass in above ground in spring regrowth, and the biomass accumulation was closely related to growth period. Vetch accumulated similar amounts of P, and K, significantly high amount of N, Ca and Mg in aboveground compared with rye. Vetch and rye accumulated 197.6 kg $N.ha^{-1}$ and 81.0 kg $N.ha^{-1}$, respectively, aboveground before incorporation. Release of N 18 weeks after incorporation was 74.5-76% for vetch and 33.5-43.2% for rye. For vetch, 60% of total N was released within the first two weeks. P, K, Ca, and Mg release patterns were also determined. Early incorporation of rye and late incorporation of vetch are recommended as one of the ways to optimize nutrient release and contribution to crop growth.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Cover crops such as cereals, legumes, or any other crops or their mixtures are grown specifically to protect the soil against erosion, ameliorate soil structure, recycle nutrients, enhance soil fertility, and suppress pests, including weeds, insects, and pathogens (Lal et al., 1991). Cover crops are generally not grown for harvest, but to fill gaps in either time or space when the absence of the cash crop would leave the ground bare. Most cover crops are grown during the cold season. In the northern latitudes, rye, oats, clover, or vetch are planted in the fall to provide a winter cover, and to provide nutrients to main crops after incorporation.

Two major attributes for an ideal winter cover crop, beyond protecting the soil from erosion, would be the ability to significantly reduce nitrate (NO_3^-) leaching, and the ability to supply N to the succeeding crop. Grasses can significantly reduce N leaching, but they generally make little or no N contribution to the following crop. Legumes, on the other hand, have great value as N source, but their impact on N leaching is uncertain. So the fate of the N taken up by cover crops is important. Ideally, any added N containing material (fertilizer, plant residue, animal manure) must be able to produce a large pool of mineral N before the period of rapid N uptake by a crop. If the mineral N pool in the soil is produced too early, it can be potentially lost to leaching and /or denitrification. If

released too late, it will not benefit the crop. So if the cover crop decomposition and N mineralization are not synchronized with N demand of a subsequent crop, the N could still be leached into the groundwater or lost into the atmosphere.

The NO_3^- concentration is often observed to be high in the soil after harvest of main crops, because of high fertilizer rates applied to main crops, lower harvest yields than expected due to unfavorable environmental conditions, and microbial mineralization of organic matter stimulated after harvest because fresh organic material has been added into soil. In northeastern USA, the precipitation is usually high in the fall and winter which makes this period susceptible to NO_3^- leaching. A well-established cover crop system could help to prevent NO_3^- leaching by influencing the water budget during the water recharge season, affecting the soil NO_3^- concentrations, effectively recycle nutrient, and improve the nutrient availability.

A lot of work has been done on nitrogen accumulation of cover crops in aboveground biomass. Researchers from different areas have reported variable results. Nitrogen accumulated in aboveground biomass ranged from about 20 kg/ha to 300 kg/ha (Brown et al., 1993; Ebelher et al., 1984; Hargrove, 1986). Values in excess of 100 kg N /ha are common for legumes, while rye generally accumulates less than 50 kg N /ha. The variation is mainly caused by the local climate, soil conditions, and cover crop management strategies. Biomass alone may be less important than N input from legume cover crops. But N concentration in winter

legumes may vary more among different species than among different experiments (Smith, 1987). Thus nitrogen input from legume cover crops in the various reports are closely related to biomass production.

Cover crop decomposition and nutrient release patterns are critical to spring management practices. Synchronizing nutrient release with plant growth is important in cover crop management. If the nutrient release peak does not coincide with the rapid growth stage of the next crop, then the nutrient contained in or immobilized by the cover crop could have a negative effect on the main crop. A better understanding of decomposition and nutrient release patterns of a cover crop residues is necessary for improving cover crop management to the benefit of farmers.

A research project was established to study the nutrient accumulation in cover crops in early spring, and the decomposition and nutrient release patterns after cover crop incorporation. This research will provide information on the amount and patterns of nutrient release, especially N, which becomes available from cover crops during the growth of the summer crop.

1.2 Objectives

The objectives of this study are to:

1. Evaluate biomass production and nutrient accumulation in hairy vetch and rye cover crops during the spring growing period.

2. Determine the decomposition and nutrient release patterns of hairy vetch and rye cover crop residues after the aboveground biomass has been incorporated into soil.

CHAPTER 2

LITERATURE REVIEW

Cover crop is defined by a natural resource glossary (Soil Cons. Soc. of Am.,1982) as "A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production." Cover crops play multitude of roles in modern agricultural ecosystems (Doran et al. 1991). They provide ground cover to protect the soil from water and wind erosion. They serve as 'sinks' for plant nutrients that might otherwise be lost by volatilization or leaching, and serve as a nutrient source after incorporation through mineralization. Planting cover crops regularly can enrich soil organic matter, improve soil structure, and improve other soil chemical and physical properties. They provide weed control through competition and allelopathy, and they assist in the control of disease and insects by increasing crop diversity, attracting beneficial insects, and killing arthropods and other harmful insects during incorporation.

2.1 Nitrate losses after harvest of the main crop, and role of cover crops in N recycling.

Nitrogen is the most difficult nutrient to manage in agriculture. Nitrogen must be supplied in large quantities to meet nutritional requirement of crops. Yet NO_3^- is one of the most mobile of nutrients because it is soluble in soil water, and it is not retained by the negatively charged soil colloid system. Thus, NO_3^- within the root zone is free to move with percolating water and could leach into ground

water when soil contains a significant amount of NO_3^- as water moves below the root zone. Excess application of manure or fertilizer N above crop requirement can result in high residual soil NO_3^- levels after crop harvest (Jokela et al., 1989; Ruth et al., 1990; Gordon et al.1993). Post-harvest NO_3^- concentrations in the root zone of summer annuals have been found to range from a few to several hundred $mg.kg^{-1}$ (Hahne et al., 1977; Linville et al., 1971; MacGregor et al. 1974). Studies in Virginia (Ditsch et al., 1993) found mineral N , predominantly NO_3^- concentrations ranging up to 105 mg kg^{-1} during October in fields planted to winter wheat. Approximately 60 percent of the fertilizer N remaining in the soil to a depth of 90 cm after the harvest, was in the surface 30 cm (Ditsch et al., 1993). In northern humid climates, fall, winter, and spring are the main water-recharge seasons when evapotranspiration is low and precipitation exceeds the soil's water-holding capacity. This season often coincides with high soil NO_3^- levels, resulting from residue fertilizer N or from the fall mineralization of soil organic matter and crop residues. Hence the primary season for potential NO_3^- leaching can usually occur between November and May. This assumption is supported by the work of Cameron et al. (1978) , Jokela (1989), Daliparthy et al.(1994), and Guillard et al. (1995). These studies showed markedly lower spring soil NO_3^- relative to autumn soil NO_3^-, and the greatest accumulations of soil NO_3^- were observed when cumulative precipitation and estimated soil water storage values were lowest. A fallow period resulted in the greatest potential losses of NO_3^- from the soil.

Heaney et al. (1992) studied overwinter NO_3^- loss and denitrification potential of cultivated soils in Alberta, Canada. They found that recovery of labeled KNO_3 in spring was extremely low in some kinds of soil when the environmental conditions were favorable to NO_3^--N leaching. They also observed that, of the 112 kg N ha^{-1} applied to two kinds of soil at the end of February, only 3% and 10%, respectively, were accounted on the end of April sampling.

Sowing a winter annual cover crop following the harvest of a summer annual has long been recognized for its importance in conserving soil and water and maintaining or increasing soil organic matter levels. A winter cover crop can be an excellent vehicle to convert mobile soil NO_3^- into immobile plant organic N. However, for adequate root development, cover crops must be seeded early to allow time for growth prior to winter (Herbert et al., 1986)

Small grain winter cover crops are efficient scavengers of residual soil N because they possess a deep, fibrous root system that is able to take up soil N efficiently from deep layers during their growing period. A soil leachate study showed that rye was effective in reducing leachate NO_3^- concentrations (Daniel et al.,1994). Significantly and consistently lower NO_3^- were measured in leachate from rye cover lysimeters than from winter fallow lysimeters. Rye cover crops held the NO_3^- concentration of leachate near zero during the fall, winter, and early spring, when discharge volumes were the greatest. Only after killing the rye and applying the N fertilizer for the succeeding corn crop did the NO_3^- concentration

of leachate rise. Evanylo (1991) studied the role of rye in N cycling in corn and potato production and reported that rye could trap much of the soil N and thereby prevent significant soil N accumulations. He also reported that dry matter accumulation and N uptake of rye were increased by increasing levels of residual N, and the C/N ratios were reduced with the increasing levels of residual N. Holderbaum et al. (1992, 1990) showed that cover crops could immobilize (including N fixation) up to 350 kg N ha^{-1}, and thereby, reduce winter NO_3^- leaching potential. Brinsfield et al. (1989, 1991) demonstrated that winter rye was superior to other small grains when planted in mid-September after the harvest of silage corn. They further reported that by increasing fertilizer rates, rye took up as much as 130 kg N ha^{-1} and greatly reduced residual NO_3^- in the upper 30 cm of soil. Based on a review by Ditsch and Alley (1991), the amount of N recovered by the cover crop was largely a function of cover crop planting date, cover crop seeding rate and subsequent plant populations, amount of residual mineral N remaining after the harvest of the previous crop, and cover crop growth stage at the time of termination (killing date). In the Northern Corn Belt, because of the short spring regrowth season, relatively dry condition, and excessive N in the soil, the total amount of N that rye could accumulate was more directly related to the total quantity of above ground biomass (Reicosky 1991). However, the use of a cereal cover crop would increase the quantity of fertilizer N required to maintain succeeding corn yields, because of the slower mineralization rate of N

immobilized in cereal residues as compared to legume cover crops (Hargrove et al., 1987; Holderbaum et al., 1990). Research work was done by Torbert et al. (1996) indicated that winter cover crops improved corn yield and that besides soil N availability, there was very little difference between the beneficial effects of clover and the rye cover crops to corn except N supply. Rye removed substantial quantities of soluble N from the root zone before the onset of ground-water recharge if the planting of cover crops was done immediately following corn harvest. Brinsfield et al. (1991) observed total N assimilation by rye cover crop was 80, 150, and 180 kg N/ha at about 145, 160, and 175 days after planting, respectively.

Legume cover crops can absorb soil N or utilize N from symbiotic N_2 fixation to meet their N requirement. It has been shown that N_2 fixation will not begin until soil NO_3^- is low (Havelka et al., 1982; Viets et al., 1950). Thus, legumes will also offer the potential to reduce NO_3^- leaching to the extent that they use soil NO_3^- rather than fixed N_2 to meet their N need. A legume cover crop was only less effective in reducing the potential for NO_3^- leaching losses than rye during winter (Guillard et al.,1995: Varvel and Peterson, 1990). Greg et al. (1991) reported the NO_3^--N levels in the top 40 cm soil were less than 2 ppm shortly before cover crop incorporation in both rye and vetch plots. Ebelhar et al. (1984) had a similar report. Legume winter cover crops commonly accumulate from 67 to 168 kg N/ha in the East and Southeast (Doran et al., 1991). Hairy vetch could

immobilize up to 350 kg N/ha, and it was particularly effective when used after the harvest of corn silage (Holderbaum et al., 1992).

2.2 Cover crop biomass accumulation

Cover crops have great potential in restoration and maintenance of soil productivity because they offer an on-site source of plant biomass to restore or maintain soil organic matter levels and soil biological activity. Most degraded soil conditions are the result of agricultural practices that have not supplied the quantity or quality of biomass to adequately maintain essential soil processes that are responsible for water and nutrient supply to the plant (Bruce et al., 1991).

Different workers have measured leguminous cover crops biomass production under diverse cultural, climatic, and edaphic conditions and for different durations. On wetland rice land (Singh et al.,1991), dry matter accumulation ranged from 0.8 to 6.7 tons.ha^{-1}, and the most productive crop crops yielded about 4 to 5 tons.ha^{-1} of dry biomass in 50-60 days. Soil inorganic N availability has a great impact on non-legume cover crop biomass production. Evanylo (1991) demonstrated that different N fertilizer application rates on potato and corn had a pronounced effect on succeeding rye biomass accumulation. Dry matter accumulation of rye following potato increased from 1446 kg.ha^{-1} to 4023 kg.ha^{-1} when the fertilizer rate to potato increased from 0 kg.ha^{-1} to 336 kg.ha^{-1}; while dry matter accumulation of rye following corn increased from 497 kg.ha^{-1} to 3567 kg.ha^{-1} when the fertilizer rate to corn increased from 0 kg.ha^{-1} to 224 kg.ha^{-1}.

Ditsch et al. (1993) had a similar report, and the dry matter accumulation varied from year to year depending on soil moisture conditions. A four sites experiment conducted by Stout (1992) in Pennsylvania showed that, on a high native N level site, an early season biomass of orchardgrass response to fertilizer N was reduced. As the season progressed the biomass accumulation response to N fertilization increased in all soils. Orchardgrass biomass accumulated faster at higher N rates as the season progressed. N fertilization also significantly increased biomass accumulation. Seeding date effected cover crop biomass accumulation by affect cover crop establishment before winter and plant density in spring regrowth. An early fall planted winter rye vs. late fall planted winter rye in Minnesota (Reicosky and Warnes, 1991) showed that rye biomass accumulations were 2048 $kg.ha^{-1}$ and 1316 $kg.ha^{-1}$, respectively, on May 19. Killing date, which is related to the growth period, also affects cover crop biomass accumulation. Hoyt et al. (1991) showed that aboveground biomass averaged 5790 $kg.ha^{-1}$ for rye and 3102 $kg.ha^{-1}$ for vetch on March 28. Forty nine days later, rye biomass was 11872 $kg.ha^{-1}$ and vetch was 6384 $kg.ha^{-1}$. Wagger (1989) found a similar change in dry matter production with regard to timing of cover crop desiccation. Averaging across years an approximately 2-wk delay in desiccation resulted in dry matter increase of 39, 41, and 61% for rye, crimson clover, and hairy vetch, respectively.

2.3 Cover crop residues decomposition and nutrient release

The capacity of winter cover crops to serve as an effective source of nutrients for grain crops depends to a large extent, on climate, growth stage and quality of the cover crop, soil and cropping characteristics, and tillage management practices. Initial residue quality plays a preeminent role in determining the rate of residue decomposition and N mineralization. Studies of significant correlations between initial N concentration, lignin content, initial C/N ratios, and decomposition rate were reported (Tian et al., 1995; Quemoda et al., 1995). The cumulative N and other nutrient mineralization is strongly influenced by crop species, nutritional status, and the interaction of all these variables (Janzen et al., 1988). Recent studies in the southeastern US have investigated the decomposition of legume residue and subsequent release of N for corn uptake. Wilson and Hargrove (1986) and Wagger (1989) used fine pored (53 *um*) litter bags to monitor the rate of residue biomass disappearance, and Varco et al.,(1989) employed ^{15}N depleted residue to monitor decomposition dynamics. These authors found that green manures decompose rapidly (i.e., a 50% loss of biomass within a month) in warm southern soils and can be a significant source of N to the following corn crop. They found that residue C:N ratios and carbon constituents (especially the amount of lignin), as well as soil humidity, time of kill, and tillage system (no-till or moldboard plowing) all affected the dynamics of decomposition and N mineralization.

Some studies suggested that plant parts with different chemical composition would be expected to show different mineralization kinetics (Harper et al., 1981). Leaves, stems, and leaf and stem mixtures of cover crops show large differences in decomposition and nitrogen mineralization or immobilization rates because of their initial N content, C/N ratios, and lignin content (Quemada et al., 1995). Tian et al. (1995) developed a plant residue quality index (PRQI) defined as:

PRQI=[1/(aC/N+bLignin +cPolyphenols)]*100%

This index is developed for assessing the quality of plant residues, and they found a close relationship between the index and the decomposition rate.

A number of models were developed to describe the residues decomposition processing (Berendse et al., 1987; Parnas, 1975; Somda et al., 1991; Quemada et al., 1995). The first order reaction kinetics, defined as one-pool model, was usually used (Hasegawa et al., 1996; Berendse et al., 1987). The newly developed two-pool model (Somda et al., 1991), which partitioned the plant residues into readily decomposable pool and recalcitrant pool, appear to provide a better fit in the early stages of the decomposition compared to one-pool models.

The nutrients contribution of cover crop to the succeeding summer crop would be largely determined by the rate and the extent of residue decomposition and associated N mineralization. It is apparent that summer grain crops can receive significant benefits from winter cover crops (Ebelhar et al., 1984; Hargrove et al., 1986). Long-term use of winter cover crops may build soil fertility levels and

provide residual sources of plant-available N. Early season N release from winter cover crops depends mainly on microbial mineralization or immobilization of C and N, which is influenced by the C/N ratio of the residue, its degree of incorporation into the soil, and soil temperature and moisture regimes (Wagger, 1989). The immobilization of N in high C:N ratio materials lasts until the C/N ratio of the decomposing material has been lowered to about 20 (Stevenson, 1985). It may take 1 to 3 weeks after the cover crop incorporation before N release can exceed N immobilization.

The N-fertilizer equivalency of winter cover crops has been used as an estimate of N-supplying capacity for summer grain crops. Winter annual legumes generally supply the equivalent of 112 kg N/ha for the subsequent crop (Meisinger et al., 1990; Anderson et al., 1990). Anderson et al. (1990) also reported that hairy vetch provided the greatest (178 kg N/ha) N production of the four legumes they tested. The average amount of fertilizer N replaced by the legume was 72 kg N/ ha on the sorghum crop (Hargrove, 1986). Power et al. (1991) studied hairy vetch as a winter cover crop for dryland corn production and indicated that the use of hairy vetch would often reduce the need to fertilize continuous dryland corn with N. He further reported that disking in hairy vetch residues before corn planting would greatly enhance the mineralization and uptake of N from these residues, particularly during grain fill. The average N uptake from residues by corn could reach as high as 83%.

A rye cover crop had little or inconsistent affect on the corn yield or N uptake compared with no cover. Decomposition of non-legume crop residues resulted in significant amounts of net N immobilization. Immobilization occurred during the first few weeks, followed by a slow N release period (Evanylo, 1991). In order for rye to prevent immobilization of N in corn production, the cover crop should be killed earlier (Evanylo, 1991; Wagger, 1989).

