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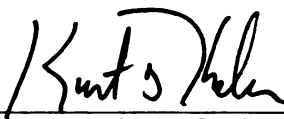
**AGRONOMIC AND ECONOMIC ASPECTS OF
INTEGRATING A WINTER ANNUAL CEREAL INTO A CORN-
SOYBEAN ROTATION IN MICHIGAN CROPPING SYSTEMS**

presented by

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has been accepted towards fulfillment
of the requirements for the

<u>Master of</u>	degree in	<u>Department of Crop and Soil</u>
<u>Science</u>		<u>Sciences</u>



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**AGRONOMIC AND ECONOMIC ASPECTS OF INTEGRATING A WINTER
ANNUAL CEREAL INTO A CORN - SOYBEAN ROTATION IN MICHIGAN
CROPPING SYSTEMS**

By

Michael R. Jewett

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ABSTRACT

AGRONOMIC AND ECONOMIC ASPECTS OF INTEGRATING A WINTER ANNUAL CEREAL INTO A CORN - SOYBEAN ROTATION IN MICHIGAN CROPPING SYSTEMS

BY

MICHAEL R. JEWETT

The addition of a winter annual cereal into a Michigan corn-soybean rotation had direct impacts on many agronomic and economic aspects of the cropping system. Winter wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.) scavenged nitrogen over the fall and winter compared with having no cover crop present. With a late April glyphosate burn down of wheat or rye cover crops, the killed plants began to release nitrogen to the soil by the first week of June. Winter annual cereals were able to provide a second profitable crop to the system when harvested as forage. Insect pressure on rotational crops following winter annual cereals varied by the crop and insect, but often were dependant on rotational crop planting date. Soybean [*Gycine max* (L.) Merr.] yield following a wheat or rye cover crop may be increased over no cover crop, while corn grain (*Zea mays* L.) and corn silage yield tended to follow a pattern of higher yield with earlier corn planting date, which ultimately depended on whether the winter annual cereal was used for a cover crop, forage, or grain. Depending on the planting date of the corn or soybean rotational crop following harvest of a winter annual cereal, the economic benefit of the additional crop may increase or decrease the net profit to the system.

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CHAPTER 1

THE EFFECT OF WINTER ANNUAL CEREALS ON RESIDUAL SOIL NITRATE LEVELS IN ROTATIONAL CORN AND SOYBEANS

Abstract

The addition of winter annual cereals into Michigan corn-soybean rotations had direct impacts on the nitrogen cycle in several cropping systems. Wheat and rye winter annual cereals scavenged nitrogen over the fall and winter compared with having no cover present. With a late April glyphosate burn down of wheat or rye cover crops, the killed plants already began to return nitrogen to the soil by the first week of June. After wheat or rye was harvested for forage or grain, although there was a removal of N from the system, the decaying plant and root matter returned some N. After harvest of the rotational crops in the fall, there were still apparent differences in soil nitrate levels depending on what winter annual cereal was present before the planting of rotational crops.

Introduction

Diverse ecological systems are often more productive with regards to the cycling of nutrients than rotational crops. Although a two-year corn soybean rotation has been a traditional cropping system in Michigan agriculture, introducing a winter annual cereal crop to the rotation may increase production efficiency. Nitrogen use efficiency is becoming increasingly important both from an environmental and economic aspect. Higher nitrate concentrations in groundwater are associated with increased fertilizer use. Winter annual crops may be used to scavenge nitrogen over the fall and winter thereby reducing the need for fertilizer inputs. Owens et al. (1995) using lysimeters in Ohio, found that the highest movement of nitrate occurred between February through April. Without a winter cover crop, nitrate may travel deeper into the soil profile and even leach into the ground water (Owens et al., 1995).

The extent of nitrate leaching is dependent on weather conditions. Mineralization of N is temperature dependant and cold wet springs have less mineralization and greater nitrate percolation (Berner et al., 1995). In general, diverse cropping systems leach less and have less subsoil nitrate concentration than annual rotations. (Entz et al., 2001). Ditsch et al. (1993) found that the combined nitrogen from the top ninety centimeters of soil and the nitrogen the corn plant took up accounted for only seventy six and fifty seven percent of the fertilizer nitrogen (FN) applied for each year, indicating a loss of FN with no cover crop. Ditsch et al. (1993) also found that a rye cover crop recovered between 2 to 36 kg N ha⁻¹ of the fertilizer N. Rye is an excellent crop at recovering residual soil nitrogen (RSN) as Ditsch et al. (1993) found that regardless of fertilizer rates applied, the soil nitrate concentration after rye was reduced to that with no fertilizer N applied, down

to a depth of ninety centimeters. Brandi-Dohrn et al. (1997) found that wheat and rye reduced nitrate leaching by 32-42 percent over three years in a vegetable cropping system. Wyland and Jackson (1996) also found that winter cover crops incorporated in a vegetable cropping system reduced nitrate leaching. The soil incorporation of the rye cover crop increased net minerizable N over six weeks and a led to a corresponding decline in inorganic N from immobilization by microbes. After six weeks there was a net mineralization and some denitrification due to the fast decomposition of incorporating the cover crop. Kessalvou and Walters (1999) said “some N-credit (~40 Kg N/ ton rye dry matter) should be given to winter rye cover crops in formulating corn N recommendations.” This credit may lower RSN accumulation and increase efficiency of fertilizer use while reducing nitrate leaching.

Another factor that effects nitrate leaching is tillage. Conservation tillage may also help conserve water (Entz et al., 2001). Meek et al. (1995) found that no till reduced nitrate leaching compared to conventional till. There are several methods of measuring soil nitrate including soil sampling and lysimeters. Logsdon et al. (2002) used lysimeters and discovered rye cover crops in a corn-soybean rotation will reduce nitrate leaching and suggested that this same trend will happen in the field. Meek et al. (1995) stated that ceramic soil solution samplers might not estimate the entire nitrate in soil solution in no-till, compared to soil sampling. The larger pores in no till may allow water to by-pass the nitrate thereby not providing an accurate reading of nitrate in the soil profile. Thurman et al. (1998) discussed an evaluation of field studies versus lysimeters that found soil monoliths have unrealistic boundaries compared with the field. Lysimeters may change the natural water flow in the soil due to the lysimeter wall and the disruption of the lower

boundary of the soil in the lysimeter. Also, field studies allow periodic soil sampling to verify N cycling whereas soil monoliths do not.

Winter annual cereal cover crops also add benefits by increasing residue cover and decreasing weed populations. Guy and Gareau (1998) found that weed populations decreased when the surface residue increased. In Iowa, a rye cover crop increased infiltration and reduced erosion and runoff in two of three years (Kaspar et al., 2001). The rye also improved soil structure by protecting the soil surface from raindrops, holding residue in place, and protecting the soil from freezing, thawing, and compression by ice and snow. Kessavalou and Walters (1997) found that rye after soybeans helped protect the soil from erosion. The rye provided thirty percent extra surface residue, which was equivalent to the residue left by corn in conservation tillage. These benefits of winter annual cereals may create a viable reason to plant winter cover crops in Michigan.

Objectives

- 1) Examine the ability of several winter annual cereal crops to scavenge subsoil nitrate over the fall and winter by measuring soil nitrate in the spring.
- 2) Determine winter annual cereals and rotational crops effects on residual soil nitrates levels.

Materials and Methods

On 28 September 1999 and 13 October 2000, winter annual cereal crops were planted into a Capac loam soil (fine-loamy, mixed, mesic Aeric Ochra-qualf) at the Michigan State University Research farm in East Lansing, MI. In both years of the study, the winter annual cereals were no-till planted in two fields on the farm, one following

soybean, and the other following silage corn. The planting was done in a randomized complete block split-split plot design replicated four times. Main plots consisted of the previous corn silage (corn silage residue) or previous soybean fields (soybean residue), sub plots consisted of the winter annual cereals, and sub-sub plots consisted of rotational crops of corn grain, corn silage, and soybean. The winter annual cereal treatments consisted of wheat cover crop (WCC) and rye cover crop (RCC) burned down with glyphosate; rye harvested for forage (RF); wheat harvested for forage early cut (WEF) and late cut (WLF); an early maturing variety of wheat harvested for grain (WEG) and a late maturing variety of wheat harvested for grain (WLG); and a no cover crop (NC). The wheat variety was “Harus” an early maturing awnless soft white winter wheat developed at the Agriculture Canada Research Station in Harrow. The WLG variety used was “Patterson” a soft red winter wheat developed at Purdue University. The rye variety used was “Wheeler” which was released by the Michigan Agricultural Experiment Station. The wheat was planted at 134 kg ha^{-1} and the rye at 125 kg ha^{-1} . The grain and forage crops received 52 kg ha^{-1} of elemental N applied as granular urea (46-0-0) at green-up the following spring. The no cover and the wheat and rye cover crops did not receive supplemental nitrogen.

The following spring, the winter annual cereals were removed at different times. WCC and RCC were burned down with glyphosate on 14 April and 26 April for 2000 and 2001, respectively. The rye forage was harvested in the early boot stage on 26 April 2000 and 7 May 2001. The early cut wheat was harvested for forage when the wheat was in the boot stage (Feeke’s scale 10.0) on 11 May 2000 and 19 May 2001; the late cut wheat was harvested when the wheat was in the early head stage (Feeke’s scale 10.1) on

22 May 2000 and 24 May 2001. The early and late wheat grain was harvested 5 July and 13 July in 2000 and 9 July and 12 July in 2001.

Rotational crops consisting of corn grain (CG), corn silage (CS), and soybean (B) were planted following burn down or harvest of the winter annual cereals. The plots were 3.0 m x 12.2 m. The calendar dates for burn down or harvest of winter annual cereals and the following planting dates of rotational crops are shown in Table 1.1.

Glyphosate applications were made to the rotational plots as needed after the burn down or harvest of the winter annual cereals. On 7 March, 2000 and 2 March, 2001 the forage and grain plots received 52 kg ha⁻¹ of elemental N applied as granular urea (46-0-0), as mentioned previously. On 22 June, 2000 and 5 June, 2001, all the corn plots except the WEG and WLG were side dressed with 468 Liters ha⁻¹ of 28% N, which equals 168 kg ha⁻¹ N. On 31 July, 00, the corn grain and silage, WEG and WLG plots received 468 Liters ha⁻¹ of 28 % N. However, in 2001, corn following WEG and WLG was not side dressed based on results from 2000, which showed no yield benefit.

The spring soil samples were taken between June 6th- 20th in 2000 and June 11th – 15th in 2001 to allow the forages to be harvested prior to soil sampling and see if the cover crops burned down with glyphosate were releasing N back into the soil by this time. Fall soil samples were taken between December 5th -8th in 2000 and November 6th - 8th in 2001. Two samples were taken per plot down to a depth of 90 cm, using a hydraulic soil probe truck. The samples were divided into 30 cm increments and dried in an oven at 38° C. The samples were processed using a 1N KCl solution in a 1:5 soil to solution ratio, to extract the nitrate and the nitrate reduction method was used, through the LaChat rapid flow injection unit, to measure the nitrate content (LaChat 1988). The sample was

Table 1.1: Calendar dates of burn down or harvest of winter annual cereals and the following planting dates of corn and soybean rotational crops in 2000 and 2001.

Winter Annual Cereal Treatment	2000			2001		
	Burn Down or Harvest Date	Corn Rotational Planting Date	Soybean Rotational Planting Date	Burn Down or Harvest Date	Corn Rotational Planting Date	Soybean Rotational Planting Date
NC	-	29 April	11 May	-	5 May	5 May
WCC	14 April	29 April	11 May	26 April	5 May	5 May
RCC	14 April	29 April	11 May	26 April	5 May	5 May
RF	26 April	11 May	11 May	7 May	14 May	14 May
WEF	11 May	15 May	11 May	19 May	22 May	22 May
WLF	22 May	22 May	22 May	24 May	26 May	26 May
WEG	5 July	6 July	6 July	9 July	10 July	10 July
WLG	13 July	14 July	14 July	12 July	13 July	13 July

NC - no cover, WCC - wheat cover crop, RCC - rye cover crop, RF - rye forage, WEF - wheat early harvested forage, WLF - wheat late harvested forage, WEG - wheat early maturing variety grain, WLG - wheat late maturing variety grain.

analyzed with a LaChat spectrophotometer at 520 nm. The data was then analyzed with SAS software using a proc-mixed model with Tukey's HSD and lsd's P ($p < 0.05$) (SAS Inst., 1999). A log transformation of the data was made so that it would be normally distributed. The rotational crops had no effect on spring soil nitrates, so in effect this allowed for twelve replications in the analysis of the winter annual cereals. The fall soil analysis included the effects of rotational and winter annual crops. The following abbreviations will be used to clarify the fields being referred to in this study, with the previous crop, season and year of the fields reported respectively: corn silage residue spring sampling year 1 (CS1), corn silage residue field spring sampling year 2 (CS2), soybean residue field spring sampling year 1 (BS1), soybean residue field spring sampling year 2 (BS2), corn silage residue field fall sampling year 1 (CF1), corn silage residue field fall sampling year 2 (CF2), soybean residue field fall sampling year 1 (BF1) and soybean residue field fall sampling year 2 (BF2) will be used from here on. The data from BF1 was eliminated from the study due to extensive ground hog damage in the field plots.

Results and Discussion

The soil nitrate-N level as affected by the cover crop for the spring soil sampling was significantly different at the 0.001 probability level in both fields, both years. The interaction of cover and soil depth for nitrate content was significant in BS2, CS1 and CS2 for the spring to the 0.001 probability level. The reason the nitrate-N content with depth was not significant for BS1 is probably due to the extremely low nitrate levels throughout, averaging less than 2 mg/kg, although the trend remains similar in BS1 to the

other fields. These low N levels may be due to the high precipitation early on in the spring, including, the April rainfall of which over 5 cm occurred on one day (Table 1.2).

In the fall, the analysis included the winter annual cereals and rotational crops to determine if there were differences in rotational crops effects on soil nitrate by the fall sampling. The soil nitrate variability with rotational crop was only significant in BF2, while soil nitrate with depth was significant at the 0.001 probability level in BF2, CF1 and CF2. The interaction of rotation*depth was also significant at the 0.001 probability level in BF2, CF1, and CF2. The nitrate level with cover crop was significant in BF2 to the 0.001 probability level and CF1 to the 0.05 probability level, although the interaction of rotational*cover was only significant in BF2. The interaction of cover*depth was significant in BF2, CF1 and CF2 to the 0.05 probability level. The interaction of cover*season was significant for BF2, CF1 and CF2 (Table 1.3).

The soil nitrate levels in the spring following winter annual cereals followed a distinct trend with significant differences in both fields for 2000 and 2001. When looking at the general pattern of soil nitrate levels across all three depths in both fields (previously in corn silage and corn grain) the no cover had significantly or tended to have higher soil nitrate levels than all treatments at all depths, especially depth two (30-60cm) and three (60-90cm). The no cover tended to have higher soil nitrate levels while going deeper into the soil profile, indicating nitrate leaching. The lower quantity of soil nitrate following the winter annual cereals was due to the winter annual cereals scavenging soil nitrate over the fall and winter. WCC and RCC had significantly or tended to have more soil nitrate at depths one (0-30cm) and two (30-60cm) than other winter annual cereals. The higher soil nitrate levels following the cover crops indicate the release of N from desiccation of

Table 1.2 Monthly precipitation and growing degree unit (GDU) accumulation for the 1999 through 2001 winter annual and rotational crop growing seasons at the experimental location. Thirty-year means have been included for comparison (1971-2000).

	PRECIPITATION				GROWING DEGREE UNITS			
Month	1999	2000	2001	30 yr	1999	2000	2001	30 yr
	---- Millimeters ----				---- Degrees Centigrade ----			
April	-	74.4	72.1	-	-	-	-	-
May	-	134.6	144.8	68.6	-	193	191	128
June	-	78.7	83.8	78.7	-	294	281	263
July	-	94.0	22.9	76.2	-	288	333	337
August	-	86.4	40.6	86.4	-	314	338	308
September	40.6	111.8	101.6	86.4	213	208	174	173
October	20.3	53.3	137.2	61.0	75	131	51	43
Seasonal total	61.0	558.8	393.7	457.2	306	1517	1457	1341

GDU calculated for corn at a base 10°C, with 10°C and 30°C minimum and maximum temperatures.

Data recorded at the Horticultural Research Station, East Lansing, MI.

Table 1.3: Significant differences in residual soil nitrate levels in the spring, after prior fall planting of winter annual cereals (wac), no-till planted into soybean residue or corn silage residue; and significant differences in residual soil nitrate levels in the fall, after rotational crops of corn or soybean were harvested.

Spring	Soil Nitrate Significant Differences	Soybean Residue Yr 1	Soybean Residue Yr 2	Corn Silage Residue Yr 1	Corn Silage Residue Yr 2	Degrees of Freedom
	Wac	***	***	***	***	7
	Depth	NS	*	***	***	2
	Wac * Depth	NS	***	***	***	14
Fall	Rotational Crop	-	*	NS	NS	2
	Depth	-	***	***	***	2
	Rotational * Depth	-	***	***	***	4
	Wac	-	***	*	NS	7
	Rotational * Wac	-	**	NS	NS	14
	Wac*Depth	-	*	*	*	14
	Rot * Wac *Depth	-	NS	*	NS	28

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels respectively.

plant material in the upper soil profile. The lower soil nitrate content following winter annual cereals over no cover, at all depths, shows that the winter annual cereals picked up nitrate over the fall and winter, while the greater soil nitrate concentration at the surface of WCC and RCC indicates release back into soil (Tables 1.4-1.7, Figures 1.1-1.4). The WEG and WLG treatments had significantly less or tended to have less soil nitrate in the upper soil profile, probably due to the corn grain and corn silage not being side dressed in these plots prior to spring soil sampling. The following provides a more in depth account of how the soil nitrate levels varied with treatment. The soil nitrate content in the no cover treatment was significantly higher than any of the winter annual cereal treatments at depth three (60-90cm) in both fields for both years except in BS1 where they tended to be higher than all but the rye forage soil nitrate levels. This indicates winter annual cereals were able to scavenge nitrate-N over the fall and winter, rather than losing it deeper into the soil profile through nutrient leaching. Soil nitrate tends to increase with depth and amount of FN (fertilizer nitrogen) applied in fallow plots compared to cover crop (Ditsch et al., 1993).

