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ABSTRACT OF THESIS

COVER CROPS AND TILLAGE SYSTEMS FOR ORGANIC CORN PRODUCTION IN KENTUCKY

Organic corn (*Zea mays L.*) producers generally use intensive tillage for weed control. No-till methods reduce soil erosion, conserve water, maintain soil structure and reduce CO₂ emissions. The objective of this study was test different cover crops, tillage systems, N sources and N rates for organic corn production. Two tillage systems (no-till and moldboard plow), two cover crops [hairy vetch (*Vicia villosa*) and rye (*Secale cereale*)] and two organic N sources [Louisville Green (LG) and Nature Safe (NF)] at four N rates (45, 90, 135, 180 kg N ha⁻¹) were evaluated during 2008 and 2009 at three sites. A roller crimper device was used for the no-till operations. A long term aerobic incubation was conducted. Hairy vetch improved yield, ear leaf N and grain N content compared with rye in all sites. Nature Safe increased ear leaf N more than LG in all three sites and yield in two out of three sites. Both sources stopped mineralizing at 28 days after application. Inorganic N production was about 50 kg N ha⁻¹ for LG and 60 kg N ha⁻¹ for NF. The combination moldboard plow and hairy vetch resulted in the highest yields at all experimental sites.

KEYWORDS: Organic production, Moldboard plow, No-till, Roller-crimper, N mineralization.

Alfonso Suarez Tapia

10/22/2010

COVER CROPS AND TILLAGE SYSTEMS FOR ORGANIC CORN PRODUCTION IN
KENTUCKY

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THESIS

Alfonso Suarez

The Graduate School
University of Kentucky

2010

COVER CROPS AND TILLAGE SYSTEMS FOR ORGANIC CORN PRODUCTION IN
KENTUCKY

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Alfonso Suarez

Lexington, Kentucky

Director: Dr. Larry Grabau, Professor of Plant and Soil Sciences

Lexington, Kentucky

2010

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ACKNOWLEDGMENTS

I would like express my gratitude to God for giving me strength to complete my studies. I would like to thank to all the people in Ecuador and in the US that made this accomplishment possible. First I would like to thank to my mother Maria Esther Tapia, for her support and encouragement during all my life. Second, I would like to thank Dr. Larry Grabau, who supported me throughout the many steps of this thesis project. I would like to thank the Department of Plant and Soil Sciences at the University of Kentucky that helped me process the samples and with the laboratory analysis. I would like to thank Laura Harris for her help during the field work, especially during the activities that involved the use of the roller crimper. I would like also to thank the persons in the Statistics Department that helped me with SAS: Dr. Cidambi Srinivasan and Angela Schoergendorfer. I would like to thank John and Josiah, our past interns, for their help during the sampling and processing of ear and grain samples. I also want to thank the graduate students that help me throughout these years. I would like to recognize three former graduate students (Vicente Vasquez, Soraya Alvarado and Eduardo Rienzi) for their friendship and help throughout these years.

Finally, I would like to thank the Department of Plant and Soil Sciences at the University of Kentucky for giving me the opportunity to complete one of my dreams.

TABLE OF CONTENTS

Acknowledgments.....	iii
List of Tables.....	vii
List of Figures.....	i
Chapter One: Introduction -----	1
Organic production -----	1
Literature Review -----	5
Cover crops and tillage in corn production-----	5
Cover crops-----	5
Amount of N contributed by legume cover crops -----	5
Tillage practices-----	7
Changes in soil C and soil N with tillage-----	7
Cover crops and tillage effects on corn ear leaf N and grain N -----	8
N release from tilled soils -----	11
No-till in organic corn production-----	11
Control of weeds in organic grain systems-----	12
Use of cover crops for weed control-----	14
Timing for killing cover crops rye and hairy vetch -----	16
N in nature -----	17
N cycle -----	17
N fertilizer sources-----	19
Use of organic amendments for corn production -----	19
N sources from organic residues commercialized in Kentucky -----	19
Use of biosolids for corn production -----	20
Timing of N uptake by corn -----	21
Chapter Two: Materials and Methods -----	22
Experimental sites -----	22
Cultural practices -----	22
Cover crops-----	22
Tillage -----	27
Planting -----	27
Fertilizer sources-----	27
Corn sampling -----	28
Corn stages and climatic data -----	28
Stand establishment sampling-----	28
Ear leaf N sampling -----	28
Yield sampling -----	28
Grain N-----	29
Weeds -----	29
Mineralization-----	29
Statistical Analysis-----	30
Field data-----	30
Mineralization-----	31
Chapter Three: Results -----	32
Experimental site conditions for cover crop and corn growing seasons-----	32
Temperature during cover crop season -----	32

Precipitation during cover crop season -----	34
Temperature during the corn growing season -----	34
Precipitation during the corn growing season -----	37
Soil fertility characteristics -----	37
Cover crops for corn production -----	40
Cover crop and site main effects -----	40
Interactions for cover crops -----	40
Cover crop biomass -----	40
C concentration -----	40
C content -----	43
Crop responses -----	45
Spindletop 2008 experimental site -----	45
Main effects for Spindletop 2008 -----	45
Interactions for Spindletop 2008 -----	45
Ear leaf N interactions Spindletop 2008 -----	45
Cover crop x tillage -----	45
Cover crop x tillage x N rate -----	49
N source x N rate -----	49
Tillage x N source x N rate -----	49
Yield interactions Spindletop 2008 -----	49
Cover crop x tillage -----	49
Tillage x N rate -----	52
Grain N interactions Spindletop 2008 -----	52
Cover crop x tillage -----	52
Cover crop x N rate -----	52
UKREC 2008 experimental site -----	55
Main effects for UKREC 2008 -----	55
Interactions for UKREC 2008 -----	55
Ear leaf N interactions for UKREC 2008 -----	55
Cover crop x N source -----	55
Yield interactions for UKREC 2008 -----	59
Cover crop x tillage -----	59
Grain N interactions for UKREC 2008 -----	59
Cover crop x N source -----	59
Cover crop x tillage x N source -----	59
Tillage x N source x N rate -----	59
UKREC 2009 experimental site -----	62
Main effects for UKREC 2009 -----	62
Interactions for UKREC 2009 -----	62
Ear leaf N interactions for UKREC 2009 -----	62
Tillage x N rate -----	62
Cover crop x N source x N rate -----	62
Yield interactions for UKREC 2009 -----	66
Cover crop x tillage -----	66
Cover crop x N rate -----	66
Grain N interactions for UKREC 2009 -----	66
Cover crop x Tillage -----	66
Weed responses in Spindletop 2008 -----	70
Main effects of weed responses for Spindletop 2008 -----	70
Interactions of weed responses for Spindletop 2008 -----	70

Grass number-----	70
Cover crop x tillage -----	70
Grass weight-----	70
Cover crop x Tillage x N rate-----	70
Weed responses in UKREC 2009 -----	70
Main effects of weed responses for UKREC 2009-----	70
Interactions of weed responses for UKREC 2009-----	75
Broadleaf number-----	75
Cover crop x Tillage x N rate-----	75
Mineralization Experiment Results -----	78
NO ₃ ⁻ accumulation -----	78
Main effects of method of application, N source, N rate at 56 days of aerobic incubation--	78
Interactions of method of application, N source, and N rate after 56 days of aerobic	
incubation. -----	82
N source x Method -----	82
N source x rate -----	82
Method x N source x N rate-----	82
NO ₃ ⁻ k values -----	82
NH ₄ ⁺ accumulation-----	86
Main effects of method of application, N source, N rate after 56 days of aerobic incubation	
-----	86
Interactions of method of application, N source, and N rate after 56 days of aerobic	
incubation. -----	86
Method x N source -----	86
NH ₄ ⁺ k values -----	93
Chapter Four: Discussion -----	95
Cover crops -----	95
Weed effects -----	97
N sources and mineralization experiment -----	99
Crop variables -----	100
Stand establishment -----	100
Ear leaf N -----	100
Corn grain yields-----	104
Grain N-----	106
Chapter Five: Conclusions -----	107
References-----	109
Vita-----	113

LIST OF TABLES

Table 1.1. Comparison between organic and conventional feed grade grain prices during 2007 and 2008. Organic feed grain prices correspond to the average of the grain traded in the Eastern Corn Belt and Upper Midwest and conventional grain prices are the average received by US farmers.	3
Table 1.2. Total soil C and N averaged over 2001 and 2002 comparing different conventional systems (cover crop, no-till) and a organic system.	10
Table 3.1. Initial soil fertility conditions for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.	39
Table 3.2. Cover crop response to main effects and their interaction depending on the experimental site and cover crops used.	41
Table 3.3. Corn crop performance under cover crop, tillage, N source and N rate for Spindletop 2008.	46
Table 3.4. Corn crop interactions for cover crop, tillage, N source and N rate for Spindletop 2008.	47
Table 3.5. Corn crop performance under cover crop, tillage, N source and N rate at the UKREC 2008 experimental site.	56
Table 3.6. Corn crop interactions for cover crop, tillage, N source and N rate at the UKREC 2008 experimental site.	57
Table 3.7. Corn crop performance under cover crop, tillage, N source and N rate at the UKREC 2009 experimental site.	63
Table 3.8. Corn crop interactions for cover crop, tillage, N source and N rate at UKREC 2009 experimental site.	64
Table 3.9. Main effects of cover crop, tillage, Nature Safe N rate (0, 90, 180 kg N ha ⁻¹) at Spindletop 2008 and their effects on weed measurements.	71
Table 3.10. Interactions for cover crop, tillage, and Nature Safe N rates (0, 90, 180 kg N ha ⁻¹) at Spindletop 2008 and their effects on weed measurements.	72
Table 3.11. Main effects of cover crop, tillage and Nature Safe N rates (0, 90, 180 kg N ha ⁻¹) at UKREC 2009 and their effect on weed measurements.	74
Table 3.12. Interactions for cover crop, tillage, and Nature Safe N rates (0, 90, 180 kg N ha ⁻¹) at UKREC 2009 and their effects on weed measurements.	76
Table 3.13. Effect of method of application, N source, N rate on NO ₃ ⁻ accumulation after 56 days of aerobic N mineralization.	81

Table 3.14. Interaction of method of application, N source, N rate on NO_3^- accumulation after 56 days of aerobic N mineralization.	83
Table 3.15. k values for NO_3^- production with two N sources with two methods of application.	87
Table 3.16. Effect of method of application, N source, N rate on NH_4^+ accumulation after 56 days of aerobic N mineralization.	90
Table 3.17. Interaction of method of application, N source, N rate on NH_4^+ accumulation after 56 days of aerobic N mineralization.	91
Table 3.18. k values for NH_4^+ production with two N sources with two methods of application.	94
Table 4.1. Effects and interactions of cover crop, tillage and Nature Safe N rate (0, 90, 180 kg N ha^{-1}) on weed measurements at Spindletop 2008 and UKREC 2009.	98
Table 4.2. Main effects and interactions of cover crops, tillage, N source and N rate on corn responses in three experimental sites.	101

LIST OF FIGURES

Figure 1.1. Roller crimper constructed by the University of Kentucky based on Rodale Institute plans	13
Figure 1.2. N cycle.....	18
Figure 2.1. Diagram of the experimental sites showing where soil samples were taken (Netstate, 2009).....	23
Figure 2.2. Diagram of the experimental site Spindletop 2008. Nitrogen sources were identified as Nature Safe (NF) and Louisville Green (LG) and N rates were 0 (control), 45, 90, 135, 180 kg N ha ⁻¹	24
Figure 2.3. Diagram of the experimental site UKREC 2008. Nitrogen sources were identified as Nature Safe (NF) and Louisville Green (LG) and N rates were 0 (control), 45, 90, 135, 180 kg N ha ⁻¹	25
Figure 2.4. Diagram of the experimental site UKREC 2009. Nitrogen sources were identified as Nature Safe (NF) and Louisville Green (LG) and N rates were 0 (control), 45, 90, 135, 180 kg N ha ⁻¹	26
Figure 3.1. Comparison of the average monthly temperature during the cover crop (CC) growing season for Spindletop 2007-2008, UKREC 2007-2008 and UKREC 2008-2009.	33
Figure 3.2. Departure from 30-yr (1971-2000) normal monthly temperatures for cover crop (CC) growing seasons for Spindletop 2007-2008, UKREC 2007-2008 and UKREC 2008-2009.	33
Figure 3.3. Comparison of the total monthly precipitation during the cover crop (CC) growing seasons for Spindletop 2007-2008, UKREC 2007-2008 and UKREC 2008-2009.....	35
Figure 3.4. Departure from 30-yr (1971-2000) normal monthly precipitation for cover crop (CC) growing seasons for Spindletop 2007-2008, UKREC2007-2008 and UKREC 2008-2009.	35
Figure 3.5. Comparison of the average monthly temperature during the corn growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.....	36
Figure 3.6. Departure from 30-yr (1971-2000) normal monthly temperatures for the corn growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.	36
Figure 3.7. Comparison of total monthly precipitation during the crop growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.....	38
Figure 3.8. Departure from 30-yr (1971-2000) normal monthly precipitation during the crop growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009..	38
Figure 3.9. Biomass yield response to cover crop and experimental site.	42
Figure 3.10. C concentration in response to type of cover crop and experimental site.	42

Figure 3.11. C content in response to cover crop and experimental site.	44
Figure 3.12. Ear leaf N response to tillage and cover crop, Spindletop 2008.....	48
Figure 3.13. Ear leaf N response to cover crop x tillage x N rate (45, 90, 135, 180 kg N ha ⁻¹), Spindletop 2008.	50
Figure 3.14. Ear leaf N response to N source, and N rate (45, 90, 135, 180 kg N ha ⁻¹), Spindletop 2008.	50
Figure 3.15. Ear leaf N response to tillage, N source, and N rate (45, 90, 135, 180 kg N ha ⁻¹), Spindletop 2008.	51
Figure 3.16. Corn grain yield response to tillage and cover crop, Spindletop 2008.	51
Figure 3.17 a and b. Corn yield response to tillage and N rate. Absolute yield (panel A) and relative yield response (panel B), Spindletop 2008.	53
Figure 3.18. Grain N response to cover crop and tillage, Spindletop 2008.	54
Figure 3.19. Grain N response to cover crop and N rate (45, 90, 135, 180 kg N ha ⁻¹), Spindletop 2008.	54
Figure 3.20. Ear leaf N response to cover crop and N source, UKREC 2008.	58
Figure 3.21. Corn grain yield response to cover crop and tillage, UKREC 2008.....	60
Figure 3.22. Grain N response to cover crop and N source, UKREC 2008.....	60
Figure 3.23. Grain N response to cover crop, tillage and N source, UKREC 2008.....	61
Figure 3.24. Grain N response to tillage, N source and N rate (45, 90, 135, 180 kg N ha ⁻¹), UKREC 2008.....	61
Figure 3.25. Ear leaf N response to tillage and N rate, UKREC 2009.....	65
Figure 3.26. Ear leaf N response to cover crop, N source and N rate (45, 90, 135, 180 kg N ha ⁻¹), UKREC 2009.....	65
Figure 3.27. Corn grain yield response to cover crop and tillage, UKREC 2009.....	67
Figure 3.28 a and b. Corn grain yield response to cover crop and N rate (panel A) and relative corn grain yield response to cover crop and N rate, UKREC 2009 (panel B).	68
Figure 3.29. Grain N response to cover crop and tillage, UKREC 2009.	69
Figure 3.30. Number of grass plants in response to tillage and cover crops for Spindletop 2008.	73
Figure 3.31. Grass number response to cover crops, tillage and N treatments (control, NF 90 kg N ha ⁻¹ and NF 180 kg N ha ⁻¹) for Spindletop 2008.....	73
Figure 3.32. Broadleaf number response to cover crop, tillage and N rate (control, NF 90 kg N ha ⁻¹ and NF 180 kg N ha ⁻¹), UKREC 2009.	77

Figure 3.33 a and b. NO_3^- accumulation with surface application for Louisville Green (panel A) and NO_3^- accumulation with incorporation for Louisville Green (panel B).	79
Figure 3.34 a and b. NO_3^- accumulation with surface application for Nature Safe (NF) (panel A) and NO_3^- accumulation with incorporation for Nature Safe (panel B).....	80
Figure 3.35. N source and application method interaction on NO_3^- accumulation after 56 days of aerobic mineralization.....	84
Figure 3.36. N source and N rate interaction on NO_3^- accumulation after 56 days of aerobic mineralization. N sources are averaged across methods of application.....	84
Figure 3.37. Method, N source and N rate interaction on NO_3^- accumulation after 56 days of aerobic mineralization.....	85
Figure 3.38 a and b. NH_4^+ accumulation with surface application for Louisville Green (panel A) and NH_4^+ accumulation with incorporation for Louisville Green (panel B).....	88
Figure 3.39 a and b. NH_4^+ accumulation with surface application for Nature Safe (panel A) and NH_4^+ accumulation with incorporation for Nature Safe (panel B).	89
Figure 3.40. Method and N source effect for NH_4^+ accumulation after 56 days of aerobic mineralization.	92

Chapter One: Introduction

Organic production

In 1990, the Organic Foods Production Act was created to facilitate the production and marketing of domestic food as well to guarantee consumers that the product they buy meets USDA standards for organic food (Greene and Kremen, 2002). Organic agriculture is defined by the USDA as “an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony.” (Gold, 2007). Thus, organic agriculture is a system to produce food, fiber and fuel without the use of synthetic compounds such as fertilizers and pesticides. Half of the \$7.8 billion spent on organic food in 2000 was on purchases in conventional retail outlets (Demitri and Greene 2002). In 2003, retail organic sales in the European Union were about \$13 billion (€10 billion). In the same year, US retail organic sales were about \$10.4 billion (€8 billion). Per capita retail sales were approximately \$34 in the European Union and \$36 in the U.S. in that year. The European Union and the U.S. together accounted for 95 percent of the \$25 billion in world retail sales of organic food products in 2003. However, European farmers have the advantage of getting paid for providing environmental services (Demitri and Oberholtzer, 2006). The 2008 farm bill promoted organic agriculture and provided a cost share for organic certification with a cap of \$750 per operation (USDA Economic Research Service, 2009a).

Organic products earn higher prices; that results from higher production and distribution costs for organic goods along with the willingness of consumers to pay higher prices for such products. In a recent study, Batte et al. (2007) found that consumers in seven central Ohio grocery stores were willing to pay premium prices for organic foods, even for those that were not 100% organic. However, this willingness to pay is associated with demographic variables. For instance, older consumers, higher income consumers and consumers with children are willing to pay higher premiums for organic food (Batte et al., 2007). Consumers prefer organically produced food because they are concerned about their health and animal welfare. As long as the demand increases faster than the supply, prices will continue to increase. Such a price premium is one of the main reasons why the retail sales have grown from \$3.5 billion in 1997 to \$10.4 billion in 2003 (Demitri and Oberholtzer, 2005). This increase in organic sales has pushed an increase in the amount of cultivated land under organic practices. The area devoted to organic crops nearly doubled between 1992 and 1997 and again between 1997 and 2001 (Greene and Kremen, 2002).

More recently, the area of organic corn has increased from 31,540 ha in 2000 to 78,804

ha in 2008 (150%). In 2008, organic corn represented about 21.5% of the total organic US production (USDA-ERS, 2009b). The organic corn prices for feed grade in the Eastern Corn Belt averaged \$360.64 Mg⁻¹ and \$408.18 Mg⁻¹ in 2007 and 2008, respectively. On the other hand, the average farm prices of conventional feed grade corn paid during 2007 and 2008 were \$165.00 Mg⁻¹ and \$153.21 Mg⁻¹, respectively (Table 1, USDA-ERS, 2009c). The main uses of organic feed grade grains in the US are in the organic beef, milk, poultry and pork industries. The animals from which meat, milk and eggs come from must be raised separately from their conventional counterparts. These animals are not provided with antibiotics or growth hormones. However preventive medicinal care (vitamins, minerals, vaccines) are allowed (Demitri and Greene, 2002).