The use of cover crops in crop rotations to improve soil fertility and crop production is one of the oldest agricultural practices. Using winter annual legumes as N sources for corn in corn production systems were generally recognized (Frye et al., 1988; Hoyt and Hargrove, 1986; Smith et al., 1987). Ebelhar et al. (1984) reported that 2-4 weeks after killing the cover crops, there was a large increase in the inorganic soil N regardless of N fertilizer rates, with hairy vetch cover treatments providing significantly higher amounts than rye or corn residue treatments. A significant amount of extractable inorganic N ($NH_4^+ + NO_2^- + NO_3^-$) was found after the legumes compared to the follow and rye (Hargrove 1986). Various methods have been used to measure legume N contributions to succeeding crops. Total N accumulation by succeeding crops is the most simple and least expensive method but does not account for residual soil N. Changes in soil N and the N response of succeeding non-legume crops are also used to estimate legume credits (Mitchell and Teel, 1977; Fleming et al.,1981; Ebelhar et al., 1984; Hargrove, 1986). Terms like "fertilizer N equivalent" are commonly used to

describe these relationships. Hargrove (1986) suggested that corn grain N content was a better estimator of N contribution by legume covers than grain yield. Most of the reports on yield response to cover crops were on corn and a few of them were on other crops (Ebelhar et al.,1984; Power et al., 1991; Decker et al., 1994; Blevins et al., 1990; Holderbaum et al., 1990; Evanylo, 1991; Schonbeck et al., 1993). The adapted legume cover crops increased total corn N uptake by 65 to 130 kg N.ha-1 over the corresponding control treatments on N deficient soils (Holderbaum et al., 1990). Corn grown without N fertilizer following crimson clover or hairy vetch yielded as much corn following rye or oats with 112 kg N ha^{-1} according to Mitchell and Teel (1977). Long-term experiments by Blevins et al. (1990) showed that vetch resulted in a higher corn grain yields than rye or fallow treatments for the 0 and 50 kg N ha^{-1}, and that the corn yield would increase after 4 years of continuous rye/zero N fertilizer treatment. Sorghum grain yields following a legume averaged about 3.91 Mg ha^{-1}, regardless of N application rate. With fallow or rye treatments, the maximum sorghum yield was 3.95 Mg ha^{-1} which was obtained with 99 kg N ha^{-1} (Hargrove, 1986).

The works done on cover crops are mainly on N conservation, cover crop residue decomposition, the overall N fertilizer equivalency, and the crop yield response to cover crops. Most is in Southern USA, and Mid-West. The quantity of nutrient accumulated in cover crops, the nutrient release patterns, and soil nutrient correspondence to cover crop incorporation are not clear in New England area.

CHAPTER 3

MATERIALS AND METHODS

3.1 Field practices

A field study was conducted in 1994 and 1995 at the University of Massachusetts Agronomy Research Farm in South Deerfield. The soil at the experiment site is Hadley fine sandy loam (coarse, mixed, Fluventic Dystrochrept). This study used a subset of treatments from a larger study designed to measure the effect of different cover crops on short season vegetables. Previous crop was corn in a conventional tillage system with regular fertilizer management. The experimental design was a Randomized Block with 4 replications. Individual plot size was 5 by 20 m. Soil test results are showed in Table 1.

Cover crop treatments consisted of hairy vetch, rye, and no cover crop seeded at the rate of:

1. Vetch (37 kg/ha)
2. Rye (118 kg/ha)
3. Control (no cover crop seeded)

Cover crops were seeded in September 9, 1994, and they were well established before winter. The cover crop samples were taken every week in the spring of 1995 from April 18 till May 30 for the purpose of measuring biomass and nutrient accumulation. The samples were taken using a 30 cm^2 quadrate in each of 4 replications. Samples were immediately brought into lab, fresh weight was recorded, then they were dried at 65-70 ^0C to determine the dry weight.

Table 1. Initial soil properties

Depth	pH	Bulk Density	Porosity	Organic Carbon
cm	(1:2 H2O)	g cm^{-3}	%	%
0-20	6.45	0.96	63.7	1.33
20-40	6.45	1.18	55.5	0.89
40-60	6.55	1.32	50.1	-

Table 2. Average initial quantities and nutrient status of the cover crop residues added in mesh bags.

Residues	Fresh wt	Dry wt	C	N	P	K	Ca	Mg
	g	g	g	mg	mg	mg	mg	mg
Rye	34.5	13.5	7.92	117.5	34.3	68.9	43.6	11.5
Hairy vetch	40.5	6.0	3.28	196.8	22.7	55.6	61.7	20.1

Samples were collected after rain were occasionally contaminated by soil when the plants were small. Such plant samples were gently washed before weighing and drying.

Cover crop decomposition and nutrient release patterns were determined as follows. Rye and vetch plant samples were hand harvested just prior to their incorporation in the main experiment on June 9, 1995. The samples were handled carefully to minimize detachment or breakage of various plant fractions, and placed in a refrigerated room, thereby maintaining plant material in a condition comparable to that represented in the field. The fresh rye and vetch plant samples were cut into 3-5 cm length and well mixed. A weighed sample was placed into individual nylon mesh bags. These residue bags were made from nylon mesh having 53-*u*m openings (Tetko, Inc., Elmsford, NY 10523). Inside dimensions of the bags were 8 cm wide and 20 cm long. Additional cover crop samples (100 g of fresh biomass) were oven-drying at 65 °C to determine the initial nutrient composition of buried residues (Table 2). These analyses and those of residue samples recovered latter in the season followed the procedures described by Wilson and Hargrove (1986).

The filled mesh bags were placed in soil in the respective cover crop field plots at depth of 7.5cm and 22.5 cm on June 13. Placement in the field corresponded to the time of main crop of cherry peppers were transplanted. The plots into which the bags were placed were 2 m x 3 m subplots for each treatment.

Mesh bags were placed at random buried 25 cm apart to minimize any interference. These subplots were not planted to peppers and were kept weed free throughout the growing season. No fertilizer was applied to the plots. Bags were recovered at 1, 3, 5, 8, 12, and 18 weeks after placement. The contents of each bag were dried at 65 ^{0}C and weighed. The entire contents of each bag were passed through a Wiley mill having a screen with 425 *u*m openings, and store in paper bags for further analysis.

After placement of the bags, temperature probes were placed at the depths of 0, 7.5, 15, 22.5, and 30 cm to collect soil temperature data. Soil temperatures were recorded weekly at 2:00 p.m. from June 13 till October 17. Soil samples were also collected weekly at the depths of 0-20, 20-40, and 40-60 cm. Soils were sampled by auger and put into plastic bags immediately, and brought into lab to determine gravimetric moisture content (Walter H. Gargner, 1986).

3.2 Laboratory analyses

3.2.1 Determination of nitrogen

3.2.1.1 Determination of total nitrogen

The total N content of oven-dry cover crop samples and residual samples was determined by the Kjeldahl digestion - Cu wire method recommended by Dr. Barker. Detail procedure is described below. Took 0.1000 g of hairy vetch or 0.2000 g of rye plant/residue sample and put into a micro-Kieldahl digestion flask , added 1.0 g of K_2SO_4, a tiny piece of Cu wire, and 4 ml H_2SO_4. Heated on

digestion block at a lower temperature (put temperature control on 4-5) for about ½ hour, and then raised the temperature (put temperature control on 7-8) for about 1-2.5 hours until it got a colorless or light blue color solution. Cooled down for more then ½ hour and dilute with 10 ml distilled H_2O. Stored the digested samples in refrigerator if did not do any further analysis immediately. Transferred the content of the flask into the distillation chamber of the Hoskin apparatus via a funnel. Rinsed the Kjeldahl flask three times with a total of about 20-40 ml of distilled water to complete the transfer. Connected the distillation chamber with the top funnel and closed the stopcock. Added 15 ml of H_3BO_3-indicator solution to a 100 ml Erlenmeyer flask and placed the flask under the condenser of the distillation apparatus so that the end of the condenser was submerged in the solution. Then added 15 ml 40% NaOH to the funnel of the apparatus, and run the alkali slowly into the distillation chamber by opening the funnel stopcock and closed it when finished. Immediately commenced distillation by turning electricity on. When the distillate reached the 50 ml mark on the receiver of the flask, stopped the distillation by shutting off the electricity and quickly removed distillation chamber, rinsed the end of the condenser, and determined NH_4^+-N in the distillate by titration with 1/70 N $KH(IO_3)_2$ until the solution turned from green to purple pink. The volume of the $KH(IO_3)_2$ that used was recorded, and N content was calculated by the following equation:

$$N(\%)= (V*N*0.014/\text{sample weight})*100$$

3.2.1.2 Determination of NO_3^--N

Determination of NO_3^--N in soil included two steps, (1) extracting procedure and (2) instrumental analysis. We used 2 M KCl as an extractant and cadmium (Cd) reduction method that recommended by Gary Griffin et al (1991) to measure NO_3^--N in soil was adopted in the analysis. Simplified procedures described as below:

Weighed 5.000 g of air-dried, and sieved (2 mm) soil into a 125 ml Erlenmeyer flask. Added 50 ml 2 M KCl . Shaken for 15 minutes in a reciprocal shaker at 200-220 oscillations per minutes. Filter the soil suspension using No. 2 Whitman paper which would provide a clear filtrate without contributing measurable amounts of NO_3^--N to the filtrate. Frozen filtrate if did not do the further analysis immediately.

The Cd reduction method involved reducing NO_3^- to NO_2^- in a "Cd column" containing copperized Cd. The NO_2^- was then measured colorimetrically by reaction with a diazotizing reagent (sulfanilamide) and a coupling reagent [N-(1-napthyl)-ethylenediamine dihydrochloride]. The pinkish-purple color that developed was measured at a wavelength between 510 and 550 nm. This procedure was conducted by a Technicon Auto Analyzer (Technicon, 1977). Soil extracts with NO_3^--N concentrations above 2 mg NO_3^-/L could be analyzed by diluting the extracts manually.

3.2.2 Determination of Organic Carbon

Organic carbon was determined by Walkley-Black procedure described by Nelson and Sommer (1982). This procedure is designed for the soil samples containing 10-25 mg of organic carbon, we used this procedure for soil, plant, and plant residue samples. When we used this procedure for plant and plant residue samples, we reduced the sample weight to 0.040 g to control the total organic carbon so as it would not exceeded 25 mg. The error among duplicated samples was not significant. The procedure is described below.

Weighed soil samples (or plant, plant residue samples) 1.5000 g (plant samples 0.040 g) into a 250 ml Erlenmeyer flask. Add 10 ml of 1 N $K_2Cr_2O_7$, and swirled the flask gently to disperse the soil (plant materials) in the solution. Then rapidly added 20 ml concentrated H_2SO_4, directing the stream into the suspension. Immediately swirled the flask gently until soil (plant materials) and reagents were mixed, then more vigorously for a total of 1 min. We allowed the flask to stand on a sheet of asbestos for about 30 min, then added 50 ml of water to the flask. Then we added 3-4 drops of o-phenanthroline indicator, and titrated the solution with 0.5 N $FeSO_4$. As the endpoint was approached, we added the 0.5 N $FeSO_4$ solution drop by drop until the color changed sharply from blue to red. Making a blank determination in the same manner, but without soil/plant materials. Calculated the results according to the following formula, using a correction factor of $f = 1.30$.

Organic C% = ((meq $K_2Cr_2O_7$ -meq $FeSO_4$)(0.003)(100)/g water-free soil)*f

3.2.3 Determination of P, K, Ca, and Mg

P, K, Ca, and Mg in plant and plant residue samples were determined by dry ashing samples described by Jones et al. (1991). Using the same solution to determine P, K, Ca, and Mg separately.

3.2.3.1 Sample preparation for analysis: Dry ashing

Weighed 0.5000 g plant (plant residue) sample to a Pyrex glass beaker. Gently shaking the beaker until the sample flattened on the bottom of the beaker, then put the beaker into a muffle furnace. The beakers should be placed in the muffle furnace away from the cool areas and contact with heated surfaces is to be avoided. Brought up the temperature to 200 °C and held at that temperature for 1 to 2 hours. Then brought the temperature to 500 °C and held at this temperature for not less than 4 hours. We shut down the furnace, left the beakers in the furnace overnight to cool and then moved them out. The ash was dissolved in 10 ml *aqua regia* (one part concentrated HNO_3 to three parts concentrated HCl), with or without warming, in order to bring the ash into solution. Transferred this solution to 100 ml volumetric flask, and washed the beaker by distilled water 3-5 times, then brought to it volume.

3.2.3.2 Determination of P

Method for determining P was described by Olsen et al. (1982). Pipetted 1 ml solution prepared in 3.2.3.1 into 25 ml volumetric flask. Added distilled water to increase the volume to 20 ml, and then added 4 ml of mixed reagent (ascorbic

acid dissolved in ammonium paramolybdate, potassium antimony tartrate, and sulfuric acid solution mixture). Made to 25 ml volume and mixed. The color was stable for 24 hours, and the maximum intensity developed in 10 min. Measured on spectrometer at 882 nm. Made a standard carve using standard P solution to calibrate the results.

3.2.3.3 Determination of K, Ca, and Mg

Prepared lanthanum solution and stock standard solution. Made a series of working K, Ca, Mg standard solutions which were diluted by lanthanum solution. Pipetted 0.5 ml solution prepared in 3.2.3.1 into 25 ml volumetric flask and brought it to volume by lanthanum solution. Measured K, Ca, Mg on all standards and samples by atomic absorption at wavelengths of 766.5, 422.7 and 285.2 nm, respectively.

3.2.4 Statistical analysis

An analysis of variance, regression was performed by using the SAS statistical software (SAS institute, 1988) for cover crop biomass accumulation, cover crop residue decomposition, and soil NO_3^--N. We determined the weekly decay rates using a two pool exponential model suggested by Somda et al. (1991), as follows:

Remaining residue weight/initial residue weight = $P_1e^{-k1t} + P_2e^{-k2t}$

where P_1 and k_1 represent the relative size and the decay rate constant for the readily decomposable pool and P_2 and k_2 represent the relative size and the decay

rate constant for the recalcitrantpool, respectively. The pool size and decomposition rates was determined by the nonlinear regression procedure of SAS software.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Biomass and nutrient accumulation in cover crops

4.1.1 Biomass accumulation

Cover crops were sampled beginning on April 18, 1995. The above ground biomass averaged 2280 kg DM.ha^{-1} for rye , 1970 kg DM. ha^{-1} for hairy vetch and 1150 kg DM.ha^{-1} for weeds which were grown in the control plots. Cover crop biomass consistently increased linearly from then on (Figure 1). Hairy vetch reached its highest biomass, of 6790 kg DM.ha^{-1}, on the sixth sampling week and then dropped down, due to loss and decay of lower leaves. This was probably a result of shading from vigorous growth of the upper canopy. The biomass of rye and weeds were continued increase throughout the sampling period. At the last sampling date, hairy vetch, rye, and weeds had accumulated 5047 kg.ha^{-1}, 6976 kg.ha^{-1}, and 4226 kg.ha^{-1}, respectively. The biomass accumulation of vetch and rye was significantly different from weeds grown in the no cover crop plots.

Biomass accumulation of cover crops largely depend on climate and environmental conditions. Theoretically, winter cover crops are possible to be grown throughout much of the temperate and subtropical regions of the world. Yet the locations where reasonable production can be expected and where they are likely to be beneficial as a winter cover for summer crops are considerably restricted. These restrictions are imposed by temperature and water availability

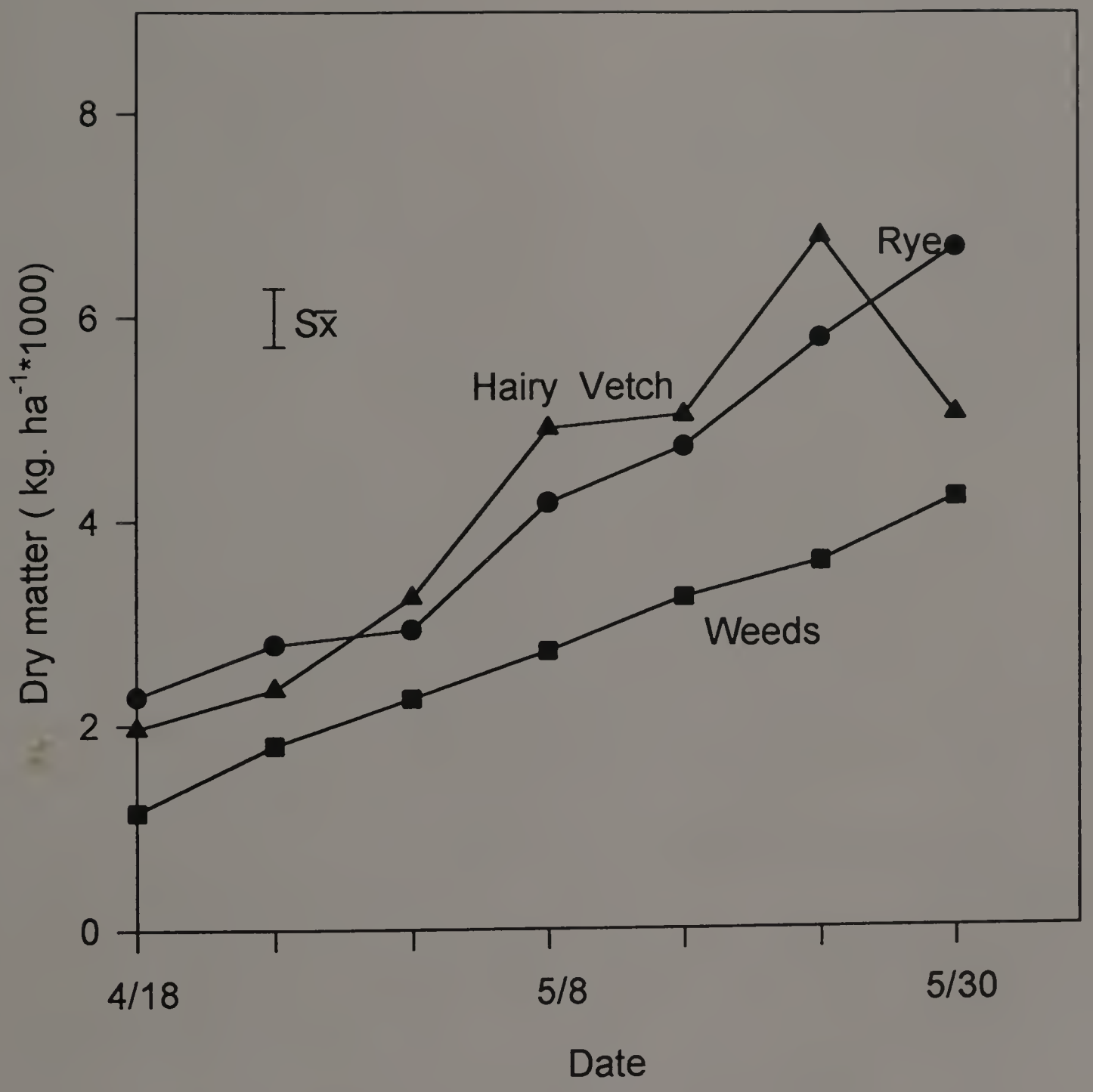

Figure 1 Aboveground biomass accumulation of cover crops

(Smith et. al. 1987). The aboveground biomass of hairy vetch varied between 2.7 to 4.2 $Mg.ha^{-1}$ from different locations (Ebelhar et al., 1984; Hoyt et al., 1986; Hargrove, 1986). Under conventional tillage systems, biomass of the cover crops are closely related with sampling date, or killing date (Hoyt, et al.,1991; Clark, et al., 1994). A seven day delay in terminating the growth of rye resulted in a 21% increase in dry matter accumulation with no corresponding increase in total N uptake averaged over previous N fertilizer applications in Virginia (Discth et al., 1993). Nitrogen fertilizer had a significant influence on rye biomass accumulation but had little, if any, effect on vetch biomass production. A field study by Torbert et al. (1996) on a Norfolk loamy sand soil in east-central Alabama shows that nitrogen fertilization increased biomass production for rye, whereas very little increase was observed for the clovers owing to N_2 fixation. The biomass production of rye had a directly linear relation with the amount of N fertilizer was applied.