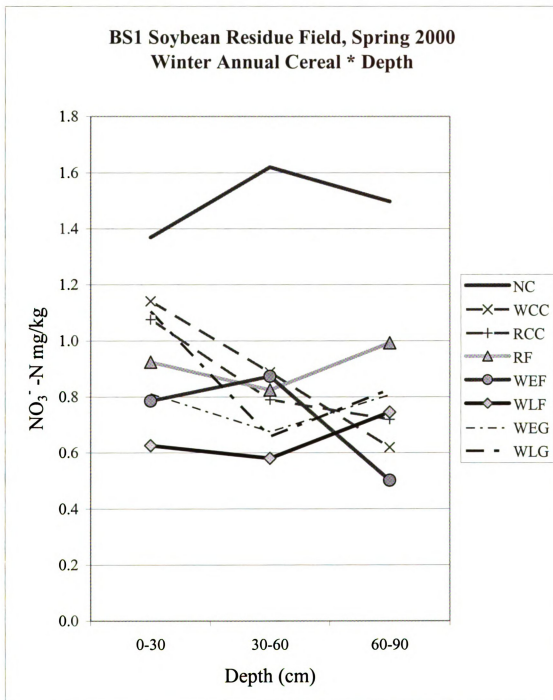
When comparing the soil nitrate content in the winter annual cereal plots of the two fields in the spring over both years at the 60-90 cm depth, the trend did not stay consistent for each field, other than NC; rather each field had unique differences. In BS1 there were no significant differences due to low soil nitrate levels throughout the field (Table 1.4, Figure 1.1). In CS1 the rye forage and wheat late forage at depth three (60-90 cm) had significantly less soil nitrate than WEF, WCC, and WEG. The WLG had less soil nitrate than WCC (Table 1.5, Figure 1.2). This was probably due to field variability since the forages only had different harvest dates and neither RCC nor WCC had

Table 1.4: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * depth in field with soybean residue, spring 2000 (BS1).

Winter Annual Cereal	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
No Cover	1.4	1.6	1.5
Wheat Cover Crop	1.1	0.9	0.6
Rye Cover Crop	1.1	0.8	0.7
Rye Forage	0.9	0.8	1.0
Wheat Early Forage	0.8	0.9	0.5
Wheat Late Forage	0.6	0.6	0.7
Wheat Early Grain	0.8	0.7	0.8
Wheat Late Grain	1.1	0.7	0.8

No significant differences.

Figure 1.1: Soil nitrate-N levels for the interaction of winter annual cereal * depth in field with soybean residue, spring 2000 (BS1).



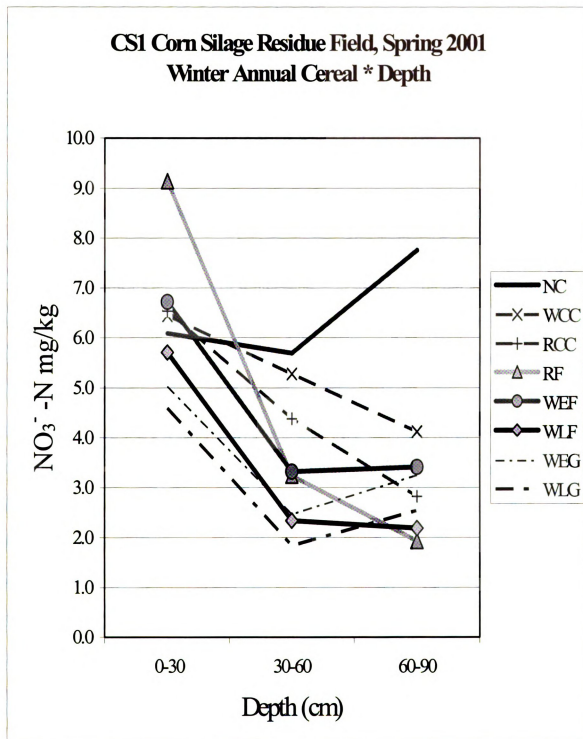
No significant differences.

Table 1.5: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * depth in field with corn silage residue, spring 2000 (CS1).

Winter Annual Cereal	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
No Cover	6.1 b	5.7 a	7.8 a
Wheat Cover Crop	6.4 ab	5.3 a	4.1 b
Rye Cover Crop	6.5 ab	4.4 ab	2.8 bcd
Rye Forage	9.1 a	3.2 bc	1.9 d
Wheat Early Forage	6.7 ab	3.3 bc	3.4 bc
Wheat Late Forage	5.7 b	2.3 cd	2.2 d
Wheat Early Grain	5.0 b	2.5 cd	3.2 bc
Wheat Late Grain	4.6 b	1.8 d	2.5 cd

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.2: Soil nitrate-N levels for the interaction of winter annual cereal * depth in field with corn silage residue, spring 2000 (CS1).



supplemental N applied. Kessalvou and Walters (1999) suggest that differences in the field beforehand make it hard to be sure all interactions are true treatment effects.

Therefore, fall sampling was done in this study, to show if the soil nitrate in each cover crop met expectations in going from spring to fall. In BS2 and CS2 (both fields the second year of the study), there were no significant differences between any of the winter annuals except the NC at the 60-90 cm depth, which had significantly more soil nitrate than any of the winter annual cereal treatments (Tables 1.6-1.7: Figures 1.3-1.4).

At depth two (30-60cm) in BS1, BS2, CS1 and CS2, the no cover had significantly more or tended to have more soil nitrate than any of the other winter annual cereals, again showing the ability of winter annuals to scavenge soil nitrate. Small grain cover crops will adsorb residual nitrogen (Ditsch et. al 1993). With CS1, the NC at depth two tended to have more soil nitrate than any of the other winter annuals at this depth, but statistically only had more nitrate than WLF, WEF, WEG, WLG, and RF. The only two treatments the NC was not statistically higher than were WCC and RCC, which had no supplemental N applied. The higher soil nitrate content for WCC and RCC was probably due to the release of nitrogen after decomposition. The WCC and RCC were killed in April. Decker, et al. (1994) found that decomposition and N release into the nitrate form was more rapid in early killed rye. Kessavalou and Walters (1999) found that cover crops release N as they decay in the spring or summer.

When comparing the winter annual cereals amongst each other at depth two (30-60cm) there were also interesting trends. In BS2, CS1 and CS2 the highest soil nitrate was in NC followed by WCC, then RCC, then and RF. The higher soil nitrate following

Table 1.6: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * depth in field with soybean residue, spring 2001 (BS2).

Winter Annual Cereal	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
No Cover	2.8 a	3.4 a	2.7 a
Wheat Cover Crop	2.7 a	2.4 b	1.9 b
Rye Cover Crop	2.2 a	2.0 bc	1.9 b
Rye Forage	2.3 a	1.7 c	1.8 b
Wheat Early Forage	1.5 b	1.3 d	1.7 b
Wheat Late Forage	1.5 b	1.3 d	1.6 b
Wheat Early Grain	1.3 b	1.2 d	1.6 b
Wheat Late Grain	1.3 b	1.2 d	1.6 b

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.3: Soil nitrate-N levels for the interaction of winter annual cereal * depth in field with soybean residue, spring 2001 (BS2).

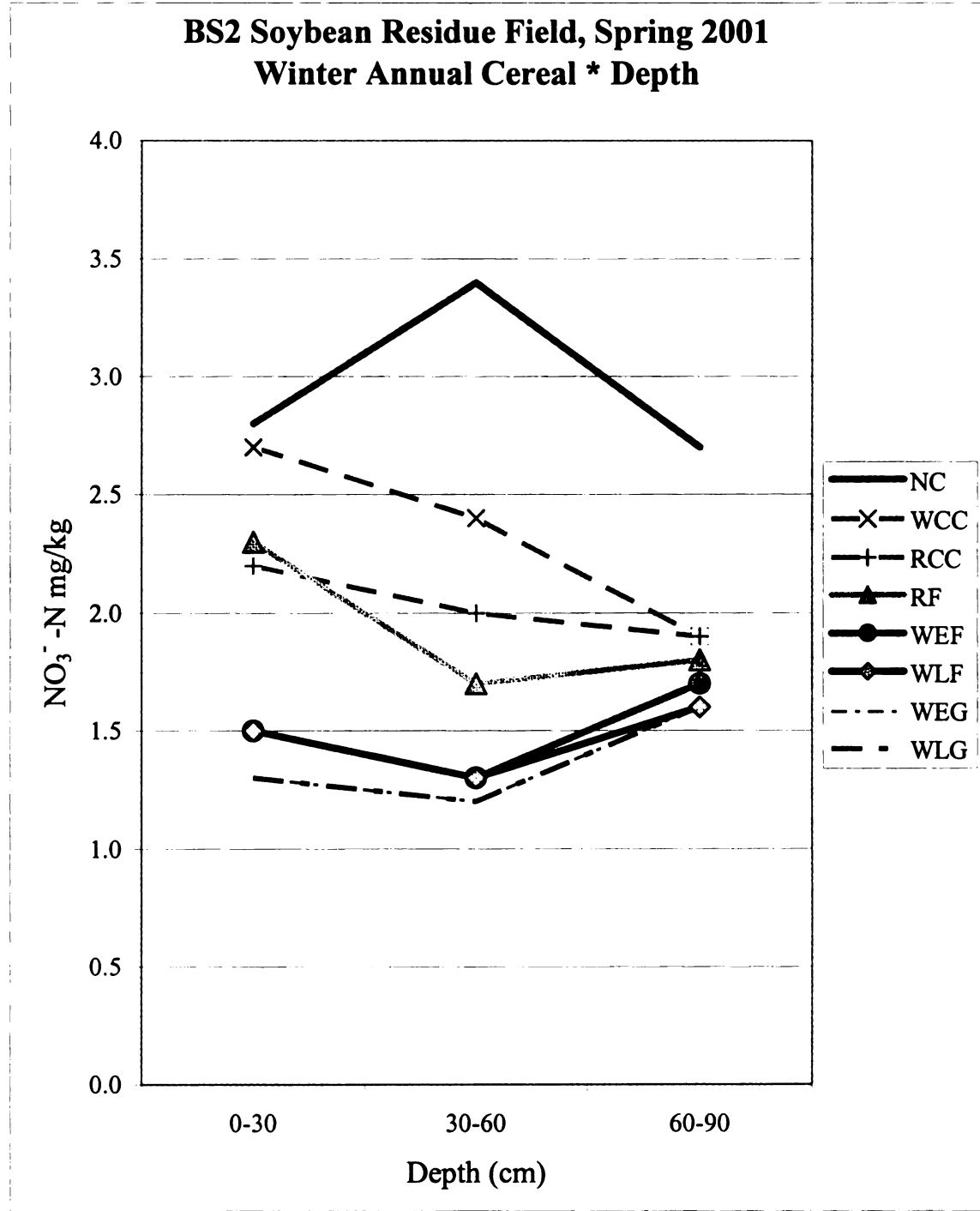
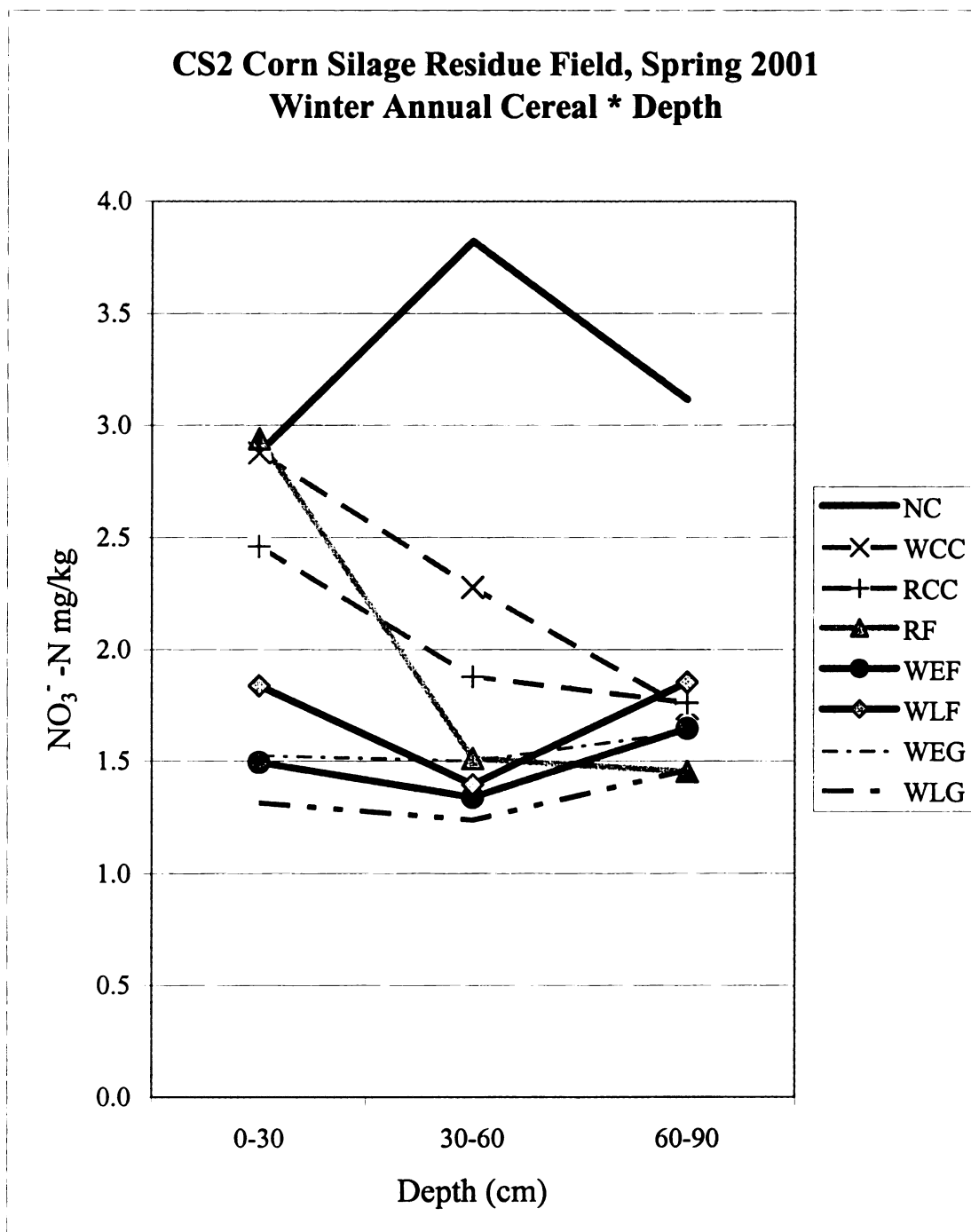


Table 1.7: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * depth in field with corn silage residue, spring 2001 (CS2).

Winter Annual Cereal	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
No Cover	2.9 a	3.8 a	3.1 a
Wheat Cover Crop	2.9 a	2.3 b	1.7 b
Rye Cover Crop	2.5 ab	1.9 bc	1.8 b
Rye Forage	2.9 a	1.5 cd	1.5 b
Wheat Early Forage	1.5 c	1.3 d	1.6 b
Wheat Late Forage	1.8 bc	1.4 cd	1.9 b
Wheat Early Grain	1.5 c	1.5 cd	1.6 b
Wheat Late Grain	1.3 c	1.2 d	1.5 b

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.4: Soil nitrate-N levels for the interaction of winter annual cereal * depth in field with corn silage residue, spring 2001 (CS2).



the cover crops was probably due to WCC and RCC releasing N after burn down, since neither had supplemental N applied. Kessavalou and Walters (1999) found that nitrogen is quickly mineralized from rye residues after desiccation and that net mineralization of soybean residue will increase if rye residue is also present. The BS1 winter annual cereals were not significantly different from each other, but they all averaged less than $2\text{mg NO}_3^- \text{N kg}^{-1}$.

In BS2 depth 2 (30-60cm) the WCC, RF, RCC, and NC had significantly more soil nitrate than WLF, WEF, WEG and WLG, again showing nitrate moving down in the soil profile after NC, while WCC and RCC release N after burn down (Table 1.5, Figure 1.2). The RF also had significantly less soil nitrate than the WCC at depth two and tended to have less than RCC, but not significantly. Kuo and Jellum 2002 found that soil nitrogen had the greatest effect on corn yield regardless of cover crop residue. Although, if a forage is needed for livestock feed it may be worthwhile to harvest the forage for an extra crop.

In CS1 depth two (30-60cm) the WCC had significantly more soil nitrate than all the other winter annual cereals except for RCC. The RCC had significantly more soil nitrate than WLF, WEG, and WLG and tended to have more than the other winter annual cereals, but not significantly. The RF and WEF had significantly more soil nitrate than WLG. RF and WEF tended to have more soil nitrate than WLF, WEG, and WLG, but not significantly, likely due to RF and WEF being harvested prior to the WLF, WEG and WLG, and therefore not drawing nitrogen from the soil as long (Table 1.6, Figure 1.3). Although, the crude protein content of the forages was measured from which the N value

could be estimated, the protein content of the grain was not measured for comparison. In 2001 the WEF only tended to have more soil nitrate than WLG.

In CS2 at depth two (30-60cm) the WCC again had significantly more soil nitrate than all the other winter annual cereals except RCC. The RCC had significantly more soil nitrate than WLG and WEF and tended to have more than the other winter annual cereals, but not significantly. This again shows the ability of the WCC and RCC to relinquish N after burn down.

When looking at the nitrate variability with depth 1 (0-30 cm) in the spring, BS1, BS2, and CS2 tended to have the highest soil nitrate in the NC treatment followed by RCC and WCC, although the differences were not significantly higher than the other winter annual cereals. In CS1 there was also a tendency for NC, WCC, and RCC to have a higher soil nitrate at depth 1 (0-30 cm) except for RF, which tended to have the highest soil nitrate. Wager (1989) found that decomposition and nitrogen release occurred more rapidly with an early burn down of the winter annual cereal. This was probably due to other winter annuals taking up nitrate N in the first thirty centimeters. With BS1, the NC soil nitrate was not significantly higher than RF, RCC, WCC or WEF, although the NC did tend to have the highest soil nitrate concentration.