McBride and Greene (2009) found that the likelihood of an operation to go toward organic soybean production depended on its size. Since organic farms are more labor intensive than conventional ones, smaller farms could reorganize resources better toward organic production practices more easily than could larger farms (McBride and Greene, 2009).

Many recent studies suggest that organic agriculture can produce as much grain as conventional agriculture. In Wisconsin, an experiment initiated in 1993 compared several organic cropping systems with a conventional cropping system. The crops used were cash-crops frequently used in the region: corn, soybean, alfalfa and oats (Posner et al., 2008). These researchers found during five years of this experiment (1993-1998), that the cropping system with the highest corn yield was conventional corn-corn-alfalfa (*Medicago sativa* L.) system with 10.15 Mg ha⁻¹. The organic counterpart that followed in corn yield was an input system of corn-alfalfa-oat (*Avena sativa* L.) plus field pea (*Pisum sativum* L.) mix, followed by a year of alfalfa hay (livestock and crop- enterprise). This system yielded 8.95 Mg ha⁻¹ of corn grain which is 88% as much as the conventional corn-alfalfa mentioned above in the five years of this experiment. The major yield barrier was weed control, which is very difficult in organic systems without the use of herbicides.

Delate and Cambardella (2004) using different crop rotations, nutrient management and weed control strategies found that during the three year transition period to organic certification, organic corn yields were not significantly different from conventional corn. Moreover, during the fourth year of their experiment, organic corn yields were higher than conventional yields (Delate and Cambardella, 2004) which according with the authors might be due to a timely management of weeds and levels of N, P and K in the sufficiency ranges.

Table 1.1. Comparison between organic and conventional feed grade grain prices during 2007 and 2008. Organic feed grain prices correspond to the average of the grain traded in the Eastern Corn Belt and Upper Midwest and conventional grain prices are the average received by US farmers.³

	2007 average organic grain prices	2007 average conventional grain prices	2008 average organic grain prices	2008 average conventional grain prices	Difference organic vs conventional 2007	Difference organic vs conventional 2008
Grain	(\$ Mg ⁻¹) ¹	(\$ Mg ⁻¹) ²	(\$ Mg ⁻¹) ¹	(\$ Mg ⁻¹) ²	%	%
Feed grade wheat	308.37	237.60	521.58	248.60	+30	+110
Feed grade corn	360.64	165.00	408.18	153.21	+119	+166
Feed grade soybean	548.53	370.33	906.58	339.17	+48	+167
Feed grade barley	297.46	222.75	366.21	154.92	+34	+136

¹ Based on a weighted average, FOB and negotiated spot market, reported in USDA, AMS Eastern Cornbelt Organic Grain & Feedstuffs Report.

² Seasonal average by crop year received by US farmers.

³ Adapted from ERS-USDA (USDA -ERS, 2009 and USDA-ERS, 2009d).

Cavigelli et al. (2009) identified adequate weed control and sufficient N nutrition as the main challenges in organic corn production in order to obtain yields similar to conventional corn. Among the strategies used to obtain high organic yields, while controlling weeds and improving soil fertility, US researchers have used: cover crops (Mischler et al., 2010), cropping systems with adequate rotations (Delate and Cambardella, 2004; Posner et al., 2008; Teasdale et al., 2007), tillage and manure management (Delate and Cambardella, 2004).

The recommended cover crops for Kentucky due to their adaptation to existing climatic conditions are hairy vetch (*Vicia villosa*) and rye (*Secale cereale*), both of which have been tested in no-till agriculture (Blevins et al., 1990; Ebelhar et al., 1984; Utomo et al., 1990). The extensive root system of rye allows this plant to capture soil nitrates from previous seasons and thus reduce nitrate leaching (Crandall et al., 2005; Miguez and Bollero, 2006; Shipley et al., 1992). Meanwhile, hairy vetch can provide N for the subsequent corn crop through N₂ fixation (Blevins et al., 1990; Ebelhar et al., 1984; Frye and Blevins, 1989; Hargrove, 1986). No-till agriculture often uses synthetic herbicides to kill cover crops. In organic agriculture, such herbicides are not permitted, thus some researchers have developed a roller crimper device in order to kill cover crops without tillage (Ashford and Reeves, 2003; Mischler et al., 2010).

In order to establish the possibility of growing organic corn in Kentucky under a no-till system, this study was carried out at Lexington (2008 only) and Princeton (both 2008 and 2009). The purpose of this study was to evaluate the effects of cover crops, tillage systems and two organic N sources at four N rates in production of organic corn in three experimental sites in Kentucky. Furthermore, the organic sources used in this study were tested in a long term aerobic mineralization study in order to determine the patterns of mineralization for these sources since they recently arrived to the Kentucky market.

Literature Review

Cover crops and tillage in corn production

Cover crops

Farmers and researchers have tried to improve soil quality through management of soil organic matter (SOM). The practices that influence SOM include planting techniques, residue management, organic amendments, crop rotations and the use of cover crops. Moreover, improving SOM helps build soil strength (biological, physical, chemical) and thus enhances water storage and root development (Weil and Magdoff, 2004).

A cover crop is one that is grown with the purpose of soil protection and to improve the soil quality between periods of regular crop production (Brady and Weil, 2008). Moreover, cover crops offer environmental benefits like control of erosion, water conservation and control of nitrate losses (Blevins et al., 1990). Cover crops can be legumes or cereals planted in fall and grown through winter, then killed in spring in order to serve as a source of organic matter and nutrient for the following cropping season. Cover crops have been studied for corn production with a variety of results under till and no-till management (Bollero and Bullock, 1994; Ebelhar et al., 1984; Mischler et al., 2010).

Amount of N contributed by legume cover crops

Blevins et al. (1990) found higher N content (above ground) for hairy vetch, followed by big flower vetch (*Vicia grandiflora*), and finally rye. These authors found that the fertilizer N equivalent was 75 kg N ha⁻¹ for vetch and 65 kg N ha⁻¹ for bigflower vetch. These amounts compared the two types of vetch against a fallow control. When the vetch species were compared with rye the equivalent amounts were 85 kg N ha⁻¹ for hairy vetch and 75 kg N ha⁻¹ for big flower vetch. Note that this study was based on the yield response curves and did not take into account the rotational effect of corn produced after a legume (Blevins et al., 1990). In Illinois, Bollero and Bullock (1994), estimated the N contribution of hairy vetch as the difference in the economical optimal N rate in three systems, corn after hairy vetch, corn after rye and corn after fallow. They used this approach since the economical optimum is the level at which farmers will work rather than at the 0 kg N ha⁻¹ that the fertilizer equivalent methodology assumes. They found out that the N contribution of hairy vetch was only 22.5 kg ha⁻¹. Moreover, these authors found that taking into account the cost of cover crop operation, a farmer would incur a net loss of \$69.2 ha⁻¹ with the inclusion of hairy vetch as cover crop. They concluded that the N contribution

and the rotational effect of this cover crop were not enough to compensate for its cost (Bollero and Bullock, 1994). Hargrove (1986) in Georgia, tested the potential of five cover crops [rye, crimson clover (*Trifolium incarnatum*), subterranean clover (*Trifolium subterraneum*), hairy vetch and common vetch (*Vicia sativa*)]. He found no difference in dry matter production by the five cover crops. However, when the cover crops were analyzed for N content, hairy vetch and crimson clover had significantly higher N content than the other cover crops over the three years of this experiment. Moreover, all legume cover crops had a superior N content than did rye. The subsequent cash crop in this experiment was sorghum (*Sorghum bicolor*) and yields of this crop did not respond to N fertilizer when following a legume but did after a non legume. Sorghum yields, averaged over three years, were higher with legumes than with either fallow or rye. Hargrove (1986) calculated the amount of N provided by the legume crops without using the fertilizer replacement value of previous authors (Blevins et al., 1990; Ebelhar et al., 1984; Mitchell and Teel, 1977). Instead, he calculated it based on the N rate at which maximum grain N content occurred since is a more direct approach to calculate the N contribution without confounding it with rotational effects. Hargrove (1986) calculated that the N contribution for the legumes after fallow averaged 78 kg N ha⁻¹ and after rye averaged 72 kg N ha⁻¹.

In another study, in Alabama, Torbert et al. (1996) separated the N₂ fixation effects from the rotation effects comparing two varieties of crimson clover, one which was highly effective in nodulation (CCa) with non-effective nodulation variety (CCb) and rye. These authors found that all cover crops (CCa, CCb and rye) were effective in improving corn yields but besides the N availability provided by the legumes, there were no other beneficial effects of crimson clover vs rye (Torbert et al., 1996). Eckert (1988) evaluated rye as cover crop tested and two N sources (anhydrous ammonia and UAN). Rye was planted together with corn and soybean residue on corn yield in two locations in Ohio. Under continuous corn, rye reduced yields in two out of four years which was related with lower stands for rye and higher ear leaf N in rye plots. Moreover on corn after soybean, rye reduced yield in two out of eight experiments and increased yield in one (four different years in two locations). The most likely explanation for this yield reduction caused by rye is the significant stand reduction that occurred in the same two years where yield reduction occurred. As a matter of fact, ear leaf N increased significantly when stand counts were low which is interpreted as fewer plants feeding on a constant N supply rather than to increases due to rye releasing N. In one out of the eight experimental sites yields under rye no-till were higher and this was interpreted as moisture conservation due to rye presence in a dry season (Eckert, 1988).

Tillage practices

Tilth is an important characteristic in soil and refers to how easily a soil can be cultivated. It can determine the final usage of the land. For instance, a soil with high clay content and poor tilth can form hard clods that are difficult to break even with machinery. Moreover poor tilth increases both power and fuel requirements (Troeh et al., 2004). Intensive tillage (sometimes called conventional management) is characterized by a disturbance of soil surface which leaves less than 15% plant residue cover after planting. Intensive tillage involves one or many of the following activities: plowing to bury residues, disking to break clods and dragging, harrowing or disking and is carried out mainly to prepare the seed and root bed, control weeds and establish surface conditions that favor root development. Conservation tillage, on the other hand, involves a series of practices that are intended to minimize the residue incorporation with the intention of reducing soil erosion. In order to be within this category more than 30% of residue should be present on the soil surface immediately after planting. Primary benefits of conservation tillage include: reduced fuel consumption, reduced labor cost, improved soil tilth, increased SOM, enhanced moisture conservation, reduced erosion and improved of water quality (Conservation Technology Information Center, 2010).

Changes in soil C and soil N with tillage

The C cycle's successful functioning in a soil system is essential to overall soil health. Organic C enters the soil mainly through plant residues and provides the principal source of energy for cell growth and metabolism of soil microorganisms that are involved as well in other nutrient cycling processes. One of the main components of plants is cellulose that provides plants with structure. Cellulose is composed of glucose subunits that form a polymer via β (1-4) bonds. Cellulose is probably the most abundant C compound and is cleaved by extracellular enzymes called cellulases (Coyne, 1999). Researchers have found that a consistent difference between no-tillage and conventional tillage (moldboard plow + disking) is that total C and N in no-till soil tends to increase compared with till soils (Blevins et al., 1983; Handayani, 1996; Utomo et al., 1990).

In order to learn about changes in soil C and N between organic compared to conventional systems, some recent publications are worthy of review. Delate and Cambardella (2004) in Iowa, evaluated soil fertility changes from 1998 to 2001. They compared changes in an organic compared to a conventional system for grain and hay production. The organic production was carried out using intensive tillage and organic amendments and the conventional system was a corn-soybean rotation which also employed intensive tillage. The levels of total N (TN), P, K,

Ca and Mg, were not significantly different at the beginning of the experiment. After 4 years, the TOC in the top 15 cm was 9% higher in the organic treatments compared with the conventional treatment (24.1 g C kg⁻¹ to 26.2 g C kg⁻¹). However this difference was not significant when it was compared with the conventional system (p<0.05). Moreover, there were no differences in TN, K, Ca, Mg between conventional and organic systems. The only difference was a higher level of P in the organic plots, mainly due to the application of swine manure (Delate and Cambardella, 2004). In another experiment comparing organic and no-till conventional systems, Teasdale et al. (2007) found significant differences in total C and total N between a no-till system (with herbicides and N inputs); a cover crop system using hairy vetch before corn and rye before soybean with herbicide input; and an organic system using organic inputs and tillage. The organic system resulted in significantly higher total C and total N at all soil depths; however the yields in the organic system averaged only 5.1 Mg ha⁻¹ (nine years) mainly due to weed presence (Table 1.2; Teasdale et al., 2007).

Cover crops and tillage effects on corn ear leaf N and grain N

In order to establish a meaningful relationship between ear leaf N and yield, the best timing for sampling should be when plants have developed sufficiently in order to cause differential concentrations among treatments. In the case of corn, it is recommended to sample the ear leaf when the crop is about 75% silked or entirely into R1. When corn plants approach maximum yields, ear leaf N levels can be used to assess the N status of those plants. In New Jersey, corn grain yields ranged from 17.9 to 21.2 Mg ha⁻¹, which are relatively high yields and it can be assumed that plant nutrients were in the sufficiency range (Munson and Werner, 1990). The researchers in this case, determined the mean values to be as follows: N, 31.4 g kg⁻¹; P, 3.6 g kg⁻¹; K, 25.1 g kg⁻¹; Ca, 5.6 g kg⁻¹; Mg, 1.8 g kg⁻¹; S, 2.2 g kg⁻¹. In Kentucky the sufficiency range for tasseling corn plants is as follows: N 28 – 40 g kg⁻¹; P 2.5 -5.0 g kg⁻¹; K 18 – 30 g kg⁻¹; Ca 2.5- 8 g kg⁻¹; Mg 1.5- 6 g kg⁻¹; S 1.5-6 g kg⁻¹ (Schwab et al., 2007).

Some researchers have attempted to use grain N to determine whether or not the plants were grown under adequate N nutrition. Pierre et al. (1977) reported the N concentration in grain and its relationship with yield as a parameter of N sufficiency. These analyses were carried out with samples from Illinois, Iowa, Indiana, Ontario and Oregon. The authors found by a graphic technique relating the yield of corn as a percentage of the maximum and the N concentration in the grain. When the corn was approaching maximum yield the N in grain concentration was about 15 g kg⁻¹; with a range from 14 to 18 g kg⁻¹. However, this relationship between grain N and yield is not as consistent as the ear leaf N concentration (Pierre et al., 1977). Other authors

have found this relationship of little use. For instance, Cerrato and Blackmer (1990) observed in 12 experiments in Iowa little relationship between grain N and yield of corn, maybe due to the fact of heavy N fertilization rates that put most of the yields around the plateau level (Cerrato and Blackmer, 1990).

In Illinois, Miguez and Bollero (2006) studied the effect of cover crops on ecophysiological characteristics of corn (number of leaves, light interception, chlorophyll meter readings, leaf carbon exchange rate). Corn was planted after hairy vetch, rye and a mixture of hairy vetch and rye. Corn after hairy vetch was superior to all other treatments when no N fertilizer was applied. However, most of beneficial effects of hairy vetch disappeared with the application of 90 kg N ha⁻¹ on rye or rye-vetch mixture. Chlorophyll meter readings (CMRs), an indication of N status, were made around R1. The CMRs readings for corn after vetch were higher than corn after biculture rye-vetch, corn after rye and corn after no cover (p<0.1) and corn after rye had the lowest CMR reading (p<0.05). The authors concluded that most of the detrimental effects on corn variables by using rye or rye-vetch disappear by applying 90 kg N ha⁻¹. In this study, rye was killed two weeks before planting corn and the mixture vetch-rye was killed one week before planting corn (Miguez and Bollero, 2006).

Mehdi et al. (1999) tested three tillage practices (conventional till, reduced till and no-till) and evaluated corn grain yield, ear leaf N and grain N. All plots received 140 kg N ha⁻¹ partitioned as 40 kg N ha⁻¹ at planting and 140 kg N ha⁻¹ side-dressed three weeks after planting. Weekly SPAD readings were transformed to leaf N concentrations (g kg⁻¹) using regression equations proposed by Dwyer et al., 1995. The no-till treatment residue (NT+ R) had significantly lower ear leaf N (g kg⁻¹) at 55 days after planting (DAP) and at 61 DAP. On July 22 (66 DAP) none of the plants in the NT+ R had silked but the other plants were about 46% in silking. Moreover, grain under NT+ R had significantly higher moisture. This difference was not consistent the following year of the experiment and all treatments were not significantly different in ear leaf N content. Grain N determined with the Kjeldahl method showed that grain N was no different in any of the years averaging 11.4 g kg⁻¹ in 1996 and 15.2 g kg⁻¹ in 1997. In this case, the grain N content in grain and yields were not correlated (Mehdi et al., 1999).

Table 1.2. Total soil C and N averaged over 2001 and 2002 comparing different conventional systems (cover crop, no-till) and a organic system.

System	Soil depth		
	0- 7.5 cm	7.5- 15 cm	15- 30 cm
	----- g kg ⁻¹ -----		
	Soil C		
No-till	15.5c ¹	11.1c	7.1b
Cover crop	17.3b	12.4b	7.8b
Organic	19.2a	15.9a	10.3a
	Soil N		
No-till	1.29c	0.93c	0.58b
Cover crop	1.43b	1.04b	0.64b
Organic	1.59a	1.3a	0.87a

¹ Values within depth followed by the same letter are not different p< 0.05

(Adapted from Teasdale et al., 2007)

N release from tilled soils

Utomo et al. (1990) tested two cover crops (hairy vetch and rye), two tillage systems (no-till vs conventional till) and three N rates 0, 85 and 170 kg N ha⁻¹ as to their effects on corn production. Hairy vetch did not respond to previous spring N fertilization but rye did with a significantly higher dry matter accumulation when 170 kg N ha⁻¹ was previously applied. This suggests that rye was more effective in scavenging previous inorganic N than was hairy vetch. The treatments were applied over a corn field previously managed as no-till for seven consecutive years. Tillage buried the SOM below 7.5 cm and there was a consistent difference in total C and total N between no-till (NT) and conventional till (CT). However, CT caused significantly higher inorganic N after 6 weeks of plowing. This data proves that moldboard plow causes acceleration in SOM decomposition and N mineralization. The higher yields were obtained under CT. There were superior corn yields with hairy vetch at all N rates and tillage systems. Moreover, the grain yields at 170 kg N ha⁻¹ under rye were not different than vetch at 0 kg N ha⁻¹ (Utomo et al., 1990).

Varco et al. (1993) using N¹⁵ labeled hairy vetch found that incorporating vetch caused a faster and more complete decomposition of the residue and a more rapid release of inorganic N. Compared to a N¹⁵ labeled inorganic fertilizer, N from vetch was less available than the N from fertilizer; however, the potential for leaching was higher for the fertilizer (Varco et al., 1993).