4.1.2 Nitrogen content

Nitrogen content of hairy vetch and rye and the patterns of change are significantly different. Nitrogen content of hairy vetch increased from 35.7 to about 43.2 g $N.kg^{-1}$ dry matter at early April, and maintained at this level until May 22 and then slightly decreased to about 35.2 g $N.kg^{-1}$ dry matter (Figure 2). N content of rye and weeds continuously decreased during cover crop growing season, the N content of rye and weeds decreased from 15.2 to 7.5 g $N.kg^{-1}$ dry

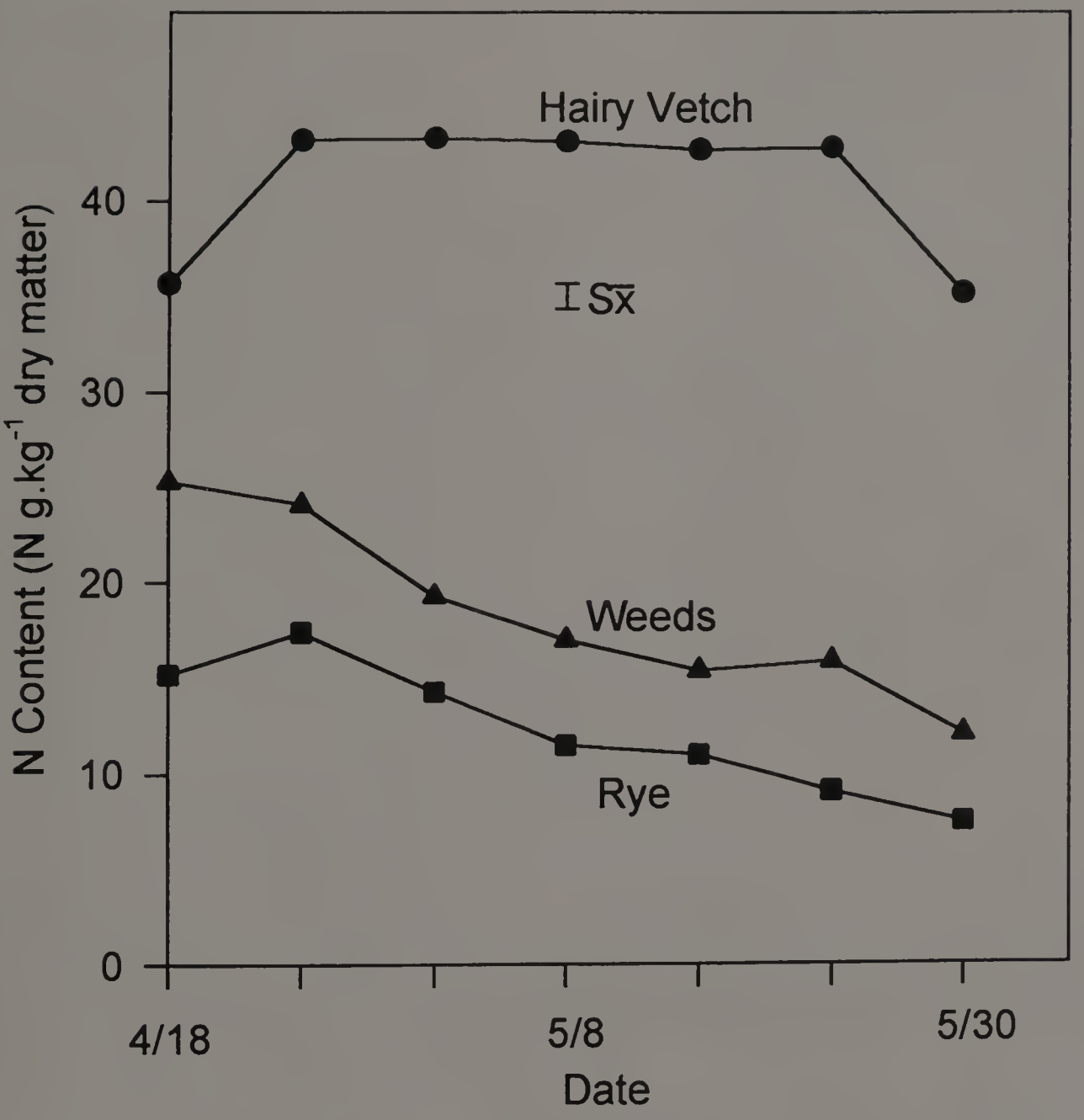

Figure 2 Cover crop N content in early spring

matter, and 25.3 to 12.1 g $N.kg^{-1}$ dry matter, respectively. Rye had the lowest N content among the three treatments. The low N content of rye and weeds was because they were totally depending on soil N, and the N content in biomass was decreased with decreasing soil N availability. This result indicated that soil N availability was the main limitation for non-legumes. And it was consistent with the results obtained by Torbert et al. (1996). Legumes utilize both soil N and atmospheric N_2 in meeting their N requirements. If the soil does not have enough N, they can fix N to meet their requirement.

Torbert et al.(1996) found that nitrogen fertilization led to a larger increase in total N uptake for rye than for two clover genotypes. They further reported that total N content of rye had a direct linear relation with N application, while the total N content of clover plants was not affected by fertilizer N application, but the proportion of N in the plant from N_2 fixation was reduced by application of fertilizer N. This is consistent with reports that application of fertilizer N reduces the level of N_2 fixed (Hardy and Havelka, 1975; Hardy and Gibson, 1977) by legumes.

4.1.3 Nitrogen accumulation aboveground

Nitrogen accumulation can be calculated from the cover crop above ground biomass and their N content. Results were shown in Figure 3. N accumulation of hairy vetch was similar to the pattern of biomass accumulation. It increased from 70.4 kg $N.ha^{-1}$ on April 18, to its highest level of 260.4 kg $N.ha^{-1}$ on May 22, and

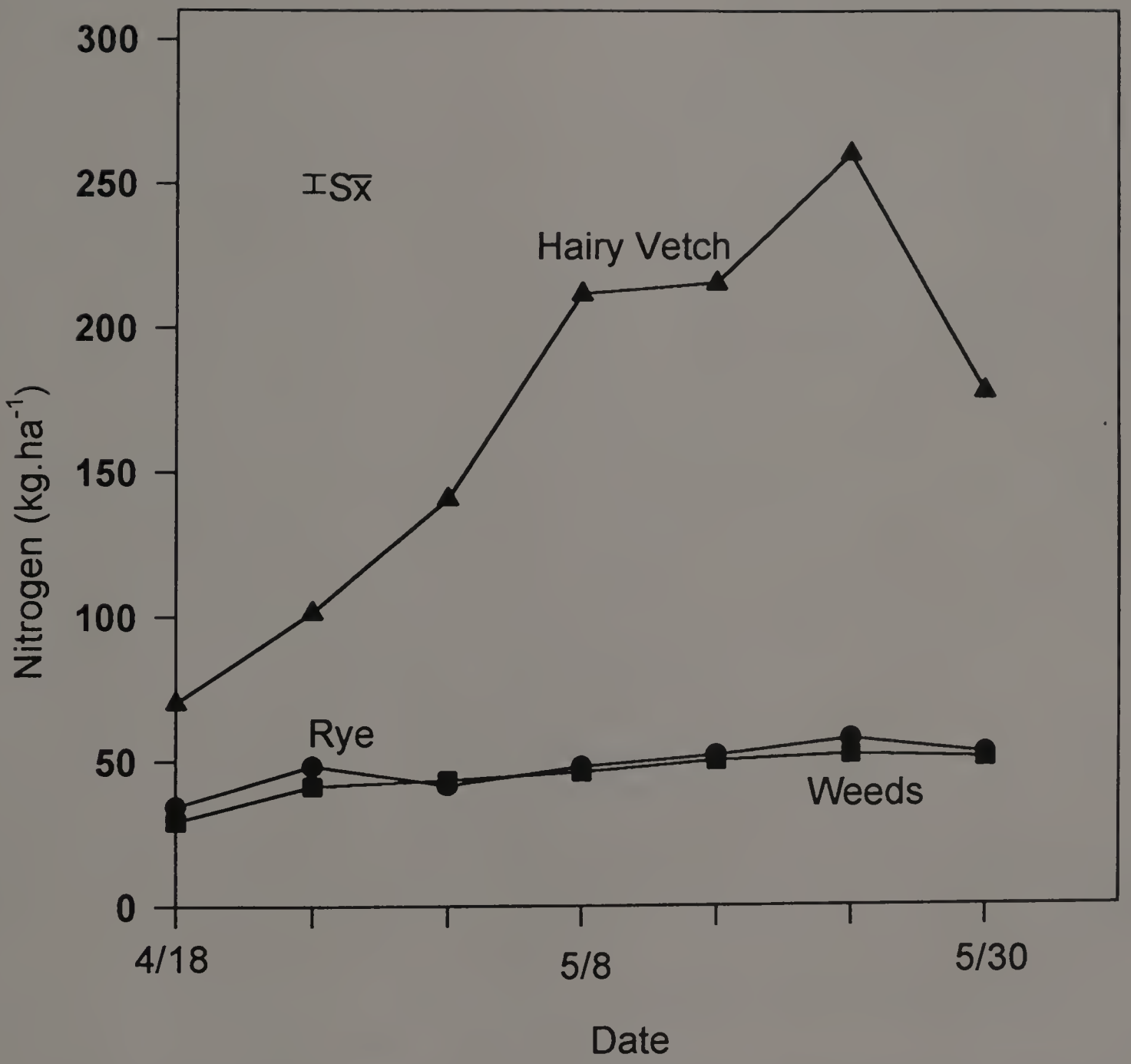

Figure 3 Nitrogen accumulation in aboveground portions of cover crops

then decreased as the quantity of dry matter and its N content decreased. By the time of last sample date, hairy vetch had a measured accumulation of 177.8 kg $N.ha^{-1}$. Rye and weeds had a similar low amount of N accumulation. On April 18, rye and weeds accumulated 34.5 and 29.2 kg $N.ha^{-1}$ in above ground biomass, respectively. They increased only slightly during the cover crop growing season. At the end of May, rye and weeds were accumulated 52.6 and 50.9 kg $N.ha^{-1}$, respectively.

Nitrogen content of rye and weeds continuously decreased in the cover crop growing season, and being similarly appears related to the amount of soil N available for accumulation by the rye and the weeds. Ditsch et al. (1993) observed that rye total N uptake increased with increasing N rate applied to the previous corn crop. Using isotope-ratio analysis, they further reported previous N application to corn strongly influenced fertilizer N recovery by winter rye. In our study, calculated N accumulation patterns of the cover crops were significantly different. Hairy vetch accumulated 3 times more N in above ground biomass than rye and weeds. For hairy vetch, N accumulation was closely related to biomass accumulation. Hairy vetch has been shown to be an efficient N fixer (Smith et al., 1987).

4.1.4 Accumulation of other nutrient in cover crops

P, K, Ca, Mg nutrient accumulations in hairy vetch and rye showed differing responses. On May 30, the last sampling data, vetch accumulated 19.1,

46.8, 51.9 and 16.9 kg/ha of P, K, Ca, Mg nutrient, respectively, in above ground biomass; compared to rye, which accumulated 17.7, 35.6, 22.5 and 5.9 kg/ha of P, K, Ca, Mg nutrient, respectively, in above ground (Figure 4). The analysis of variance indicated a significant difference of Ca and Mg accumulation between hairy vetch and rye, while the amount of P and K accumulation were similar.

There is little information available on P, K, Ca, Mg nutrient accumulation and the roles of cover crops in these nutrient cycles, especially in temperate systems. However, studies in tropical and subtropical systems reveal the significant effects of cover crops on soil and plant P (Samson et al. 1990). An experiment conducted by Samson et al.(1991) in sandy loam in Ontario showed that there were trends of increased N and P content following legume cover crops compared to following oilseed radish and control plots, which resulted in significant reductions of N and P. Even though there is little information on K, Ca and Mg cycling in cover crop systems, cover crops may pelp in prevent available K, Ca and Mg from leaching, especially in acidic and/or sandy soils in humid area.

4.1.5 Carbon:Nitrogen ratios

The C:N ratios of the cover crops in different growing stages was calculated from chemical analyses for organic carbon, and N content (Figure 5). C:N ratio of hairy vetch decreased in late April from 15.1:1 to 11.6:1 and kept around 12:1 until the end of May, when it slightly increased to 14.2 : 1. C:N ratio of rye and weeds continually increased during the sampling period from 34.1:1 to 77.8:1 and

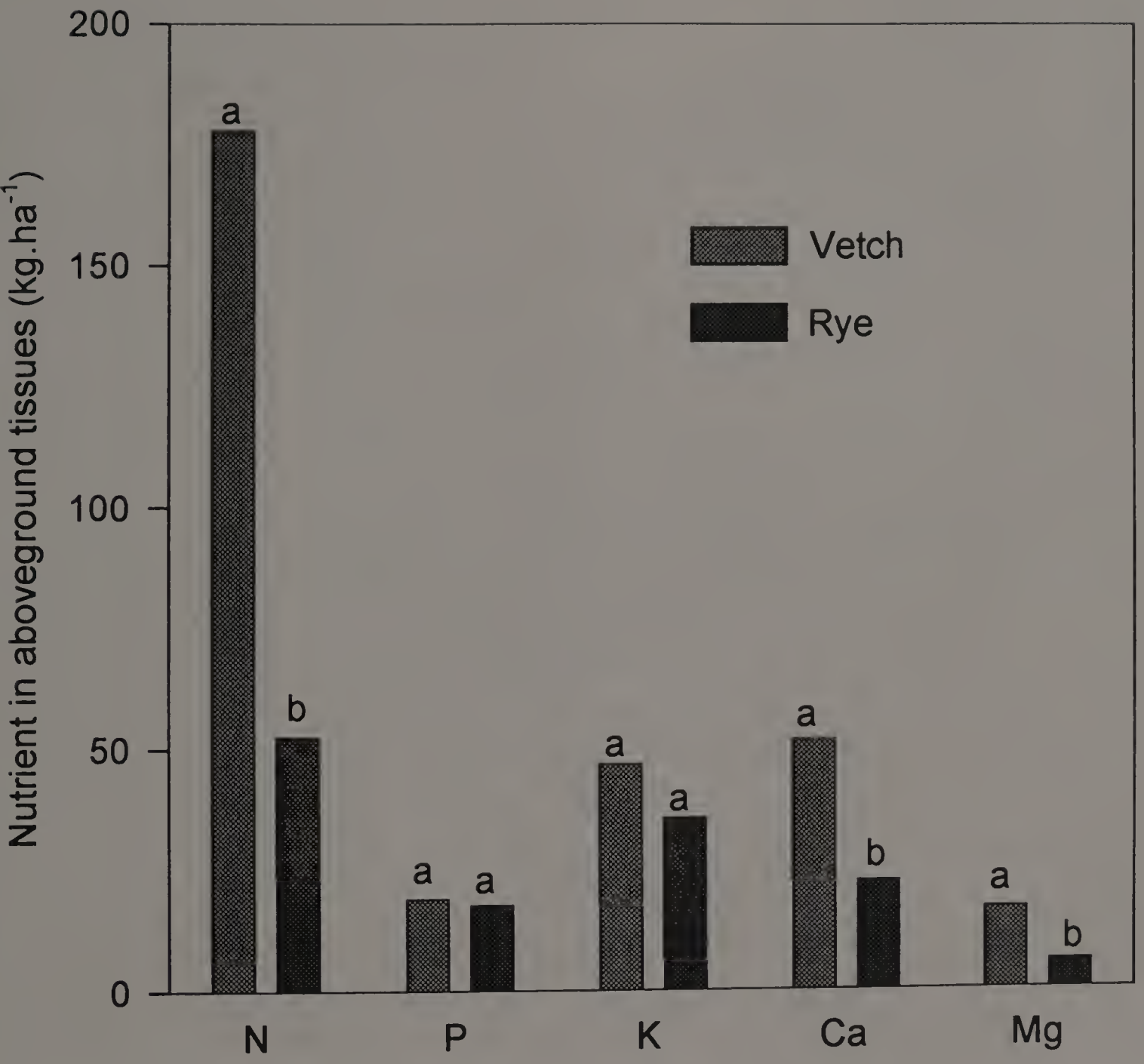

Figure 4 Nutrient accumulated in aboveground on May 30

* Bars with the same latter within each element are not significantly different at the 0.05 level of probability for F ratio in ANOVA

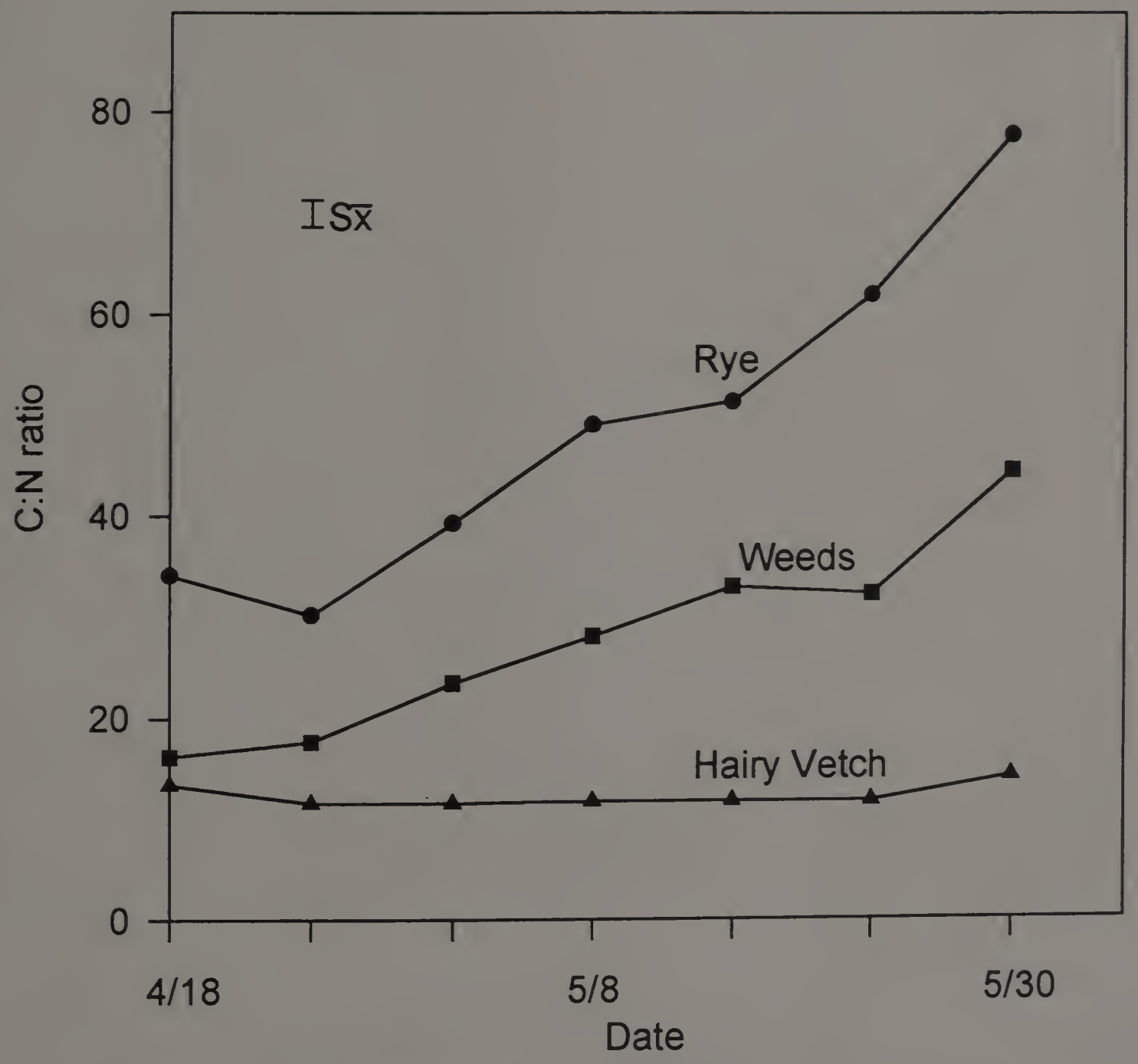

Figure 5 C:N ratio of cover crops

16.2:1 to 44.5:1, respectively. High C:N ratios found for rye were reported to cause N immobilization and slow the process of decomposition and nutrient release of incorporated plant residues (Saini, 1989; Tian et al., 1992; Quemada et al.,1995) Therefore, early to mid-May incorporation of rye is suggested in this area.