In BS1, depth 1 (0-30 cm), WCC, RCC, and WLG have significantly more soil nitrate than WLF. NC tended to have the highest soil nitrate, although significantly was only higher than WLF, WEF and WEG. With CS1, RF tended to have the highest soil nitrate, but significantly RF was only higher than WLF, WEG, WLG and NC. The other winter annual cereals were not significantly different, although RCC and WCC

tended to have more soil nitrate, supporting the idea they were releasing N into the soil profile after burn down (Table 1.4, Figure 1.1).

In BS2 depth one (0-30 cm) NC, WCC, RCC and RF had significantly more soil nitrate than the other winter annual cereals. Again, the WCC and RCC were probably releasing N after burn down while the NC had no crop present to scavenge N over the fall and winter (Table 1.5, Figure 1.2).

In CS1, depth 1 (0-30 cm), the RF, WEF, RCC, WCC and NC tended to have more soil nitrate than the other winter annual cereals, although only the RF had significantly more soil nitrate than the wheat grains and WLF (Table 1.6, Figure 1.3).

In CS2, depth 1 (0-30 cm), the NC, RF, and WCC had significantly more nitrate than all other winter annuals except RCC. The RCC had significantly more nitrate than WEF, WEG and WLG (Table 1.7, Figure 1.4). This also supports that wheat and rye burned down with glyphosate released nitrate by early June, when spring soil sampling was done. The tendency for higher soil nitrate following WCC and RCC in the upper soil profile suggests that the addition of a cover crop should be accompanied by a PSNT to determine available nitrate levels prior to side dressing corn.

The fall analysis portrayed unique differences in nitrate variability with treatment as shown in tables 1.8-1.15 and figures 1.5-1.12. For CF1, BF2 and CF2 there were differences among winter annual cereals with depth at $p < 0.05$. There was also a significant interaction in soil nitrate for rotational crop * depth at $p < 0.001$ in BF2, CF1 and CF2. There was a significant interaction of soybean and corn rotational crops * winter annual cereals for BF2 (Table 1.3).

In BF2 there was a significant interaction of winter annual cereal with depth. At depth one (0-30 cm), wheat late grain had significantly less soil nitrate than any of the other winter annuals including NC. WEG had significantly less soil nitrate than RF and NC. The lower soil nitrate for the wheat grain crops was most likely due to the corn in these plots not having been side dressed with nitrogen in 2001. RF had the most soil nitrate at depth one, having significantly more than WCC, WEG, WLW and RCC. NC only had significantly more soil nitrate than WEG and WLW, although it tended to have more than all but RF (Table 1.8, Figure 1.5). The wheat and rye cover crops had already released their nitrogen back into the soil and had likely been absorbed by the rotational crops. Kuo and Jellum (2002) stated that soil N may still be increased with root degradation even if the top growth is removed. Decker et al. (1994) found that fertilizer nitrogen (FN) requirements increased after wheat compared to no cover.

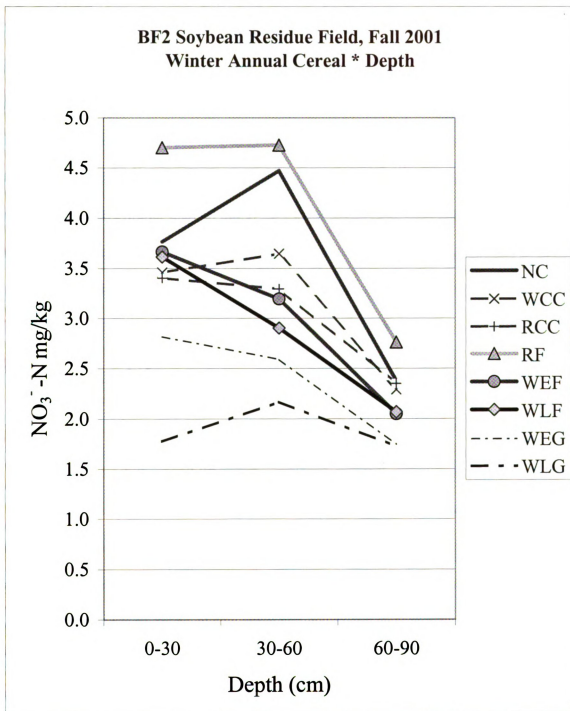
In BF2 depth two (30-60 cm), the pattern was similar to the above although the significance was slightly different (Table 1.8, Figure 1.5). WLW had significantly less soil nitrate than all the winter annual cereals including NC, except for WEG. WEG had significantly less soil nitrate than all except WLW, WLF, WEF and RCC. NC and RF had significantly more soil nitrate than all treatments except for WCC. WCC had significantly more soil nitrate throughout than WEG and WLW. The lower soil nitrate for the plots with wheat grain was again probably due to the lack of side dressing, which was still apparent at this depth. The no cover also had a higher soil nitrate at this depth, perhaps due to the dry summer, where the rotational crops were not taking up as much nitrogen.

Table 1.8: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * depth in field with soybean residue, fall 2001 (BF2).

Winter Annual Cereal	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
No Cover	3.8 ab	4.5 a	2.4 ab
Wheat Cover Crop	3.5 bc	3.7 ab	2.3 ab
Rye Cover Crop	3.4 bc	3.3 bc	2.4 ab
Rye Forage	4.7 a	4.7 a	2.8 a
Wheat Early Forage	3.7 abc	3.2 bc	2.1 bc
Wheat Late Forage	3.6 abc	2.9 bc	2.1 bc
Wheat Early Grain	2.8 c	2.6 cd	1.7 c
Wheat Late Grain	1.8 d	2.2 d	1.7 c

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.5: Soil nitrate-N levels for the interaction of winter annual cereal * depth in field with soybean residue, fall 2001 (BF2).



In 2001, the soybean yields following RCC and RF were significantly higher than NC and soybean yield following WCC tended to be higher. The higher soybean yield following RCC, RF and WCC may be due to factors such as improved soil physical properties, since the soil nitrate differences were probably not large enough to cause significant yield differences (Table 1.9). In 2000, the corn grain yields tended to be higher with an earlier corn planting date. In 2001, the corn grain yields in both fields tended to be highest with earliest corn planting date with corn following NC and RCC being significantly higher than all but WCC (Table 1.10). The corn silage yields in 2000 were not significantly different, although there was a tendency for a higher yield with an earlier corn planting date, with corn silage following the cover crops somewhat higher than following the NC (Table 1.11). The corn silage yields followed a similar pattern in 2001, with corn silage planted the earliest having the highest yields. Corn silage yield following NC was significantly higher than following all winter annual cereals except WCC.

In BF2 depth three (60-90 cm) the trend in soil nitrate levels was similar to depth 1 and 2 (0-30 and 30-60 cm), although there was less variation than with the first two depths. WLG had significantly less soil nitrate than WCC, RF, RCC and NC. WEG had significantly less soil nitrate than RF, RCC and NC. RF had the most soil nitrate, significantly more than WLG, WEG, WEF and WLF. The lack of side dressing the wheat grain crops was still apparent in the fall. All of the plots tended to have less soil nitrate at this depth due to the rotational crops taking up nitrogen during the growing season.

There was an interaction of rotational crop with depth one and two, from 0-30 and 30-60 cm for BF2. The corn grain and silage had significantly more soil nitrate than

Table 1.9: Soybean yields following winter annual cereals no-till planted into corn silage or soybean residue fields.

Winter Annual Cereal	Yield	
	Corn Silage Residue Field Previous 2000	Soybean and Corn Silage Residue Fields 2001
	Mg ha ⁻¹	Mg ha ⁻¹
No Cover	3.6	2.8 b
Wheat Cover Crop	3.6	3.0 ab
Rye Cover Crop	3.2	3.1 a
Rye Forage	3.4	3.1 a
Wheat Early Forage	3.5	2.8b
Wheat Late Forage	3.5	2.64c
Wheat Early Grain	-	-
Wheat Late Grain	-	-

Treatment yields followed by the same letters were not significantly different at $P < 0.05$.

Table 1.10: Corn grain yields following winter annual cereals no-till planted into corn silage or soybean residue fields.

Winter Annual Cereal	Yield	
	Corn Silage Residue Field 2000	Soybean and Corn Silage Residue Fields 2001
	Mg ha ⁻¹	Mg ha ⁻¹
No Cover	12.1	8.6a
Wheat Cover Crop	12.0	7.4abc
Rye Cover Crop	11.7	8.4a
Rye Forage	11.5	6.9bc
Wheat Early Forage	10.2	5.7d
Wheat Late Forage	8.0	6.9bc
Wheat Early Grain	-	-
Wheat Late Grain	-	-

Treatment yields followed by the same letters were not significantly different at $P < 0.05$.

Table 1.11: Corn silage yields following winter annual cereals no-till planted into corn silage or soybean residue fields.

Winter Annual Cereal	Yield	
	Corn Silage Residue Field 2000	Soybean and Corn Silage Residue Fields 2001
	Mg ha ⁻¹ (DM)	Mg ha ⁻¹ (DM)
No Cover	17.9	11.6 a
Wheat Cover Crop	18.6	11.2 ab
Rye Cover Crop	19.7	10.1 bc
Rye Forage	16.1	8.7 cd
Wheat Early Forage	16.4	8.5 d
Wheat Late Forage	14.3	9.2 cd
Wheat Early Grain	5.8	5.4 e
Wheat Late Grain	4.5	3.1 f

Treatment yields followed by the same letters were not significantly different at $P < 0.05$.

soybean plots at depths one (0-30 cm) and two (30-60 cm), however for depth three (60-90 cm) the soil nitrate content dropped off suddenly for corn grain and silage, so there were no significant differences with rotational crop (Table 1.12, Figure 1.6). There are a couple of possibilities for the higher soil nitrate following the corn crops. The extra nitrogen from the corn may be due to fertilizer N, especially with the dry summer, the corn may not have picked up all the nitrogen from the soil. The soybean plant and root residue also may not have decomposed enough by the fall sampling in order to release N back into the system.

In BF2, when evaluating the interaction of rotational crop with winter annual cereal, there were interesting trends (Table 1.13, Figure 1.7). The soybean rotational crop had little variation in soil nitrate, although WLG had significantly less soil nitrate than WLF, otherwise there were no significant differences.

In the plots with corn silage there was more variation in soil nitrate among winter annual cereals. WLG had significantly less soil nitrate than all but WLF and WEG. WLF and WEG had significantly less soil nitrate than WCC, RF, RCC, and NC. WEF had significantly less soil nitrate than WCC and RF. NC, WCC, RCC and RF had significantly more soil nitrate than all, but WEF.

In the plots with corn grain, the WLG and WCC had significantly less soil nitrate than WLF and RF. The RCC and WEG had significantly less soil nitrate than the RF. Therefore, the RF had significantly more soil nitrate than WCC, WEG, WLG, and RCC. The higher soil nitrate following corn silage compared to corn grain may be due to the earlier harvest date for the silage, allowing for a quicker start toward root and plant residue decomposition and release of nitrogen back to the soil. The corn grain may also

Table 1.12: Soil nitrate-N levels in mg kg⁻¹ for the interaction of rotational crop * depth in field with soybean residue, fall 2001 (BF2).

Rotational Crop	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
Soybean	2.6 b	2.4 b	2.0 a
Corn Silage	3.8 a	4.0 a	2.3 a
Corn Grain	3.6 a	3.7 a	2.1 a

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.6: Soil nitrate-N levels for the interaction of rotational crop * depth in field with soybean residue, fall 2001 (BF2).

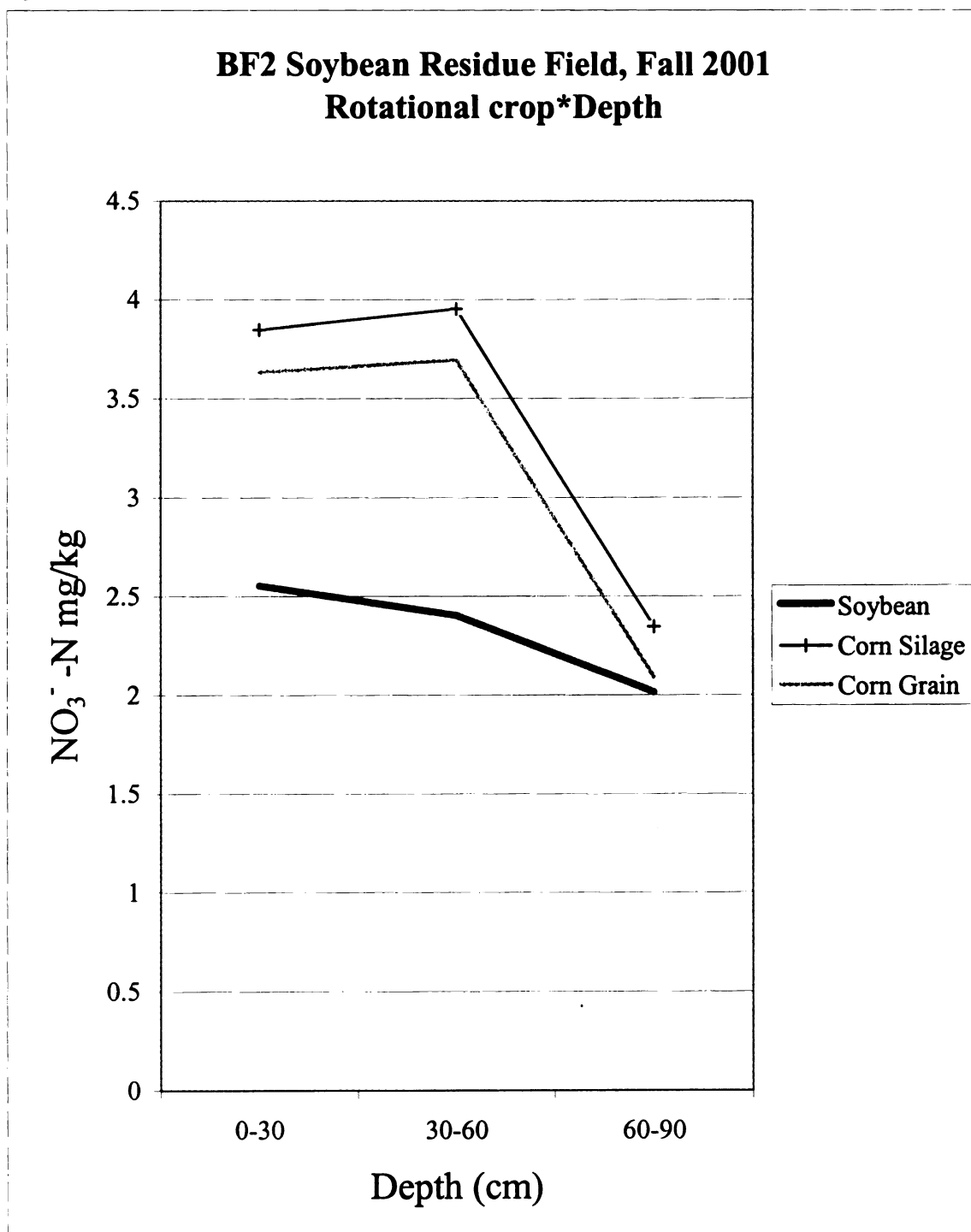
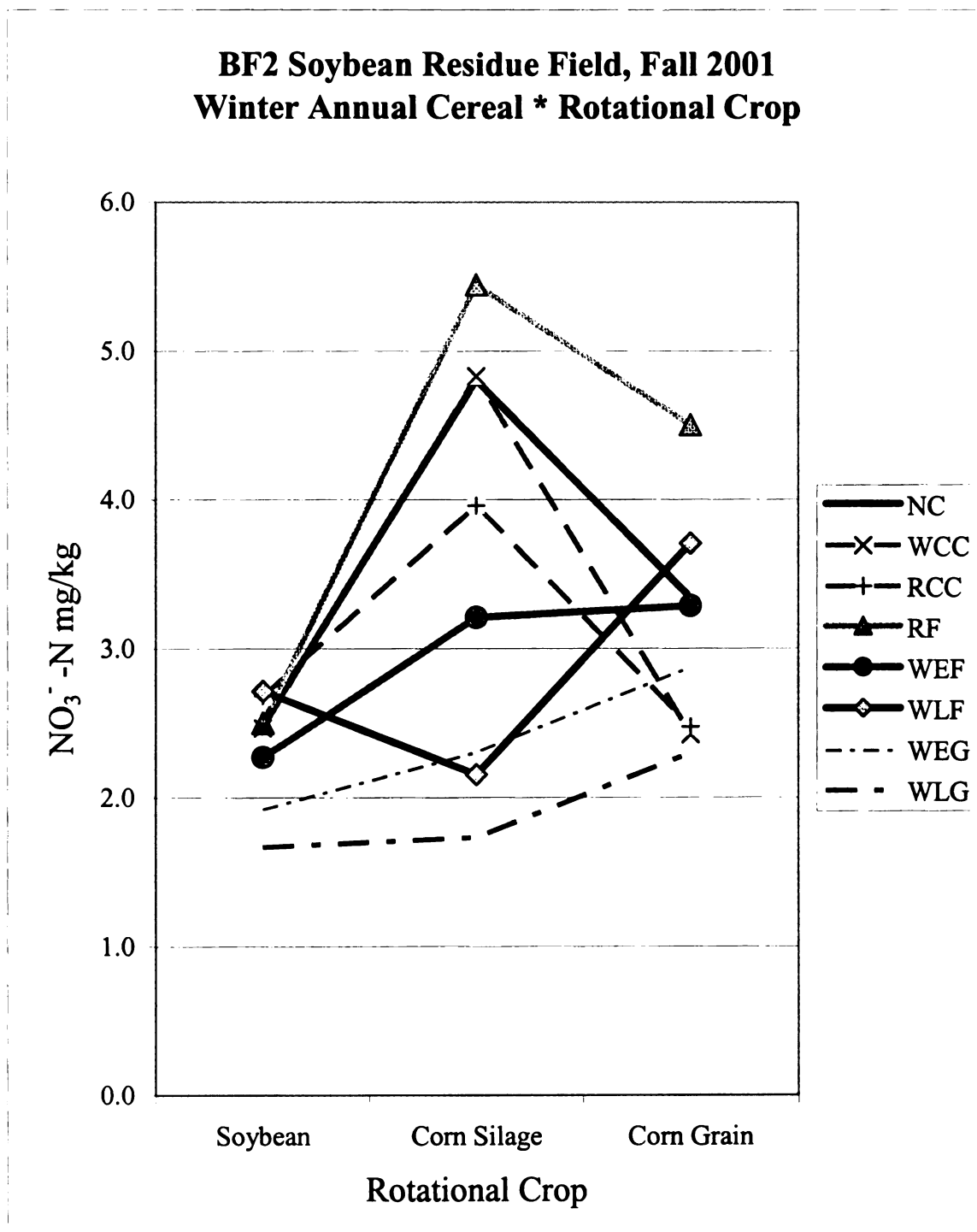


Table 1.13: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * rotational crop in field with soybean residue, fall 2001 (BF2).