No-till in organic corn production

The original roller crimper was developed in Brazil and consisted of a hollow steel cylinder (60 cm in diameter) up to 2 m wide which allowed water to enter for more weight and pressure. Blunt blades (7 to 10 cm height) were placed along the cylinder every 19 cm. The roller crimper was developed to manage cover crops in Latin America, specifically in Brazil and Paraguay. Farmers there know it as a “knife roller” that is designed not to roll down the cover crops but to squash and break their stems, killing the plants. In Brazil, one or a maximum of two passes are recommended when the cover crop is in full bloom under optimal weather conditions (dry). The preferred species in Brazil to be managed using the roller crimper is black oat (*Avena strigosa*). In the states of Parana and Rio Grande do Sul of Brazil, there are approximately 3.2 million ha of black oat, while in Paraguay there are approximately 300 000 ha. The preferred cash crop in these conditions is soybean (Derpsch, 2003). The original “knife roller” developed in Brazil consisted of long-straight blades welded in the drum. In order to improve the long-straight standard model of the roller, some experiments were carried out in Alabama. Farmers complained that the original long straight model caused a lot of vibration during the crimping

operation, so different designs of blades were tested. The results show that the vibration is significantly reduced by a short-staggered straight blade or a spiraled blade model. The system that presented significantly less vibration over a rye cover crop, grass and concrete was the spiral model (Raper et al., 2004). The Rodale Institute has adapted the concept of the roller crimper with the blades welded to the cylinder in a chevron pattern and tested as a tool for organic no-till production in the United States (Fig. 1.1). Rodale's current roller-crimper design is freely available on its webpage (The Rodale Institute, 2010).

Ashford and Reeves (2003) tested the roller crimper with blades in the chevron pattern in Alabama for its effectiveness in killing the following cover crops: black oat, rye and winter wheat (*Triticum aestivum*). The experiment compared the roller crimper with two herbicides (glyphosate and paraquat) as follows: 1) each at their respective label rate, 2) ½ glyphosate label rate with the roller crimper, 3) ½ paraquat label rate with the roller crimper, and finally only the roller crimper. Ashford and Reeves (2003) found a consistent interaction between cover crop x growth stage x kill method in two years of study. At flag leaf stage, there was a significantly lower kill percentage using only the roller crimper for all cover crops. However, at anthesis the roller only treatment increased to an average cover crop kill percentage of 81% in 1999 and to 85% in 2000. By the soft dough stage in 1999 and in 2000, there were no significant differences between the roller crimper and the other treatments (Ashford and Reeves, 2003). In a recent study by Mischler et al. (2010), the roller crimper was used in three locations under three different experimental site conditions in Pennsylvania. This study tested a split-split-plot design where planting date was the main plot, cover crop (hairy vetch) vs no cover was the split-plot and the split-split plot was herbicide vs no herbicide treatment. The authors found that is possible to use the roller crimper for organic corn production with yields ranging from 1.7 to 8.2 Mg ha⁻¹. However, as the planting day was delayed from the last week of May, the risk of obtaining lower yields increased (Mischler et al., 2010). Thus, it is possible to kill cover crops effectively using the roller crimper but the risk of problems with pests and low yields will increase, especially as planting date is delayed.

Control of weeds in organic grain systems

Posner et al. (2008) compiled results of several experiments comparing conventional and organic cropping systems in Pennsylvania, Minnesota, Iowa, Michigan and Wisconsin. The authors found a pattern in which weed control was primarily responsible for differences in final yields. Where weed control was poor, organic corn yields ranged from 72 to 84% of conventional yields, while for organic soybean this range was 64 to 79% of conventional yields.



Photo taken by Suarez, 2010.

Figure 1.1. Roller crimper constructed by the University of Kentucky based on Rodale Institute plans.

However, when weed control was good, yields of organic corn ranged from 98 to 114% of the conventional and in soybean ranged from 94 to 111% of conventional (Posner et al., 2008). Thus, controlling weeds is one of the principal concerns in organic corn and soybean production.

On the long-term agroecological site (LTAR) in Iowa, Delate and Cambardella (2004) compared weed densities of grasses and broadleaves (plants m⁻²) for both a conventional corn-soybean (C-S) rotation and organic cropping systems. The organic rotations consisted of corn-soybean-alfalfa/oats (C-A-O/A) and corn-soybean-oats/alfalfa-alfalfa (C-S-O/A-A). The system C-S used herbicide for weed control but the organic systems used cultivation and the rotations as means of weed control. Weeds were counted after all tillage events occurred in both organic and conventional to make sure that the weeds had an opportunity to influence yield. Results for corn showed that in the first year of transition to organic there were no significant differences in weed density between organic and conventional systems. In the second year of the experiment there were significantly more grasses in the organic plots along with reduced corn stands; both factors may have been responsible for the observed yield reduction. In the third year there were more grasses in the organic rotations, but no yield effect. Likewise, in the fourth year there were significantly more weeds in the organic C-S-O/A-A rotation but its yields were not affected (Delate and Cambardella, 2004). In this study, the authors concluded that the success of rotations in controlling weeds might be due to the inclusion of a legume, an observation previously reported by Dyck et al., 1995.

Use of cover crops for weed control

Teasdale et al. (2007) in Maryland used a no-till (NT) corn production system with herbicides and N inputs, a cover crop (CC) with hairy vetch before corn with herbicide and low N inputs, a crown vetch (CV) (*Coronilla varilla*) living mulch system (with corn grown in this perennial vegetation where herbicides were applied before planting) and finally an organic system with weed control based on chisel-plow+ rotary hoeing and cultivation. The systems were evaluated for corn grain yield, weed percentage and stand counts during 9 years (1994-2002). The amount of weeds was based on visual inspection of the percentage of area covered by them. The researchers found that averaged across the 9 years of this experiment, the best yields were obtained with no-till corn at 7.07 Mg ha⁻¹. Moreover, weed control in that system was the best with a mean of 5% ground cover. The CC system was not significantly different from NT in terms of yield (6.88 Mg ha⁻¹). The organic system had the lowest overall yield (5.1 Mg ha⁻¹); however weed control for this system (44% ground cover) was better than both the control and CV. This yield reduction for the organic system was mainly caused by low stand counts due to

uneven seedbed after plowing and due to plant loss during cultivation (Teasdale et al., 2007). Thus, the best system to control weeds with the highest yield was NT and the living mulch (CV) was the worst weed control strategy. The organic system based weed control on mechanical practices and was not as bad as the CV treatment but the main yield reduction factor were low stands and killing of plants during cultivation (Teasdale et al., 2007). Mischler et al. (2010) studied how timing of vetch that was killed with the roller crimper and planting date of corn affected weed density (weeds m⁻²) and weed biomass (kg ha⁻¹). The authors found that there was a consistent effect of cover crop hairy vetch in all three experimental sites where there was significantly more weed density and weed biomass without cover crop than with cover crop. In one of the three experimental sites in this study there was a significant interaction between corn planting date and cover crop. Weed density increased rapidly from four to eight weeks after planting in the plots planted at the two first planting dates without cover crop but not in those with cover crop (Mischler et al., 2010). Thus, hairy vetch was a successful management tool to control weeds in their experiment.

Including rye as a cover crop has benefits on weed control (Ateh and Doll, 1996; Delate and Cambardella, 2004). However, low stand problems have been reported due to excessive mulch (Bollero and Bullock, 1994; Utomo et al., 1990).

Ateh and Doll (1996) found that rye was an effective strategy to control weeds. The ground cover provided by rye suppressed weed germination and growth. Moreover, the marginal returns from using rye as a weed suppressor were significantly higher than weed free plots treated just with herbicide (Ateh and Doll, 1996).

Rye has been tested for its allelopathic properties. Barnes and Putnam (1983) found that a living mulch of rye vs a no-rye control was effective in controlling 98% of common lambsquarter (*Chenopodium album*), 42% of crabgrass (*Digitaria sanguinalis*) and 90% of ragweed (*Ambrosia artemisifolia*). Barnes and Putnam (1983) also tested rye root leechates in tomatoes grown in greenhouses and found that the dry weight of tomato was negatively affected by 25-30% compared with the untreated control (Barnes and Putnam, 1983). Sung et al. (2010) in Korea tested hairy vetch and rye (soil incorporated) to determine total phenolic content (presumed allelochemicals). They found an opposite pattern for vetch and rye in phenolic content showed that vetch initially had about 2.6 more phenolics than rye (45.5 vs 17.7 µg g⁻¹); however after incorporation the rye increased phenolic content to 37 µg g⁻¹ whereas vetch decreased to 21.3 µg g⁻¹. Moreover, the rye significantly suppressed weeds compared with vetch 50 days after incorporation. Allelochemicals, mainly phenolics, found in rye were suspected by

these authors as the primary cause of weed suppression (Sung et al., 2010). Thus, including rye in the rotation has proven to be effective as weed control strategy.

Timing for killing cover crops rye and hairy vetch

In Maryland, Clark et al. (1994) tested different killing dates for rye and hairy vetch with four N rates under two different topographic sites during 1990 and 1991. Late planted corn yielded more than early planted corn at the Coastal Plain location compared with the Piedmont location. In this case the cover crops were killed in late April or early May and corn was planted in mid-May. The higher yield results were attributable to higher moisture conservation, timely rainfall and N contribution by vetch. Moreover, there were higher yields when vetch and rye-vetch were killed late especially at lower N fertilizer rates due to a higher N contribution from vetch. At the Piedmont location, where higher SOM and higher clay provided higher water holding capacity, the cover crop and kill date were not significant and cover crop and kill date did not present any interaction (Clark et al., 1994). In an experiment conducted in Illinois from 1986 to 1989 to evaluate the effect of rye used as cover crop to control weeds, researchers found that the weed control in rye plots was >90% better than corn residue five weeks after planting soybeans. Moreover, late killed rye (rye killed at planting) reduced stand counts of soybean compared with early kill rye (killed 2 wks prior planting) due to excessive amount of rye residue (Liebl et al., 1992).

Ruffo and Bollero (2003) modeled the residue decomposition of hairy vetch and rye as function of growing degree days and decomposition days. Cover crops were killed using herbicides. After planting corn, they found that by V6 33% of the initial N content of vetch and 75% of the N content of rye had been released from the residue and by the end of season almost all vetch was decomposed but 5% of rye residue was still undecomposed. Moreover killing rye 1 week before planting corn was not optimal for coordinating the release of N with the corn plant needs (Ruffo and Bollero, 2003). Crandall et al. (2005) studied the effect of killing rye one week before planting date (KT1), two weeks before planting date (KT2) or three weeks before planting date (KT3). Different N application timings were also tested. Their study showed that killing rye less than 2 weeks before planting corn should be avoided especially when N is applied only at V6. This combination reduced N uptake and biomass and produced the lowest yields. The best combinations in terms of yield were KT3 and N supplemented at planting or early kill dates KT1 or KT2 but with all N supplied pre-planting or at planting (Crandall et al., 2005). Mischler et al. (2010) found that the optimal time to kill hairy vetch and to obtain higher corn yields (range from 5.2 to 10.2 Mg ha⁻¹) was using herbicides and killing vetch around the end of May and early June.

If an alternative method of killing was employed (like the roller crimper), corn planting should be delayed until hairy vetch reached early pod set (95% to 100% flowering by the visual method) or later that is mid June but the risk of production due to pests and low yields will increase (Mischler et al., 2010).

N in nature

N cycle

N is an essential plant nutrient and is the most commonly deficient nutrient in cereal crop production. Many N sources exist, including synthetic fertilizers, atmospheric electrical discharges that break the triple N₂ bond, organic N from animal and plant residues and N₂ fixation by legumes. Even though the atmosphere is 78% N, higher plants cannot metabolize N₂ to protein directly, so N₂ must be converted to available N through:

- Microorganisms that live symbiotically in the roots of legumes (*Rhizobium*, *Bradyrhizobium*) and certain non leguminous plants (*Azospirillum*).
- Free living or non symbiotic soil microorganisms (*Frankia*, *Azotobacter*).
- Atmospheric electrical discharges that form NO₃⁻.
- Manufacture of synthetic N fertilizers mainly through the Haber-Bosch cycle.

(Havlin et al., 1999).

N limits production and yield in intensive agricultural systems which are designed to maximize the production protein for human and animal consumption. When N fertilizer is added to the fields some of the N that is not captured by plants or microorganisms may end up in streams and ground water, causing a pollution problem. In a system where no legumes are included, the combination of N losses and lack of fertilization ensures a short supply of N that renders this system dependent upon N fertilization. In undisturbed ecosystems like forests where there is no regular harvest and relatively infrequent disturbance of soil, this system creates a pool that accumulates elements. Moreover if N fixers can colonize they are capable of adding enough N to compensate for any N losses (Vitousek et al., 2002).

The N cycle is presented in Fig. 1.2. In the first step one can see the different N inputs from the atmosphere (lightning breaking triple N₂ bond) from industrial processes and combustion, N that comes from plant and animal residues and N₂ fixed by legumes. In step 2 the N from SOM is mineralized to NH₄⁺ by soil microorganisms. Some of this N can be absorbed by plant roots as NH₄⁺, another fraction can be fixed by clays while the remainder may go on to

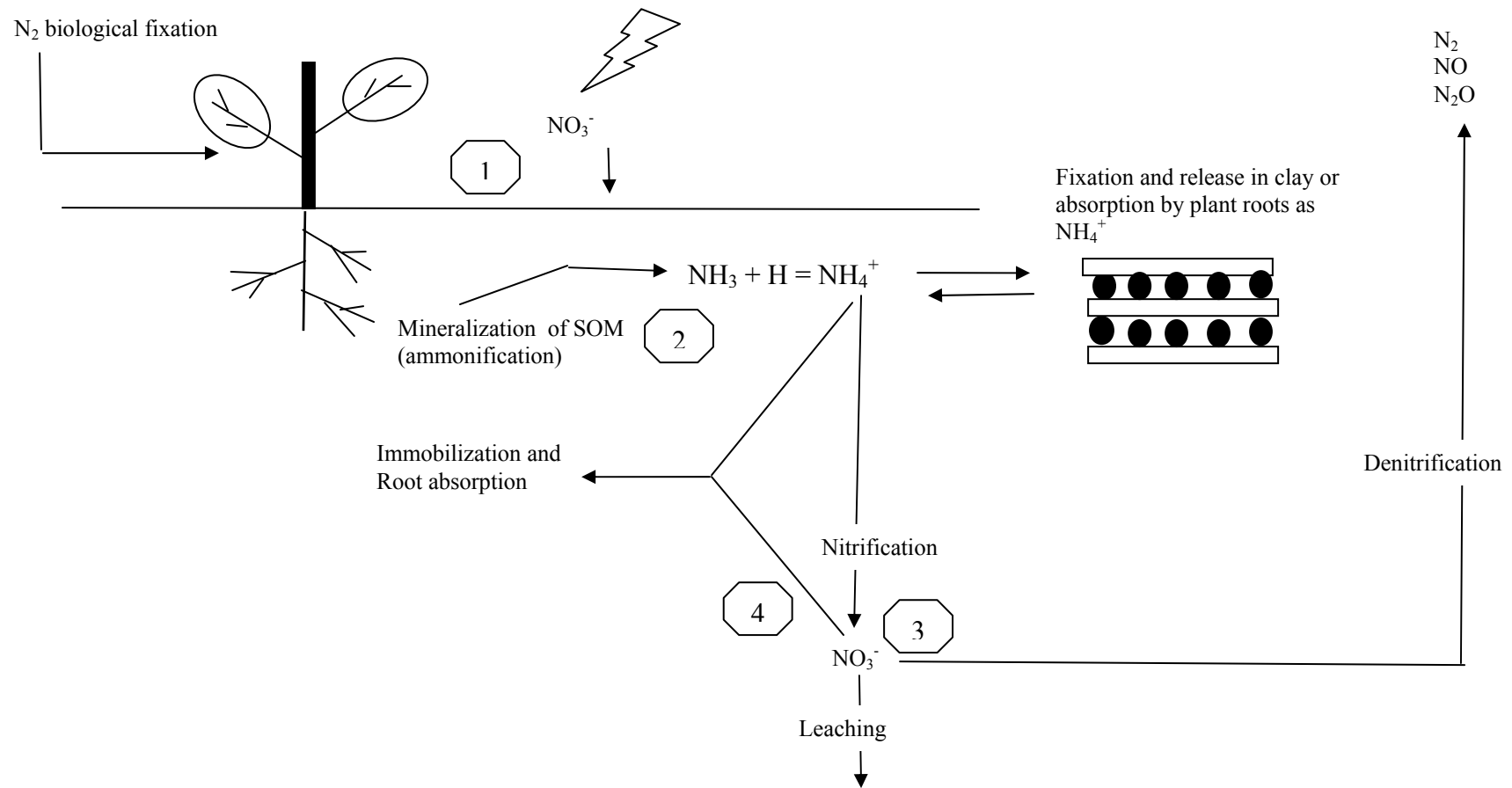


Figure 1.2. N cycle
 (Adapted from Havlin et al. 1999 and Foth and Ellis, 1997)

further mineralization to step 3 where NH_4^+ is oxidized to NO_2^- and then to NO_3^- by a group of chemoautotrophic bacteria known as nitrifiers. In step 4, NO_3^- can be taken up by plant roots, immobilized by microorganisms or be leached to ground water. In step 5 some NO_3^- could be exposed to an anaerobic experimental site and start the process known as denitrification where NO_3^- is lost in the atmosphere as N_2O , NO or N_2 .

N fertilizer sources

Perhaps the oldest N fertilizer is animal manure that has been used for thousands of years. Manure content of plant nutrients will depend on the animals' diet, but can be managed to help maintain soil fertility. The first imported fertilizer to the U.S was guano from Peru in 1824. This guano contained about 13% N and came from bird excreta along the Peruvian coastline. In 1830 another source of N appeared in the form of NaNO_3 imported from Chile. This material contained about 16% N. Later the first factory to synthesize NH_3 opened in Oppau, Germany in 1913 using the Haber-Bosch cycle which reacts N_2 from the atmosphere under high temperature and pressure in the presence of an iron catalyst to break the N_2 triple bond and obtain NH_3 . Today 95% or more of the N fertilizers use in US are produced by synthesis of NH_3 (Foth and Ellis, 1997).

Use of organic amendments for corn production

Organic nutrient sources for plants can range from farm manure, animal manures, compost, biosolids but all of them should follow some principles of utilization to avoid pollution. The first insight is that the rate of application depends on the amount of N or P that will be available to plants. If the P/N in the source is higher than the N plant requirements then P pollution is likely to occur (Brady and Weil, 2008). The second insight is that for organic sources, most of the N will not be readily available; N will gradually become plant available over time. The third insight is that if the field is treated annually with organic material, application rates over succeeding years should become progressively lower (Brady and Weil, 2008). Synthetic fertilizers are banned from organic agriculture so farmers and researchers must use composts, cover crops and animal manure in order to provide enough nutrients for grain crops (Cavigelli et al., 2009; Delate and Cambardella, 2004; Posner et al., 2008).

N sources from organic residues commercialized in Kentucky

Organic and sustainable farmers try to minimize external inputs in their farms and make use of the resources that they have in hand like manure, compost, vegetable residue, and the like. In recent years in Kentucky, however, there have been some commercial options available to

farmers like Nature Safe and Louisville Green. Nature Safe (10-2-8) is produced by Griffin Industries and is an organic N source that is composed of poultry byproducts (feather meal, meat meal, bone meal and blood meal), sulfate of potash, yeast, sugars, carbohydrates and humus. Moreover, this product is accepted for organic production under the USDA's National Organic Program (NOP) (Nature Safe, 2010). Louisville Green (5-3-0) is a heated sewage product in pellet form that comes from activated sewage biosolids promoted by the Municipality of Louisville. Marketing materials call it "an organic-based fertilizer with slow release nitrogen that is ideal for many applications" (Louisville and Jefferson County MSD, 2010). It is manufactured by the Louisville and Jefferson County Metropolitan Sewer District. The product is currently not accepted for organic corn production (Louisville and Jefferson County MSD, 2010). These sources are relatively new to the Kentucky market and there is a lack of scientific literature about their effect in agronomic crops.