4.2. Environment conditions during the decomposition period

On site precipitation data (Figure 6) was collected from a local weather station for the duration of the experiment (August 1994 to December 1995). Soil moisture content as showed in Figure 7. The large variation in moisture content of topsoil (0-20 cm), was closely related to amount and timing of precipitation. Moisture contents varied from a low of 16.9% in September 11th to a high of 25.2% in October 17th. The two dry periods which each lasted 3 weeks occurred in mid-July to early August, and late August to mid-September, restricted the cover crop decomposition at 7.5 cm depth. The variation of moisture contents in the subsoil (20-40, 40-60 cm) were dependent on water availability and soil texture, the 20-40 cm soil was a sandy loam which had a higher water holding capacity, the moisture content of this layer was higher and more stable. The 40-60 cm soil was a loamy sand which had a lower water holding capacity. The moisture content of this layer was lower and more stable. Relatively stable moisture content in 20-40 cm soil was beneficial to residue decomposition in 22.5 cm.

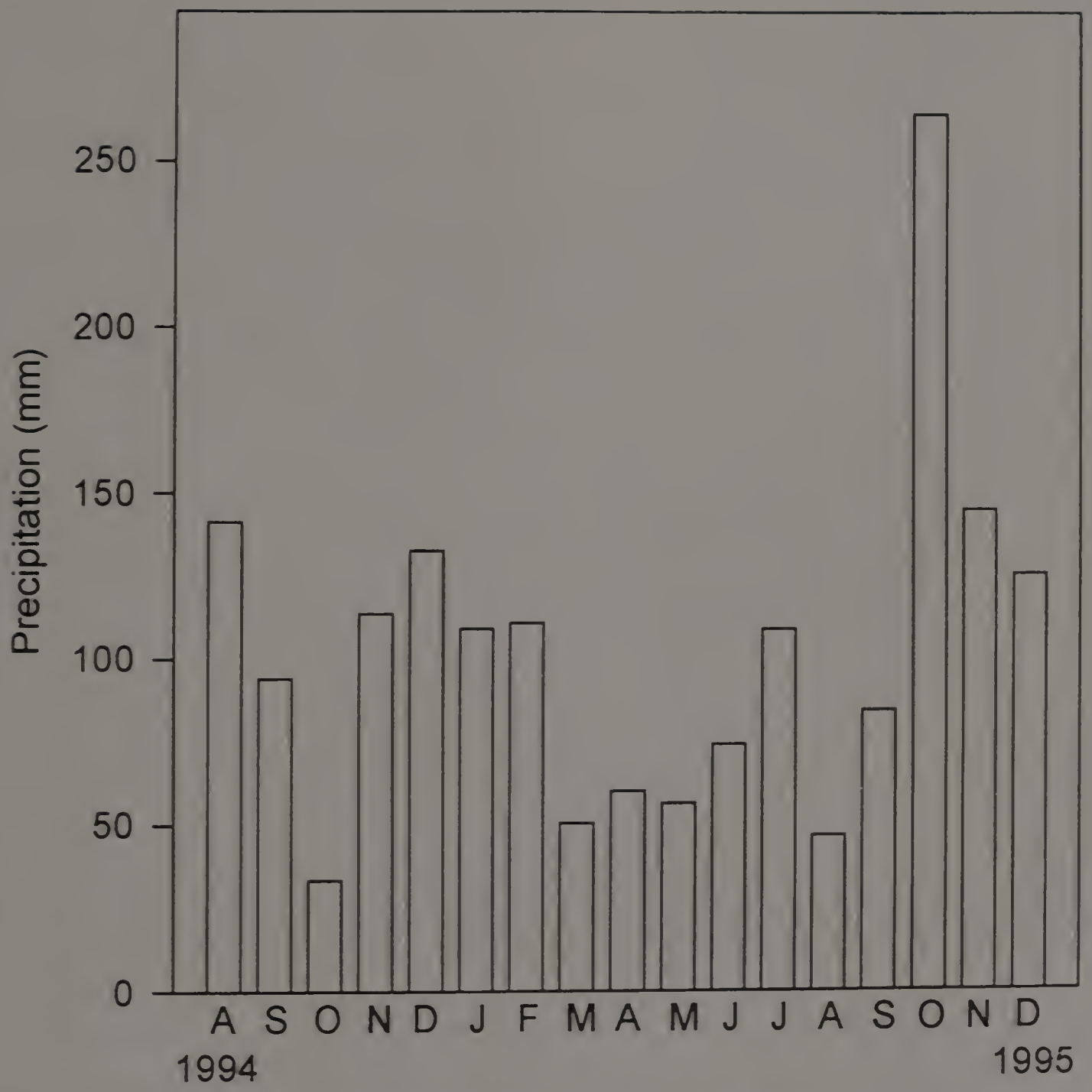

Figure 6 Monthly cumulated precipitation during the experiment

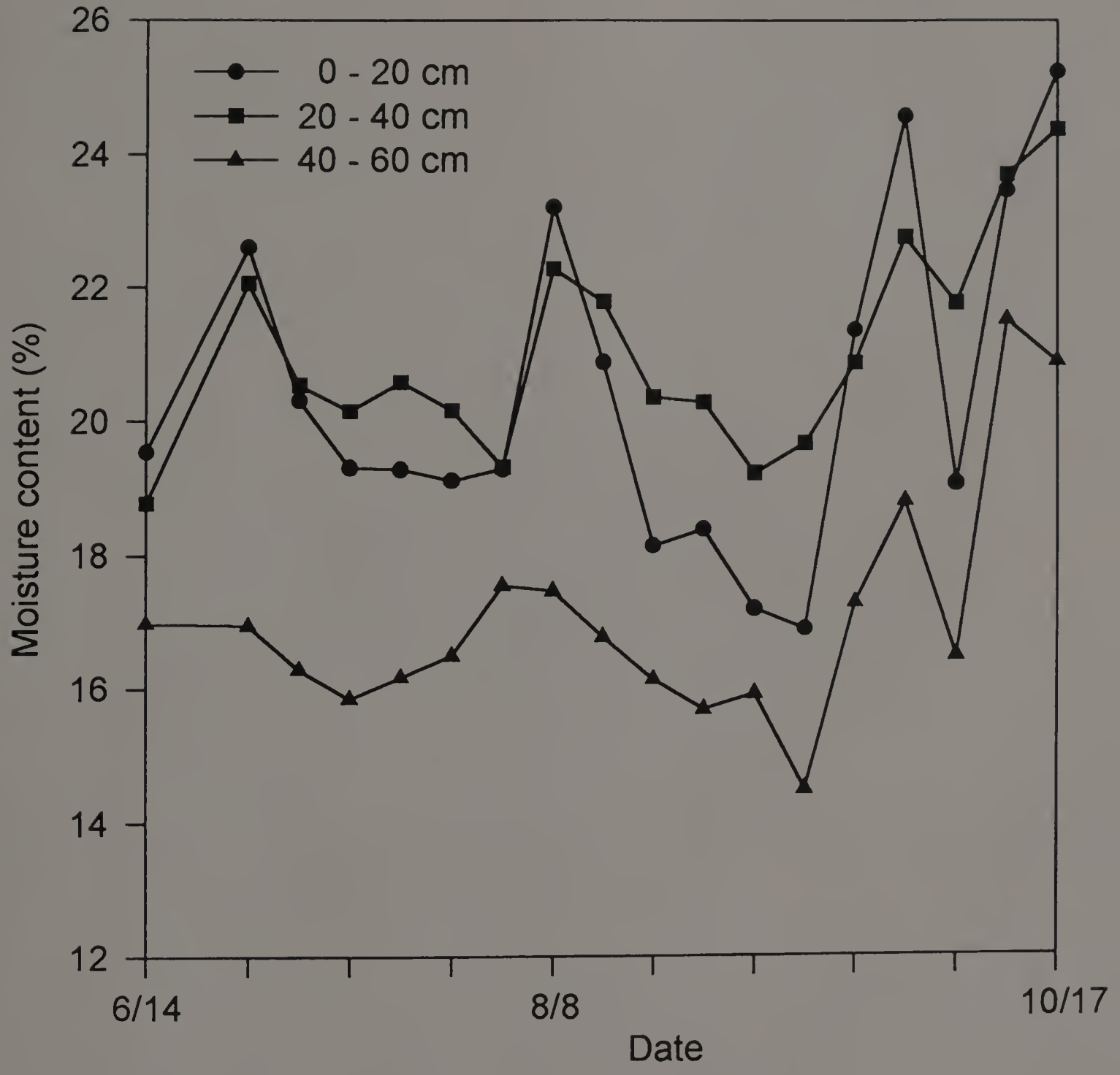

Figure 7 Soil moisture content in different depth

Observed soil temperature results are plotted in Figure 8. Temperature variation on soil surface were ranged from 16.8 °C to 48.2 °C, while the temperature variation at 7.5 cm and 22.5 cm were ranged from 12.5 °C to 30.5 °C, and 11.3 °C to 28.0 °C, respectively. Temperature at 15 cm depth and below were similar. The highest temperature appeared in mid-June and then slowly decreased afterward. The vertical distribution of monthly average temperature (Figure 9) indicated that the highest temperature at 7.5 cm and 22.5 cm depth was 26.6 °C, and 23.2 °C, respectively. The temperature at 7.5 cm depth was slightly but consistently higher than that at 22.5 cm depth.

4.3 Cover crop residues decomposition

4.3.1 Dry matter losses of cover crop during decomposition

Dry matter losses of the cover crop during decomposition is shown in Figure 10. Statistically, the 2 depths were not significantly different, so data is presented as the means of the two depths for comparisons of the decomposition of hairy vetch and rye. A rapid drop in dry matter occurred during the first week after buried of both cover crop residuals. Hairy vetch had a significantly faster rate of decomposition. Fifty percent of the dry matter loss took 3 weeks for hairy vetch, and 9 weeks for rye. Decomposition over time for cover crop residues was best described using two-pool models for hairy vetch as:

$$y = 100*(0.521*e^{-0.9992t} + 0.479*e^{-0.02503t}) \qquad (R^2 = 0.9967**)$$

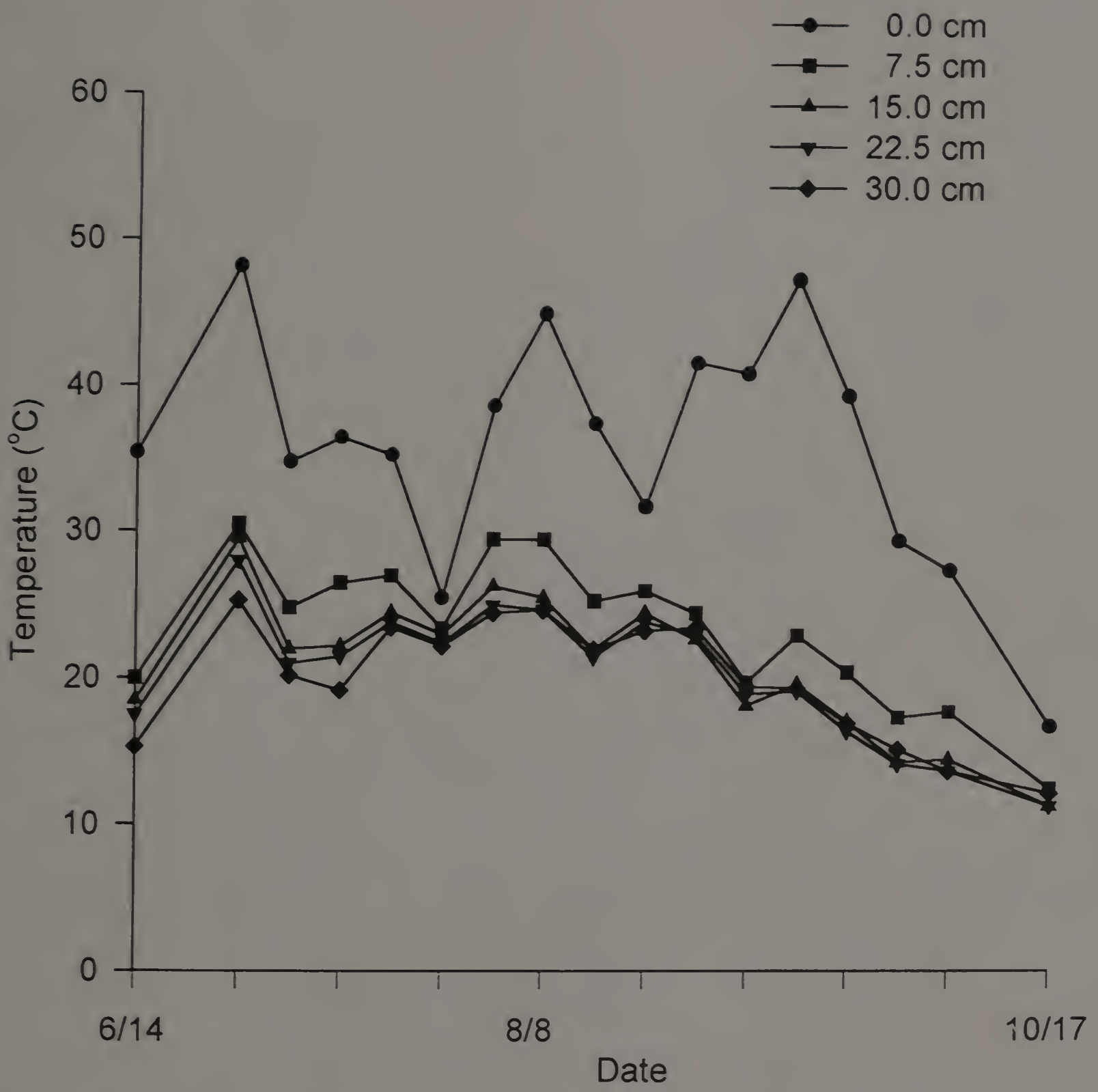

Figure 8 Changes of soil temperature at different depth during residue decomposition