Winter Annual Cereal	Soybean	Corn Silage	Corn Grain
No Cover	2.5 ab	4.8 ab	3.3 abc
Wheat Cover Crop	2.5 ab	4.8 ab	2.4 c
Rye Cover Crop	2.7 ab	4.0 ab	2.5 bc
Rye Forage	2.5 ab	5.4 a	4.5 a
Wheat Early Forage	2.7 ab	3.2 bc	3.3 abc
Wheat Late Forage	2.7 a	2.2 cd	3.7 ab
Wheat Early Grain	1.9 ab	2.3 cd	2.9 bc
Wheat Late Grain	1.7 b	1.7 d	2.3 c

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.7: Soil nitrate-N levels for the interaction of winter annual cereal * rotational crop in field with soybean residue, fall 2001 (BF2)



have continued to take up soil nitrogen after the harvest of silage. The reason the soil nitrate differences between grain and silage only show up in the NC, WCC, RCC and RF plots may be due to these plots being planted to corn earlier and therefore the corn was able to obtain more biomass, with more plant and root residue available to release N back into the soil. The corn in these plots was also side dressed the earliest allowing for the uptake of the fertilizer and soil nitrogen, sooner then following the other winter annual cereals. This effect may be compounded by the dry summer, where the corn in the other plots was not growing as rapidly and therefore taking up less nitrogen. Rotational crop yields for BF2 can be seen in (Tables 1.9-1.11) and are described for BF2 previously.

In CF1 with the interaction of winter annual cereal * depth (Table 1.14, Figure 1.8), WEG had significantly more soil nitrate than all but WLG at depth one (0-30 cm). WLG had significantly more soil nitrate than WLF, WEF, and NC. At depth 2 (30-60 cm), RF had significantly more soil nitrate than WLF, WEF and RCC. WLG had significantly more soil nitrate than WEF. At depth 3 (60-90 cm), WLF had significantly less soil nitrate than WCC, WEG and RF, otherwise there were no significant differences. The greater soil nitrate from 0-30 cm for the grain plots may be due to the late nitrogen side dress application to these plots. The wheat grain plots were side dressed this year on 31 July and the effects of this late nitrogen application was probably still apparent during the fall sampling. The effect of side dressing the wheat grain plots was also still apparent from 30-60 cm.

In CF1 there was an interaction of rotational crop and depth with a tendency toward less soil nitrate in the soybeans then the corn grain or silage, but not significantly (Table 1.15, Figure 1.9). This may be an apparent effect of the late side dress application

Table 1.14: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * depth in field with corn silage residue, fall 2000 (CF1).

Winter Annual Cereal	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
No Cover	3.8 c	3.8 abc	3.7 ab
Wheat Cover Crop	5.1 bc	4.3 ab	4.2 a
Rye Cover Crop	4.8 bc	3.4 bc	3.2 ab
Rye Forage	4.6 bc	4.7 a	4.2 a
Wheat Early Forage	4.3 c	3.1 c	3.4 ab
Wheat Late Forage	4.1 c	3.4 bc	2.9 b
Wheat Early Grain	6.9 a	4.2 abc	4.1 a
Wheat Late Grain	5.9 ab	4.4 ab	3.5 ab

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.8: Soil nitrate-N levels for the interaction of winter annual cereal * depth in field with corn silage residue, fall 2001 (CF1).

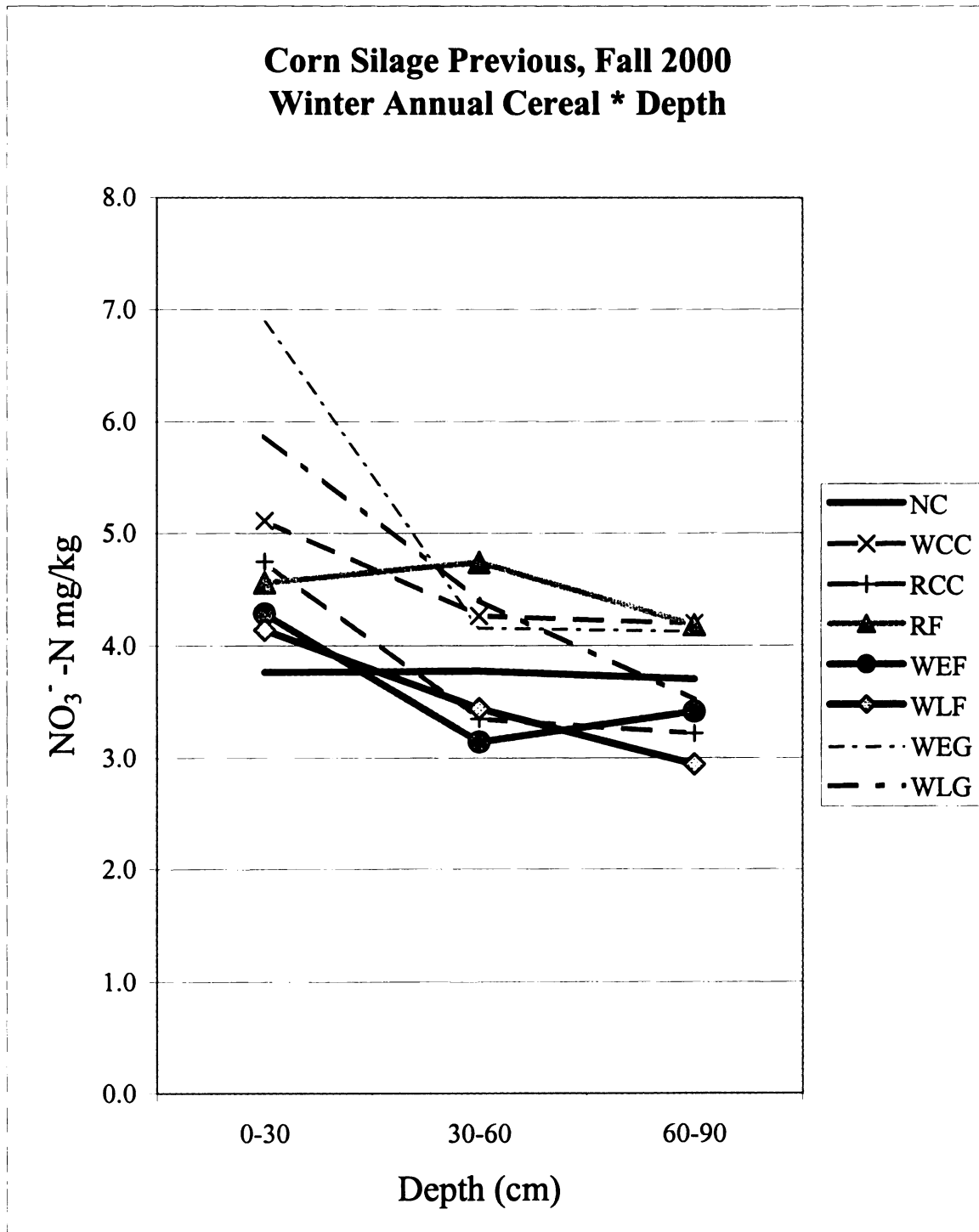
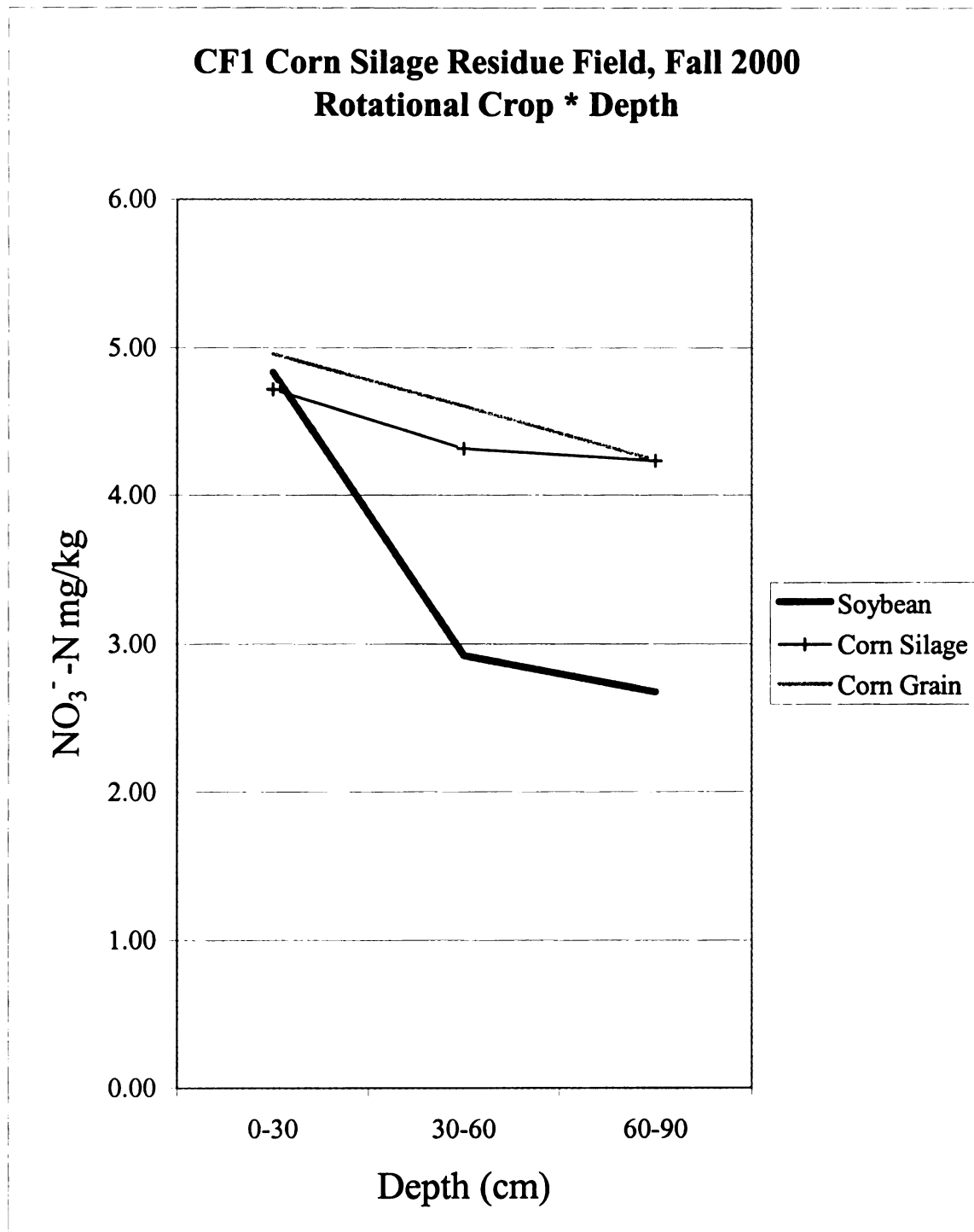


Table 1.15: Soil nitrate-N levels in mg kg⁻¹ for the interaction of rotational crop * depth in field with corn silage residue, fall 2000 (CF1).

Rotational Crop	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
Soybean	4.8 a	2.9 a	2.7 a
Corn Silage	4.7 a	4.3 a	4.2 a
Corn Grain	5.0 a	4.6 a	4.2 a

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.9: Soil nitrate-N levels for the interaction of rotational crop * depth in field with corn silage residue, fall 2000 (CF1).



to the corn following the wheat grain plots, allowing the over all average for the corn grain and silage soil nitrate to be higher than the soybean plots. Also, the soybeans had significantly higher nitrate content in the upper thirty cm of the soil profile, then at depth two (30-60 cm) and three (60-90 cm). The soybean roots and residue may have decayed and released nitrogen back into the soil. The rotational crop yields are shown in Tables 1.9-1.11. The soybean, corn grain and corn silage yields followed a pattern of greater yield with earlier rotational crop planting date. The rotational crops following NC, WCC and RCC had the highest yield. The rotational crop yield differences in CF1 are more likely due to improved soil physical properties such as increased soil aeration and increased water permeability, rather than due to N differences.

In CF2, there was a significant interaction of winter annual cereal * depth (Table 1.16, Figure 1.10). At depth one (0-30 cm) WLG had significantly less soil nitrate than WCC, otherwise there were no significant differences. WLG and WEG had significantly less soil nitrate than WCC and NC at depth two (30-60 cm). At depth three (60-90 cm), there were no significant differences in soil nitrate. The significant differences in soil nitrate levels would probably not be of practical importance. The wheat early and late grain plots tended to have less soil nitrate than any of the other treatments, probably due to a lack of side dress application on the late planted corn for these plots.

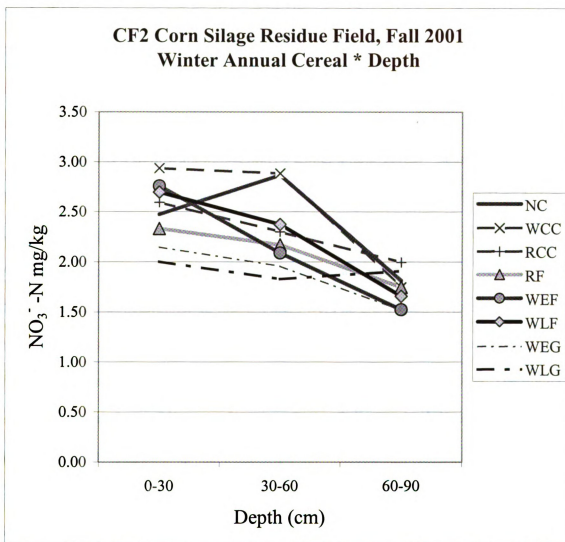
In CF2 the soybean yields following RCC and RF were significantly higher than NC, WEF and WLF (Table 1.9). The soybean yields following WCC tend to be higher than following NC, but not significantly. The higher yields following WCC, RCC and RF are more likely due to soil physical benefits than due to soil nitrate differences. The

Table 1.16: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * depth in field with corn silage residue, fall 2001 (CF2).

Winter Annual Cereal	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
No Cover	2.5 ab	2.9 a	1.8 a
Wheat Cover Crop	2.9 a	2.9 a	1.8 a
Rye Cover Crop	2.6 ab	2.3 ab	2.0 a
Rye Forage	2.3 ab	2.2 ab	1.8 a
Wheat Early Forage	2.8 ab	2.1 ab	1.5 a
Wheat Late Forage	2.7 ab	2.4 ab	1.7 a
Wheat Early Grain	2.2 ab	2.0 b	1.5 a
Wheat Late Grain	2.0 b	1.8 b	1.9 a

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.10: Soil nitrate-N levels for the interaction of winter annual cereal * depth in field with corn silage residue, fall 2001 (CF2).



corn grain and corn silage yields follow a pattern of increased yield with earliest planting date with NC tending to have the highest yield (Tables 1.10-1.11).

For CF2, there was a significant interaction of rotational crop * depth (Table 1.17, Figure 1.11). At depth one (0-30 cm), soybeans and corn silage had significantly less soil nitrate than corn grain and at depth two (30-60 cm) soybeans had significantly less soil nitrate than corn silage. At depth three (60-90 cm) there were no significant differences. This may be due to the shallow root system of soybeans, or as in BF2 the extra nitrogen in the soil that had corn planted may be due to fertilizer N.

There was a significant interaction of winter annual cereal * season for both fields (corn silage residue and soybean residue) in 2000 and 2001 (Tables 1.18-1.21 and Figures 1.12-1.15). In B1 (Table 1.18 and Figure 1.12) the NC had significantly more soil nitrate in the spring than the other winter annual cereals, although from a practical value the difference was negligible. In the fall, there were no significant differences in soil nitrate following winter annual cereal treatments. This figure stands out because of the higher soil nitrate levels after fall sampling compared with spring sampling. The higher soil nitrate levels in the fall may reflect the release of nitrogen back into the soil from plant or root decay following rotational crop harvest.

In B2, the NC also had significantly more soil nitrate compared with winter annual cereals in the spring and tended to in the fall (Table 1.19 and Figure 1.13). Again, all of the winter annual cereal treatments tended to have more soil nitrate in the fall than the spring. This difference between spring and fall for the winter annual cereals is probably due to the winter annual cereals holding on to soil nitrate in the spring which

Table 1.17: Soil nitrate-N levels in mg kg⁻¹ for the interaction of rotational crop * depth in field with corn silage residue, fall 2001 (CF2).

Rotational Crop	Depth (0-30 cm)	Depth (30-60 cm)	Depth (60-90 cm)
Soybean	2.1 b	2.0 b	1.7 a
Corn Silage	2.4 b	2.7 a	1.8 a
Corn Grain	3.0 a	2.3 ab	1.7 a

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.11: Soil nitrate-N levels for the interaction of rotational crop * depth in field with corn silage residue, fall 2001 (CF2).