Use of biosolids for corn production

Sewage sludge is a byproduct of industrial and/or domestic wastewater treatment plants. When such a product passes through treatment to be spread in agricultural fields meeting certain standards (low pathogen and contaminants), it receives the name of biosolid (Brady and Weil, 2008). Kizilkaya and Bayrakli (2005), studied the effects of sewage from Ankara, Turkey on the soil enzymes β -Glucosidase, urease, alkaline phosphatase, aryl-sulphatase which are involved in the C, N, P, S cycles, respectively. They found that the enzymatic activity diminished with increasing available concentration of heavy metals (Kizilkaya and Bayrakli, 2005). For instance, the sewage applied to soil in this study significantly elevated the levels of available Cu, Ni, Pb and Zn concentrations in soil. Thus this study concluded that sewage application would have harmful effects on soil enzymatic activity. Moreover, Mc Bride (1998) found that heavy metals could be transported to surface and ground waters after application. King and Dunlop (1982) tested two types of sewage sludge [one from Pittsburgh, PA (PS) and one from Wilmington, NC (WS)] for their effects on corn in a greenhouse experiment. They applied PS at rates of 0, 9, 18 and 36 Mg ha⁻¹ and WS at 0, 154, 308, 461 Mg ha⁻¹ and tested the effects on 4 type of soils [one mineral (Norfolk loamy sand) and 3 Histosols with low, medium and high SOM]. One goal of this research was to predict the metal concentrations of sludge in corn so they applied the sludge to provide 0, 2, 4, 8 kg Cd ha⁻¹. They applied about 178 kg N ha⁻¹ to obtain 2 kg Cd ha⁻¹. These authors found that sludge applications reduced yields but those yields reductions were not caused by excessive accumulation of heavy metals. There was a significant sludge x rate x soil interaction since yields responded to higher rates of WS on a mineral and all organic soils. When

PS was applied yields did not respond in organic soils and responded negatively in the mineral soil (King and Dunlop, 1982).

Timing of N uptake by corn

Both NH_4^+ and NO_3^- are readily available for plant uptake. In well aerated soils with a pH between 6 to 8, plants absorb N mainly in the form of NO_3^- where it remains nearby the plant root zone and is readily available mainly via mass flow. For corn it has been estimated that 79%, 20% and 1% of the nitrogen is absorbed via mass flow, diffusion and root interception (Foth and Ellis, 1997). Mixtures of NH_4^+ and NO_3^- are beneficial in certain corn growth stages and vary depending on the genotypes. For instance, corn yields increased from 8 to 25% when treated with a mixture of NO_3^- and NH_4^+ compared with NH_4^+ alone. This was more related to the increment in the number of kernels rather than to the weight per kernel (Havlin et al., 1999).

Nutrient absorption curves generally follow dry matter accumulation curves for corn. However, while the uptake of K is almost completed after silking, the uptake of N and P continues until near maturity. There is big increase in N demand that starts at V6 and then N and other nutrients are translocated from vegetative parts to reproductive tissue later in the season. High concentrations of nutrients at early growth are beneficial for root development; however the soil maybe too cold to start mineralizing if all the N is applied at planting in early spring. If N was not applied at planting it should be side-dressed at V6 stage since the nodal root system is well distributed and the period of intense N requirement is starting. Side-dressing of N can be performed up to V8 (Iowa State University Extension Service, 1993).

To increase knowledge of organic corn production using cover crops, tillage systems and organic N sources available in Kentucky this study was initiated. This experiment was designed to accomplish these objectives:

- 1) Determine the effects and interactions of cover crops, tillage, N sources and N rates on corn plant variables (yield, ear leaf N, and grain N),
- 2) Evaluate the effects of cover crop, tillage, and N treatment (Nature Safe at three rates) on weed variables (grass number, grass weight, broadleaf number, and broadleaf weight), and
- 3) Determine the patterns of mineralization of Louisville Green and Nature Safe through a long term aerobic incubation.

Chapter Two: Materials and Methods

Experimental sites

The experiment was carried out in three experimental sites which were located at the University of Kentucky Spindletop Farm (Fayette County, Kentucky) in 2008 or at the University of Kentucky Research and Educational Center (UKREC) (Caldwell County, Kentucky) in both 2008 and 2009. The coordinates of the central points of each experiment were as follows: 38° 8' 2'' N and 84° 30' 29'' W for Spindletop 2008, 37° 06' 29'' N and 87° 52' 21'' W for UKREC 2008 and 37° 6' 11'' N and 87° 52' 32'' W for UKREC 2009. The soil series corresponding to Spindletop 2008 was a Maury silt loam (fine, mixed, active, mesic Typic Paleudalfs). The soil for both UKREC 2008 and UKREC 2009 was a Crider silt loam (fine-silty, mixed, active, mesic typic Paleudalfs) (USDA-NRCS, 2010). The preceding crop was tall fescue (*Festuca arundinacea*) for Spindletop 2008 and orchard grass (*Dactylis glomerata*) for both UKREC 2008 and UKREC 2009.

Cultural practices

Cover crops

The experimental sites were sampled for soil fertility characteristics on September 01, 2007 (Spindletop 2008), on October, 03, 2007 (UKREC 2008) and on November 4, 2008 (UKREC 2009). Soil samples were collected from every whole plot for a total of eight samples, two for every replication (Fig. 2.1). In 2008 the dimensions of the experimental sites were 79.2 m by 88.4 m plus a central alley (15 m) to allow tractor circulation for Spindletop 2008 (Fig. 2.2) and UKREC 2008 (Fig. 2.3). For UKREC 2009 the dimensions were enlarged in order to facilitate plot separation. The dimensions in that case were 85.2 m by 88 m as well with 15 m for tractor circulation (Fig. 2.4). The plot sizes were corn was planted were 7.6 x 3.3 m for all three experimental sites. Cover crops were planted in 4 replications at each experimental site. The equipment used for planting the cover crops was a Great Plains 605 NT Solid Stand drill; planting rates were 34 kg ha⁻¹ for vetch and at 126 kg ha⁻¹ for rye. Planting dates (which depend on climatic and soil moisture conditions) were as follows: October 31, 2007 for Spindletop 2008; October 15, 2007 for UKREC 2008; and November 6, 2008 for UKREC 2009. Cover crops were sampled just prior to corn planting for biomass, N and C concentration using a 0.25 m² square placed near the center of every replication. The samples were dried for five days at 65 °C before dry weights were taken.

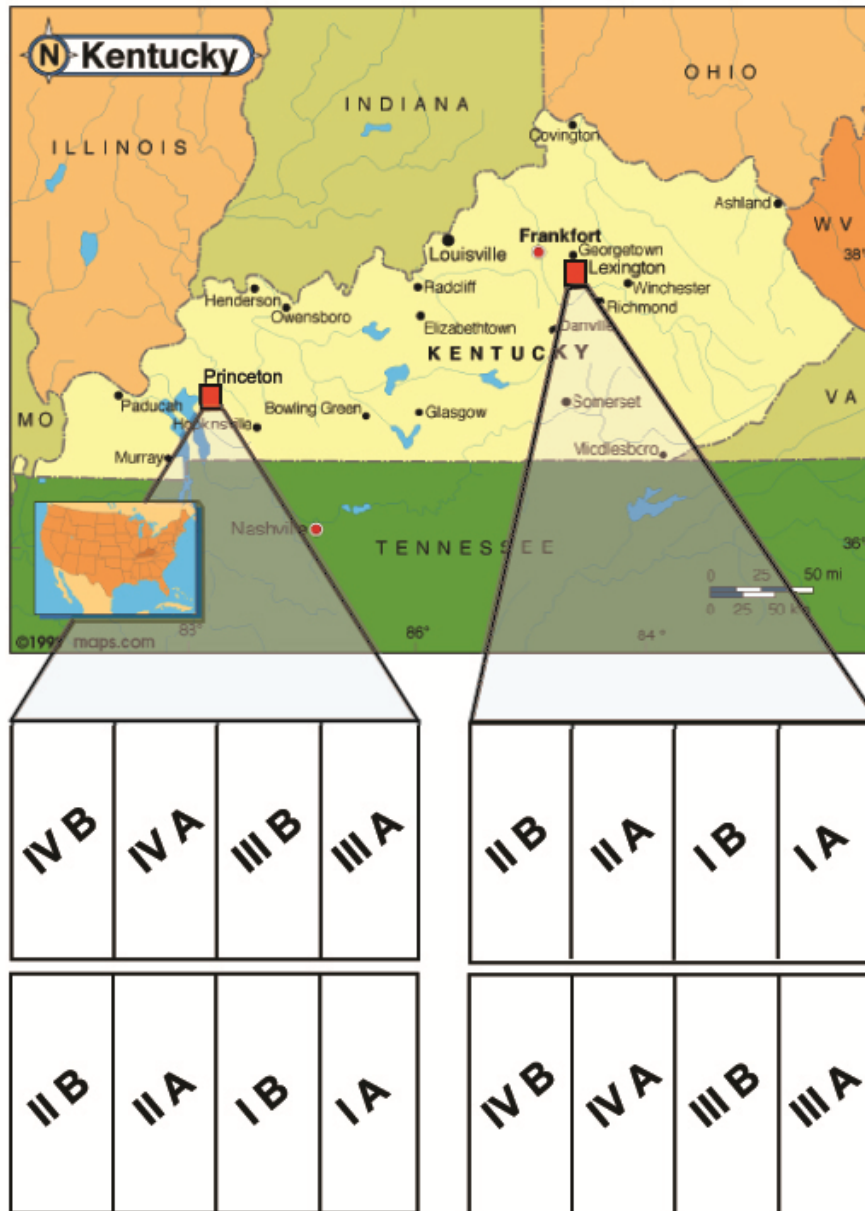


Figure 2.1. Diagram of the experimental sites showing where soil samples were taken (Netstate, 2009).



Figure 2.2. Diagram of the experimental site Spindletop 2008. Nitrogen sources were identified as Nature Safe (NF) and Louisville Green (LG) and N rates were 0 (control), 45, 90, 135, 180 kg N ha⁻¹.

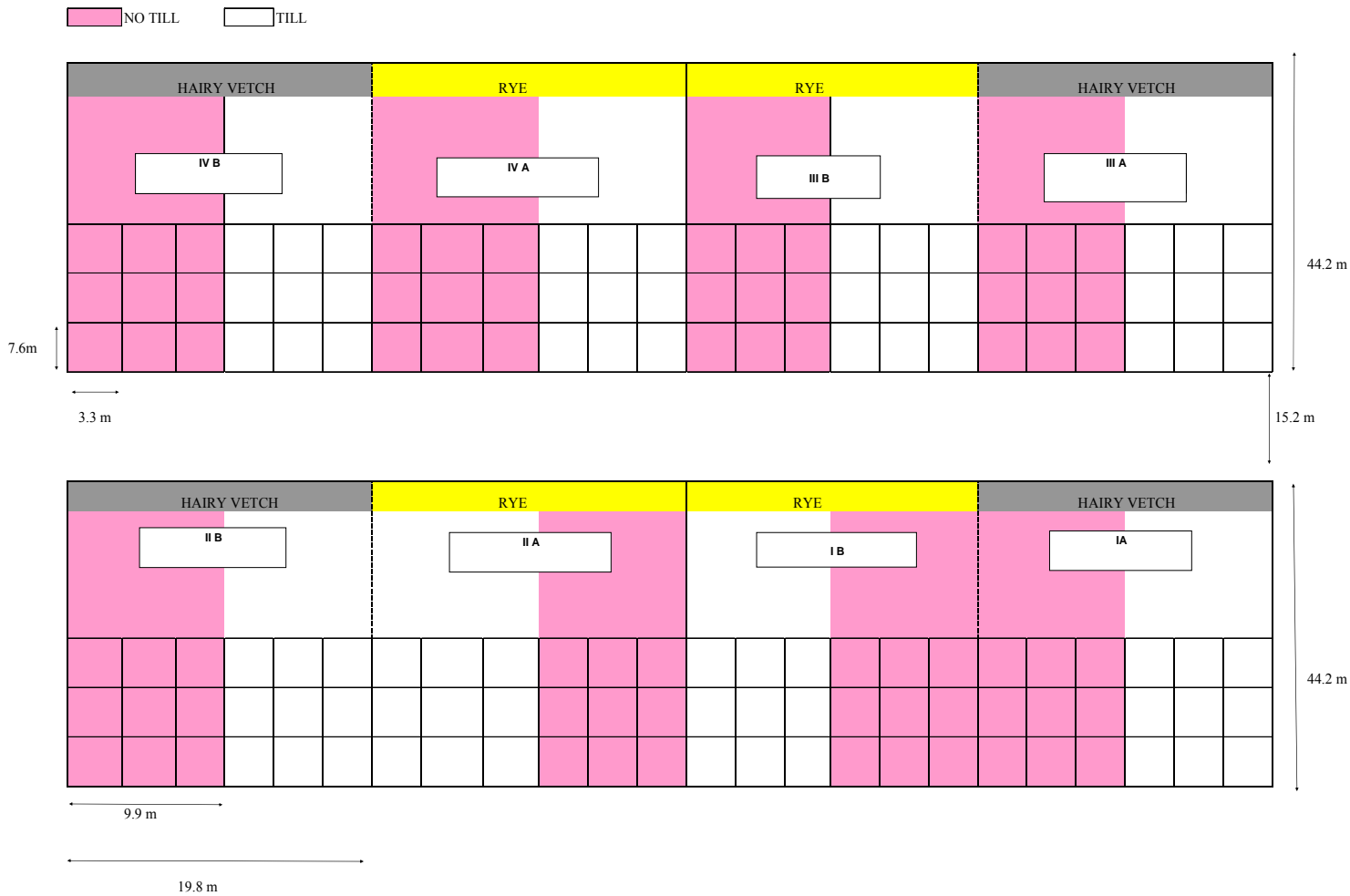


Figure 2.3. Diagram of the experimental site UKREC 2008. Nitrogen sources were identified as Nature Safe (NF) and Louisville Green (LG) and N rates were 0 (control), 45, 90, 135, 180 kg N ha⁻¹.

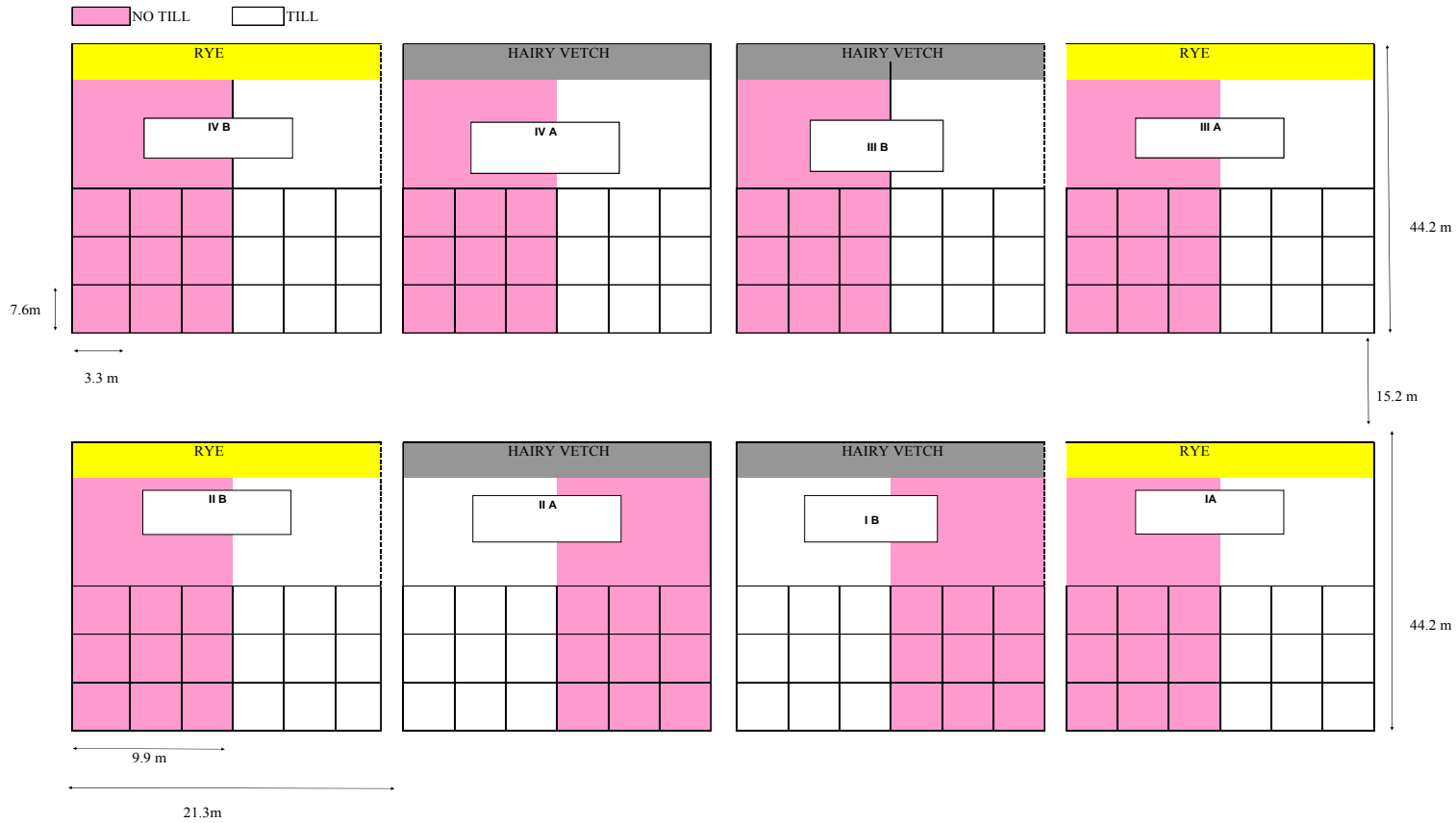


Figure 2.4. Diagram of the experimental site UKREC 2009. Nitrogen sources were identified as Nature Safe (NF) and Louisville Green (LG) and N rates were 0 (control), 45, 90, 135, 180 kg N ha⁻¹.

Tillage

Tillage and planting operations for each experimental site were carried out on a single day on the designated whole plots on June 13, 2008 for Spindletop 2008; June 4, 2008 for UKREC 2008; and June 2, 2009 for UKREC 2009. Cover crops in the whole plots identified for moldboard plowing were cut down with a rotary mower prior to plowing. No-till operations were performed with a front-mounted roller-crimper device in order to roll down both the hairy vetch and rye cover crops. This device was fabricated by the University of Kentucky's farm shop based on plans provided by Rodale Institute (The Rodale Institute, 2010).

Planting

Experimental sites were configured in a split-split-plot design, where the whole plots were cover crops (rye or vetch), the split plots were tillage systems (no-till or moldboard plow) and the split-split plots were the N treatments applied. The dimensions of each split-split-plot were 6 m by 3 m (Figs. 2.2, 2.3, 2.4) with a 0.76 m row spacing; the equipment used for planting was a John Deere 1750 Max Emerge Plus 4-row planter. The corn seed used was certified organic seed from Great Harvest Organics (hybrid 61K7). This is a 111 day hybrid adapted to maturity zones 6, 7, and 8. The planting rate was 74,100 kernels ha⁻¹.

Fertilizer sources

Nitrogen sources were applied at the rates of 45, 90, 135 or 180 kg N ha⁻¹ plus a common control (0 kg N ha⁻¹). The sources were applied completely at planting on June 13, 2008 for Spindletop 2008; June 5, 2008 for UKREC 2008 and June 3, 2009 for UKREC 2009.

The fertilizer sources used were Nature Safe (NF) and Louisville Green (LG). Nature Safe (10-2-8) is produced by Griffin Industries (Cold Spring, Kentucky) and is an organic N source is composed of poultry byproducts (feather meal, meat meal, bone meal and blood meal), sulfate of potash, yeast, sugars, carbohydrates and humus. Moreover, this product is accepted for organic production under the USDA's National Organic Program (NOP) standards (Nature Safe, 2010). Louisville Green (5-3-0) is a heat treated sewage promoted by the Municipality of Louisville, and sold in the form of dried pellets. Marketing materials call it "an organic-based fertilizer with slow release nitrogen that is ideal for many applications" (Louisville and Jefferson County MSD, 2010). The product is currently not accepted for organic production but is promoted for use in Kentucky.