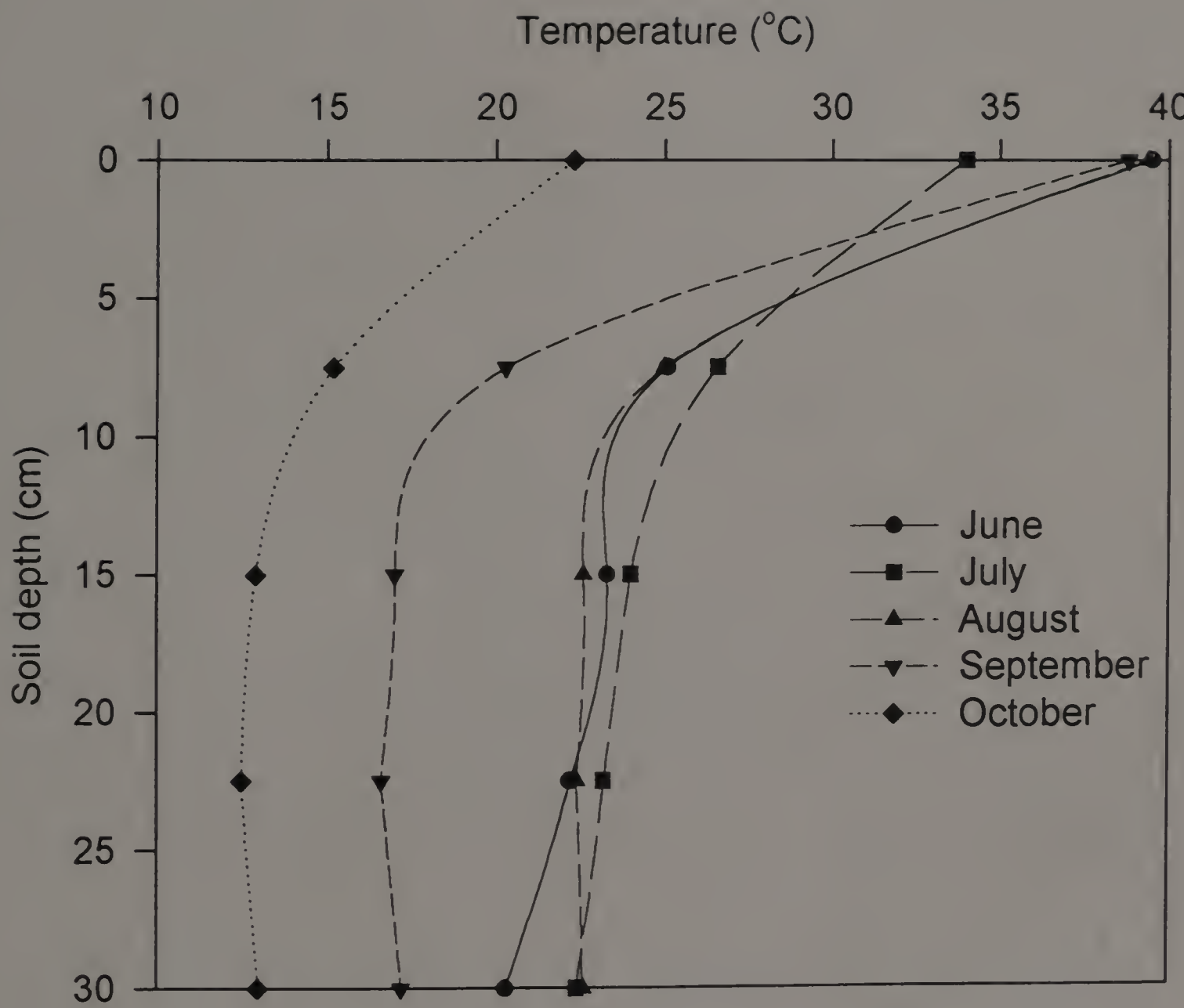

Figure 9 Monthly averaged temperature during residue decomposition

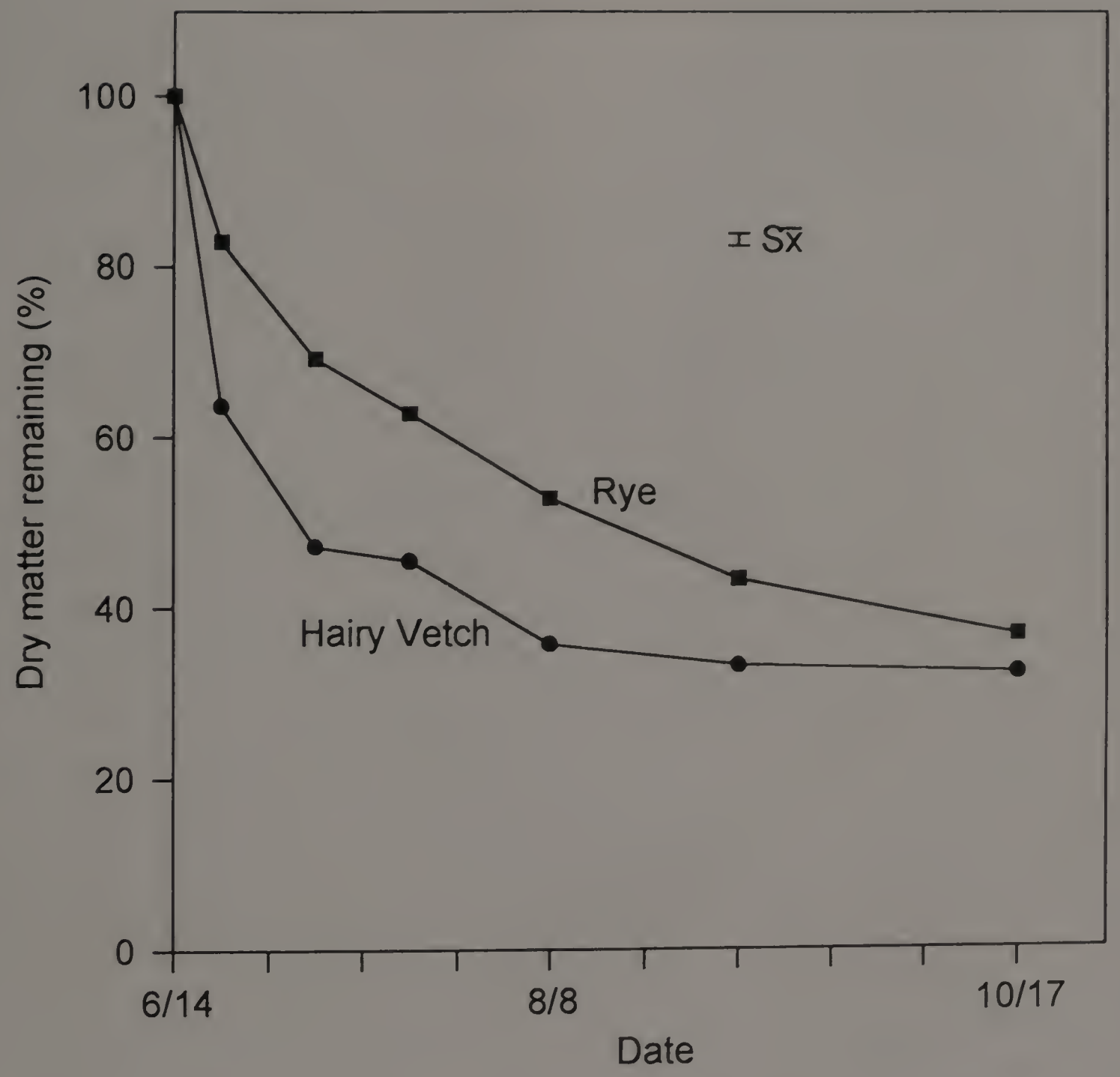

Figure 10 Dry matter remaining of cover crop residues during decomposition

and for rye as:

$$y = 100*(0.252*e^{-0.7490t} + 0.748*e^{-0.04165t}) \qquad (R^2 = 0.9985^{**})$$

where y = remaining organic matter, and t = time in weeks.

The first weekly decomposition constant (k_1) indicated more rapid initial decomposition and the second decomposition constant (k_2) reflected a slower rate of decomposition over a longer time period. High decomposition rates in the first pool were indicative of the rapid decay of simple carbohydrates, protein, and other low C:N ratio compounds, and the lower decay rates in second pool were representative of slow decomposition of recalcitrant materials like lignin. The two cover crops had different pool sizes. Hairy vetch had a larger readily decomposable pool (P_1 =0.521), while the rye had a larger recalcitrant pool (P_2 = 0.748).

The decomposition and mineralization kinetics are determined by residue characteristics including N content, C chemistry, particle size, and quantity added. Important soil characteristics include soil texture, pH, aeration, and, for low nutrient residues, soil nutrient status (Parr et al., 1978). Among environmental or climatic factors, temperature and moisture is surely most significant.

Residue decomposition requires water for microbial growth and for the diffusion of nutrients and by-products during the breakdown process. In the field, water content of the soil and residue fluctuate seasonally with the greatest and most rapid changes occurring in the surface layers because they are the first to

receive moisture from precipitation and the first to dry from evaporation. Major changes in the deeper soil layers occur only through rain, irrigation, or plant extraction. Temperature also has a profound influence on the growth and activity of microorganisms and consequently will greatly affect the decomposition rate of cover crop residues. Most soil microorganisms exhibit maximum growth and activity in the 20 to 35 °C temperature range. Sommers and Biederbeck (1973) reviewed the selective effect of temperature on the total soil microflora and concluded that temperature increases in the mesophilic range usually results in increased numbers and activities of the microflora. Moisture and temperature are combined together to control the residue decomposition. In our experiment, soil at 7.5 cm depth had a favorable temperature condition but a more variable moisture status, in contrast, soil at 22.5 cm depth had a high moisture content but a lower and stable temperature. These two factors are the main reasons causing no difference between the two depths.

Plant residues with high nitrogen content showed high a decomposition rates and nutrient release (Swift et al., 1979). Frankenberger and Abdelmagid (1985) and Melillo et al. (1982) reported high correlations between N content, N release and biomass loss. The role of lignin as a regulator in the decomposition process has been elucidated in several studies (Meentemeyer, 1978; Berendse et al., 1987). Increasing lignin concentration reduces the decomposition rate of plant residues. The negative effect of polyphenols on decomposition and nutrient release

was reported by Vallis and Jones (1973). Negative correlations were observed between decomposition rate constants and C:N ratio, percent lignin and polyphenol content of plant residues (Tian et al., 1992). A high silica content in plant residues may also affect decomposition as it has been reported to reduce the digestibility of plant residues (Georing, et al., 1970; Ma, et al., 1989).

Soil inorganic N availability is another major factor to influence residue decomposition. This is especially true for the low N content plant residue, like non-legume cover crop and cereal crop residues. The effect of soil inorganic N availability on the decomposition of maize residues were tested under aerobic conditions in soil samples incubated for 125 days at 15 °C (Recous et al. 1995). They applied 4 g dry matter per kg soil (equivalent to the uniform incorporation of 8 t DM ha^{-1} into the 0-15 cm soil layer) at five initial inorganic N concentrations (10, 30, 60, 80, and 100 mg N kg^{-1} soil). Inorganic N remained available in those soils having the three highest initial N concentrations, in this case the rates of C mineralization and N immobilization were similar. Soil inorganic N completely disappeared at the beginning of C decomposition in the soil samples with the two lowest N contents, resulting in a marked decrease of C mineralization rate compared to the three highest N contents. Gross N immobilization amounted to 39 mg N g^{-1} added C after 40 days (end of the net immobilization period) for the three highest N concentrations. N immobilization was much lower in the two lowest-N treatments because decomposition was slow and microbial N

immobilization per unit of mineralized C was reduced. The ratio N immobilized: C mineralized also decreased in all treatments during decomposition due to changes in microbial N demand with time or increasing contributions from other sources of N.

4.3.2 Nitrogen mineralization

Nitrogen release patterns, expressed as a percentage of the initial residue N, are illustrated in Figure 11. A significant difference was found in the N release patterns of the 2 cover crop residues. Rapid N release happened in the first 3 weeks in hairy vetch, followed by a slow N release. After the first 3 weeks, less than 40% of N remained in hairy vetch residues, and at the end of the sampling period only 20% of N remained in the residues. A relatively small amount of N release was found in rye in the first week, the quantity of N in the bags were almost maintained at the same level afterward. N release in the first week may be caused by quick decomposition of readily decomposable tissues such as leaves. Rye had more than 60% of N still remaining in the residues at the end of the sampling period. This was consistent with the results from the work of Quemada et al. (1995).

Most studies conducted in the Southeast USA have shown that, regardless of tillage system, decomposing legumes release a pulse of available mineral N for 2 to 5 weeks after killing of the cover crops in spring, followed by a gradual decline over the growing season (Utomo et al.,1990; Sarrantonio and Scott, 1988;

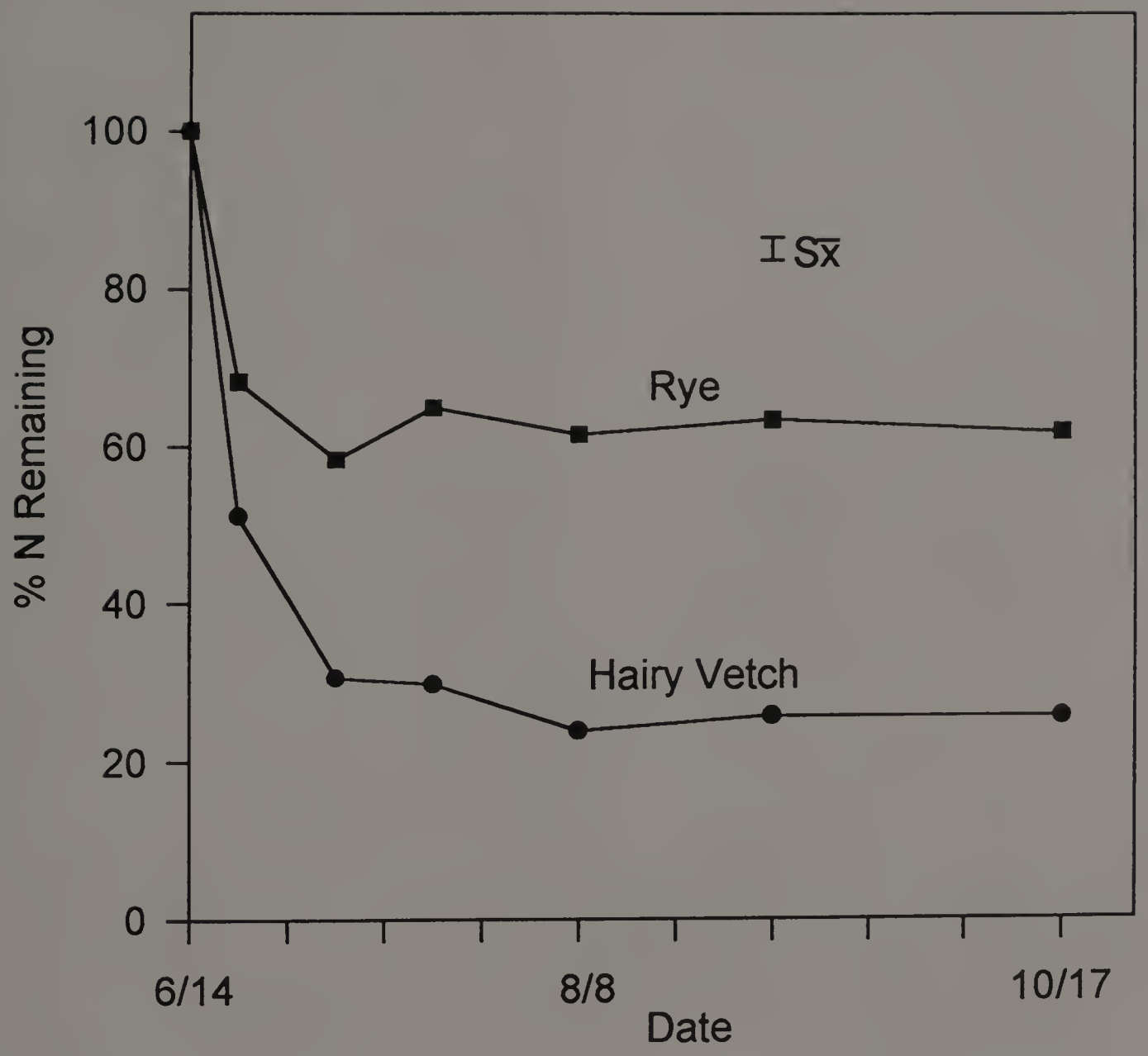

Figure 11 Percent N remaining of quantity initially incorporated in soil

Groffman et al., 1987; Ebelhar et al., 1984). Somda et al. (1991) studied the decomposition of 4 kinds of legumes and 8 kinds of non-legumes, they concluded that most leguminous residues released the majority of their N within first 14 days, whereas the decomposition of non-legume crop residue resulted in significant amount of net N immobilization. Immobilization in all residues occurred during the first 56 days, followed by a slow N-release period. The rapid N release is related to the rapid decomposition of an initial pool of N due to high microbial activity in response to the large amount of available N. Berg and Staaf (1981) reviewed the works that have been done in 1960's to 1980's of the effect of initial N content on the N mineralization / immobilization of litter decomposition in the natural ecosystems. They concluded that the N level in litter for N immobilization ranging from about 0.3 to about 1.4% depending on the system. The N level in litter higher than this range likely had a net N mineralization. Nitrogen mineralization took place only when N level reached a critical level. Once the N release started, it appeared to follow the weight loss pattern, and the N release from the residue appeared to be in a linear relation to the weight loss (Staaf and Berg, 1977; Wood, 1974).

A field study was conducted in Wisconsin (Stute et al., 1995) during 1991 and 1992 that measured the release of legume N throughout the growing season using mesh bags, and compared resultant levels of soil mineral N following legume incorporation to those following fertilizer N applied at the recommended

rate (179 kg N ha^{-1}) and a control (no cover crop, no fertilizer) in a conventional tillage system. Corn N uptake during the growing season was also measured to determine if legume N could meet uptake demands. The result showed that hairy vetch and red clover residual decomposed rapidly, releasing half of their N within 4 weeks after burial, while very little N was released after 10 weeks. Soil tests indicated an increase in mineral N levels corresponding to legume N release, similar to those following an application of 179 kg ha -1 fertilizer N, occurring before the period of rapid N uptake by corn. The mean corn grain yields of 11.25 Mg ha in 1991 and 10.89 Mg ha in 1992 following the legumes were similar to those produced with 179 kg ha fertilizer N, indicating that, legume cover crop can be an effective N source for corn in the Upper Midwest of USA.

A experiment conducted in Nigeria (Tian et al., 1992) showed that during the decomposition of maize stover and rice straw, which have higher C:N ratio, some N was immobilized despite the decrease in total N in the remaining maize stover and rice straw. High lignin content of plant residues could also enhance nutrient immobilization especially of nitrogen (Melillo et al., 1982). Sivapalan et al. (1985) reported that N mineralization was lowered by the presence of high concentrations of polyphenols, due to the binding of mineralized N into an insoluble organic compound. Our results were consistent with all the other research works that showed that legume cover crops which have low C/N ratio released pronounce amount N after incorporation. Non-legumes which have a high

C/N ratio, high lignin content immobilized N from soil after incorporation.

4.3.3 Changes in N content and C:N ratios of residues during decomposition

The N contents of the cover crop residues were changed soon after bags were buried in the soil (Figure 12). N content of hairy vetch decreased from 3.3% to below 2.5% and then remained at 2.5% for most dates until the end of sampling. Rye N content decreased slightly in the first week and then it increased continuously until the last sampling date, and still showed a tendency for increase. The initial rye N content was 0.78%, which increased to 1.5% at the end of the sampling.

Changes of C:N ratios were determined for residues during their decomposition (Figure 13). C:N ratio of hairy vetch increased from 16:1 to 24.5:1 in the first 5 weeks and then slightly decreased to 19:1 and kept this ratio until the last sampling date. The overall C:N ratios of rye decreased from 78:1 to 40:1 during the sampling period. The C:N ratio dropped quickly in the first 8 weeks, from 78:1 to 56:1, and then continuously decreased.

C:N ratio is a very important indicator for N mineralization or immobilization during the residue decomposition. Parnas (1975) studied the relationship between N immobilization and C:N ratio and concluded that N immobilization occurs if the plant residue has a C:N ratio of ≥ 30. According to Stevenson (1985), net immobilization lasts until the C:N ratio of the decomposing material has been lowered to $\approx$ 20. Residues like corn stover, rice straw, and rye