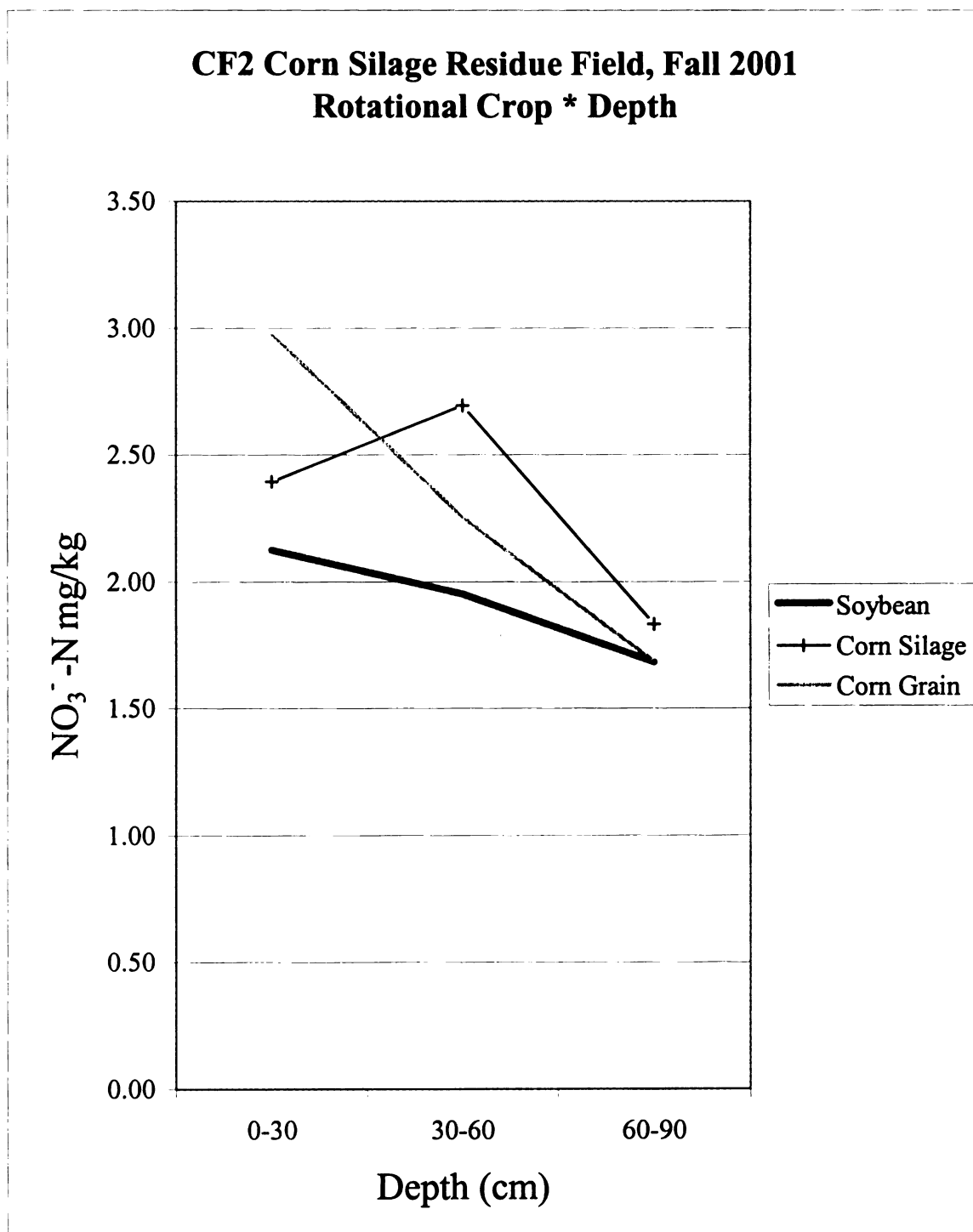


Table 1.18: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * season in field with soybean residue, 2001 (B1).

Winter Annual Cereal	Spring	Fall
No Cover	1.5 a	3.0 a
Wheat Cover Crop	0.9 bc	3.5 a
Rye Cover Crop	0.9 bc	3.2 a
Rye Forage	0.9 bc	3.7 a
Wheat Early Forage	0.7 c	3.5 a
Wheat Late Forage	0.7 c	3.8 a
Wheat Early Grain	0.8 bc	3.4 a
Wheat Late Grain	0.8 bc	3.5 a

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.12: Soil nitrate-N levels for the interaction of winter annual cereal * season in field with soybean residue, 2000 (B1).

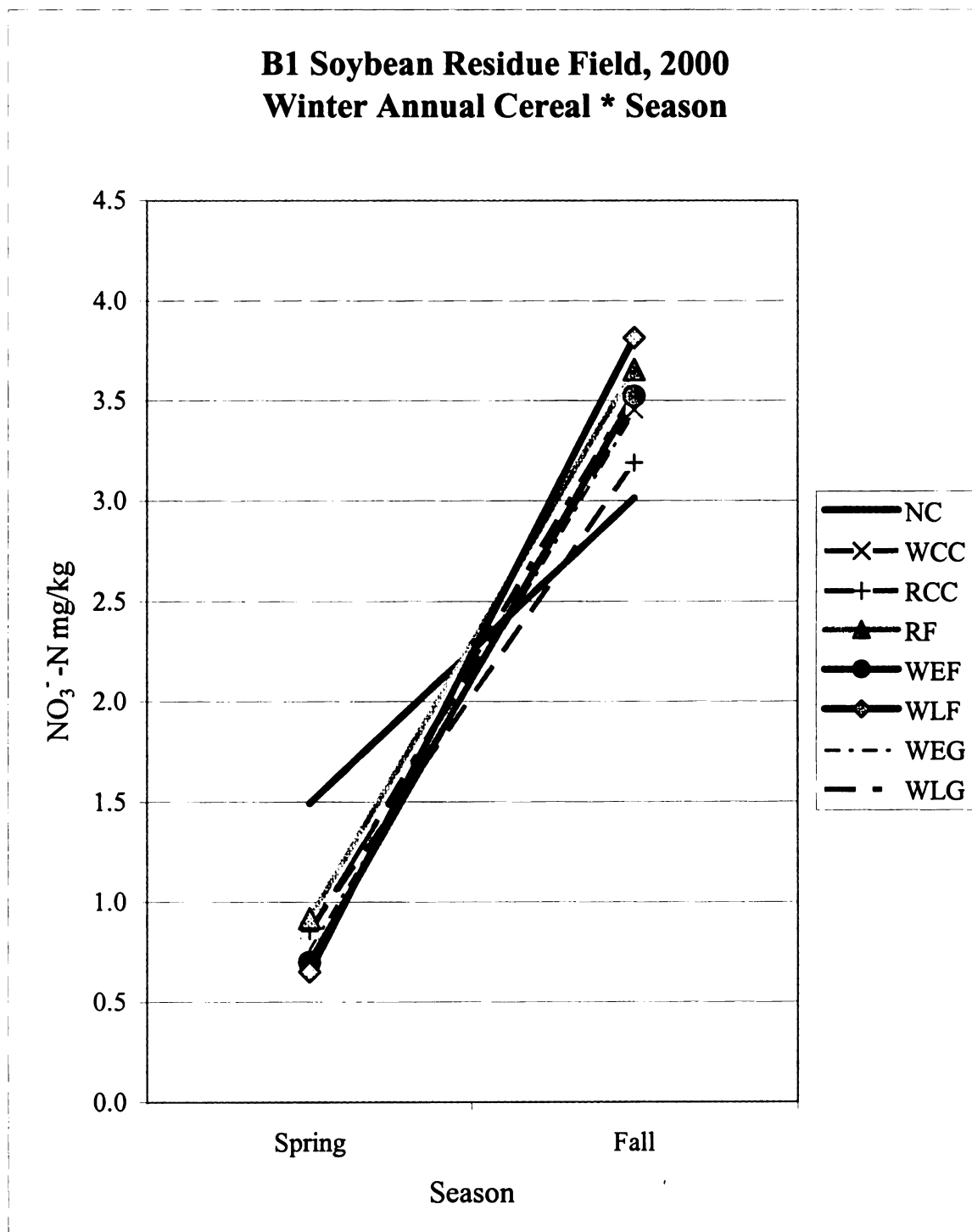
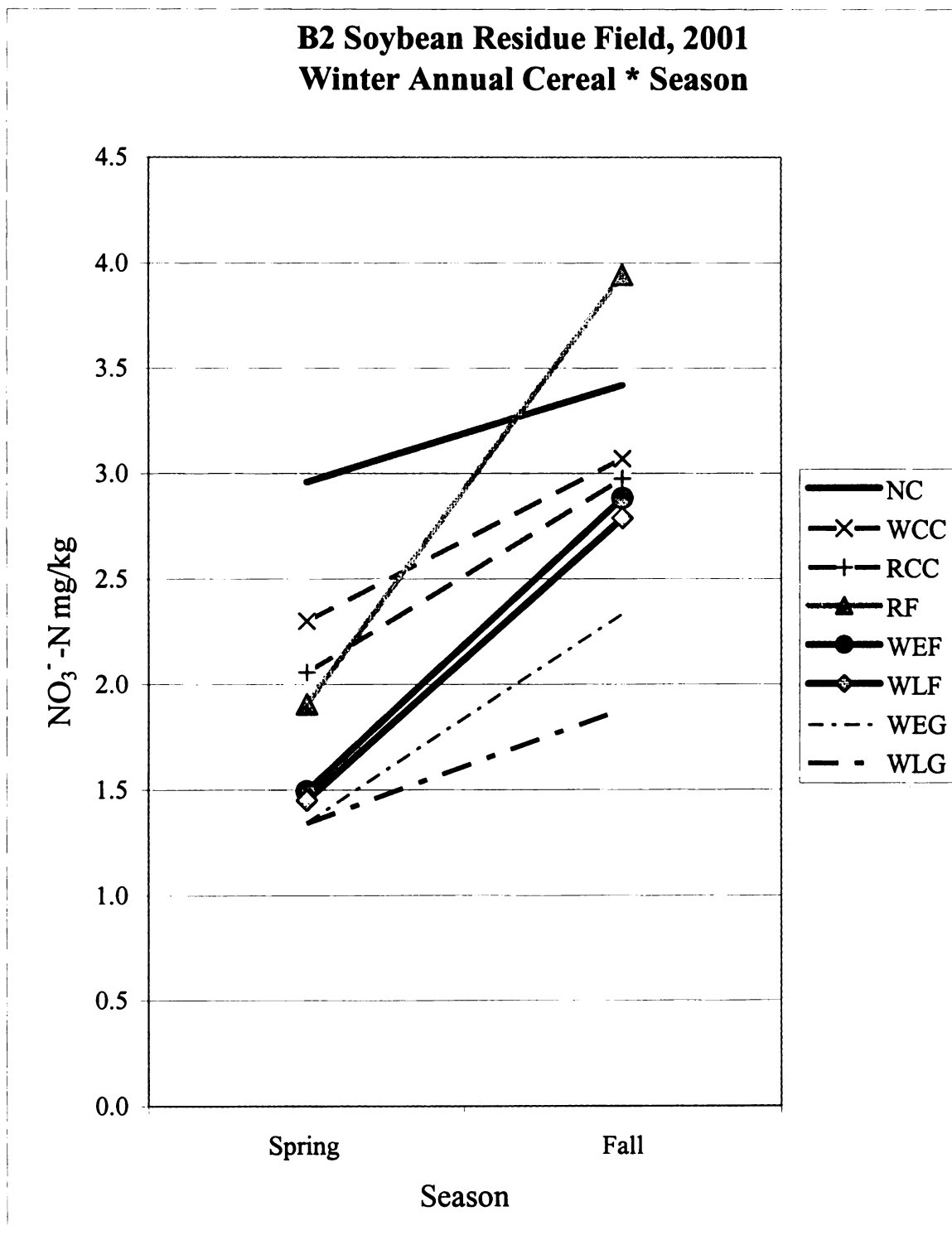


Table 1.19: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * season in field with soybean residue, 2002 (B2).

Winter Annual Cereal	Spring	Fall
No Cover	3.0 a	3.4 ab
Wheat Cover Crop	2.3 b	3.1 bc
Rye Cover Crop	2.1 b	3.0 bc
Rye Forage	1.9 b	3.9 a
Wheat Early Forage	1.5 cd	2.9 bcd
Wheat Late Forage	1.5 cd	2.8 cd
Wheat Early Grain	1.3 d	2.3 de
Wheat Late Grain	1.3 d	1.9 e

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.13: Soil nitrate-N levels for the interaction of winter annual cereal * season in field with soybean residue, 2001 (B2).



was scavenged over the previous fall and winter, then released back into the soil either from plant or root decay, after harvest or burn down. Kessavalou and Walters (1999) showed that rye reduced RSN after soybeans.

In C1, there was a significant interaction of winter annual cereal * season (Table 1.20, Figure 1.14). The NC had significantly higher soil nitrate in the spring than all winter annual cereals except for WCC, where there was still a tendency for NC to have a higher soil nitrate level. The NC soil nitrate had the most dramatic drop by the fall compared to the winter annual cereals, while the WEG and WLG soil nitrate levels rose in the fall. The increase of the WEG and WLG soil nitrate levels by the fall may be due to the late side dress application necessary for the late corn planting dates following the wheat grain harvest. The decline of the no cover soil nitrate from spring to fall was mainly due to initially higher spring soil nitrate levels in the no cover compared to the winter annual cereals, which was taken up by the corn grain and corn silage during the growing season. In the fall the differences in soil nitrate were probably not of practical importance. (Kessavalou and Walters 1999) showed that fall planted rye following soybeans, but before corn planting, reduced RSN by 18-33%, although the RSN increased after corn the following spring. Johnson and Raun (1995) found that nitrogen immobilized into organic N by microbes might be released later in the season, especially with higher fertilizer N rates.

When looking at what happens to soil nitrate from spring to fall, in C2 (Table 1.21, Figure 1.15) there was also an interaction of winter annual cereal * season, similar to that of C1. The NC soil nitrate was significantly higher in the spring than the winter annual cereals, while in the fall NC had similar soil NO_3^- levels to the winter annual

Table 1.20: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * season in field with corn silage residue, 2000 (C1).

Winter Annual Cereal	Spring	Fall
No Cover	6.5 a	3.7 ab
Wheat Cover Crop	5.2 ab	4.5 ab
Rye Cover Crop	4.3 bc	3.7 ab
Rye Forage	3.9 cd	4.5 ab
Wheat Early Forage	4.2 bc	3.6 b
Wheat Late Forage	3.1 de	3.5 b
Wheat Early Grain	3.4 ce	4.9 a
Wheat Late Grain	2.8 e	4.5 ab

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.14: Soil nitrate-N levels for the interaction of winter annual cereal * season in field with corn silage residue, 2000 (C1).

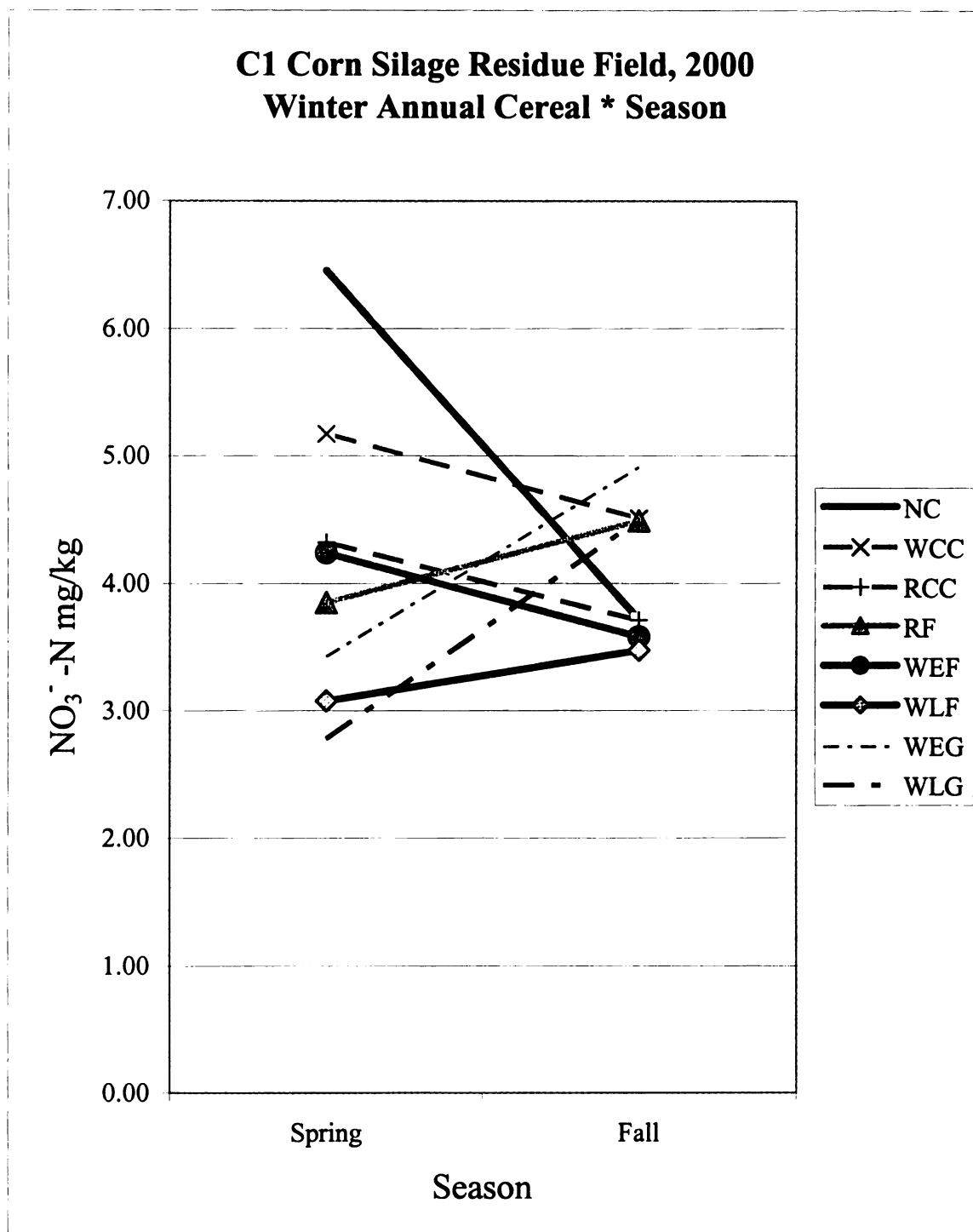
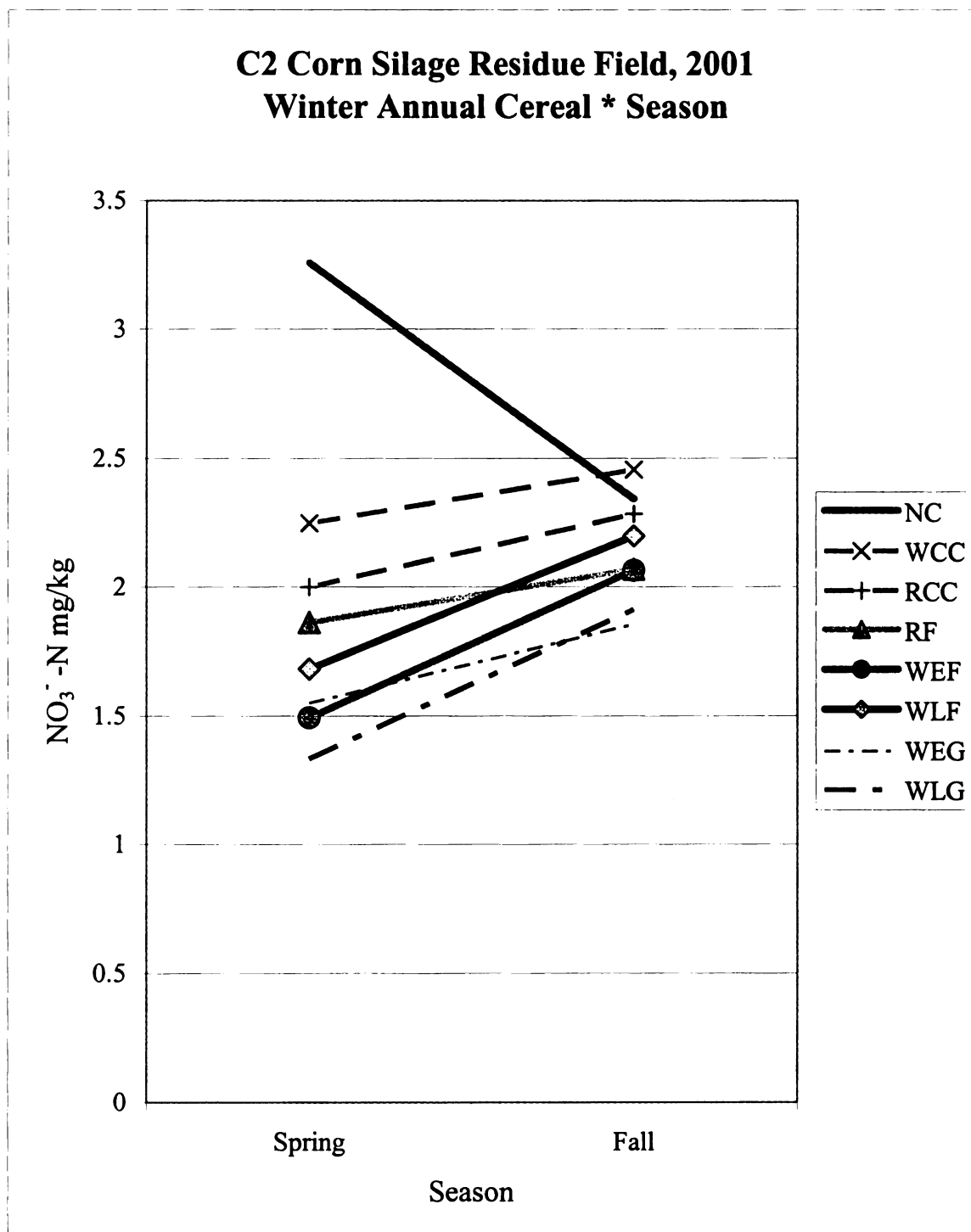