Corn sampling

Corn stages and climatic data

Corn development was assessed by a visual inspection and by using the growing degree days (GDD) calculator from the UK Ag Weather (UK Ag Weather Center, 2010a). The GDD were related with the expected growth stage for the hybrid use according with National Corn Hand book for a 2700 hybrid (Purdue University Cooperative Extension Service, 1990). In this experiment, a 2400-2800 GDD hybrid was used for the three experimental sites. The climatic data presented in the corresponding sections were also obtained as well from the UK Ag Weather Center (UK Ag Weather Center, 2010b).

Stand establishment sampling

Corn plants were counted from 0.5 m of each of the two central rows in each split-split plot. The data was then transformed to a plants ha⁻¹ basis. Counts were taken on July 2, 2008 for Spindletop 2008; on June 25, 2008 for UKREC 2008; and on June 18, 2009 for UKREC 2009.

Ear leaf N sampling

The ear leaf N samples were collected on the central rows of every plot at silking. Three ear leaves were collected in from each split-split-plot on August 18, 2008 for Spindletop 2008; August 6, 2008 for UKREC 2008 and August 4, 2008 for UKREC 2009. Ear leaf samples were put in cloth bags and dried for 5 days at 65 °C. After being dried, ear leaf samples were finely ground using a Thomas sample mill and a Cyclone sample mill (Udy Corp. Model No. 3010-060). The samples were stored in sampling bags (Whirlpak; Nasco Corp.). From these samples, 0.01 g subsamples were put in test tubes to determine total N by the Kjeldahl method (Bradstreet, 1965).

Yield sampling

Yield was sampled from the two central rows of each split-split plot, using row lengths of 4.57 m for Spindletop 2008 and UKREC 2008 and 3.00 m for UKREC 2009. Corn was harvested on October 10, 2008 for Spindletop 2008; September 26 and 27 for UKREC 2008; and October 17, 2009 for UKREC 2009. Whole ears were weighed using a field balance and the moisture content of the grain was estimated from five ears for every one in nine plots using a Dickey-John meter for UKREC 2008 and Spindletop 08. In the case of UKREC 2009, five random ears from every plot were field weighed, then dried for 5 days at 60 °C and reweighed.

The moisture content was calculated with the formula:

$$\frac{\text{field weight} - \text{dry weight}}{\text{field weight}}$$

Grain yield was based on a market standard of 15.5% moisture and expressed in Mg ha⁻¹.

Grain N

Grain N was determined from a sample of 5 dried ears for every split-split-plot. Grain was ground using a coffee grinder (Mr. Coffee Model IDS77) and ground finer with a cyclone sample mill (Udy Corp. Model No. 3010-060). Aliquots of 0.01 g were put in test tubes and total N was determined by the modified Kjeldahl method (Bradstreet, 1965).

Weeds

Weeds were sampled in Spindletop 2008 and UKREC 2009 from a 0.5 m row length between the third and fourth rows (0.76 m width) at corn maturity. The split-split plots sampled were the ones under Nature Safe 90 and 180 kg N ha⁻¹ plus the control. Grass and broadleaf weeds were cut at the soil surface and separately placed in paper bags to be dried for 5 days at 65 °C before being weighed. No species distinctions were made within weed classes. Besides dry weights for grasses and broadleaves, numbers of these weed classes on a unit area basis were also recorded. Weed control operations were carried as needed before R1 in all locations.

Mineralization

Soil samples from the Spindletop research site were collected to a 10 cm depth using a soil auger on March 5, 2009 from the areas of the experiment where no N fertilizer was applied the previous season. The experimental site by that time was planted with vetch and rye. The whole plots with vetch were mostly bare soil since the vetch did not survive the winter. This soil was passed through a 2 mm sieve. Cores made of PVC were sealed with a plastic grid on the bottom, another layer of fiberglass was added at the bottom and 100 g of the sampled soil was added to each core. The treatments were applied in a complete random design. The applied treatments were two methods of application of fertilizer (surface applied or incorporated); three rates of fertilizer 45, 90 and 180 kg ha⁻¹ converted to 100 g basis (assuming 1 ha = 2,000,000 kg of soil) plus a common control; and including three replications per treatment. Cores were incubated at 25° C using an incubator Lib-line Biotronette (Model 681-853). After seven days of

incubation, the first flush was carried out using 100 ml 0.01 M CaCl₂ for each core, then every seven days an additional flush was carried out throughout day 56. A sample of 1 ml was collected into microtubes (a sample for each core and each week) and from this an aliquot of 2 µl of each sample were placed in microplates and analyzed for NH₄⁺ and NO₃⁻ by the Greiss colorimetric method adapted to the microplate reader model (Crutchfield and Burton, 1989). Each sample was analyzed twice and the results were averaged.

The rate of change of NH₄⁺ and NO₃⁻ for each experimental time interval (7 days) and change in leachate concentration were used to derive k values for the rate of reaction. In this process initial N values were compared to final ones while deriving k values for accumulation for each experimental time interval. The concentration obtained by subtracting the amount of NH₄⁺ and NO₃⁻ generated with 0 kg N ha⁻¹, was considered as N mineralization from the fertilizer sources and used to report the kinetic analysis. The formula: $[A] - [A]_0 = -kt$ was employed based on the zero order reaction obtained from the curves, where:

[A]₀= initial concentration

[A]= final concentration

k= rate constant (mg inorganic-N day⁻¹)

t= time (days)

Statistical Analysis

Field data

The experimental design used for Spindletop 2008, UKREC 2008 and UKREC 2009 was a split-split-plot design where the whole plots were the cover crops hairy vetch and rye. Split plots were tillage systems (no-till and moldboard plow), and the split-split plots were the N treatment combinations including two N sources Nature Safe (NF) and Louisville Green (LG) and four rates of N at 45, 90, 135 and 180 kg N ha⁻¹ plus a common control. The analysis was carried out using SAS software using the PROC MIXED procedure (SAS Institute, 2008). All treatments were used to evaluate the effect of cover crop, tillage and the interaction between cover crop and tillage. To evaluate the effect of N source and N rate and their interactions with cover crops and tillage, a similar PROC MIXED procedure was used; in this case, the 0 kg N ha⁻¹ control was not included in the analysis. In Spindletop 2008 the weed variables grass weight and broadleaf weight and in UKREC 2009 the variables grass number, grass weight, broadleaf number needed to be transformed using natural logarithm. This transformation was needed so the variance of the random errors was constant across the treatments and replications so a homoscedastic model was

attained. The reported values were transformed back using anti- natural log.

Means were separated using LSD at the 0.1 significance level. The means were ordered using a macro for converting mean separation into groups by letters (Saxton, 1998).

Mineralization

In order to determine the NH_4^+ and NO_3^- accumulation a nested design was used, where:

N rate|N source|method of application.

This analysis also used the SAS PROC MIXED. The means were separated using LSD at the 0.1 significance level and the means were order using mean separation into groups by letters (Saxton, 1998).

Chapter Three: Results

Experimental site conditions for cover crop and corn growing seasons

Temperature during cover crop season

The experiment was conducted at two locations: Spindletop and UKREC. Spindletop corresponds to the University of Kentucky Research Farm located near Lexington, Kentucky and UKREC corresponds to the University of Kentucky Research and Education Center located near Princeton, Kentucky, respectively. The cover crop (CC) growing seasons consisted of three experimental sites: Spindletop CC 2007-2008, UKREC CC 2007-2008 and UKREC CC 2008-2009. These cover crop growing seasons preceded the corn growing seasons Spindletop 2007, UKREC 2008 and UKREC 2009, respectively.

Temperatures presented are from November to May of the specified cover crop growing seasons. The experimental sites UKREC CC 2007-2008 and UKREC CC 2008-2009 had milder temperatures than Spindletop CC 2007-2008 (Fig. 3.1.) The average temperature for both UKREC CC 2007-2008 and UKREC CC 2008-2009 was 9.0 °C whereas for Spindletop CC 2007-2008, it was 7.4 °C. The coldest months for the three cover crop growing seasons were December, January and February for all three experimental sites; however, Spindletop was colder over these three months than the other two experimental sites. In Spindletop CC 2007-2008, the coldest months averaged 2.4 °C whereas for UKREC 2007-2008 and UKREC 2008-2009 those months averaged 4.1 and 3.3 °C, respectively (Fig. 3.1).

Departures from normal temperatures for cover crop growing seasons are presented in Fig. 3.2. The sites UKREC CC 2007-2008 and Spindletop CC 2007-2008 were milder compared with UKREC 2008-2009, especially during the winter. For Spindletop CC 2007-2008, the greatest departure from normal occurred in December (2.1 °C above normal); in general, the temperatures were close to normal. In UKREC CC 2007-2008 temperatures were milder than UKREC CC 2008-2009 and the greatest departures occurred in March and May (1.2 and 1.4 °C below normal, respectively). For UKREC CC 2008-2009 the greatest departures from normal temperatures occurred in November and January (2.2 and 1.4 °C below normal, respectively).

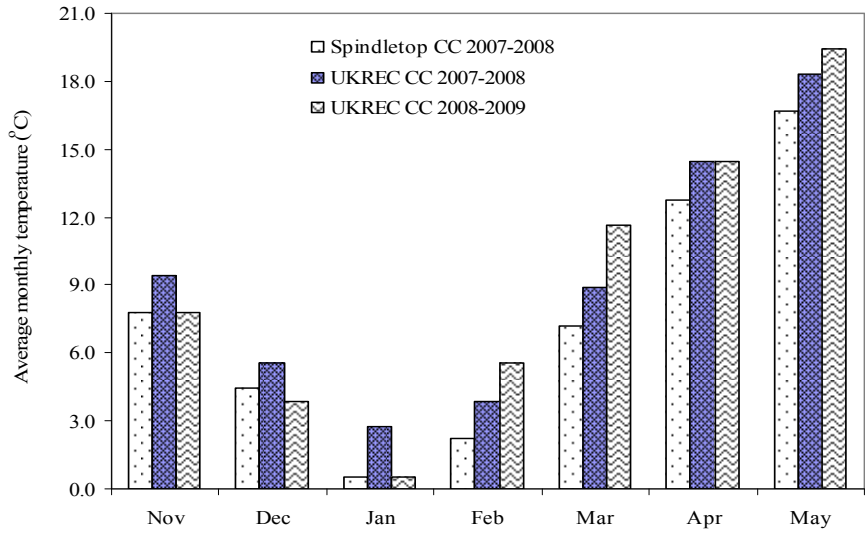


Figure 3.1. Comparison of the average monthly temperature during the cover crop (CC) growing season for Spindletop 2007-2008, UKREC 2007-2008 and UKREC 2008-2009.

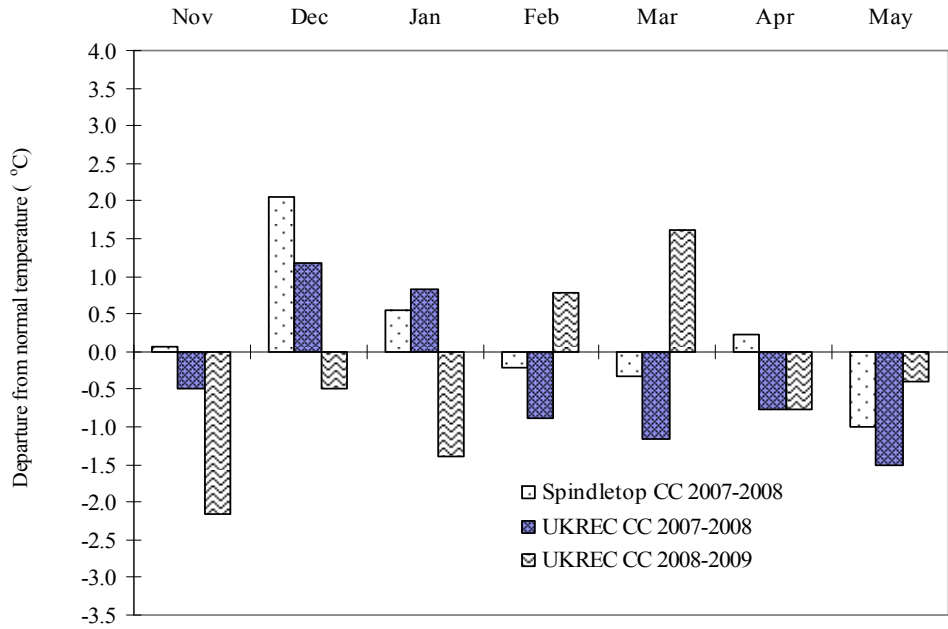


Figure 3.2. Departure from 30-yr (1971-2000) normal monthly temperatures for cover crop (CC) growing seasons for Spindletop 2007-2008, UKREC 2007-2008 and UKREC 2008-2009.

Precipitation during cover crop season

Precipitation amounts for the cover crop growing seasons are presented in Fig. 3.3. Comparatively, UKREC CC 2007-2008 was wetter than either Spindletop CC 2007-2008 or UKREC CC 2008-2009. The total precipitation for the cover crop growing season was 889, 1082 and 715 mm for Spindletop CC 2007-2008, UKREC CC 2007-2008 and UKREC CC 2008-2009, respectively. Spindletop CC 2007-2008 presented uniform precipitation especially during March, April and May that averaged 143 mm, months in which biomass greatly increases. In UKREC CC 2007-2008 there was higher precipitation throughout the season especially during December, March and April and May. In UKREC CC 2008-2009 there was comparatively lower precipitations especially March but during April and May precipitation was greater.

Departures from the normal precipitation for the cover crop growing seasons are shown in Fig. 3.4. The site UKREC CC 2008-2009 was drier than the other two experimental sites. Spindletop CC 2007-2008 presented a comparatively more uniform precipitation pattern averaging 136 mm above normal, UKREC CC 2007-2008 was the wettest experimental site with five out of seven months above normal averaging 70 mm above normal. The season UKREC 2008-2009 was drier than normal four out of seven months and was especially dry during March (46 mm below normal).

Temperature during the corn growing season

The corn growing season experimental sites sampled in this experiment were Spindletop 2008, UKREC 2008 and UKREC 2009. Temperatures presented are from June to October which included with the corn growing seasons for these experiments. The experimental site UKREC 2008 had warmer temperatures than the other two experimental sites (Fig. 3.5). Temperatures for that experimental site were consistent over the entire growing season. The growing season mean temperature for UKREC 2008 was 22.3 °C. The experimental sites UKREC 2009 and Spindletop 2008 each averaged 21.5 °C. The warmest months for the three experimental sites were June, July and August, although with different magnitude depending on the site. For these three months, Spindletop 2008 averaged 23.9 °C, UKREC 2008 averaged 25.6 °C and UKREC 2009 averaged 24.1 °C. The coolest month for every site was October. For instance, Spindletop 08 was 13.9 °C, UKREC 2008 15.6 °C and UKREC 2009 12.8 °C.

Departures from normal temperatures for each experimental site are shown in Fig. 3.6. For Spindletop 2008, temperatures were warmer than normal. The highest departures from normal for that experimental site occurred in June and September with 1.0 and 2.2 °C, respectively.

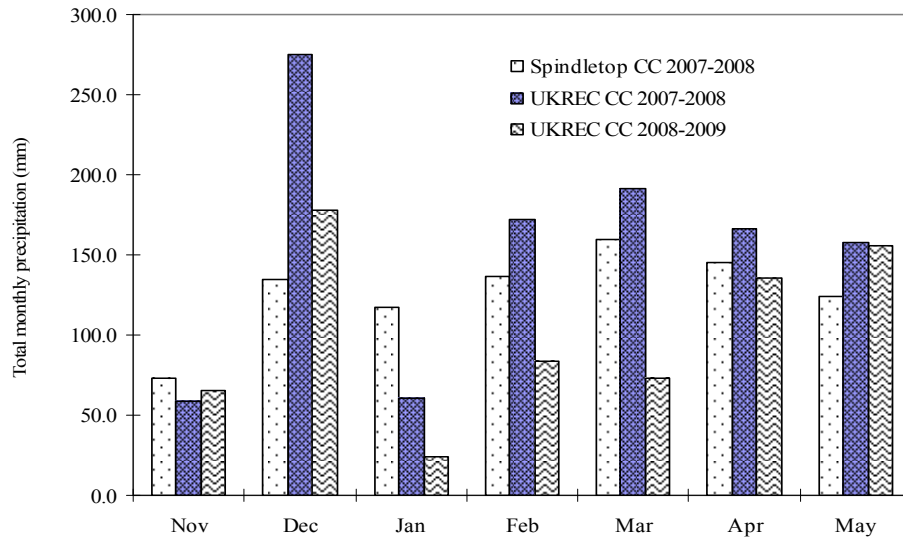


Figure 3.3. Comparison of the total monthly precipitation during the cover crop (CC) growing seasons for Spindletop 2007-2008, UKREC 2007-2008 and UKREC 2008-2009.

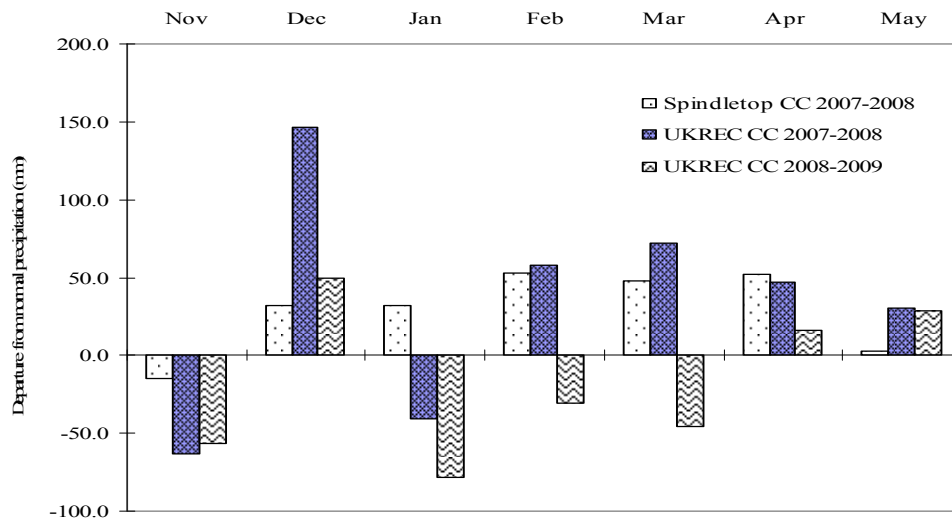


Figure 3.4. Departure from 30-yr (1971-2000) normal monthly precipitation for cover crop (CC) growing seasons for Spindletop 2007-2008, UKREC 2007-2008 and UKREC 2008-2009.