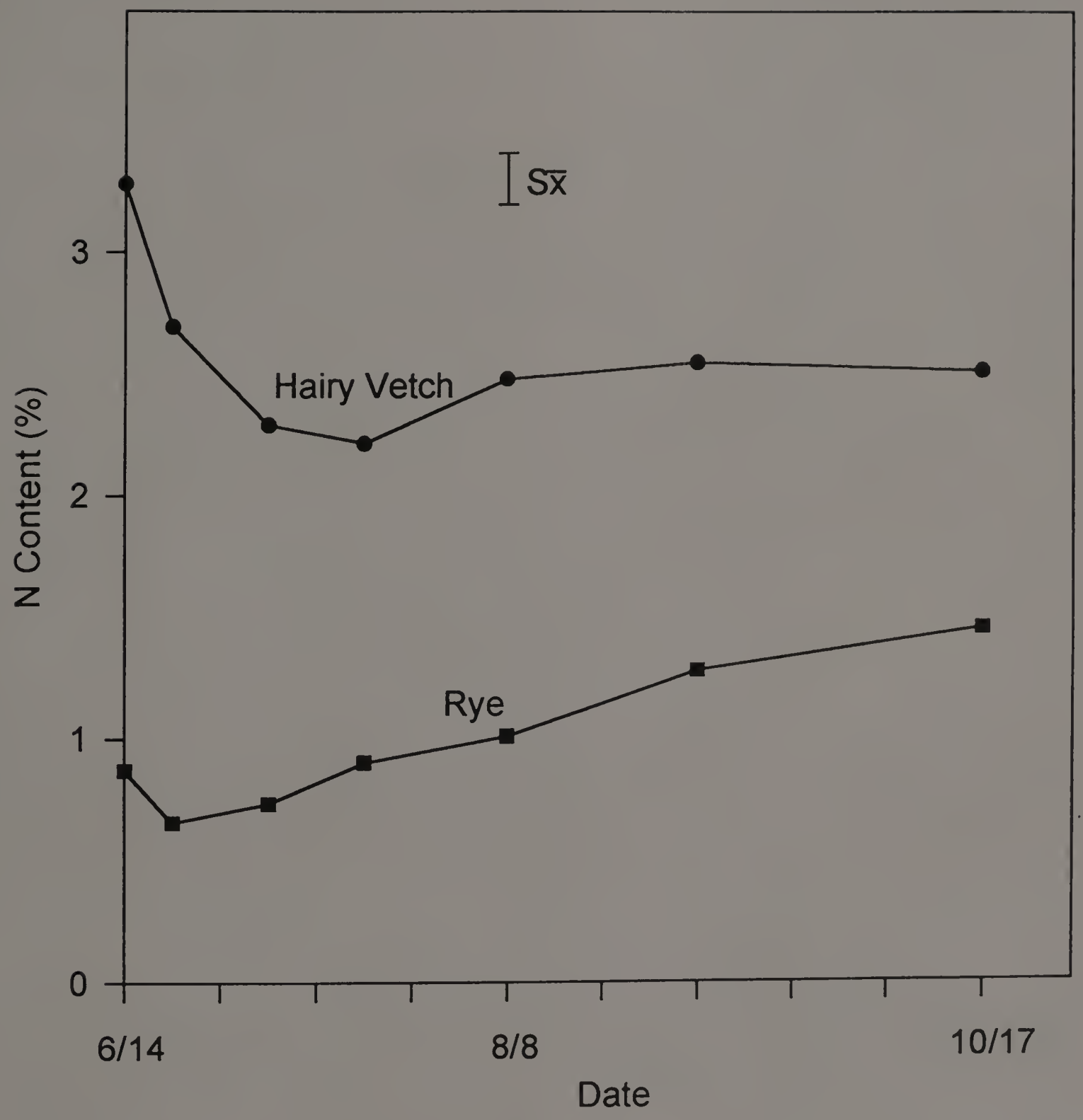

Figure 12 Nitrogen content in cover crop residues after incorporation

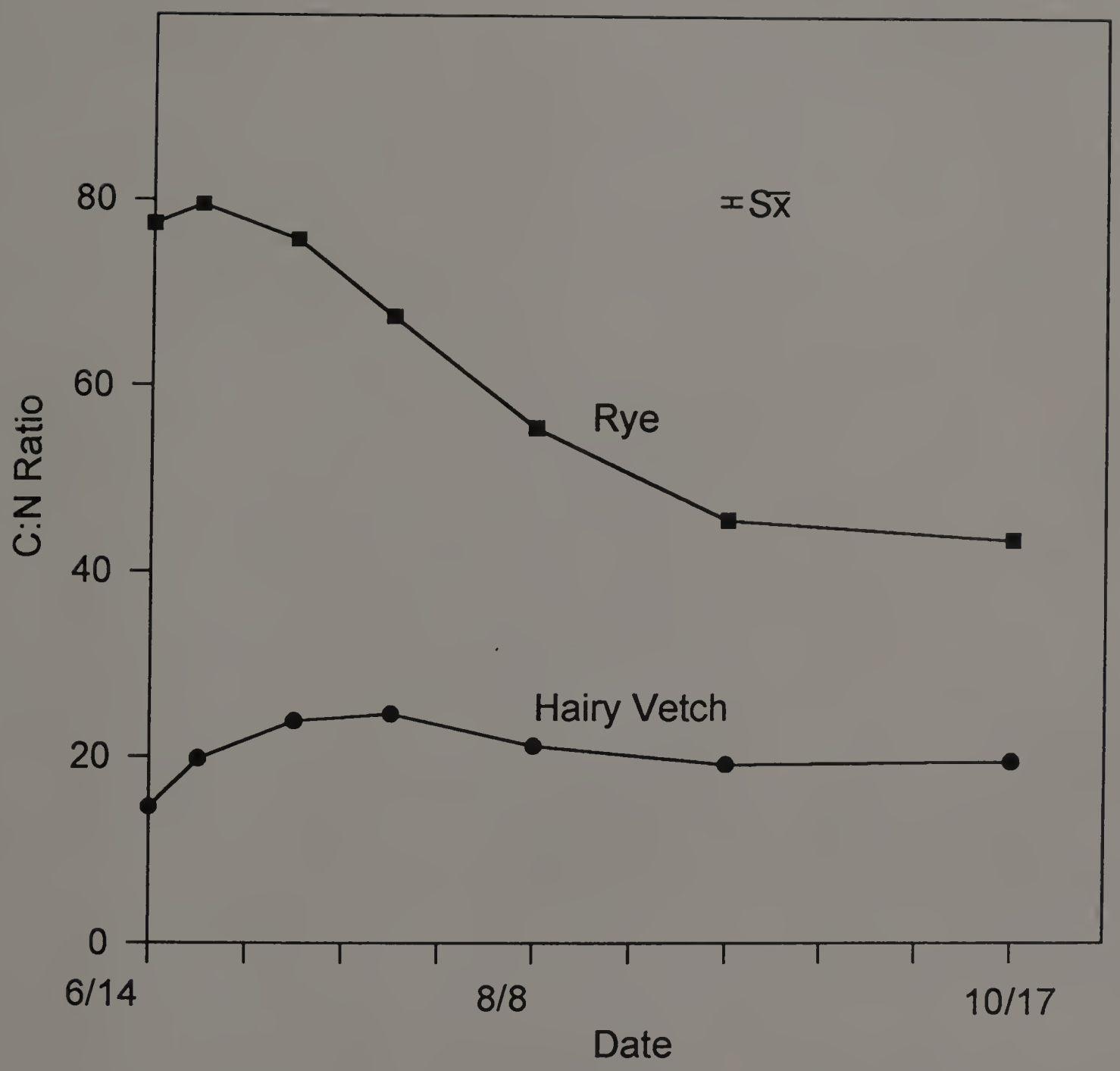

Figure 13 C:N ratio of cover crop residues during decomposition

have C:N ratios higher than this critical value immobilized N (Saini, 1989; Tian et al., 1992; Quemada et al.,1995). In our case, the changes of N content of residues (Figure 12) and the C:N ratios where vetch increased from 16 to around 20, and rye decreased from 78 to 40 indicate N mineralization from vetch and N immobilization to rye, and that the N immobilization by rye would still last for a period of time.

4.3.4 Other nutrient release from cover crop residue during decomposition

4.3.4.1 Potassium

Potassium release patterns were similar to dry matter loss patterns (Figure 14). K release from both cover crop residue was rapid. However, the release pattern of K from hairy vetch was faster than that in rye. At the last sampling date, 6.2% of K was left in the hairy vetch residue compared to 23.8% of K in the rye residue. K release peak for hairy vetch was in the first 3 weeks and followed by a slow release, whereas K release of rye was slow in the first 5 weeks, and then were rapid in next 3 weeks. Tian et al.(1992) also observed rapid K release for different plant residues, where 77% of K in maize stover and rice straw residues was released in 98 days. Potassium release was less affected by chemical characteristics than other nutrient release. This may be due to the relatively high mobility of K in soil, and that there are no organic compound formed from K. In acid soil K is very easily leached, and K deficiency is often a problem. Cover

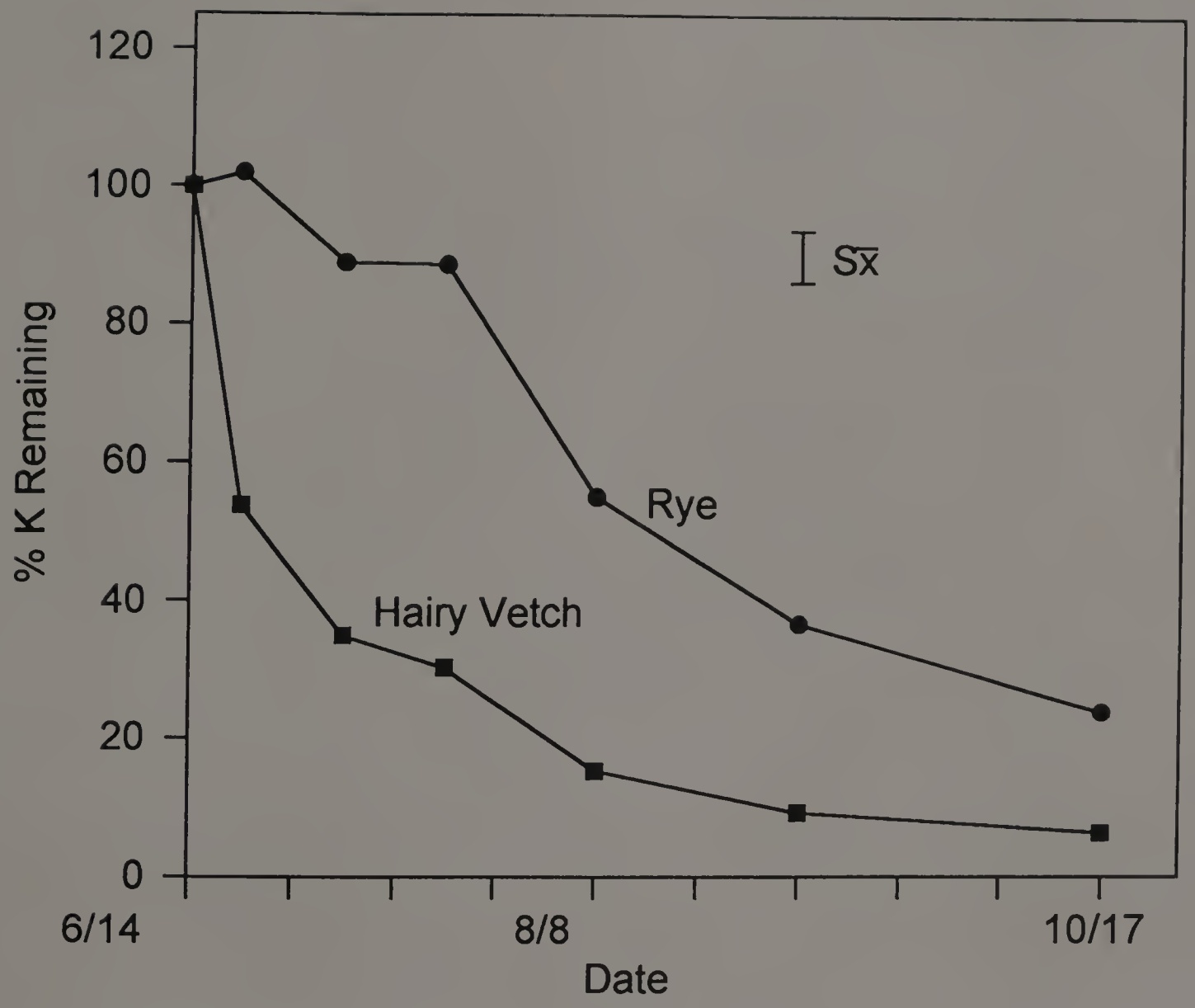

Figure 14 Percent K remaining of quantity initially incorporated in cover crops

crops retained the available K in the plant tissues and released it to soil during their decomposition. This was very important for main crops in acid soil.

4.3.4.2 Phosphorus

Phosphorus (P) release patterns were very different from N and K and dry matter loss patterns. For hairy vetch, almost all of the P (about 85 to 90%) was retained in the residues during the sampling period. In contrast, rye had a relatively fast, smooth P release (Figure 15). During 18 weeks of sampling period, calculated cumulative P release from rye reached about 60%. P concentration increased and C:P ratio (Table 3) were decreased in both plant residues. Hairy vetch had a greater increase in P concentration and greater decrease in C:P ratio than rye residue. This indicated that hairy vetch residue had a stronger P immobilization than rye residue. This results were consistent with the results obtained by Tain et al.(1992). Phosphorus immobilization may be due to low initial P concentration in plant residues (Budelman, 1988).

Phosphorus is a very important nutrient which is involved in plant growth and plant residue decomposition. In the decomposition process, P release largely depends on the population of microbes involved. Hairy vetch had a low C:N ratio and relatively lower C:P ratio compared to rye. Vetch then was much easier to access for microbes, and a large number of microbes and of different varieties probably participated in the rapid decomposition. Most of the P released from hairy vetch residue was again fixed by the microbes as they continued to

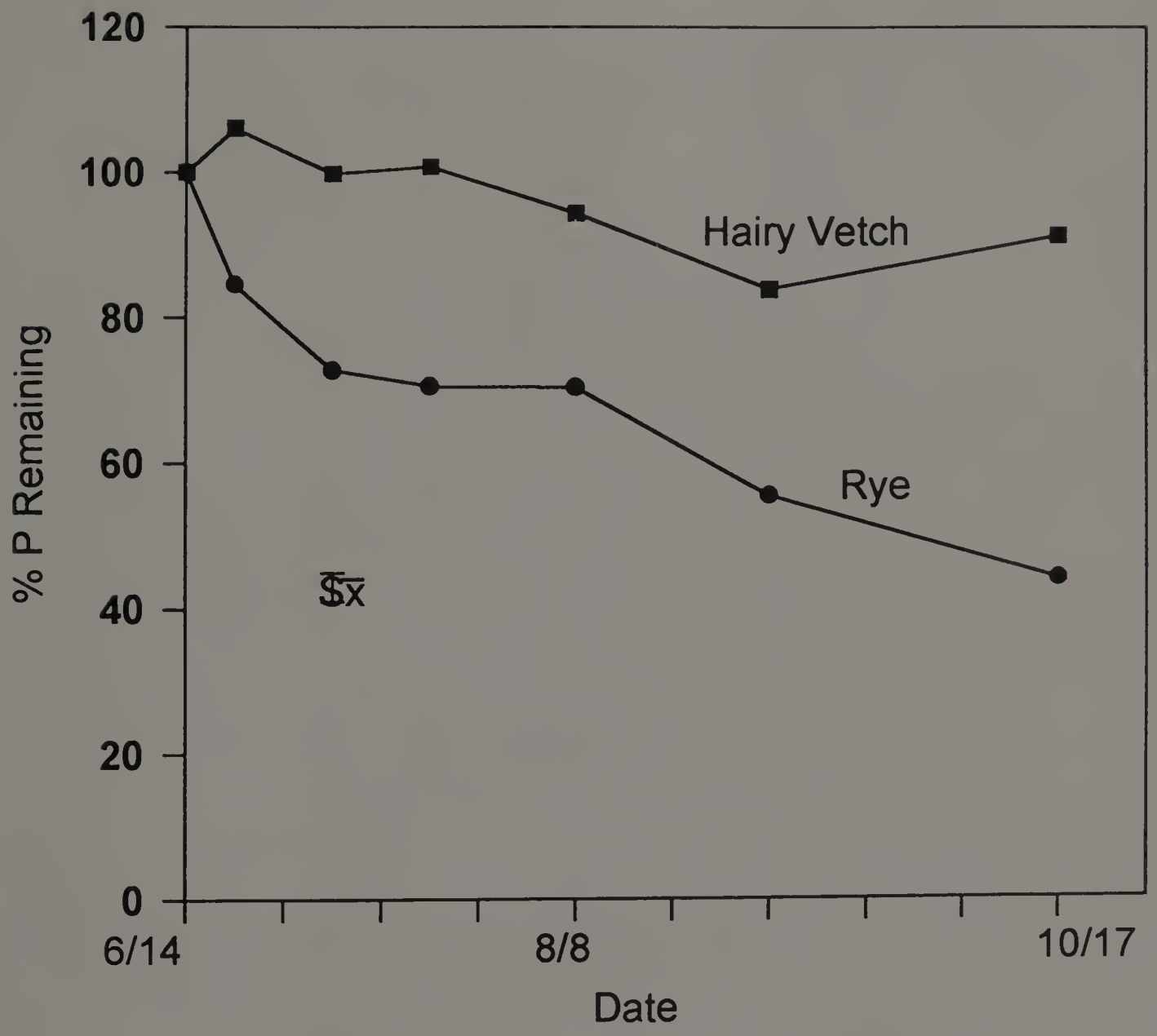

Figure 15 Percent P remaining of quantity initially incorporated in cover crops

Table 3. Change in concentration of nutrients and nutrient ratios of decomposing materials with time.

Plant residues	Time (weeks)	N %	P %	K %	Ca %	Mg %	C/N	C/P
Hairy vetch	0	3.28	0.378	0.927	1.029	0.335	14.6	144.6
	1	2.70	0.631	0.659	1.800	0.680	19.8	87.8
	3	2.29	0.798	0.688	2.306	0.890	23.8	67.2
	5	2.21	0.837	0.593	2.691	1.031	24.6	65.1
	8	2.48	1.003	0.397	3.312	1.108	21.2	52.9
	12	2.55	0.955	0.257	3.651	1.127	19.2	53.9
	18	2.51	1.063	0.179	3.899	0.845	19.5	48.4
Rye	0	0.87	0.254	0.510	0.323	0.085	77.4	230.9
	1	0.66	0.260	0.754	0.288	0.073	79.5	228.1
	3	0.73	0.270	0.655	0.329	0.093	75.7	218.9
	5	0.91	0.285	0.722	0.418	0.139	67.4	204.5
	8	1.02	0.339	0.530	0.607	0.172	55.5	169.3
	12	1.28	0.325	0.430	0.818	0.250	45.6	191.2
	18	1.45	0.304	0.328	1.059	0.302	43.5	194.8

decompose the residue. Rye had a high C:N and C:P ratios and is relatively hard to access for microbes. The quantity of the microbes involved in rye decomposition was small, and there seems to have been a small amount of P released in to soil. The increasing in concentration of P and decreasing C:P ratio in residue indicated P was immobilized as it was released in the decomposition process. This was less apparent with rye (Table 3).

4.3.4.3 Calcium and Magnesium

Figure 16, 17 show the change in percentage remaining during decomposition of residues for Ca and Mg. Release patterns for Ca and Mg from rye residue were similar. They were decreased during the first 3 weeks to about 70% of the initial value, then constantly increased to reaching 120% for Ca and 130% for Mg of the initial amount incorporated. In the hairy vetch residue, the quantity of Ca constantly increased, while the quantity of Mg increased during the first week to 130% of the initial amount, and then decreased to about 80% of the initial amount. The concentrations of Ca and Mg consistently increased in both vetch and rye residues (Table 3).

Different researchers from different locations using different plant materials determined quite variable Ca and Mg release patterns. In humid tropical conditions, Budelman (1988) found a fast release of Ca and Mg from most of the plant residues he used, and Tian et al. (1992) indicated that release of Ca and Mg followed the same pattern as loss of plant residue biomass. However, Swift et al.