Table 1.21: Soil nitrate-N levels in mg kg⁻¹ for the interaction of winter annual cereal * season in field with corn silage residue, 2001 (C2).

Winter Annual Cereal	Spring	Fall
No Cover	3.3 a	2.3 ab
Wheat Cover Crop	2.2 b	2.5 a
Rye Cover Crop	2.0 bc	2.3 ab
Rye Forage	1.9 bcd	2.1 ab
Wheat Early Forage	1.5 de	2.1 ab
Wheat Late Forage	1.7 cde	2.2 ab
Wheat Early Grain	1.6 de	1.9 b
Wheat Late Grain	1.3 e	1.9 ab

Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 1.15: Soil nitrate-N levels for the interaction of winter annual cereal * season in field with corn silage residue, 2001(C2).



cereals. As in 2000, NC soil nitrate tended to drop dramatically by the fall while the winter annual cereal plots tended to have an increase in soil nitrate. This was also likely due to the high initial spring levels of soil nitrate in the no cover plots during the spring soil sampling compared to winter annual cereals. The higher soil nitrate following NC was probably picked up by the corn grain and silage during the growing season. Also, the tendency for higher fall soil nitrate levels following winter annual cereals may reflect the decomposition of plant and root residue releasing N back into the soil after the harvest of rotational crops. Kessavalou and Walters (1999) showed that mineralization from rye residue may build soil N and cause leaching later in the season. All the winter annual cereals tended to have higher soil nitrate in the fall, but only the ones mentioned above were significantly higher. Ditsch et al. (1993) stated that rye N uptake varies with previous crop, its influence on soil moisture and subsequent residual N levels.

Conclusions

Use of a winter annual cereal to scavenge nitrogen over the fall and winter has potential to reduce fertilizer use and make more efficient use of nitrogen already in the system. In both years of the study with either soybeans or corn as the previous crop, winter annual cereals had a significantly reduced soil nitrate level in the spring compared to having no cover. Excluding the no cover treatment, discovering trends in nitrate content with depth between different winter annual cereals, across different fields and years is difficult. The greater amount of rainfall the first year may have been a big factor in creating these differences, although soil variability between fields and landscape features may also make a difference in the extent that a winter annual cereal may help

reduce nitrogen loss. Johnson and Raun (1995) showed that wheat would continue to take up N with increased fertilizer use even after the maximum yield was reached. Perhaps this buffer zone is where the plant is increasing its protein content, although they also found that plant N loss through ammonia volatilization continued to increase with increased fertilizer N applied even after maximum yields were reached. Bauder et al. (1979) found that under optimum irrigation in greenhouses, split urea applications may reduce nitrate leaching. Perhaps cover crops also play a role by changing the time soil nitrate is available for the rotational crop. Kuo and Jellum (2002) found that cover crops and residue management affected corn yield and N-uptake by their influence on nitrogen. Garwood et al. (1999) did a study in England where winter cover crops created a positive N balance, which may be held as immobilized organic N that is available for years. In the future a new method of burn down may be available for cover crops. Stanislaus and Cheng (2002) are working on genetically engineered tobacco plants that will self-destruct under heat induction according to the photoperiod. Perhaps this technology will be perfected for wheat and rye as well.

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CHAPTER 2

AGRONOMIC AND ECONOMIC ASPECTS OF INTEGRATING A WINTER ANNUAL CEREAL INTO A CORN OR SOYBEAN ROTATION IN MICHIGAN

Abstract

The addition of winter annual cereals into a corn-soybean rotation impacts many agronomic and economic aspects of cropping systems. Ground cover and residue may be increased by the presence of a winter annual cereal. A winter annual cereal may also provide a second profitable crop to the system. Insect pressures on rotational crops following winter annual cereals vary by the crop and insect, but often are dependant on rotational crop planting date. Armyworm (*Pseudaletia unipacta*) infestations often occur in winter wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.) and if the cereal grains are burned down with glyphosate, the armyworms may move to corn (*Zea mays* L.) in adjacent fields or plots. European corn borer (ECB) (*Ostrinia nubilalis*) stalk tunneling tends to be higher in corn at an ideal maturity during peak moth flight times. Bean Leaf Beetle (BLB) (*Cerotoma trifurcate*) damage tends to be higher in earlier planted soybeans [*Gycine max* (L.) Merr.], and soybean aphid (*Aphis glycines*) numbers tend to be higher in later planted soybeans. The winter annual cereals provide an extra crop when harvested for forage or grain. Later harvest dates of forages provide an increased yield, but lower quality. Soybean yields following a wheat or rye cover crop may be increased over no cover crop, while corn grain and corn silage yields tend to follow a pattern of higher yield with earlier corn planting date, which ultimately depends on whether the winter annual cereal is used for a cover crop, a forage, or a grain. Depending

on the planting date of a corn or soybean rotational crop following harvest of a winter annual cereal, the economic benefit of the additional crop may increase the net profit to the system.

Introduction

There are many prospects for integrating a winter annual cereal into a corn - soybean rotation in Michigan. The possibilities range from harvesting the winter annual cereal as a small grain or early spring forage, to simply utilizing it as a cover crop. Entz (1994) found rotating a forage with an annual grain crop increased annual grain crop yields in years with adequate moisture, but reduced yields in dry years.

The benefits of integrating a winter annual cereal into a traditional corn-soybean rotation exist at the soil and agronomic level. When making management decisions on what cropping system to plant, it is important to take into account all agronomic factors including soil water, nutrients and microbes, as well as above ground aspects such as insects and yields.

Soil benefits of using winter annual cereals include scavenging residual nitrogen over the fall, winter, and early spring, improving soil quality, reducing soil erosion, increased soil aeration and water infiltration. Kessavalau (1997) found that rye planted after soybean increased residue 16%, providing erosion control equivalent to that of corn. Eckert (1988) found rye provided 60% greater ground cover than other covers, due to rye's winter hardiness. Kaspar (2001) showed rye increased soil water infiltration and reduced erosion and runoff. The infiltration improved soil structure and protected the soil from rain pounding, while the roots held the residue together. The rye also protected soil

from freezing, thawing and compression. While no-till planting also conserved soil water (Entz 1994), no-till combined with a cover crop, reduced runoff and erosion Hartwig (2002). Cover crops add organic matter to the soil, increasing soil tilth and productivity (Hartwig 2002). The high root production of rye increases soil microbe biomass. Soil microbes break down plant residues producing “gums” that hold larger soil particles together in “peds”, allowing for greater soil permeability and aeration (Hartwig 2002). Earthworms increase in soil with a green cover crop, up to seven times in no-till, providing increased soil quality and aeration (Hartwig 2002).

The effects of winter annual cereals on soil moisture and corn yield depend on the quantity and distribution of rain, soil type, cover species and kill date. These environmental conditions and kill date allow for a large variation in spring water depletion and summer water conservation in different years and field locations (Clark 1997). The residue from winter annual cereals conserves soil moisture, creating increased yields in corn following a cover crop (Eckert 1988, Moschelr 1967). Clark (1997) showed residues reduce evaporation. Vaughan (1998) reported rye was better for soil moisture conservation than in combination with hairy vetch.

However, the kill date of cover crops is important in determining the benefits of cover crop soil water conservation. Clark (1997) reported late April or early May kill dates in Maryland, increased corn yields over earlier kill dates due to increased soil moisture conservation and differences in soil-N availability. The later kill dates provided an increase in cover biomass and N release. Clark (1997) showed summer moisture conserved by killed covers was more important than spring moisture conservation to corn

yield. Actively growing covers did not deplete spring soil moisture. Moisture deficits in corn are most detrimental to yield during silking, around mid to late July (Clark 1997).

Delaying corn planting for several weeks after cover crop kill provides better synchronization between N release and corn N uptake (Vaughan 1998). Rye may have allelopathic effects, which reduce subsequent corn yields (Kessavalou 1997) or decrease corn yield due to poor stand at planting (Eckert 1988). However, delayed spring planting after rye may reduce any allelopathic affects (Garwood 1999). N availability may be more important for increasing corn yields than soil moisture. An early desiccation (late April) provided greater corn yields than a mid May desiccation (Vaughan 1998). The main effect on corn yield was due to N availability, rather than cover crop management (Kuo 2002). In fields with excess nitrogen the cover crops may scavenge the nitrogen and make it available the next season (Hartwig 2002). Living corn roots are able to increase inorganic N by mineralization in conditioned soil by over 50% (Sanchez 2002).

Soybean may have a higher yield following a grass crop than in continuous monoculture. There was greater N immobilization following grain sorghum, which may have become available during pod fill. Also, soybean yield increased following grain sorghum with the addition of fertilizer N, but not following corn (Peterson 1989 I).

Objectives:

- 1) Compare the percent ground cover from winter annual cereal and no-till residue.
- 2) Compare insect pressure in corn and soybean following several winter annual cereal treatments.
- 3) Evaluate early and late harvested winter annual cereal forage yield.

- 4) Evaluate wheat (early and late maturing variety) grain yield, following no-till planting into soybean and corn silage fields.
- 5) Compare the yields of rotational crops (soybeans, corn grain and corn silage) following several winter annual cereal treatments.
- 6) Compare the commodity returns of several cropping systems to determine the economic values of different management strategies in Michigan.

Materials and Methods

On 28 September, 1999 and 13 October, 2000, winter annual cereal crops were no-till planted into a Capac loam soil (fine-loamy, mixed, mesic Aeric Ochra-qualf) at the Michigan State University Research farm in East Lansing, MI. In both years of the study, the winter annual cereals were planted in two fields on the farm, one following soybean, and the other following silage corn. The planting was done in a randomized complete block split-split plot design replicated four times. Main plots consisted of the fields previously in corn silage (corn silage residue) or soybeans (soybean residue), sub plots consisted of the winter annual cereals, and sub-sub plots consisted of rotational crops of corn grain, corn silage, and soybean. The winter annual cereal treatments consisted of the following: wheat cover crop (WCC) and rye cover crop (RCC) burned down with glyphosate; rye harvested for forage (RF); wheat harvested for forage early (WEF) and late (WLF); an early maturing variety of wheat harvested for grain (WEG) and a late maturing variety of wheat harvested for grain (WLG); and an untreated check with no winter cereal (NC). The wheat variety was “Harus” an early maturing awnless soft white winter wheat developed at the Agriculture Canada Research Station in Harrow. The

WLG variety used was “Patterson” a soft red winter wheat developed at Purdue University. The rye variety used was “Wheeler” which was released by the Michigan Agricultural Experiment Station. The wheat was planted at 134 kg ha⁻¹ and the rye at 125 kg ha⁻¹. The grain and forage crops received 52 kg ha⁻¹ of elemental N applied as granular urea (46-0-0) at green-up the following spring. The no cover and the wheat and rye cover crops did not receive any supplemental nitrogen.

The following spring, the winter annual cereals were removed at different times. WCC and RCC were burned down with glyphosate on 14 April and 26 April for 2000 and 2001, respectively. The RF was harvested in the early boot stage on 26 April, 2000 and 7 May, 2001. The WEF was harvested when the wheat was in the boot stage (Feeke’s scale 10.0) on 11 May, 2000 and 19 May, 2001; the WLF was harvested when the wheat was in the early head stage (Feeke’s scale 10.1) on 22 May, 2000 and 24 May, 2001. A Carter flail harvester (Carter Manufacturing Co. Inc., Brookston, IN) was used to harvest the forage plots. The WEG and WLG plots were harvested on 5 and 13 July respectively in 2000, and 9 and 12 July respectively in 2001 using a small plot combine with a five foot head to harvest the center five feet of each plot. Wheat grain moisture content and field weights were automatically measured by a GrainGageTM, HarvestData SystemTM mounted on the plot combine. The wheat grain yields were corrected to 13.5% moisture.

Rotational crops of corn grain (CG), corn silage (CS), or soybean (B) were planted following burn down or harvest of the winter annual cereals. The plots were 3.0 m x 12.2 m (Table 2.1).

Glyphosate applications at one quart per acre were made to the rotational plots as needed after the burn down or harvest of the winter annual cereals. On 22, June 00 and 5

Table 2.1: Dates of burn down or harvest of winter annual cereals and following planting dates of corn and soybean rotational crops.

Winter Annual Cereal Treatment	2000			2001		
	Burn down or Harvest Date	Corn Rotational Planting Date	Soybean Rotational Planting Date	Burn down or Harvest Date	Corn Rotational Planting Date	Soybean Rotational Planting Date
NC	-	29 April	11 May	-	5 May	5 May
WCC	14 April	29 April	11 May	26 April	5 May	5 May
RCC	14 April	29 April	11 May	26 April	5 May	5 May
RF	26 April	11 May	11 May	7 May	14 May	14 May
WEF	11 May	15 May	11 May	19 May	22 May	22 May
WLF	22 May	22 May	22 May	24 May	26 May	26 May
WEG	5 July	6 July	6 July	9 July	10 July	10 July
WLG	13 July	14 July	14 July	12 July	13 July	13 July

NC- no cover, WCC - wheat cover crop, RCC - rye cover crop, RF - rye forage, WEF - wheat early harvested forage, WLF - wheat late harvested forage, WEG - wheat early maturing variety grain, WLG - wheat late maturing variety grain.

June, 01, all the corn plots except the WEG and WLG were side dressed with 468 Liters ha^{-1} of 28% N, which equals 168 kg ha^{-1} N. On 31 July, 2000, the corn grain and silage, WEG and WLG plots received 468 Liters ha^{-1} of 28% N, which equals 168 kg ha^{-1} N. However, in 2001, corn following WEG and WLG was not side dressed based on results from 2000, which showed no yield benefit. The corn silage was harvested when the grain was approximately at the 2/3 milk line (Wiersma et al. 1993). The soybeans were harvested after maturity and leaf drop. Soybean and corn grain moisture content and field weights were automatically measured by a GrainGageTM, HarvestData SystemTM mounted on a plot combine. Soybeans yields are reported at 13% moisture and corn grain yields are reported at 15.5% moisture. Corn grain, corn silage and soybean rotational crop yield data was eliminated from the soybean previous field in 2000, due to extensive ground hog damage.

Ground cover and residue measurements were made on 23 June, 2000 and 29 June, 2001 using a rope with a knot every 15.2 cm (6 inches) strung diagonally across the length of a plot from corner to corner. The knots above ground cover or residue were counted and the percentage of knots was used as an estimate of percent ground cover and residue for each plot. The method was repeated diagonally the other way across the plot and results were averaged, similarly to (Sloneker 1977). The WEG and WLG was not yet harvested at the time of ground cover measurement, and therefore had a full stand of wheat, so ground cover was considered to be 100% in these plots.

Measurements of numbers or damage were taken for insect pests noted in the experiment. Armyworm damage in corn plots was evaluated on 12 June, 2001 (due to a large outbreak in the study) by examining 20 consecutive plants in a center row of each

plot. The percentage of plants with feeding damage was calculated and averaged across treatments. After sampling, all plots in the study were sprayed with esfenvalerate (Asana XL, DuPont) at 83.6 ml ha^{-1} on 6 June, 2001. In the fall of 2001, European corn borer was sampled by splitting 5 randomly chosen plants per corn grain plot. The number of larvae, number of tunnels, and centimeters of tunneling was recorded for each plant, and averages were calculated per plot.