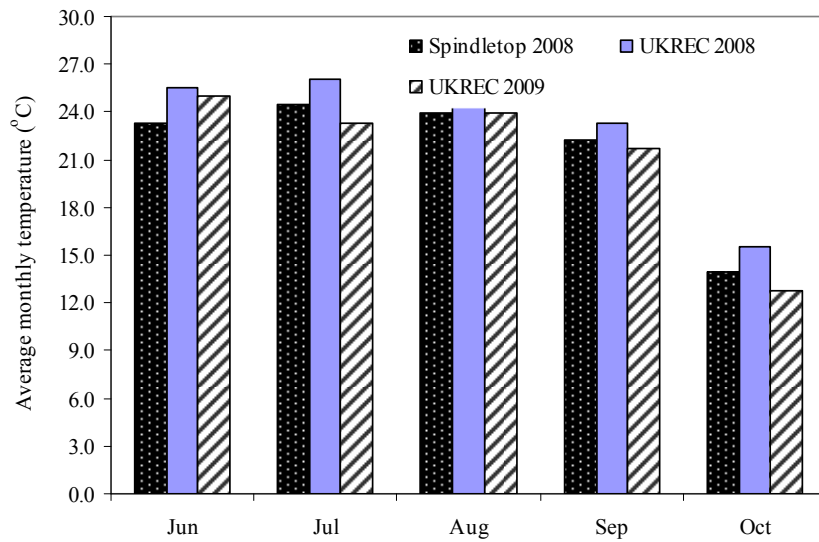


Figure 3.5. Comparison of the average monthly temperature during the corn growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.

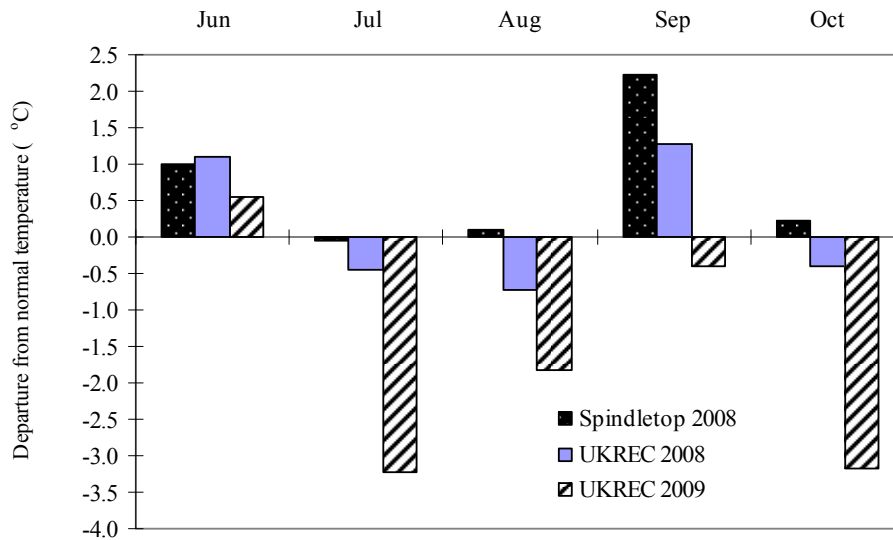


Figure 3.6. Departure from 30-yr (1971-2000) normal monthly temperatures for the corn growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.

For UKREC 2008, the temperature was closer to the normal than the other experimental sites. The highest departure from normal for that experimental site occurred in June and September with 1.0 and 1.3 °C. UKREC 2009 temperatures were considerably cooler than normal and cooler than the other two other experimental sites. July, August and October registered 3.2 °C, 1.8 °C and 3.2 °C below normal, respectively, in that experimental site.

Precipitation during the corn growing season

Total monthly precipitation for the experimental sites considered in this study is shown in Fig. 3.7. The UKREC 2009 experimental site was wetter than the other two experimental sites. Precipitation totals for Spindletop 2008, UKREC 2008, and UKREC 2009 were 241, 252 and 800 mm, respectively. As one can see, UKREC 2009 had the greatest monthly rainfall which was consistent over the entire growing season. For all the three experimental sites considered in this study, the wettest months were June and July and the drier months were August and September. October was wet in UKREC 2009 with a departure from the normal of 150 mm; however, October was dry for both Spindletop 2008 and UKREC 2008 (Fig. 3.7).

Spindletop 2008 was drier than normal for all five months (Fig. 3.8). The greatest departure from normal occurred in August with 68.3 mm below normal but in general all months were close to each other averaging 48.2 mm below normal. The experimental site UKREC 2008 was also drier than normal with exception of July. June, August and September were close to each other and averaged 71 mm below normal in that experimental site. The experimental site UKREC 2009 was a wet season with four out of five months above normal. The greatest deviations from normal for that experimental site occurred in June and October (99 and 147 mm above normal, respectively). On the other hand, August was 29 mm below normal.

Soil fertility characteristics

The initial soil fertility conditions for all three experimental sites are shown in Table 3.1. While water pH for UKREC 2008 was low, a lime application was not made. Phosphorus levels at the Spindletop 2008 test site were inherently high. Given the high soil test levels for P, K and Zn, there was no need to apply fertilizer for these elements at any of the experimental sites. Organic matter levels were higher for Spindletop 2008 than in the other two sites; this resulted in correspondingly higher C levels. Nitrogen levels for Spindletop 2008 were 1.9 times the average levels of UKREC 2008 and UKREC 2009. In spite of higher C content for Spindletop 2008, that experimental site had the lowest average C/N ratio. This was due to the higher N levels observed for that site.

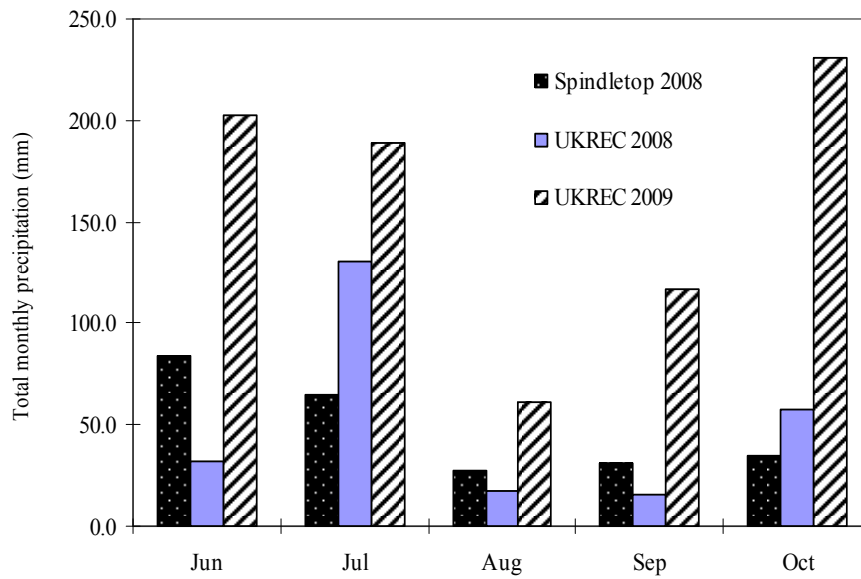


Figure 3.7. Comparison of total monthly precipitation during the crop growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.

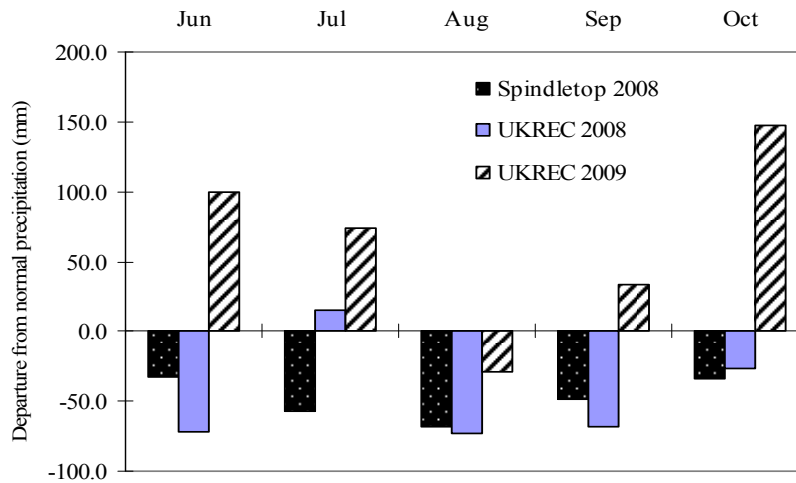


Figure 3.8. Departure from 30-yr (1971-2000) normal monthly precipitation during the crop growing seasons for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.

Table 3.1. Initial soil fertility conditions for the experimental sites Spindletop 2008, UKREC 2008 and UKREC 2009.

		pH	Buffer pH	P	K	Ca	Mg	Zn	OM	Total N	Total C	C/N
						-----kg ha ⁻¹ -----			-----g kg ⁻¹ -----			
Spindletop 2008	mean ^a	6.16	6.50	713	606	4426	472	5.9	37.9	2.25	22.10	9.8
	SE ^b	0.10	0.07	28	56	158	50	0.7	1.5	0.06	0.85	0.2
UKREC 2008	mean	5.90	6.80	33	355	3375	161	3.3	24.7	1.28	14.40	11.2
	SE	0.09	0.03	5	37	241	22	0.3	2.5	0.04	1.44	0.8
UKREC 2009	mean	6.57	7.00	98	385	3806	146	5.3	22.6	1.14	13.50	11.5
	SE	0.15	0.07	12	48	323	16	0.2	1.6	0.07	0.95	0.5

^a Each mean is drawn from 8 samples taken from each experimental site (2 from each of 4 replications)

^b SE= standard error

Cover crops for corn production

Cover crop and site main effects

Biomass production (g m^{-2}) was significantly different depending on the site. UKREC 2008 produced higher biomass than the other two sites (Table 3.2). Moreover, there were significant differences in biomass production depending on the type of cover crop. Rye produced 519 more g m^{-2} or 2.2 times more biomass than did hairy vetch. The sampled sites did not differ in N concentration. Meanwhile, there were significant differences depending on the type of cover crop with hairy vetch containing about five times more N than rye. C concentration was not influenced by site or by cover crop. C/N ratio was not influenced by the site. However, there were differences depending on the type of cover crop; rye had about five times higher C/N ratio than did hairy vetch. This was due to the difference in N concentration between the two cover crops. Hairy vetch had a much higher N concentration which caused its C/N ratio to be lower. N content presented no significant differences for sampled sites. On the other hand, there were significant differences depending on the cover crop with hairy vetch producing 136% more N content than rye C content was significantly different depending on the experiment site. UKREC 2008 had a higher C content than the other sites which was related with the biomass production. Furthermore, cover crops presented differences with rye producing 122% more C content than hairy vetch.

Interactions for cover crops

In this section only significant interactions between experimental site and cover crop will be presented.

Cover crop biomass

There were differences in the amount of biomass depending on the site (Fig. 3.9). Rye produced more biomass than hairy vetch in every site. The interaction is explained by the fact that rye in UKREC 2008 had higher biomass than rye at UKREC 2009 or rye at Spindletop 2008. Hairy vetch at UKREC 2008 and hairy vetch at UKREC 2009 were not significantly different but hairy vetch at Spindletop 2008 had higher biomass than hairy vetch UKREC 2009 ($p < 0.1$).

C concentration

Spindletop 2008 and UKREC 2008 cover crops were not significantly different in terms of C concentration within experimental site (Fig. 3.10). However, C concentration of hairy vetch

Table 3.2. Cover crop response to main effects and their interaction depending on the experimental site and cover crops used.

Main effect	Corn growing	N		C		C/N	N content	C content
	season	Biomass	concentration	concentration				
		g m ⁻²	g kg ⁻¹	g kg ⁻¹	g m ⁻²			
Site	Spindletop 2008	711b ¹	18.57	431	43.5	11.3	307a	
	UKREC 2008	830a	19.37	427	44.6	10.8	353a	
	UKREC 2009	560c ** ²	19.91 NS	430 NS	38.2 NS	8.8 NS	243b **	
Cover crop	Hairy vetch	434	32.03	427	13.7	14.2	185	
	Rye	953	6.53	432	70.5	6.0	411	
		**	**	NS	**	**	**	
Site x Cover crop		**	NS	*	NS	NS	**	

¹ Site means with the same letter are not significantly different at the 0.1 probability level.

² Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

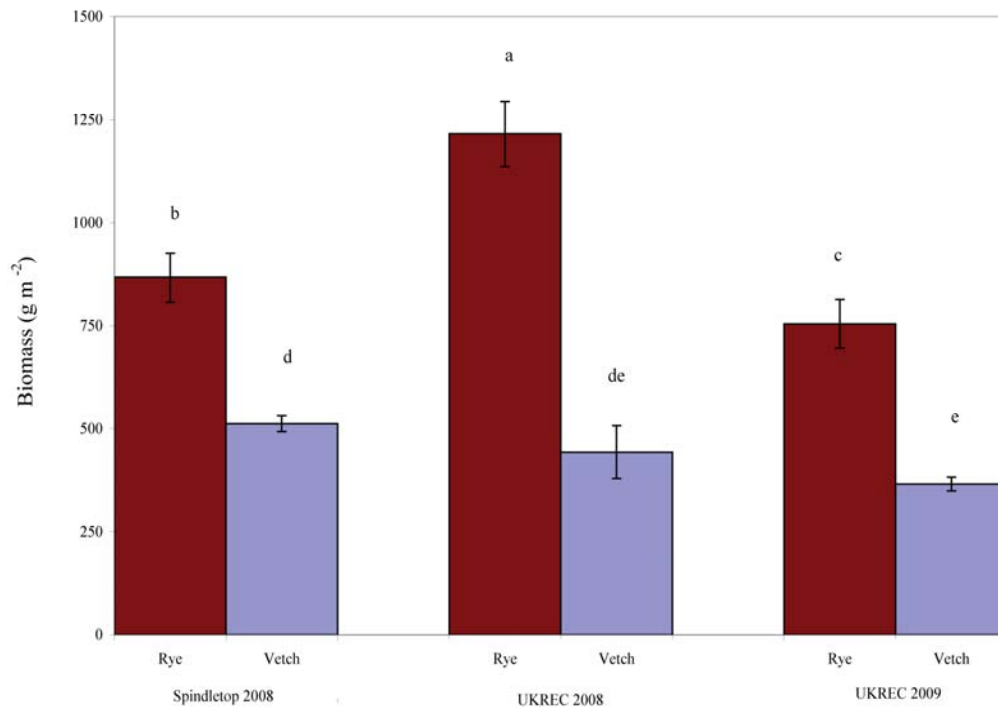


Figure 3.9. Biomass yield response to cover crop and experimental site.

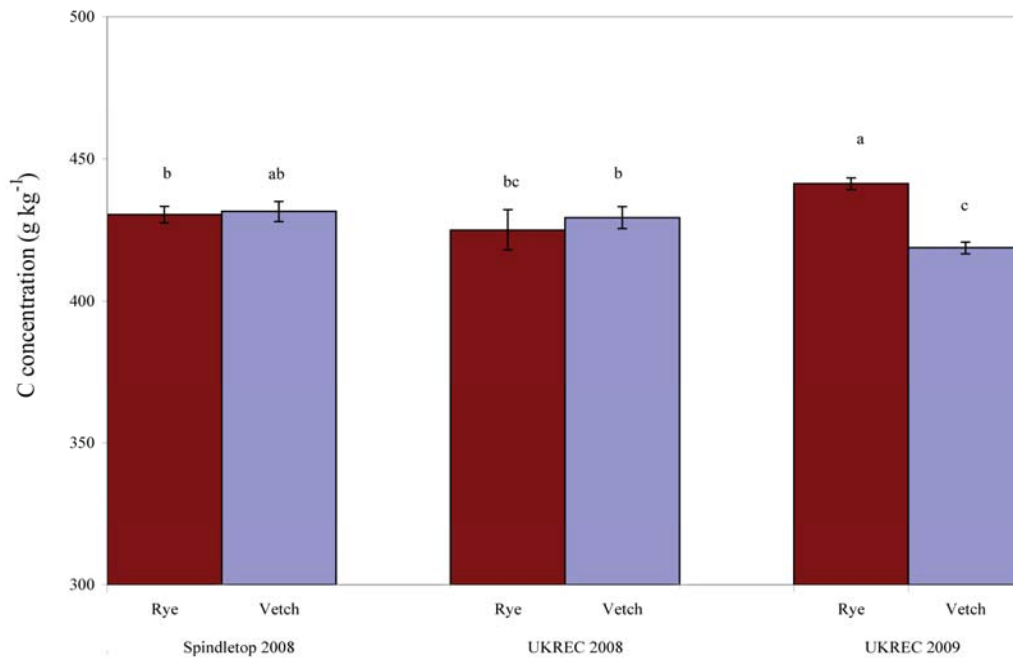


Figure 3.10. C concentration in response to type of cover crop and experimental site.

was significantly lower than that of rye for UKREC 2009; this difference accounts for the observed interaction.

C content

Fig. 3.11 shows that rye produced higher C content than hairy vetch regardless of the site. The interaction is due to 46% greater C content for rye in UKREC 2008 than in either UKREC 2009 or Spindletop 2008, which averaged 353 g m^{-2} . Hairy vetch produced greater C content in Spindletop 2008 than in UKREC 2009. The differences in C content mirrored the differences in biomass (Fig. 3.9) which was expected since C content is a function of the amount of biomass present.

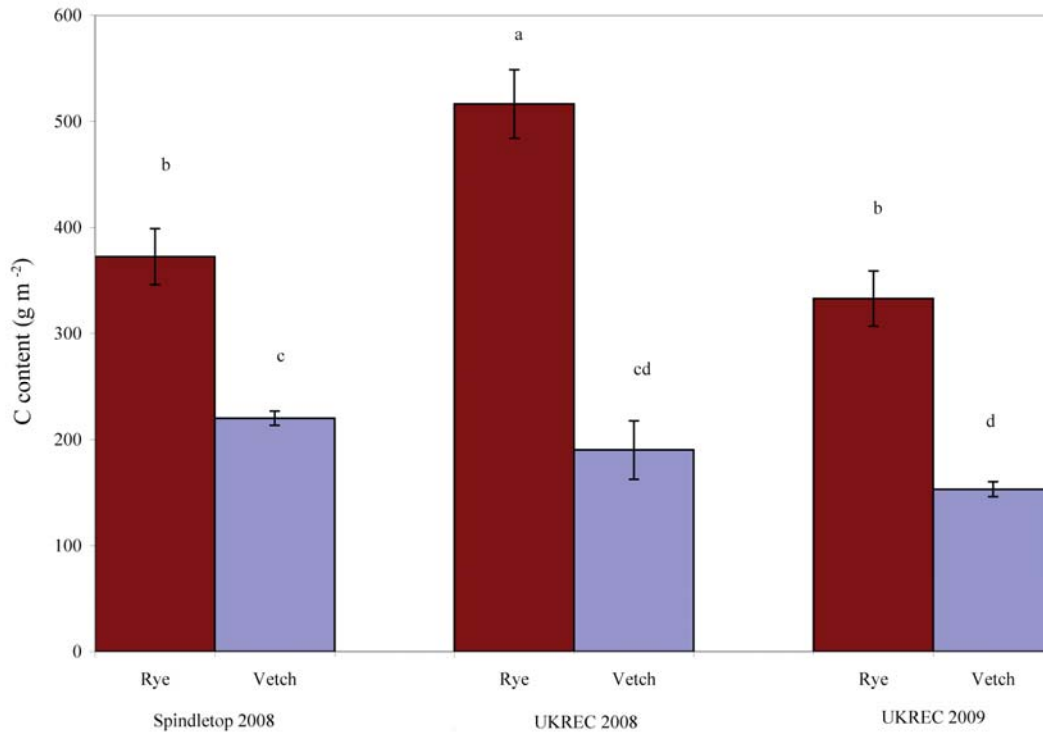


Figure 3.11. C content in response to cover crop and experimental site.

Crop responses

Spindletop 2008 experimental site

Main effects for Spindletop 2008

Stand establishment for Spindletop 2008 was influenced by cover crop (Table 3.3). Under hairy vetch there were 8.3% more plants than under rye, enough to cause a significant difference. Meanwhile, establishment under moldboard plow (MP) was 16.8% higher than under no-till (NT). Unsurprisingly, neither N source nor N rate influenced stand establishment.