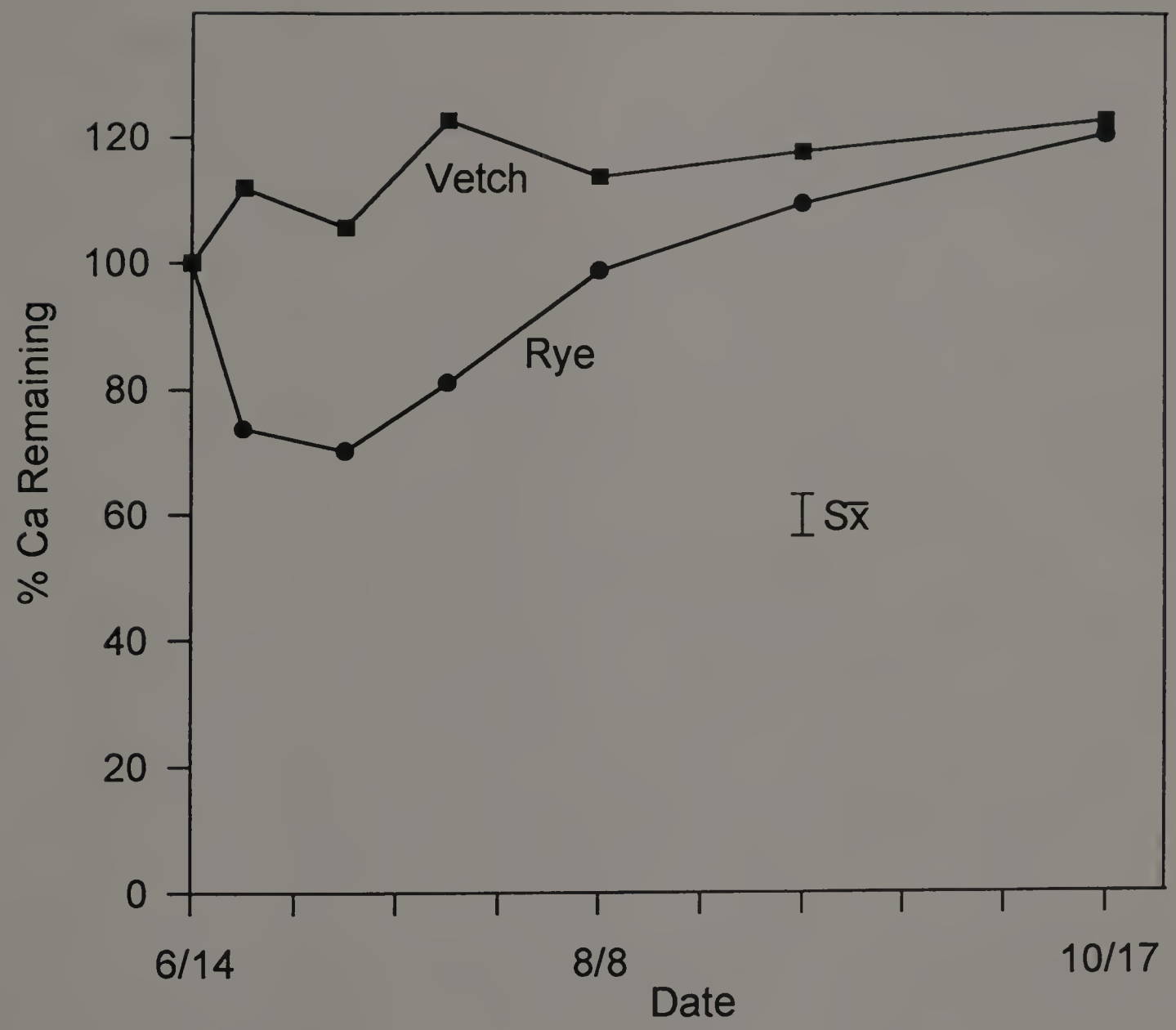

Figure 16 Percent Ca remaining of quantity initially incorporated in soil

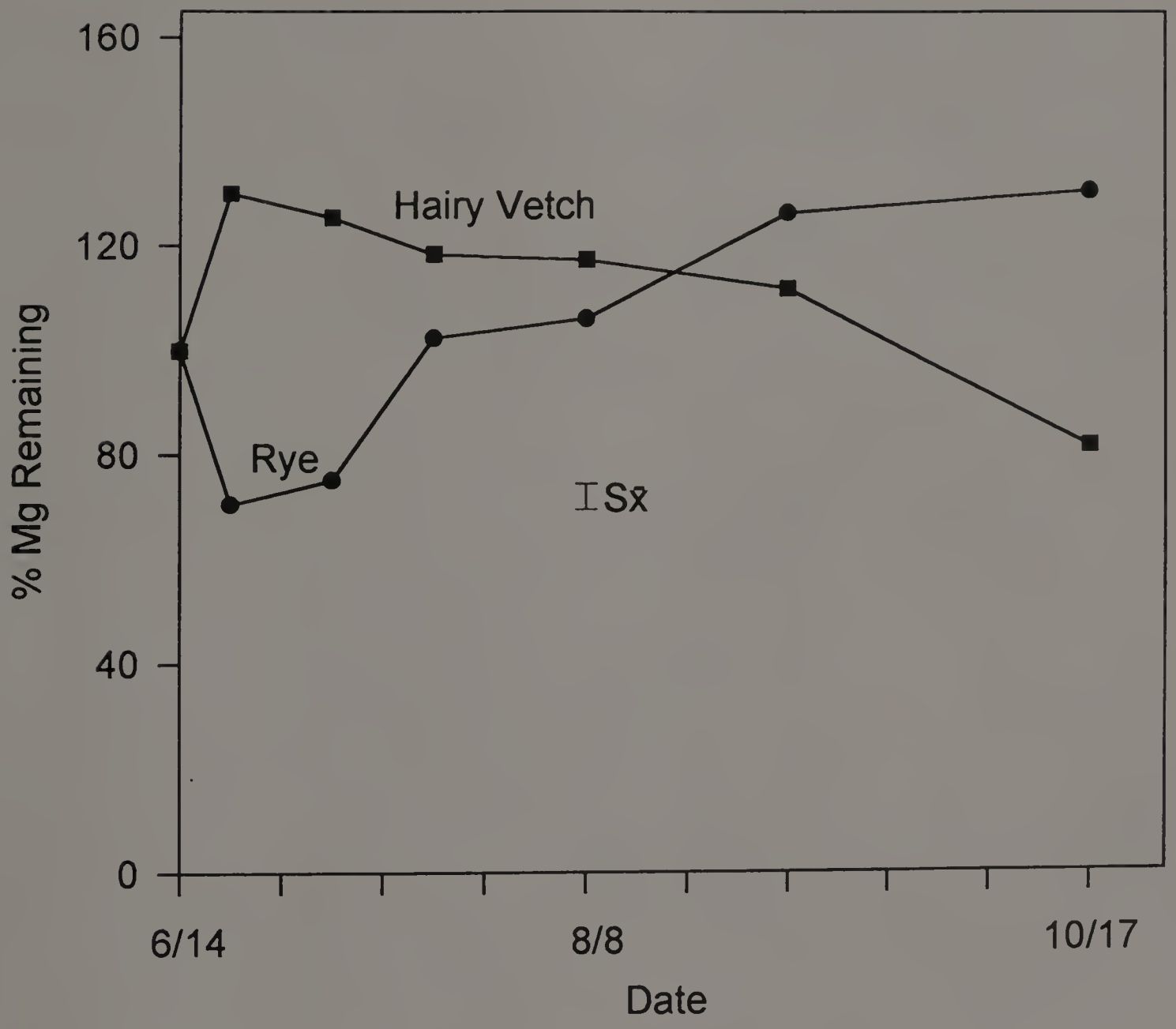

Figure 17 Percent Mg remaining of quantity initially incorporated in soil

(1981) showed a slow release of Ca and Mg. A four year pine needle decomposition study conducted in Japan (Motohiro et al., 1996) showed that Mg mass rapidly decreased during the first three months, which was probably due to strong acid leaching, while changes of Ca mass were similar to the dry weight loss, except with a mass increment during the first three months. They further reported that the concentration of Mg almost maintained the same level, and Ca concentration increased at beginning and then remained constant. These results are obtained from acid soils under humid conditions which were favorable to the mobility of Ca and Mg. Our results showed a different Ca and Mg release patterns probably due to the dry summer in 1995 and the soil characteristics.

4.4 Soil response of the nutrient release from cover crop residue decomposition.

Figures 18, 19 show the NO_3^- - N content in soils from vetch and rye plot during the sampling period. There was no significant difference between the rye and vetch plots at time of cover crop incorporation (June 14). The NO_3^- concentration were low in both vetch and rye plots. Soil nitrate content in 0-20 cm depth in vetch plots increased during the first 8 weeks from 11.8 mg . kg^{-1} to 63.5 mg . kg^{-1}, and then decrease to below 10 mg . kg^{-1}. Nitrate content in 20-40 cm depth showed a similar pattern, but the peak nitrate level was much less. At the 40-60 cm depth, nitrate level remained much the same during the first 8 weeks and then increased from 8.6 mg . kg^{-1} to 44.5 mg . kg^{-1}.

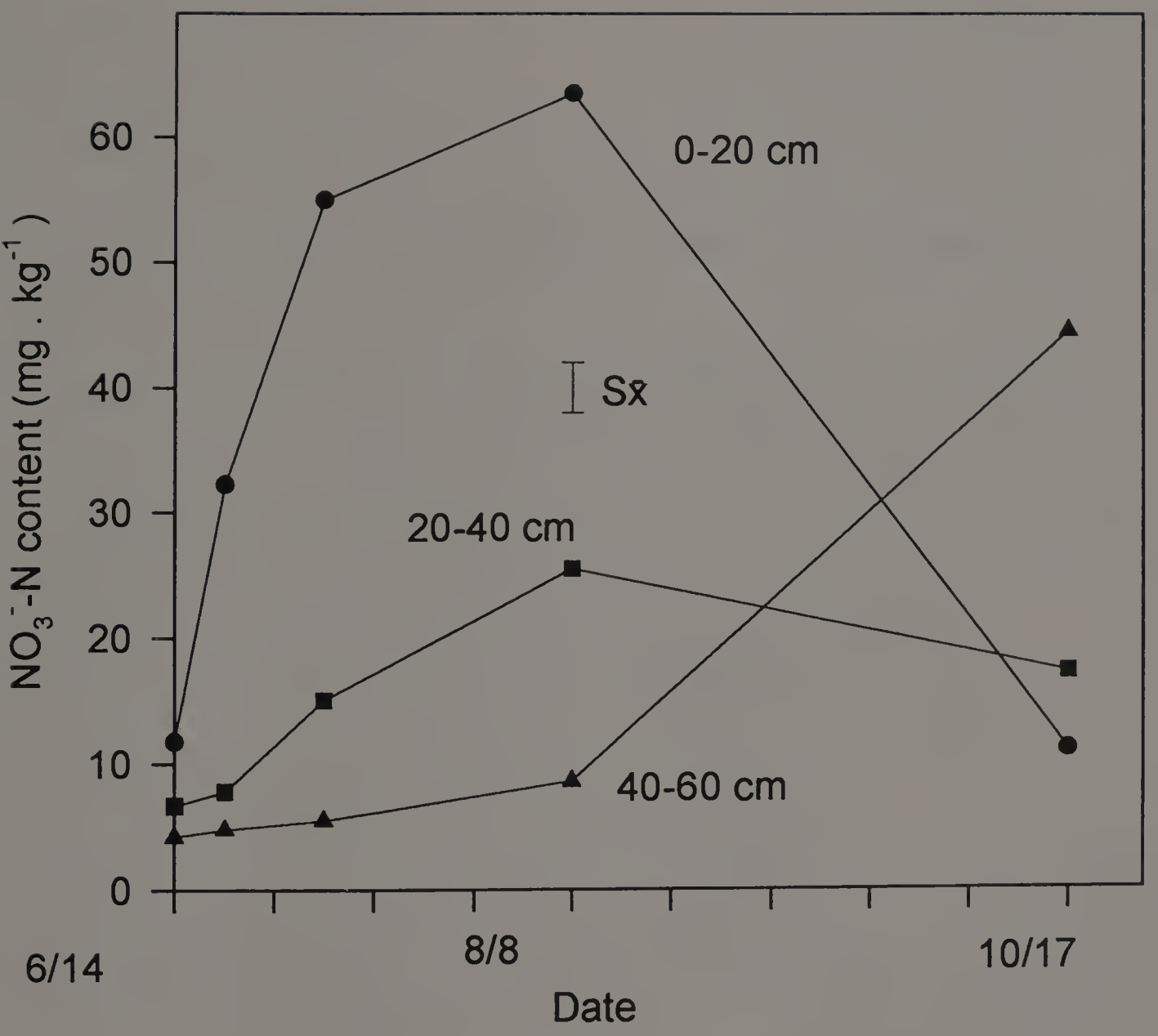

Figure 18 Soil NO_3^--N content at different depth during vetch decomposition

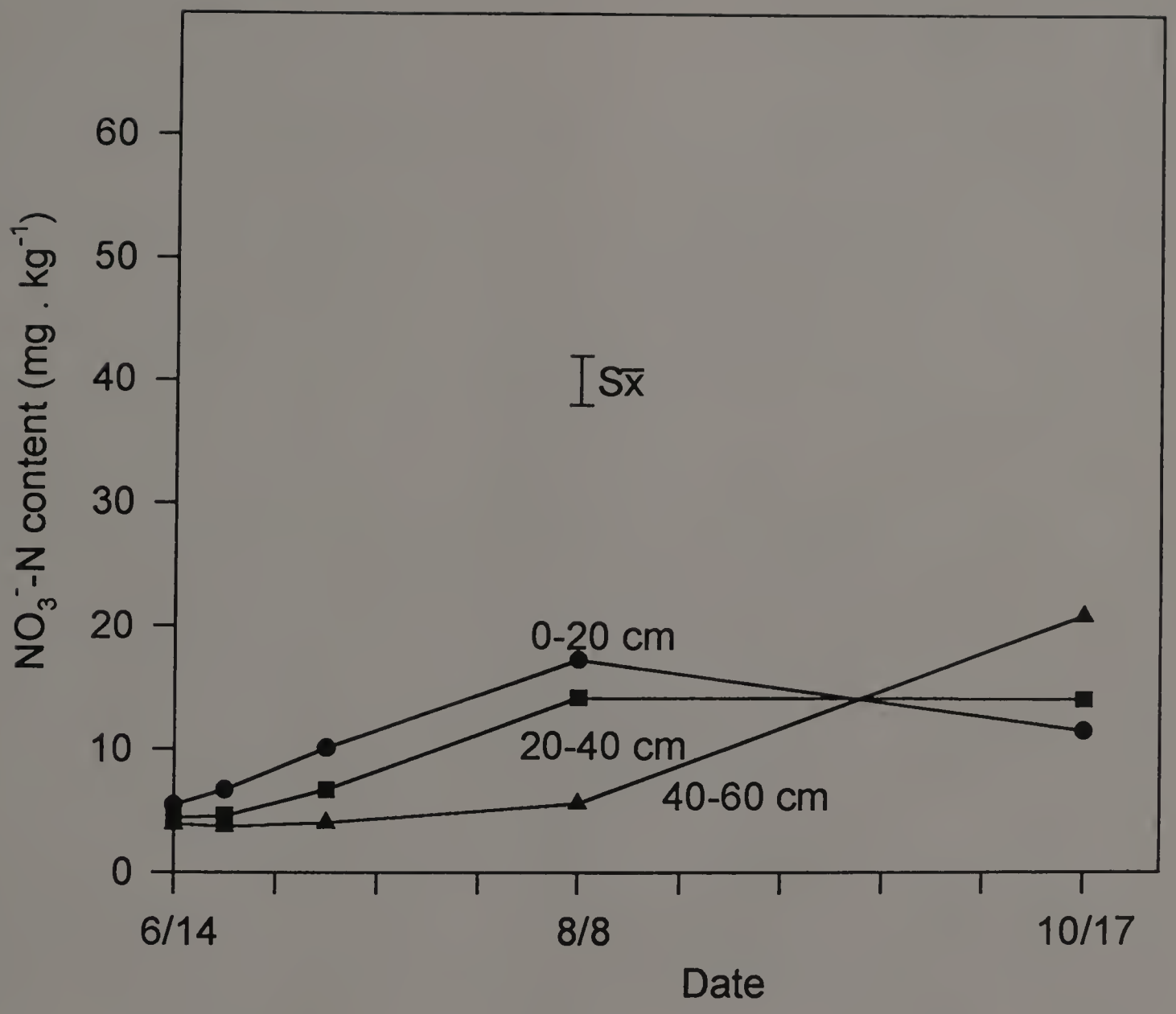

Figure 19 Soil NO_3^--N content at different depth during rye decomposition

Soil NO_3^- content in rye plots differed significantly from that in vetch plots during the decay of the cover crops. Nitrate content in 0-20 cm depth in rye plots increased slowly from 5.5 mg . kg^{-1} to 17.3 mg . kg^{-1} in mid-June to early August. Considering the high organic matter mineralization rate at this time of the season, this increase was a possible contribution from the decomposition of soil organic matter. There was likely little, if any, contribution to soil nitrogen from rye decomposition at the first few months, rather as shown previously rye decomposition resulted in N immobilization.

Cover crops are good scavengers to soil N. Grass cover crops are totally dependant on soil N, and the N content in biomass is increased with increasing soil N availability (Torbert et al.,1996). Legumes utilize both soil N and atmospheric N_2 in meeting their N requirements. In general, the proportion of legume N derived from soil rather than from N_2 fixation increased with the increasing availability of soil N (George et al.,1988; Herridge and Brockwell, 1988). Herridge et al.(1984) showed that NO_3^- in the top 120 cm layer of a high-nitrate soil is reduced during growth of irrigated soybean in Australia. Initial soil NO_3^- level at 15 days after soybean sowing was 30 mg $N.kg^{-1}$ in the top 30 cm layer and 267 kg $N.ha^{-1}$ in the top 120 cm layer . Soil nitrate in both inoculated and uninoculated treatments was reduced to less than 8 mg $N.kg^{-1}$ soil in all soil layers to the 120 cm depth in the 145 days till soybean maturity. By comparison, nitrate in bare fallow soil fluctuated little between 15 and 154 days, except for redistribution down the soil

profile, and was 292 kg $N.ha^{-1}$ after the 154 day soybean crop. An experiment conducted in Virginia (Ditsch et al., 1993) reported that little or no fertilizer-derived mineral N was detected in each 30 cm increment of soil to 90 cm depth immediately following the termination of winter rye cover crop where the previous fertilizer N application to corn ranged from 84 to 336 $kg.ha^{-1}$. The overall soil mineral N levels to a depth of 90 cm for all N rates, were reduced by winter rye to the same level as plots receiving no applied N.

When plant residue started to decay, it would release or immobilize nutrient to or from the soil depending on the properties of the residue. If the residue contained more of a nutrient than the requirement of the microbes which participated in the decomposition, then the nutrient would be released into the soil. If the residue could not meet the nutrient need of the microbes, then the nutrient would be fixed. The changes of nutrient content in soil revealed this nutrient balance. Stute and Posner (1995) determined that soil mineral N (NH_4+NO_3) concentrations in 0-30 cm following incorporation of hairy vetch and red clover reached their maximum at 2 and 4 weeks, respectively. Then decreased beginning at week 6 following red clover and with a sharp decline after week 8 following hairy vetch. Low inorganic N concentration after rye incorporation except with N fertilizer application is well recognized (Hoyt, et al., 1991; Evanylo, 1991).

CHAPTER 5

CONCLUSION

Vetch and rye cover crops accumulated similar amounts of biomass above ground in spring regrowth, and the biomass accumulation was closely related to the growth period. Vetch accumulated more N, Ca and Mg than rye, however, there was no different in P and K accumulation between these two cover crops. For vetch crops more dry matter meant more nitrogen accumulated aboveground, but for rye and weeds, nitrogen accumulation was not related to dry matter accumulation. As biomass of rye increased (growing longer), C:N ratio increased and N concentration in plant tissue decrease. Rye should be incorporated at a time when its biomass typically possesses a C:N ratio that should favor mineralization rather than immobilization of N. Based on biomass accumulation, C:N ratios, and nutrient release patterns, early incorporation of rye and late incorporation of vetch are recommended. This would maximize N contribution from vetch and help to prevent immobilization of N following incorporation of rye. With proper management, residual N trapped by a non-legume cover crop may supply a certain portion of main crop's N needs. But N fertilizer at planting may still be necessary with rye to ensure a better yield of the main crop.

The decomposition and nutrient mineralization kinetics are determined by the residue characteristics, soil conditions, and environmental factors. In our experiment, we found both rye and hairy vetch dry matter losses followed a

positive exponential model. The two pool models had a better prediction on both rye and hairy vetch dry matter loss. Nitrogen and potassium nutrient release patterns followed the similar patterns to dry matter loss. Hairy vetch had a greater N, K release rate than rye, and 60% of N, K was released within the first 2 weeks. Even though the release of Phosphorous, Calcium, and Magnesium was unpredictable, the release patterns still showed some difference between hairy vetch and rye cover crops. Rye had a quicker P release than hairy vetch. Rye had a small release of Ca and Mg during the first few weeks and then immobilize these two nutrient, while hairy vetch retain almost all of these two nutrients in the whole sampling period. C:N ratio is a good indicator of residue N release. Cover crop residues will not release N until the C:N ratio reduced to a critical level.