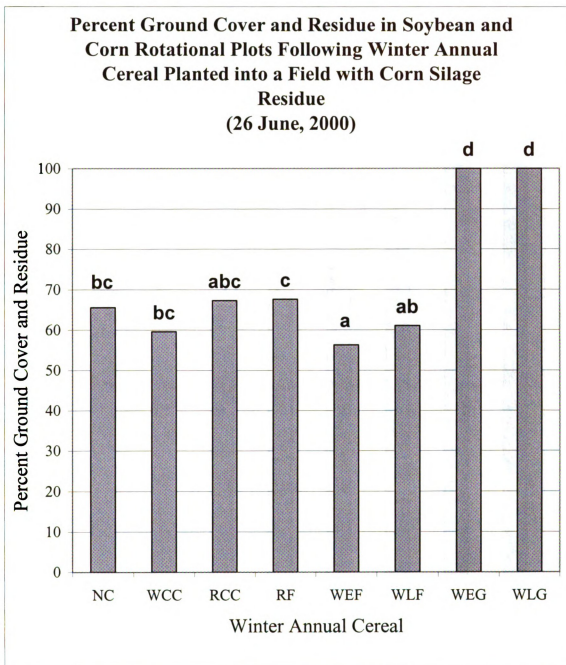
In soybean, bean leaf beetle damage was rated on 12 June, 2001 by determining the percentage of 20 consecutive plants with BLB feeding in each soybean plot. Soybean aphid numbers were assessed on 8 August, 2001 by rating 30 leaflets per soybean plot using the following scale: 0 (no aphids), 1 (<10 aphids), 2 (10-24 aphids), 3(25-99aphids), and 4(>100 aphids) per trifoliate leaf (DiFonzo and Hines 2002). All ground cover, insect and yield data was analyzed with SAS software using a proc-mixed model with Tukey's HSD and lsd's $P(p < 0.05)$ (SAS Inst.,1999).

For the economic analysis the input costs used were the actual costs accrued for fertilizer, seed, equipment, labor for planting, harvesting, and herbicide applications. These costs reflect 2000 prices as reported in Schwab (2001). The insecticide application cost was not included because all plots were sprayed for armyworm to prevent movement from one plot to another and therefore didn't represent a realistic need for insecticide application in an isolated cropping system. The cash receipts reflect the most recent five-year average commodity price as reported by the Michigan Agricultural Statistics Service.

Results and Discussion

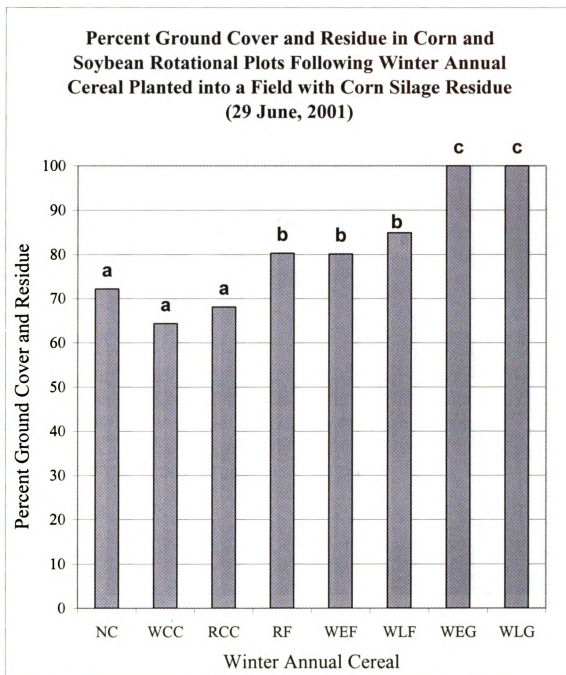
Ground Cover: The percentage ground cover following winter annual cereal was significantly different in both fields for both years. The WEG and WLG had significantly more ground cover and residue than any of the other winter annual cereals including the no cover plots. This was due to the grain crops remaining on the field at the time of residue measurement, contributing to 100% ground cover. In 2000, the soybean previous field was eliminated due to ground hog damage. In 2000, the corn silage previous field showed significant differences in percent ground cover with winter annual cereal at $p < 0.0001$ (Figure 2.1). The significant differences in 2000 were mainly because the wheat grain plots were not yet harvested and contained 100% cover at the time of measurement. In 2001, there was a significant difference in ground cover between the fields planted into a previous corn silage field (corn silage residue) and a previous soybean field (soybean residue), winter annual cereal * previous crop was significant at $p < 0.0001$. The field with corn silage residue showed no significant differences in ground cover and residue between the rotational crops (soybean, corn grain and corn silage) so the results were pooled for the analysis. The corn silage residue field in 2001 showed significant differences in percent ground cover and residue between winter annual cereal treatments at $p < 0.0001$ (Figure 2.2). Although, in 2001 the soybean residue field showed significant differences in percent ground cover and residue in the soybean and corn rotational crops at $p < 0.05$ (Figures 2.3 and 2.4 respectively). The soybean residue field tended to have greater cover than the corn silage residue field, but only significantly higher in the wheat cover crop treatment. The greater ground cover in the

Figure 2.1: Percent ground cover and residue averaged between soybean and corn rotational crops planted after winter annual cereal harvest in 2000. The field was previously in corn silage.



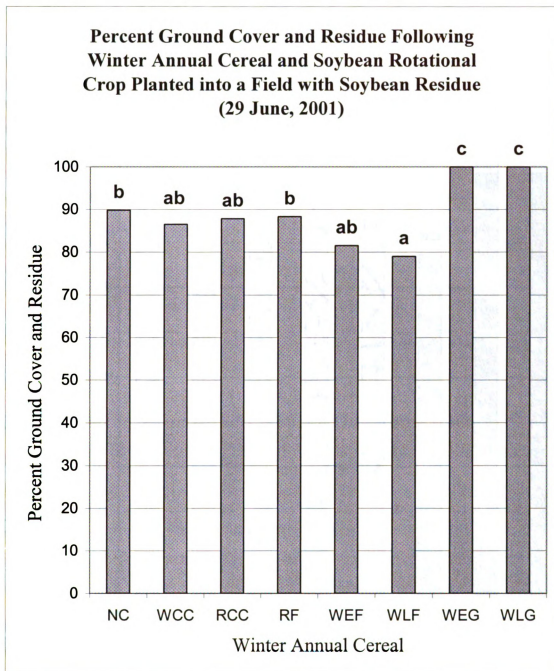
Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 2.2: Percent ground cover and residue averaged between soybean and corn rotational crops planted after winter annual cereal harvest in 2001. The field was previously in corn silage.



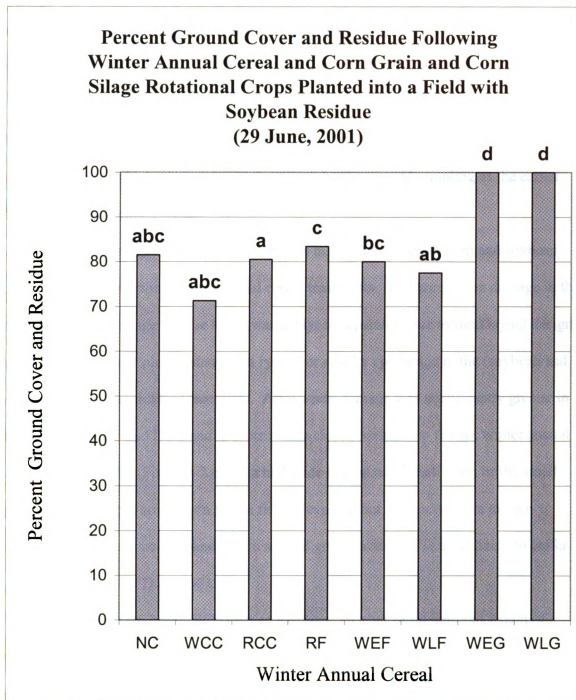
Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 2.3: Percent ground cover in soybean rotational crops planted following winter annual cereal harvest.



Treatments followed by the same letters were not significantly different at $P < 0.05$.

Figure 2.4: Percent ground cover in corn grain and corn silage rotational crops planted following winter annual cereal harvest.



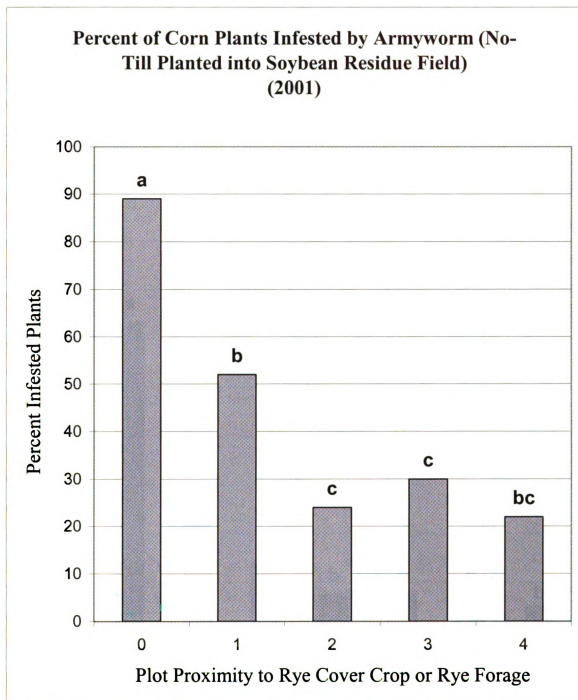
Treatments followed by the same letters were not significantly different at $P < 0.05$.

soybean residue field was most likely due to the soybean plants originally having a higher plant population (more plant residue cover per square meter) than the corn and therefore leaving more cover in the plots. Another possibility is the greater amount of biomass being removed via corn silage and therefore less residue. In 2001, in the corn silage residue field, the later harvested winter annual cereals tended to have more ground cover than earlier harvested winter annual cereals. The later harvested winter annual cereals may not have broken down and decayed as much by the time of sampling as the earlier harvested winter annual cereals.

Insect Damage: There were differences in insect pressure in corn and soybean rotational crops following winter annual cereal treatments. The armyworm damage in the soybean and corn silage residue fields was analyzed separately due to field layout design of being (four or six) plots distant from rye cover crop or rye forage in the (soybean and corn silage) residue fields respectively. Armyworm damage was significantly greater in corn following RF and RCC and in plots within close proximity to the rye winter annual cereals at $p < 0.0001$ (Figs 2.5-2.6). If a herbicide is used on a small grain or the small grain matures before armyworm larvae finish development they may move to corn (Steffey 1999). Corn no-till planted into a small grain cover crop is most likely to suffer armyworm injury (O'Day 1998).

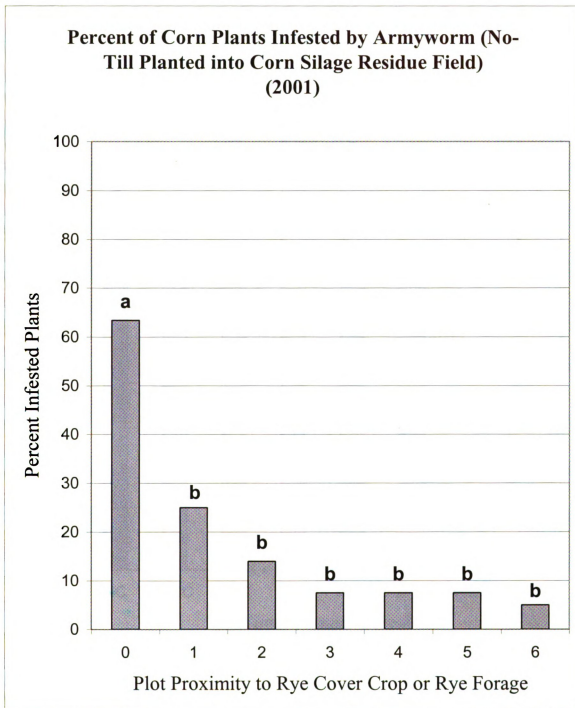
European corn borer (ECB) larvae numbers, number of tunnels and length of tunnels in corn stalks following winter annual cereal treatments was significant at $p < 0.05$. The number of larvae, number of tunnels and length of tunnels were all significantly lower in the wheat early and late grain plots. This was probably related to the corn not reaching maturity, due to the later corn planting date associated with the

Figure 2.5: Percent of corn plants damaged by armyworm in the **soybean** residue field on 12 June, 2001. The treatment differences were based on the plots proximity to rye, rather than the particular winter annual cereal; rye cover crop and rye forage plots were considered to be point 0.



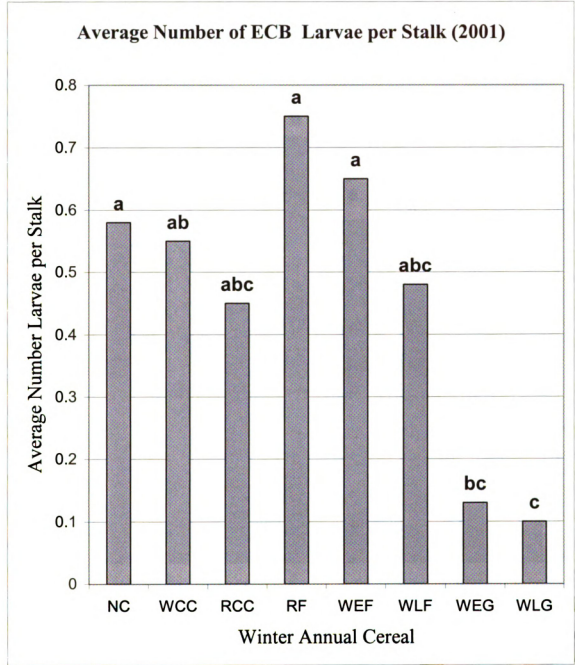
Armyworm damage based on proximity to rye was not significantly different when followed by the same letters at $P < 0.05$.

Figure 2.6: Percent of corn plants damaged by armyworm in the **corn silage** residue field on 12 June, 2001. The treatment differences were based on the plots proximity to rye, rather than the particular winter annual cereal; rye cover crop and rye forage plots were considered to be point 0.



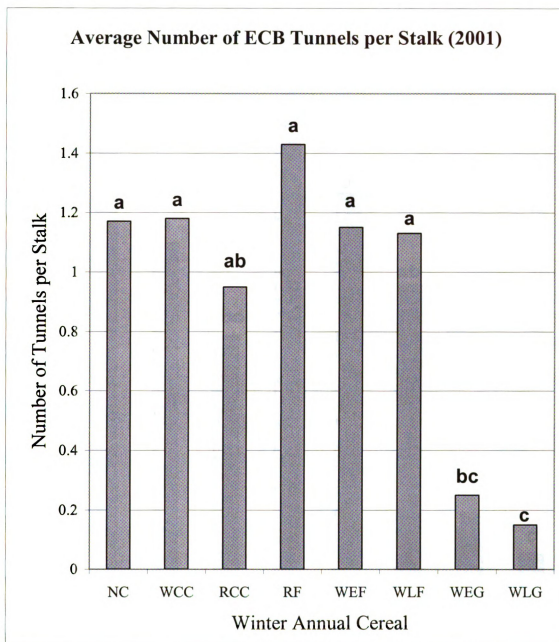
Armyworm damage based on proximity to rye was not significantly different when followed by the same letters at $P < 0.05$.

Figure 2.7: Average number of European corn borer larvae per corn stalk in relation to the preceding winter annual cereal in corn grain rotational plots, planted following harvest of winter annual cereals. Sampling done on 18 October, 2001.



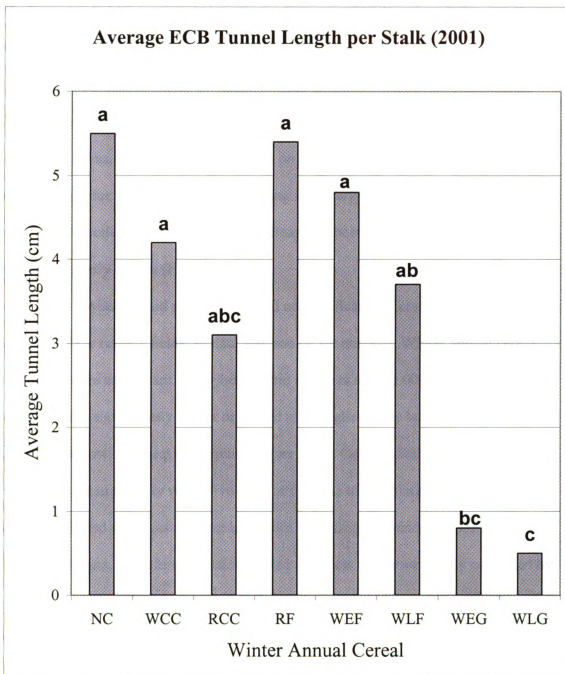
Winter annual cereal treatments followed by the same letter were not significantly different at $P < 0.05$.

Figure 2.8: Average number of European corn borer larvae per corn stalk in relation to the preceding winter annual cereal in corn grain rotational plots, planted following harvest of winter annual cereals. Sampling done on 18 October, 2001.



Winter annual cereal treatments followed by the same letter were not significantly different at $P < 0.05$.

Figure 2.9: Average European corn borer tunnel length per corn stalk in relation to the preceding winter annual cereal in corn grain rotational plots, planted following harvest of winter annual cereals. Sampling done on 18 October, 2001.



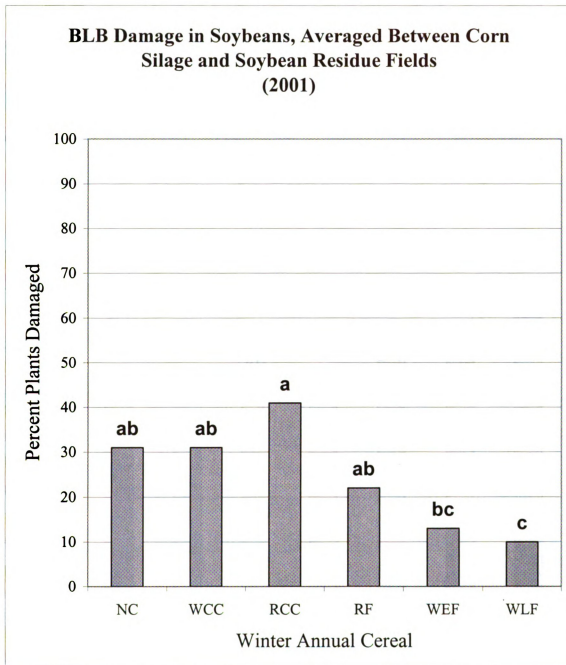
Winter annual cereal treatments followed by the same letter were not significantly different at $P < 0.05$.

wheat grain treatments. The stalks remained small and wet at the time of ECB second-generation moth flight (Figures 2.7-2.9). Only the corn grain rotational plots in the corn silage residue field were sampled, as a representation of ECB in corn following a winter annual cereal.