Ear leaf N was significantly different depending on cover crop; plots with hairy vetch produced 51.8% more ear leaf N than did those with rye (Table 3.3). Moreover, tillage was also significant and plots with MP had 6.3% more ear leaf N than NT. In terms of N source, plots fertilized with NF resulted in 3.4% more ear leaf N than did plots fertilized with LG. N rates were significantly different for ear leaf N content with the greatest two N rates resulting in higher ear leaf N content than the lowest two N rates.

Yield did not significantly differ between cover crops (Table 3.3). However, tillage was significantly different, with MP plots registering on average 92.6% more grain than NT plots. N source did not influence yield. N fertilizer rates of 45, 135 and 180 kg ha⁻¹ were not different, averaging 2.37 Mg ha⁻¹ but the 90 kg ha⁻¹ rate was significantly lower at 1.86 Mg ha⁻¹.

Hairy vetch led to significantly more grain N than did rye (Table 3.3). There were no differences for tillage. N source did not influence grain N. N rates were significantly different, with the highest grain N level obtained with 180 kg N ha⁻¹, whereas the 90 and 135 kg N ha⁻¹ rates did not differ. The lowest grain N was obtained with 45 kg N ha⁻¹ (Table 3.3). N rates significantly influenced grain N, in a nearly step-wise fashion.

Interactions for Spindletop 2008

In this section only significant interactions will be discussed (Table 3.4).

Ear leaf N interactions Spindletop 2008

Cover crop x tillage

Ear leaf N for corn following hairy vetch was not affected by tillage (Fig. 3.12). However, MP rye resulted in 24% higher ear leaf N content than did NT rye.

Table 3.3. Corn crop performance under cover crop, tillage, N source and N rate for Spindletop 2008.

Main effect	Level	Stand establishment	Ear leaf N	Yield	Grain N
		Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹
Cover crop ¹	Hairy vetch	66739	21.70	2.41	14.65
	Rye	61628	14.30	1.96	10.88
		† ³	**	NS	**
Tillage ¹	Moldboard plow (MP)	69144	18.50	2.87	12.75
	No-till (NT)	59223	17.40	1.49	12.79
		**	†	**	NS
N source ²	Louisville Green (LG)	64259	17.78	2.18	12.71
	Nature Safe (NF)	64462	18.38	2.31	12.95
		NS	†	NS	NS
N rate ²	45 kg N ha ⁻¹	65070	17.52 b ⁴	2.28 a	12.39 c
	90 kg N ha ⁻¹	62906	17.36 b	1.86 b	12.61 bc
	135 kg N ha ⁻¹	63853	18.50 a	2.44 a	12.82 b
	180 kg N ha ⁻¹	65611	18.95 a	2.40 a	13.48 a
		NS	**	†	**

¹ Analysis for cover crop and tillage including control.

² Analysis for N source and N rate excluding control.

³ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

⁴ N rate means with the same letters are not significant different (NS).

Table 3.4. Corn crop interactions for cover crop, tillage, N source and N rate for Spindletop 2008.

	Stand establishment	Ear leaf N	Yield	Grain N
	Plants ha⁻¹	g kg⁻¹	Mg ha⁻¹	g kg⁻¹
Cover crop x tillage¹	NS ³	**	*	*
Cover crop x N source²	NS	NS	NS	NS
Tillage x N source²	NS	NS	NS	NS
Cover crop x tillage x N source²	NS	NS	NS	NS
Cover crop x N rate²	NS	NS	NS	**
Tillage x N rate²	NS	NS	†	NS
Cover crop x tillage x N rate²	NS	†	NS	NS
N source x N rate²	NS	†	NS	NS
Cover crop x N source x N rate²	NS	NS	NS	NS
Tillage x N source x N rate²	NS	*	NS	NS
Cover crop x tillage x N source x N rate²	NS	NS	NS	NS

¹ Analysis for cover crop x tillage including N rate control.

² Analysis for interactions that include N source and N rate exclude control.

³ Significant levels are noted as: not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

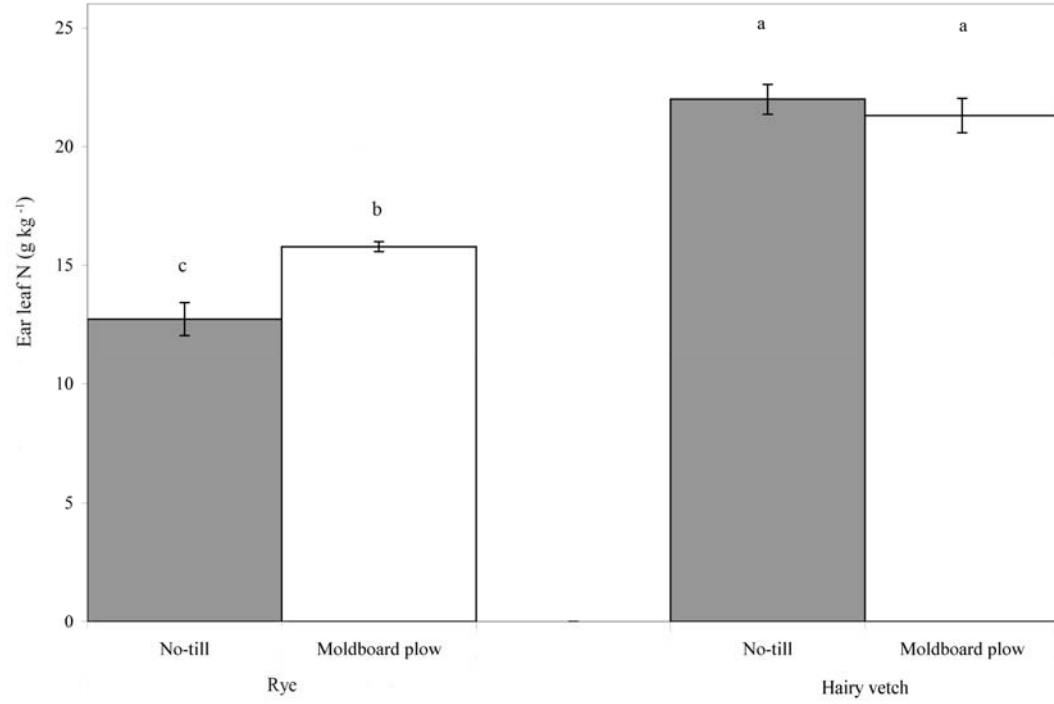


Figure 3.12. Ear leaf N response to tillage and cover crop, Spindletop 2008.

Cover crop x tillage x N rate

Ear leaf N was greater following vetch than following rye regardless of fertilizer N rate (Fig. 3.13). Tillage influenced the response of corn following hairy vetch no-till at 135 kg N ha⁻¹ but all other responses were not different between vetch treatments. Moldboard plow rye showed increasing ear leaf N content response with increasing N rates. No-till rye showed no N rate response.

N source x N rate

Nature Safe (NF) and Louisville Green (LG) responded to N rate differently (Fig. 3.14). At 45, 90 and 135 kg ha⁻¹, the two sources did not differ in ear leaf N. However, at 180 kg ha⁻¹, NF had significantly higher ear leaf N (7%) than did LG.

Tillage x N source x N rate

In general, MP resulted in higher levels of ear leaf N compared with NT. The significant interaction was primarily the result of a nearly step-wise N rate response for MP NF (Fig. 3.15).

Yield interactions Spindletop 2008

Cover crop x tillage

Moldboard plowing gave a higher corn grain yield than no-till regardless of cover crop for Spindletop 2008 (Fig. 3.16). The interaction is explained by the fact that hairy vetch no-till resulted in a significantly higher yield (114%) than did rye no-till.

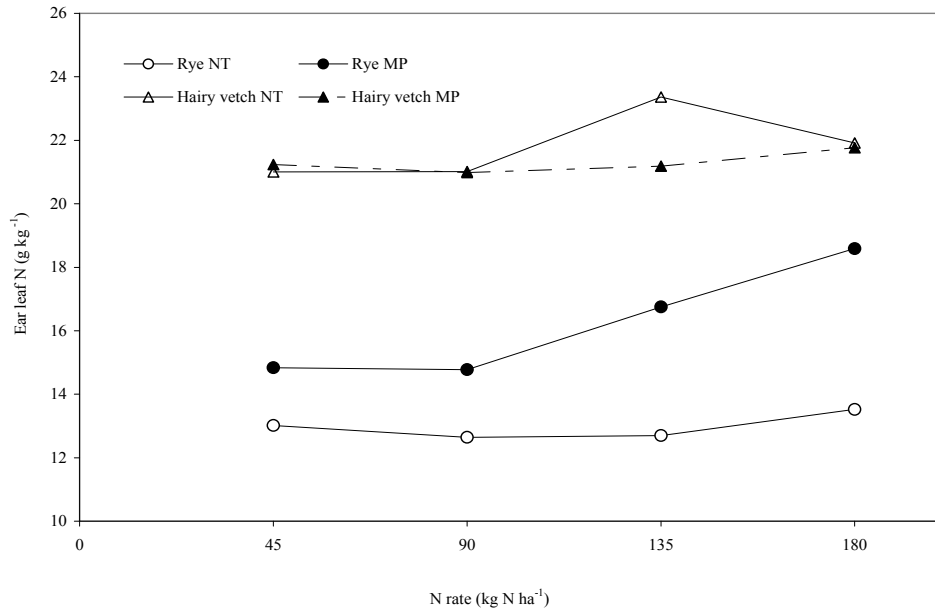


Figure 3.13. Ear leaf N response to cover crop x tillage x N rate (45, 90, 135, 180 kg N ha⁻¹), Spindletop 2008.

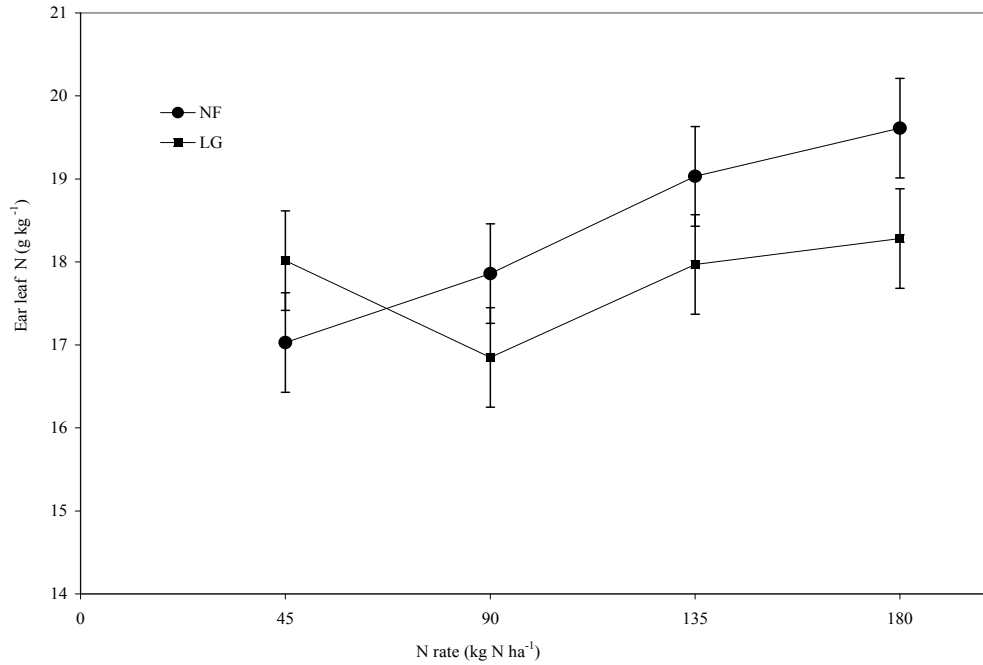


Figure 3.14. Ear leaf N response to N source, and N rate (45, 90, 135, 180 kg N ha⁻¹), Spindletop 2008.

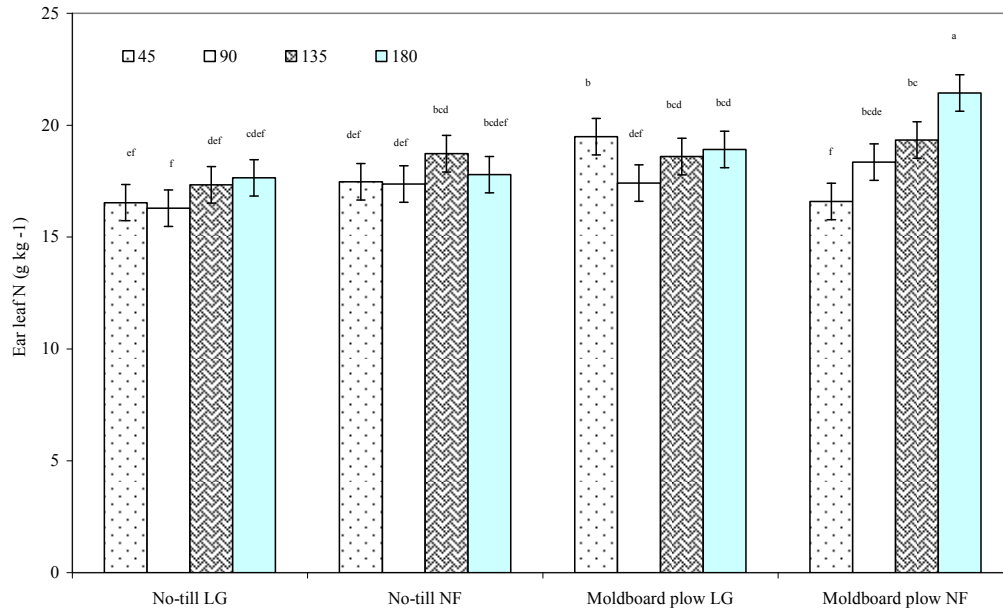


Figure 3.15. Ear leaf N response to tillage, N source, and N rate (45, 90, 135, 180 kg N ha⁻¹), Spindletop 2008.

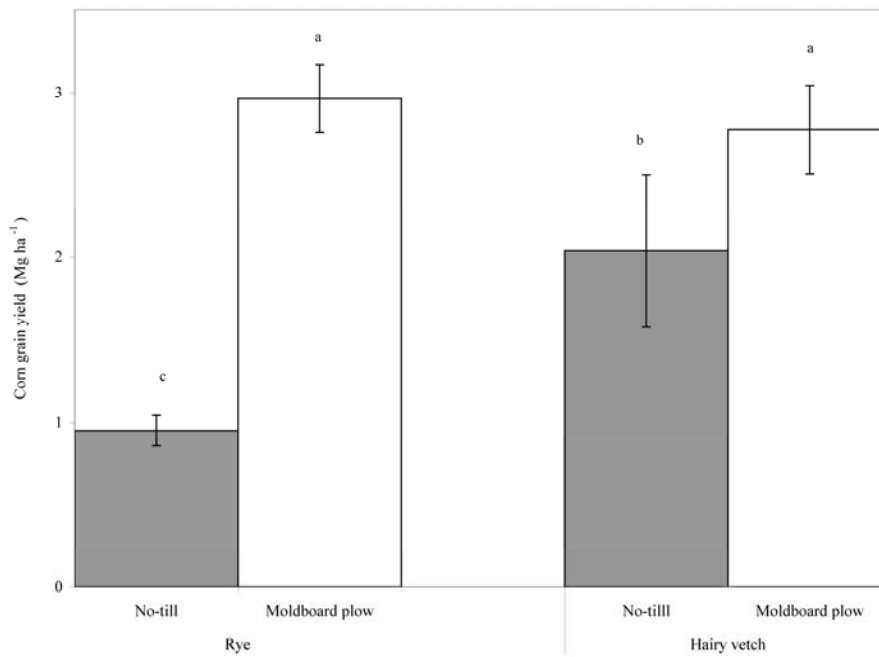


Figure 3.16. Corn grain yield response to tillage and cover crop, Spindletop 2008.

Tillage x N rate

Absolute and relative yield response to fertilizer N rate and tillage is presented in Fig. 3.17 a and b. For relative yield, the maximum yield for each tillage treatment is set as 100%. For MP, N rates did not affect either absolute (Fig. 3.17 a) or relative yields (Fig. 3.17 b). In contrast, moving from 90 to 135 kg N ha⁻¹ significantly increased both absolute and relative yields of NT corn. Maximum yield was obtained with 45 and 135 kg N ha⁻¹ for MP and NT, respectively.

Grain N interactions Spindletop 2008

Cover crop x tillage

Grain N for Spindletop 2008 was significantly influenced by the type of cover crop with hairy vetch resulting in higher grain N than rye (Fig. 3.18), as occurred with ear leaf N. However, NT hairy vetch produced 6.0% higher grain N than did MP vetch, enough to be significantly different.

Cover crop x N rate

Grain N for plots under hairy vetch did not respond to N rate (Fig. 3.19). However there was a strong response to N fertilizer under rye. Both 135 and 180 kg N ha⁻¹ rates applied to corn following rye resulted in significant ($p < 0.1$) increases in grain N.

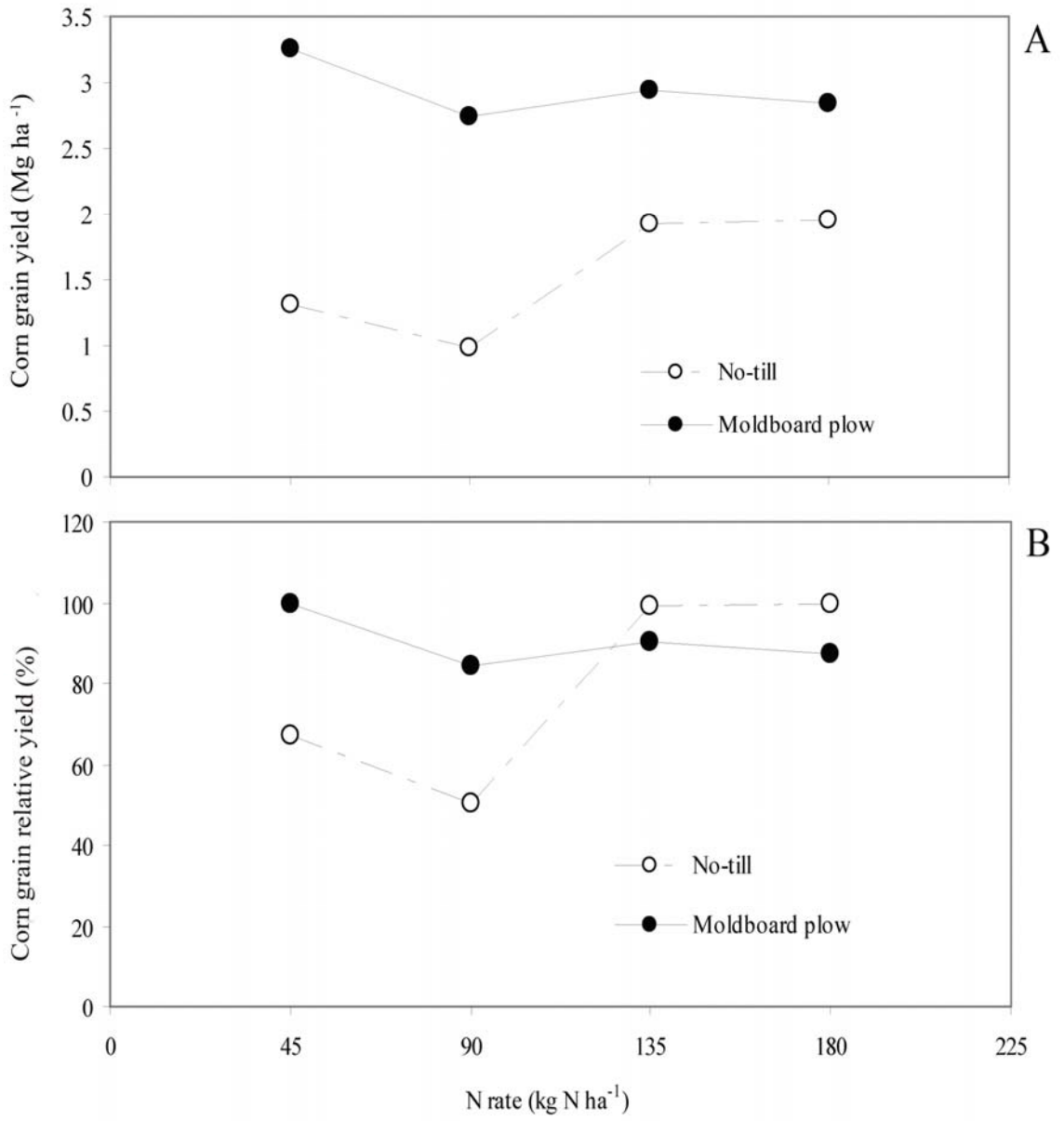


Figure 3.17 a and b. Corn yield response to tillage and N rate. Absolute yield (panel A) and relative yield response (panel B), Spindletop 2008.