Cover crops are good scavengers of soil N. Soil NO_3^--N was reduced to less than 10 $mg.kg^{-1}$ right before cover crop incorporation in both rye and hairy vetch plots. This result indicated that even though hairy vetch could fix N, using soil N is still an important source for the legume cover crop. Soil NO_3^--N dramatically increase in the 0-20 cm depth in hairy vetch plot during the first 5 weeks after cover crop incorporation, and showed a redistribution down the soil profile in early fall. Change pattern of soil inorganic N in vetch plots indicated that vetch N release might be synchronized with summer crop N requirement if vetch was incorporated just before summer crop seeding. The low NO_3^--N concentration in rye plots, indicated that rye had little N contribution after incorporation.

LITERATURE CITED

Anderson, J. R., N. L. Hubbard, F. D. Shaw, and F. W. Smith. 1990. Managing winter annual legumes as nitrogen sources for no-till corn on sandy coastal plain soils. In J.P. Mueller and M. G. Wagger [eds.]. Proceedings of the 1990 Southern Region Conservation tillage Conference. N. Car. State Univ., Raleigh. pp. 104-107.

Berendse, F., B. Berg, and E. Bosatta. 1987. The effect of lignin and nitrogen on the decomposition of litter in nutrient-poor ecosystems: A theoretical approach. Can. J. Bot. 65: 1116-1120.

Berg, B and H. Staaf. 1981. Leaching, accumulation and release of nitrogen in decomposing forest litter. In: Clark, F.E. and T. Rosswall [eds.]. Terrestrial nitrogen cycles. Ecosystem strategies and management impacts. Ecological bulletins. (Stockholm) 33: 163-178.

Blevins, R. L., J. H. Herbek, and W. W. Frye. 1990. Legume cover crops as a nitrogen source for no-till corn and grain sorghum. Agron. J. 82:769-772.

Brinsfield, R. B. and K.W. Staver. 1991. Use of cereal grain cover crops for reducing groundwater nitrate contamination in the Chesapeake Bay region. pp.79-82. In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. 1991. Soil Conserv. Soc. Am., Ankeny, IA.

Brinsfield, R. B. and K.W. Staver. 1989. Cover crops: A paragon for nitrogen management. In Ground water Issues and Solutions in the Potomac River/Chesapeake Bay Region. Nat. Water Works Assoc., Washington D.C. pp.271-286.

Brown, R.E., G.E. Varvel, and C.A. Shapiro. 1993. Residual effects of interseeded hairy vetch on soil nitrite-nitrogen levels. Soil Sci. Soc. Am. J. 57:121-124.

Bruce, R. R., P. F. Hendrix, and G. W. Langdale. 1991. Role of cover crops in recovery and maintenance of soil productivity. p. 109-115. In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn.,Jackson, TN. 9-11 Apr.1991. Soil Conserv. Soc. Am., Ankeny, IA.

Budelman A. 1988. The decomposition of the leaf mulches of *Leucaena leucocephala, Gliricidia sepium and Flemingia macrophylla* under humid tropical condition. Agroforestry systems. 7:33-45.

Cameron, D. R., C. G. Kowalenko, and K. C. Ivarson. 1978. Nitrogen and chloride distribution and balance in a clay loam soil. Can. J. Soil Sci. 58:77-88.

Clark, A.J., A.M. Decker, and J.J. Meisinger. 1994. Seeding rate and kill date effects on hairy vetch-cereal rye cover crop mixtures for corn production. Agron. J. 86:1065-1070.

Daliparthy, J., S.J. Herbert., and P.L.M. Veneman. 1994. Dairy manure applications to alfalfa: crop response, soil nitrate, and nitrate in soil water. Agron. J. 86:927-933.

Daniel, V. M., M.S. Smith, J.H. Grove, C.T. MacKown, and R.L. Blevins. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. Soil Sci. Soc. Am. J. 58:1476-1483.

Decker, A.M., A.J. Clark, J.J. Meisinger, F.R. Mulford, and M.S. McIntosh. 1994. Legume cover crop contributions to no-tillage corn production. Agron. J. 86:126-135.

Ditsch, D.C., and M.M. Alley. 1991. Nonleguminous cover crop management for residual N recovery and subsequent crop yields. J. Fertilizer Issues. 8:6-13.

Ditsch, D.C., M.M. Alley, K.R. Kelley, and Y.Z. Lei. 1993. Effectiveness of winter rye for accumulating residual fertilizer N following corn. J. Soil and Water Cons. 48(2):125-132.

Doran, J. W. and M. S. Smith. 1991. Role of cover crops in nitrogen cycling. pp. 85-90. In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn.., Jackson, TN. 9-11 Apr.1991. Soil Conserv. Soc. Am., Ankeny, IA.

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.

Evanylo, G. K. 1991. Rye nitrogen cycling for corn and potato production. pp. 101-103. In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. 1991. Soil Conserv. Soc. Am., Ankeny, IA.

Fleming, A.A., J.E. Giddens, and E.R. Beaty. 1981. Corn yields related to legumes and inorganic nitrogen. Crop Sci. 21:977-980.

Frankenberger, W.T. Jr and H.M. Abdelmagid 1985. Kinetic parameters of nitrogen mineralization rates of leguminous crops incorporated into soil. Plant and Soil 87:257-271.

Frye, W.W., R.L. Blevins, M.S. Smith, S.J. Corak, and J.J. Varco. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. pp. 129-154. *In* W.L.Hargrove (ed.) Cropping strategies for efficient use of water and nitrogen. ASA Spec. Publ. 51. ASA, CSSA, and SSSA, Madison, WI.

Gary G., J. William, and R. Donald. 1991. Recommended soil nitrate-N tests. In recommended soil testing procedures for the northeastern United States. Agricultural experiment station, University of Delaware, Bulletin #493.17-24.

George, T., P.W. Singleton, and B.B. Bohlool. 1988. Agron. J. 80:563-567.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analysis. Agriculture Handbook No. 379. USDA, Washington.

Gordon, W. B., D. A. Whitney, and R. J. Raney. 1993. Nitrogen management in furrow irrigated, ridge-tilled corn. J. Prod. Agric. 6:213-217.

Groffman, P.M., P.E. Hendrix, and D.A. Crossley, Jr. 1987. Nitrogen dynamics in conventional and no-tillage agroecosystem with inorganic fertilizer or legume nitrogen inputs. Plant Soil 97:315-332.

Guillard K., G. F. Griffin, D. W. Allinson, W. R. Yamartino, M. M.Rafey. and S. W. Pietrzyk. 1995. Nitrogen utilization of selected cropping system in the U.S. northeast: Soil profile nitrate distribution and accumulation. Agron. J. 87:199-207.

Hahne, H,C., H.W. Kroontie, and J.A. Lutz Jr. 1977. Nitrogen fertilization: I. Nitrate accumulation and losses under continuous corn cropping. Soil Sci. Soc. Am. J. 41:562-568.

Hardy, R.W.F., and A.H. Gibson (eds.). 1977. A treatise on dinitrogen fixation: Section IV. Agronomy and ecology. John Wiley & Sons, New York.

Hardy, R.W.F., and U.D. Havelka. 1975. Nitrogen fixation research: a key to word food? Science (Washington, DC) 188:633-643.

Hargrove, W .L., and W. W. Frye. 1987. The need for legume cover crops in conservation tillage. In J. F. Power [ed.] The Role of Legumes in Conservation Tillage Systems Soil Cons. Soc. Am., Ankeny, Iowa. pp. 1-5.

Hargrove W .L. 1986. winter legumes as a nitrogen source for no-till Grain sorghum. Agron. J. 78:70-74.

Harper, S. H. T., and J. M. Lynch. 1981. The chemical components and decomposition of wheat straw leaves, internodes and nodes. J. Sci. Food Agric. 1981. 32:1057-1062.

Hasegawa, M. and H. Takeda. 1996. Carbon and nutrient dynamics in decomposing pine needle litter in relation to fungal and faunal abundances. Pedobiologia. 40:171-184.

Havelka, U. D., M. G. Boyle, and R. W. F. Hardy. 1982. Biological nitrogen fixation. In F.J. Stevenson et al. [ed.] Nitrogen in Agricultural Soils. Monog. No. 22. Am. Soc. Agron., Madison Wisc. pp. 365-422.

Heaney, D. J., M. Nyborg, E. D. Solberg, S. S. Malhi and J. Ashworth. 1992. Overwinter nitrate loss and denitrification potential of cultivated soils in Alberta. Soil Biol. Biochem. 24(9): pp.877-884.

Herbert, S.J., G.V. Litchfield, and Z.Y. Liu. 1986. An examination of cover crop seeding dates. Applied Agricultural research. 1:91-95.

Herridge, D.F., and J. Brockwell. 1988. Soil Biol. Biochem. 20:711-717.

Herridge, D.F., R.J. Roughley, and J. Brockwell. 1984. Aust. J. Agric. Res. 35:149-161.

Holderbaum, J. F., A. M. Ducker, J. J. Meisinger, F. R. Mulford, and L.R. Vough. 1992. Fallseeded legume cover crops for no-tillage corn in the humid east. Agron. J. 84:117-124.

Holderbaum, J. F., A. M. Ducker, J. J. Meisinger, F.R.Mulford, and L.R. Vough. 1990. Harvest management of a crimson clover cover crop for no-tillagecorn production. Agron. J. 82:918-923.

Holderbaum, J. F., A. M. Ducker, J. J. Meisinger, F.R.Mulford, and L.R. Vough. 1990. Fall-seeded legume cover crops for no-tillage corn in the Humid East. Agron. J. 82:117-124.

Hoyt, G.D., and W.L. Hargrove. 1986. Legume cover crops for improving crop and soil management in the Southern United States. Hort Science 21:397-402.

Hoyt, G.D., and R.L. Mikkelsen. 1991. Soil nitrogen movement under winter cover crops and residues.In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr.1991. Soil Conserv. Soc. Am., Ankeny,IA.

Janzen, H. H., and M. N. Kucey. 1988. C, N, and S mineralization of crop residues as influenced by crop species and nutrient regime. Plant and Soil. 106:35-41.

Jokela, W. E., and G. W. Randall. 1989. Corn yield and residual soil nitrate as affected by time and rate of nitrogen application. Agron. J. 81:720-726.

Jones J. Benton, B. Wolf, and M. Harry. 1991. Plant analysis handbook. Micro-Macro Publishing, Inc. 25.

Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture. In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn.., Jackson, TN. 9-11 Apr.1991. Soil Conserv. Soc. Am., Ankeny, IA. pp.1-11.

Linville, K.W., and G.E. Smith. 1971. Nitrate content of soil cores from corn plots after repeated nitrogen fertilization. Soil Sci. 112:249-255.

Ma, J.F. and E. Takahashi 1989. Release of silicon from rice straw under flooded conditions. Soil Science and plant nutrition. 35:663-667.

MacGregor, J.M., G.R. Blake, and S.D. Evans.1974. Mineral nitrogen movement into subsoils following continued annual fertilization for corn. Soil Sci. Soc. Am. Proc.38:110-448.

Magdoff, F. R., D. Ross, and J. Amadon. 1984. A soil test for nitrogen availability in corn. Soil Sci. Soc. Am. J. 53:1,495-1,464.

Meentemeyer V. 1978. Macroclimate and lignin control of litter decomposition. Ecology 59:405-472.

Meisinger, J. J., P. R. Shipley, and A. M. Decker.1990. Using winter cover crops to recycle nitrogen and reduce leaching. In J.P. Mueller and M.G. Wagger [eds.] Proceedings of the 1990 Southern Region Conservation tillage Conference. N. Car. State Univ., Raleigh. pp. 104-107.

Melillo, J.M., J.D. Aber, and J.F. Musatore 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology 63:621-626.

Mitchell, W. H., and M. R. Teel. 1977. Winter-annual cover crops for no-tillage corn production. Agron. J. 69:569-573.

Motohiro Hasegawa and Hiroshi Takeda. 1996. Carbon and nutrient dynamics in decomposing pine needle litter in relation to fungal and faunal abundances. Pedobiologia. 40:171-184.

Nelson D. W., and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. In A.L. Page edt. Methods of soil analysis. Part 2, chemical and microbiological properties. 539-594.

Olsen S.R., and L.E. Sommers. 1982. Phosphorus. In Page A. L., et al., (ed). Method of soil analysis. Part 2 Chemical and Microbiological Properties. Second edition. 403-430.

Parnas, H. 1975. Model for decomposition of organic material by microorganisms. Soil Biology & Biochemistry. 7:161-169.

Parr, J.F. and R.I. Papendick. 1978. Factors affecting the decomposition of crop residues by microorganisms. *In* Crop residue management systems. ASA Special Publication Number 31. Madison. pp.101-129.

Power J. F., J. W. Doran, and P.T. Koerner. 1991. Hairy vetch as a winter cover crop for dryland corn production. J. Prod. Agric. 4:62-67.

Quemada, M. and M. L. Cabrera. 1995. Carbon and nitrogen mineralized from leaves and stems of four cover crops. Soil Sci. Soc. J., 59:471-477.

Quemada, M. and M. L. Cabrera. 1995. CERES-N Model prediction of nitrogen mineralized from cover crop residues. Soil Sci. Soc. Am. J. 59:1059-1065.

Recous, S., D. Robin, D. Darwis and B. Mary. 1995. Soil inorganic N availability: effect on maize residue decomposition. Soil Biol. Biochem. 27(12):1529-1538.

Reicosky, D. C., and D. D. Warnes. 1991. Evapotranspiration and nitrogen accumulation in a winter rye cover crop in the Northern Corn Belt. pp. 74-75. In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. 1991. Soil Conserv. Soc. Am., Ankeny, IA.

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

Saini, R.C. 1989. Mass loss and nitrogen concentration changes during the decomposition of rice residues under field conditions. Pedobiologia. 33:229-235.

Samson, R.A., A.M. Foulds and D.G. Patriquin. 1990. Choice and management of cover crop species and varieties for use in row crop dominant rotations. *In* Final report of resource efficient agriculture production-Canada to the soil and water environment enhancement program (SWEEP). Agr. Canada Res. Stat., Harrow, Ont. 99 pp.

Samson, R.A., A.M. Foulds and D.G. Patriquin. 1991. Effect of cover crops on cycling of nitrogen and phosphorus in a winter wheat-corn sequence. *In* W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn.,Jackson, TN. 9-11 Apr.1991. Soil Conserv. Soc. Am.., Ankeny, IA. pp.106-107.

Sarrantonio, M., and T.W. Scott. 1988. Tillage effect on availability of nitrogen to corn following a winter green manure crop. Soil Sci. Soc. Am. J. 52:1661-1668.

SAS institute. 1988. SAS/STAT user's guide. Version 6.03. SAS Inst. Cary, NC.

Schonbeck, M.W., S.J. Herbert, R. DeGregorio, F.X. Mangan, K. Guillard, E.Sideman, J.Herbst, and R.Jaye. 1993. Cover crop systems for brassicas in the Northeastern United States: 1. Cover crop and vegetable yields, nutrients and soil conditions. J. of Sustainable Agriculture. 3:105-132.

Singh Y., C.S. Khind, and B. Singh. 1991. Efficient management of leguminous green manures in wetland rice. *In* Advances in Agron. Vol.49. pp.135-189.

Sivapalan, K., V. Fernando, and M.W. Thenabadu 1985. N-mineralization in polyphenol-rich plant residues and their effect on nitrification of applied ammonium sulphate. Soil Biology & biochemistry. 17:547-551.

Slinkard, A., V. Biederbeck, L. Bailey, P. Olson, W. Rice, and L. Townley-Smith. 1987. Annual legume as a fallow substitute in the northern Great Plains of Canada. In J. F. Power [ed.] The Role of Legumes in Conservation Tillage Systems Soil Cons. Soc. Am., Ankeny, Iowa. pp.6-7.

Smith, M.S., W.W. Frye, and J.J. Varco. 1987. Legume winter cover crops. *In* Stewart, B.A. (ed.) Adv. Soil Sci. 7:95-139.

Soil Conservation Society of America. 1982. Resource Conservation Glossary. 3rd ed. Ankeny, Iowa. pp.37.

Somda, Z. C., P. B. Ford, and W. L. Hargrove. 1991. Decomposition and nitrogen recycling of cover crops and crop residues. pp.103-105. In W.L. Hargrove (ed.) Cover crops for clean water. Proc. Int. Conf. W. Tenn. Exp. Stn.,Jackson, TN. 9-11 Apr.1991. Soil Conserv. Soc. Am., Ankeny, IA.

Sommers, L.E., and V.O. Biederbeck. 1973. Tillage management principles: Soil microorganisms. p.87-108. *In* Conservation tillage: The proceedings of a national conference. Soil Conservation Society of America, Ankeny, Iowa.

Staaf, H. And B. Berg. 1977. Mobilization of plant nutrients in a Scots pine forest mor in Central Sweden. Silva Fennica. 11:210-217.

Stevenson, F. J. 1985. Cycles of soil carbon, nitrogen, phosphorus, sulfur, micronutrients. John Wiley & Sons, New York.

Stout, W.L., and G.A. Jung. 1992. Influences of soil environment on biomass and nitrogen accumulation rates of orchardgrass. Agron. J. 84:1011-1019.

Stute J.K.,and J. L. Posnor. 1995. Synchrony between legume nitrogen release and corn demand in the Upper Midwest. Agro. J. 87:1063-1069.

Swift M.J., O.W. Heal, and J.M. Anderson. 1979. Decomposition in Terrestrial Ecosystems. Studies in Ecology, Vol. 5. University of California Press, Berkeley.

Tian G., L. Brussaard, and B. T. Kang. 1995. An index for assessing the quality of plant residues and evaluating their effects on soil and crop in the (sub-)humid tropics. Applied Soil Ecology. 2:27-32.

Tian, G., B.T. Kang and L. Brussaard. 1992. Biological effects of plant residues with contrasting chemical compositions under humid tropical conditions--decomposition and nutrient release. Soil Biology & biochemistry. 24:1051-1060.

Torbert H.A., D.W. Reeves, and R.L. Mulvaney 1996. Winter legume cover crop benefits to corn: rotation vs. Fixed-nitrogen effects. Agro. J. 88:527-535.

Utomo, M., W.W. Frye and R.L. Blevins. 1990. Sustaining soil nitrogen for corn using a hairy vetch cover crop. Agron. J. 82:979-983.

Vallis, I.,and R.J. Jones. 1973. Net mineralization of nitrogen in leaves and leaf litter of *Desmodium intortum* and *Phaseolus atropurpureus* mixed with soil. Soil Biology & biochemistry. 5:391-398.

Viets, F. J., and C. L. Crawford. 1950. The influence of nitrogen supply on the growth and nitrogen fixation of hairy vetch. Soil Sci. Soc. Am. Proc. 14:234-237.

Wagger, M. G. 1989. Time of desiccation effects on plant composition and subsequent nitrogen release from several winter annual cover crops. Agron. J. 81:236-241.

Walter H. Gardner. 1986. Water content. In Arnold Klute (ed.). Method of soil analysis, Part 1. 483-541.

Wilson, D.O., and W.L. Hargrove. 1986. Release of nitrogen from crimson clover residue under two tillage systems. Soil Sci. Soc. Am. J. 50:1251-1254.

Wood, T.G. 1974. Field investigations on the decomposition of leaves of *Eucalyptus delegatensis* in relations to environmental factors. Pedobiologia. 14: 343-371.