The winter annual cereal treatment was significant at $p < 0.01$ for bean leaf beetle (BLB) damage in soybeans. The BLB feeding was significantly higher in the earlier planted soybeans, (planting date dependant on winter annual cereal harvest date). This was probably due to the soybean plants being in an early developmental stage at the time of bean leaf beetle feeding (Figure 2.10). Bean leaf beetle feeding tends to be more prevalent in early season (Higley 1994).

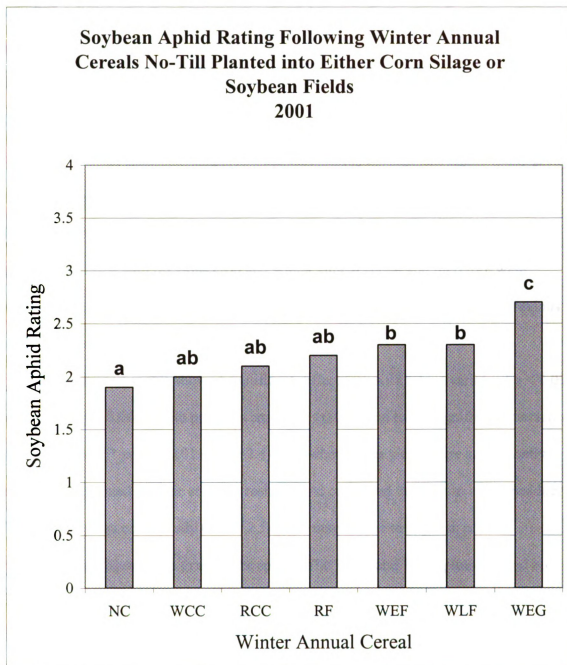
The soybean aphid numbers showed no significant differences between soybean and corn silage residue fields, so data was pooled for analysis. Winter annual cereal treatments were significant for soybean aphid numbers at $p < 0.001$. The soybean aphid numbers were significantly higher or tended to be higher in the late planted soybeans especially following wheat early grain (Figure 2.11). One possibility is the late-planted soybeans were in an early vegetative stage at the time of sampling due to late emergence. The later planted soybeans may not have been colonized by aphids as soon as earlier planted soybeans. Therefore, the later planted soybeans were more likely colonized by aphids from surrounding soybeans that already were infested by aphids. This “new” colonization may have contributed to an increased reproductive efficiency of the aphids on these plants. The soybean plants in the wheat late grain treatments had not emerged in most of the plots at the time of aphid sampling.

Figure 2.10: Bean leaf beetle damage in soybeans planted following winter annual cereal harvest (12 June 01)



Winter annual cereal treatments followed by the same letter were not significantly different at $P < 0.05$.

Figure 2.11: Soybean aphid rating on 8 August, 2001 in soybeans following winter annual cereals. Soybean aphid rating consisted of a 0-4 scale; 0 (no aphids), 1 (<10 aphids), 2 (10-24 aphids), 3(25-99aphids), and 4(>100 aphids) per trifoliolate leaf.



Winter annual cereal treatments followed by the same letter were not significantly different at $P < 0.05$.

Winter Annual Cereal Yields: There were significant differences in forage yields among winter annual cereals. The winter annual cereal forage yields showed no significant differences in year or previous crop, however there was a three way interaction of winter annual cereal * rotational crop * year in the forage yields. Later harvest dates contributed to significantly greater yields in both years of the study except for wheat early forage, which was significantly greater than the wheat late forage, in the corn silage residue field in 2001 (Tables 2.2-2.3). The rye forage had significantly greater yields in the corn silage residue field the first year, probably due to groundhog damage in the field where soybean was the previous crop. The yield differences by year, although significant, varied with previous crop and winter annual cereal and therefore were probably due to standard yield variances. The forage quality was reported in a previous paper (Thelen and Leep 2002).

Wheat grain yields showed significant differences with wheat variety at $p < 0.01$, with year at $p < 0.0001$, with previous crop at $p < 0.001$, and had a significant interaction of wheat variety * year at 0.01 (Table 2.4). The wheat grain yields were significantly higher when planted into the soybean residue field compared to the corn silage residue field in both years of the study (Table 2.5). This may be due to soybean plants contributing nitrogen to the grain in the spring. The WEG and WLG plots showed no significant difference in yield in 2000, however in 2001 the wheat late grain had a significantly greater yield (Table 2.6). The lower yield in the wheat early grain plots may be due to varietal differences.

Rotational Crop Yields: In 2000 there were no significant differences in soybean yields following winter annual cereal in the corn silage residue field (Table 2.7).

Table 2.2: The significance of factors and interactions affecting wheat (early and late harvested) forage yields, planted after corn or soybeans (two year average).

Factors and Interactions	Significance Level
Winter Annual Cereal	0.0001
Year	Not Significant
Winter Annual Cereal*year	0.0001
Previous crop	Not Significant
Winter Annual Cereal * Previous Crop	0.05
Year * Previous Crop	Not Significant
Winter Annual Cereal * Year * Previous Crop	0.05

Table 2.3: Yields of winter annual cereal forages no-till planted into corn silage or soybean residue fields, over two years. The first, second and third letters following the yield represent significant differences between winter annual cereal, previous crop and year respectively.

Winter Annual Cereal	Yield			
	2000		2001	
	Corn Silage Residue Field	Soybean Residue Field	Corn Silage Residue Field	Soybean Residue Field
	Mg ha⁻¹	Mg ha⁻¹	Mg ha⁻¹	Mg ha⁻¹
Rye forage	4.48 Aay	2.91 Aby	3.36 Aaz	3.81 Aaz
Wheat early forage	4.93 Aay	4.26 Bay	6.72 Caz	6.5 Baz
Wheat late forage	6.5 Bay	6.94 Cay	5.6 Baz	6.05 Baz

Treatment yields followed by the same letters were not significantly different at $P < 0.05$.

Table 2.4: The significance of factors and interactions for the following tables 2.6-2.7, showing yields for wheat (early and late maturing) grains harvested after no-till planting into soybean residue or corn silage residue fields over two years.

Factors and Interactions	Significance Level
Winter Annual Cereal	0.01
Year	0.0001
Wheat Variety * Year	0.01
Previous Crop	0.001
Wheat Variety * Previous Crop	Not Significant
Year * Previous Crop	Not Significant
Wheat Variety * Year * Previous Crop	Not Significant

Table 2.5: The interaction of year * previous crop in wheat grain yields following corn silage or soybean previous fields, over two years.

Previous Crop	Yield	
	2000	2001
	Mg ha ⁻¹	Mg ha ⁻¹
Corn Silage Residue	79.5a	65.7a
Soybean Residue	95.2b	72.5b

Treatment yields followed by the same letters were not significantly different at $P < 0.05$.

Table 2.6: The interaction of wheat variety * year in wheat grain yields (early and late maturing variety), following corn silage and soybeans over two years.

Previous Crop	Yield	
	2000	2001
	Mg ha ⁻¹	Mg ha ⁻¹
Wheat Early Grain	87.9a	63.9a
Wheat Late Grain	86.8a	74.3b

Treatment yields followed by the same letters were not significantly different at $P < 0.05$.

Table 2.7: Soybean yields following winter annual cereals no-till planted into corn silage or soybean residue fields.

Winter Annual Cereal	Yield	
	Corn Silage Residue Field Previous 2000	Soybean and Corn Silage Residue Fields 2001
	Mg ha ⁻¹	Mg ha ⁻¹
No Cover	3.6	2.8 b
Wheat Cover Crop	3.6	3.0 ab
Rye Cover Crop	3.2	3.1 a
Rye Forage	3.4	3.1 a
Wheat Early Forage	3.5	2.8b
Wheat Late Forage	3.5	2.64c
Wheat Early Grain	-	-
Wheat Late Grain	-	-

Treatment yields followed by the same letters were not significantly different.

However, soybean yields following NC and WCC tended to be greater, probably due to an earlier planting date. In 2001, there were no statistical differences in yields based on previous crop and no significant interaction of winter annual cereal * previous crop, so the yield data from plots in the soybean and corn silage residue fields was pooled for analysis. In 2001, soybean yield following winter annual cereal treatment was significant at $p < 0.001$ with RCC and RF having significantly higher soybean yield than NC, while soybean yield following the wheat cover crop tended to be greater than no cover (Table 2.7). This may be due to the winter annual cereals improving soil physical properties, such as increased soil aeration and water infiltration or the cover crops releasing N after burn down and rye forage roots releasing N from decomposition. Peterson and Varvel (1989 a) found soybean yields following sorghum but not corn, may be increased with fertilizer N additions. The soybeans following wheat grain were planted too late to reach maturity and were not harvested.

In 2000, the corn grain yields showed a significant difference following winter annual cereal treatment at $p < 0.01$. The corn grain yields were significantly higher or tended to be higher with earliest planting date, following NC being the highest (Table 2.8). Corn grain following wheat late forage yielded significantly less than corn following other winter annual cereals due to the late planting date. In 2001, there were no statistical differences in yields based on previous crop so the yield data from plots in the soybean and corn silage residue fields was pooled for analysis. The winter annual cereal treatment was significant for corn grain yield at $p < 0.001$, while previous crop and winter annual cereal * previous crop were not significant. The corn grain yields following NC, WCC and RCC were significantly greater than corn grain following other cover crops,

Table 2.8: Corn grain yields following winter annual cereals no-till planted into corn silage or soybean residue fields.

Winter Annual Cereal	Yield	
	Corn Silage Residue 2000	Soybean and Corn Silage Residue Fields 2001
	Mg ha ⁻¹	Mg ha ⁻¹
No Cover	12.1	8.6a
Wheat Cover Crop	12.0	7.4abc
Rye Cover Crop	11.7	8.4a
Rye Forage	11.5	6.9bc
Wheat Early Forage	10.2	5.7d
Wheat Late Forage	8.0	6.9bc
Wheat Early Grain	-	-
Wheat Late Grain	-	-

Treatment yields followed by the same letters were not significantly different.

again mainly due to an earlier planting date facilitated by the earlier removal of the winter annual cereal in these treatments. The armyworm infestation may have also contributed to a lower corn grain yield following the winter annual cereals. As in 2000, the corn grain following wheat grain in 2001 never reached maturity due to the late corn planting date and was not harvested.

In 2000, the corn silage yield was significant for winter annual cereal at $p < 0.0001$. The corn silage yield was significantly higher or tended to be higher with earlier planting date following winter annual cereal (Table 2.9). Corn silage yield following the wheat and rye cover crop tended to be greater, possibly due to N release following burn down or improved soil physical properties. Peterson and Varvel (1989 b) reported greater yields in corn following legumes. The rainfall was above the 30-year average in July 2000 (Table 2.10). This precipitation may have contributed rain at a key time for corn silage taking up soil N after cover crop release. Corn moisture stress around silking is the most detrimental time for yields (Clark et al. 1997). Corn may benefit from later plantings when silking occurs during timely July and August rains (Clark et al. 1997). In 2001, there were no significant differences between previous crop, so the yields were averaged between corn silage residue and soybean residue fields, however corn silage following winter annual cereal treatment was significant at $p < 0.0001$. Corn silage yields were significantly lower or tended to be lower with later planted corn, similar to 2000 (Table 2.10). The rainfall was below the thirty-year average in July 2001 (Table 2.2). Peterson and Varvel (1989 b) showed lack of rain during pollination (July) may reduce corn yields.

Table 2.9: Corn silage yields following winter annual cereals no-till planted into corn silage or soybean residue fields.

Winter Annual Cereal	Yield	
	Corn Silage Residue 2000	Soybean and Corn Silage Residue 2001
	Mg ha ⁻¹ (DM)	Mg ha ⁻¹ (DM)
No Cover	17.9	11.6 a
Wheat Cover Crop	18.6	11.2 ab
Rye Cover Crop	19.7	10.1 bc
Rye Forage	16.1	8.7 cd
Wheat Early Forage	16.4	8.5 d
Wheat Late Forage	14.3	9.2 cd
Wheat Early Grain	5.8	5.4 e
Wheat Late Grain	4.5	3.1 f

Treatment yields followed by the same letters were not significantly different.

Table 2.10: Monthly precipitation and growing degree unit (GDU) accumulation for the 1999 through 2001 winter annual and rotational crop growing seasons at the experimental location. Thirty-year means have been included for comparison (1971-2000).

Month	Precipitation				Growing Degree Units			
	1999	2000	2001	30 yr	1999	2000	2001	30 yr
	---- Millimeters ----				---- Degrees Centigrade ----			
May	-	134.6	144.8	68.6	-	193	191	128
June	-	78.7	83.8	78.7	-	294	281	263
July	-	94.0	22.9	76.2	-	288	333	337
August	-	86.4	40.6	86.4	-	314	338	308
September	40.6	111.8	101.6	86.4	213	208	174	173
October	20.3	53.3	137.2	61.0	75	131	51	43
Seasonal Total	61.0	558.8	393.7	457.2	306	1517	1457	1341

GDU calculated for corn at a base 10°C, with 10°C and 30°C minimum and maximum temperatures.

Data recorded at the Horticultural Research Station, East Lansing, MI.

Economics: The economics showed the greatest profit when incorporating a winter annual forage into the cropping system, whether followed by soybeans, corn grain, or corn silage (Table 2.11). This was due to the added value of a forage crop in all systems and the higher yield of soybeans following rye forage. Cropping systems including wheat and rye cover crops still made a profit, although reduced from no cover. However, the economic analysis did not consider the long-term environmental and soil quality aspects associated with cover crops. The cropping systems with wheat grains showed little profit when followed by corn silage and loss when followed by soybean or corn grain. The wheat grain cropping systems had rotational crops planted too late for adequate maturation time, demonstrating that a wheat grain-double crop system is usually not feasible at the Northern latitude associated with the East Lansing study site.

Conclusions:

Integrating a winter annual cereal into a corn-soybean rotation will increase the ground cover and residue present, which may improve the soil physical properties. The presence or damage by insect pests mainly depends on the timing of rotational crop planting, which is based on whether the winter annual cereal is burned down, harvested for forage or harvested for grain. Although, wheat and rye winter annual cereals increase the likelihood of an armyworm infestation. If the wheat or rye is burned down with glyphosate, there is an increased chance of the armyworms moving to adjacent fields or plots of corn to find a source of food. ECB moth flight does not coincide with very late-planted corn, such as that planted following harvest of a wheat grain crop, therefore tunneling will not take place in this corn. BLB damage is often higher in soybeans with

Table 2.11: Economic net return of following a winter annual cover crop, forage or grain by soybeans, corn grain or corn silage.

Net Return in \$/Hectare					
Winter Annual Cereal	Rotation	Forage	Wheat Grain	Rotational Crop	Cropping System
No Cover	Soybean	-	-	55.39	337.33 c
Wheat Cover	Soybean	-	-	41.54	252.81 d
Rye Cover	Soybean	-	-	39.49	251.70 d
Rye Forage	Soybean	3.71	-	57.75	379.86 c
Wheat Early Forage	Soybean	28.84	-	54.46	463.00 b
Wheat Late Forage	Soybean	32.01	-	56.97	583.35 a
Wheat Early Grain	Soybean	-	41.74	-55.45	-59.54 e
Wheat Late Grain	Soybean	-	49.84	-60.07	-71.28 e
No Cover	C. Silage	-	-	92.63	560.79 ab
Wheat Cover	C. Silage	-	-	78.38	469.90 bc
Rye Cover	C. Silage	-	-	80.89	485.92 bc
Rye Forage	C. Silage	3.71	-	63.15	423.64 c
Wheat Early Forage	C. Silage	28.84	-	69.04	607.25 a
Wheat Late Forage	C. Silage	32.01	-	60.36	520.27 abc
Wheat Early Grain	C. Silage	-	41.74	-11.32	211.56 d
Wheat Late Grain	C. Silage	-	49.84	-34.44	96.86 d
No Cover	C. grain	-	-	62.90	383.33 ab
Wheat Cover	C. grain	-	-	42.82	260.93 c
Rye Cover	C. grain	-	-	45.79	279.12 c
Rye Forage	C. grain	3.71	-	48.17	324.73 bc
Wheat Early Forage	C. grain	28.84	-	36.86	438.60 a
Wheat Late Forage	C. grain	32.01	-	35.61	421.47 a
Wheat Early Grain	C. grain	-	41.74	-83.63	-231.63 d
Wheat Late Grain	C. grain	-	49.84	-83.63	-82.84 d

Economic values followed by the same letters within a rotational cropping system were not significantly different at $P < 0.05$.

an earlier planting date such as those planted following burn down of wheat and rye rather than following wheat or rye harvested as forage or grain. Soybean aphid numbers tend to be higher in later planted soybeans such as those following a wheat grain crop, probably due to colonization by generations of aphids from neighboring soybean plots that were previously colonized. Planting wheat and rye for a forage will add a second profitable crop to the system. The later harvested forages have a higher yield than the earlier harvested forages, but a lower plant quality. Double cropping with wheat for grain will provide a small grain profit, but the late planting of soybeans or corn following wheat grain harvest is not profitable in the northern climates such as Michigan.

Rotational crop yields following winter annual cereals tend to be higher with an earlier rotational crop planting date for both soybeans and corn. The rotational crop planting date occurs after the burn down or harvest of the winter annual cereal and therefore is dependent on whether the winter annual cereal is used for a cover crop, a forage or a grain. The only exception to this is soybeans following a cover crop have a greater yield over no cover crop. The overall economics of the system depend on whether the winter annual cereal is burned down, harvested for a forage or for a grain. Integrating a wheat or rye forage into the system will increase the net profit to the system over no cover, especially when followed by soybeans, although also when followed by corn silage or corn grain. Although the wheat and rye cover crops burned down with glyphosate do not show a short-term economic benefit, the long-term environmental benefits of improving soil physical properties and nutrient dynamics was not measured by this study.

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