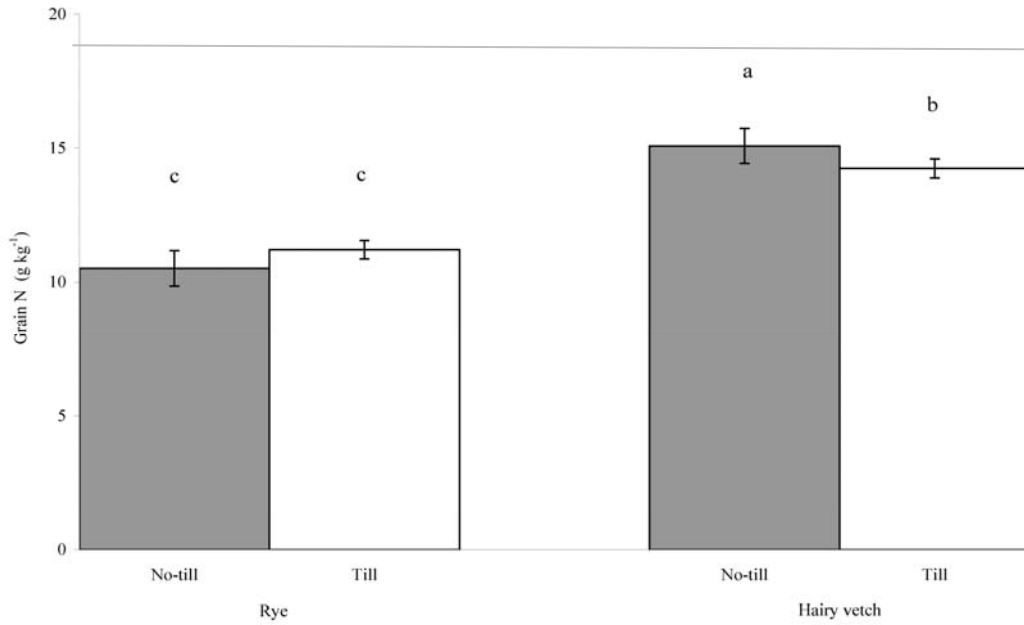


Figure 3.18. Grain N response to cover crop and tillage, Spindletop 2008.

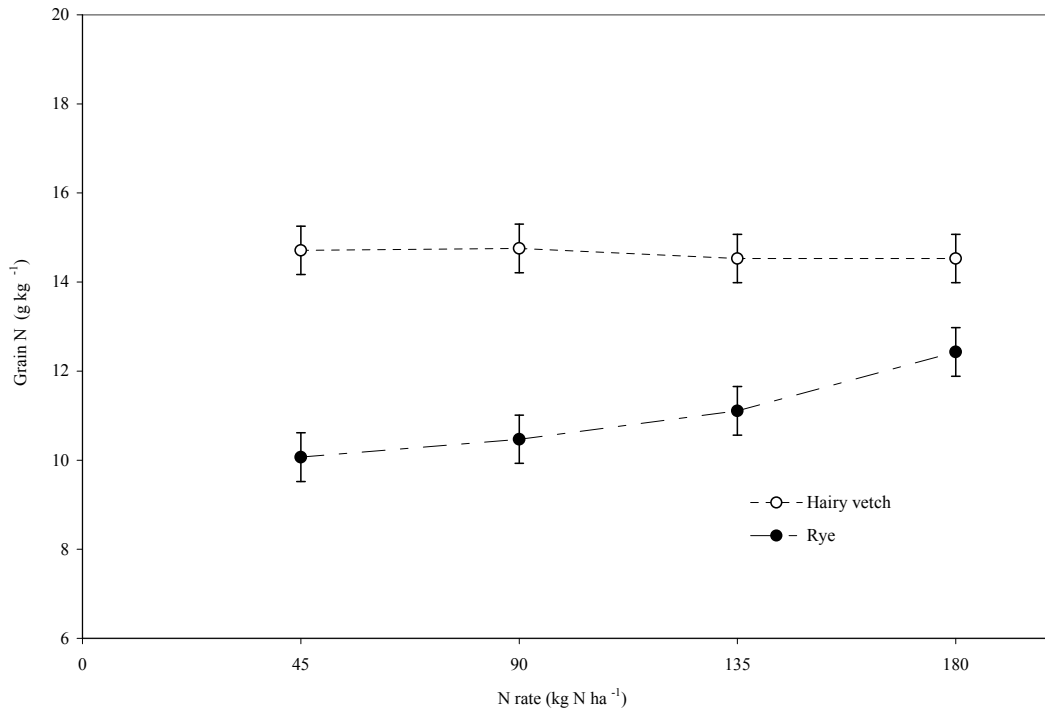


Figure 3.19. Grain N response to cover crop and N rate (45, 90, 135, 180 kg N ha⁻¹), Spindletop 2008.

UKREC 2008 experimental site

Main effects for UKREC 2008

None of the main effects influenced stand establishment for UKREC 2008 (Table 3.5). Meanwhile, ear leaf N was significantly higher (by 24%) for plots following hairy vetch than for rye (Table 3.5). Tillage type did not influence ear leaf N content. N source was significantly different with NF resulting in 5.5% more ear leaf N than LG. For N rates, the only significant difference was between the lowest and the highest application rates.

Yield was significantly different for cover crops; hairy vetch produced 33% more yield than did rye (Table 3.5). However, tillage did not differ significantly. In terms of N source, plots that received NF produced 5.4% more yield than plots that received LG. The N rate effect on yield was very similar to the N rate effect on ear leaf N.

Grain N presented significant differences for cover crop; plots following hairy vetch had 26.4% than did plots following rye (Table 3.5). There were no differences for tillage type. However, N sources were different with NF producing 2.6% more grain N than LG (Table 3.5). Higher grain N values were obtained with 135 and 180 kg ha⁻¹ which were not different from each other averaging 12.17 g kg⁻¹ while 45 kg N ha⁻¹ produced the lowest grain N with 11.16 mg N kg⁻¹. Grain N was somewhat more responsive to N rates than either ear leaf N or yield in terms of statistical significance.

Interactions for UKREC 2008

In this section only significant interactions will be discussed. The four way interaction cover crop x tillage x N source x N rate for yield will not be discussed because its lack of logical meaning (Table 3.6).

Ear leaf N interactions for UKREC 2008

Cover crop x N source

Ear leaf N was not influenced by N source for corn following hairy vetch (Fig. 3.20). In contrast, NF for rye resulted in 11.5% higher ear leaf N than did LG.

Table 3.5. Corn crop performance under cover crop, tillage, N source and N rate at the UKREC 2008 experimental site.

Main effect	Level	Stand establishment	Ear leaf N	Yield	Grain N
		Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹
Cover crop ¹	Hairy vetch	65296	25.65	7.90	13.18
	Rye	60366	20.74	5.94	10.27
		NS	**	**	**
Tillage ¹	Moldboard plow	61147	23.39	7.08	11.53
	No-till	64514	22.99	6.76	11.93
		NS	NS	NS	NS
N source ²	Louisville Green (LG)	62838	22.64	6.74	11.66
	Nature Safe (NF)	63312	23.75	7.10	11.98
		NS	*	†	†
N rate ²	45 kg N ha ⁻¹	62771	22.25b	6.49b	11.16c
	90 kg N ha ⁻¹	62229	23.36ab	6.86ab	11.80b
	135 kg N ha ⁻¹	64394	23.13ab	7.12a	12.22a
	180 kg N ha ⁻¹	62906	24.04a	7.22a	12.11ab
		NS	†	†	**

¹ Analysis for cover crop and tillage including control.

² Analysis for N source and N rate excluding control.

³ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

⁴ N rate means with the same letters are not significant different (NS).

Table 3.6. Corn crop interactions for cover crop, tillage, N source and N rate at the UKREC 2008 experimental site.

	Stand establishment	Ear leaf N	Yield	Grain N
	Plants ha⁻¹	g kg⁻¹	Mg ha⁻¹	g kg⁻¹
Cover crop x tillage¹	NS ³	NS	*	NS
Cover crop x N source²	NS	†	NS	†
Tillage x N source²	NS	NS	NS	NS
Cover crop x tillage x N source²	NS	NS	NS	†
Cover crop x N rate²	NS	NS	NS	NS
Tillage x N rate²	NS	NS	NS	NS
Cover crop x tillage x N rate²	NS	NS	NS	NS
N source x N rate²	NS	NS	NS	NS
Cover crop x N source x rate²	NS	NS	NS	NS
Tillage x N source x N rate²	NS	NS	NS	*
Cover crop x tillage x N source x N rate²	NS	NS	†	NS

¹ Analysis for cover crop x tillage including N rate control.

² Analysis for interactions that include N source and N rate exclude control.

³ Significant levels are noted as: not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

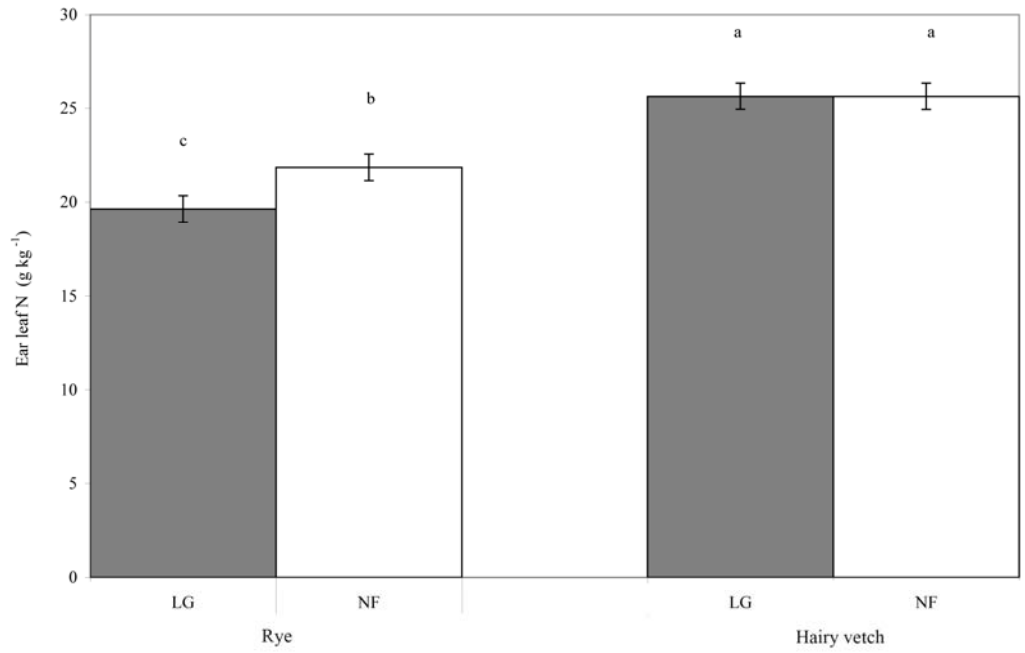


Figure 3.20. Ear leaf N response to cover crop and N source, UKREC 2008.

Yield interactions for UKREC 2008

Cover crop x tillage

Yields of corn following hairy vetch were not influenced by tillage treatment; however, yields of corn following rye were 17% higher for MP than for NT (Fig. 3.21). This is a different result than for Spindletop 2008 (Fig. 3.16) in which tillage provided significantly higher yield than did no-till.

Grain N interactions for UKREC 2008

Cover crop x N source

Hairy vetch provided significantly higher levels of grain N compared with rye regardless of N source (Fig. 3.22). However, rye plots fertilized with NF produced significantly higher grain N (6.1%) than did rye with LG.

Cover crop x tillage x N source

In general, hairy vetch provided higher grain N levels than did rye. Within tillage systems, N sources did not significantly affect grain N of corn following hairy vetch (Fig. 3.23). In contrast, NF MP rye resulted in an increase of 8.4% in grain N compared with LG MP rye. Grain N of NT rye was not significantly affected by N source.

Tillage x N source x N rate

In general, tillage systems did not affect grain N content. However, the interaction is due to the stepwise response of no-till NF to N rates (Fig. 3.24).

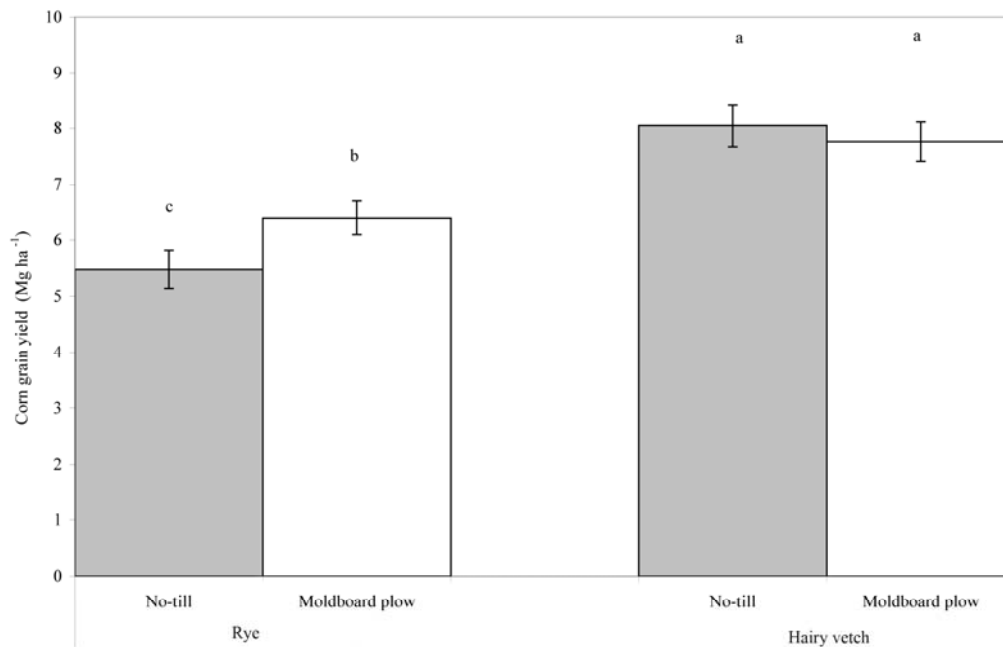


Figure 3.21. Corn grain yield response to cover crop and tillage, UKREC 2008.

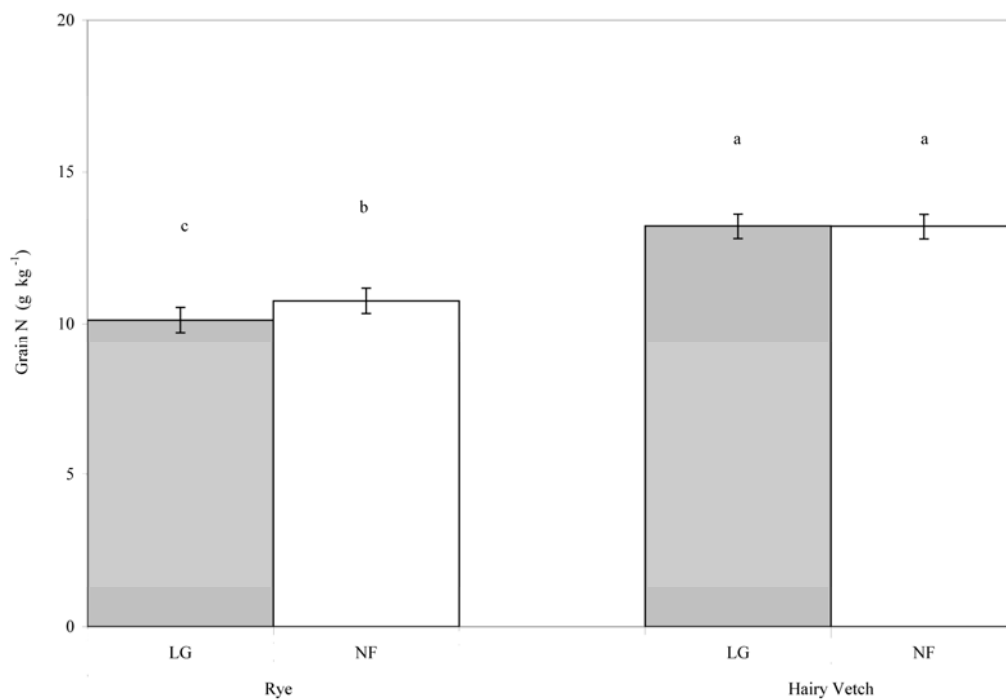


Figure 3.22. Grain N response to cover crop and N source, UKREC 2008.

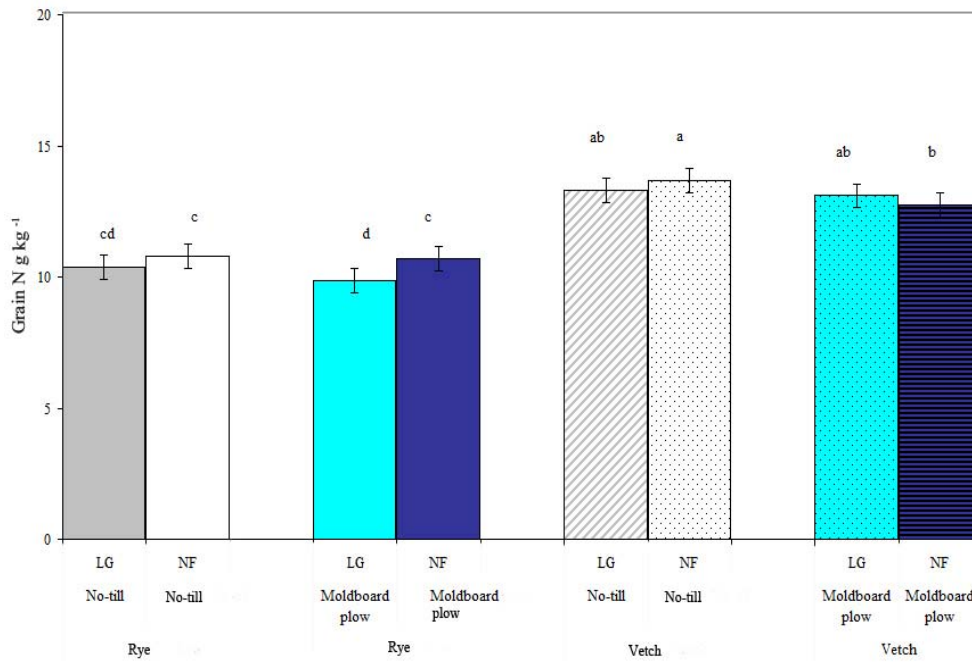


Figure 3.23. Grain N response to cover crop, tillage and N source, UKREC 2008.

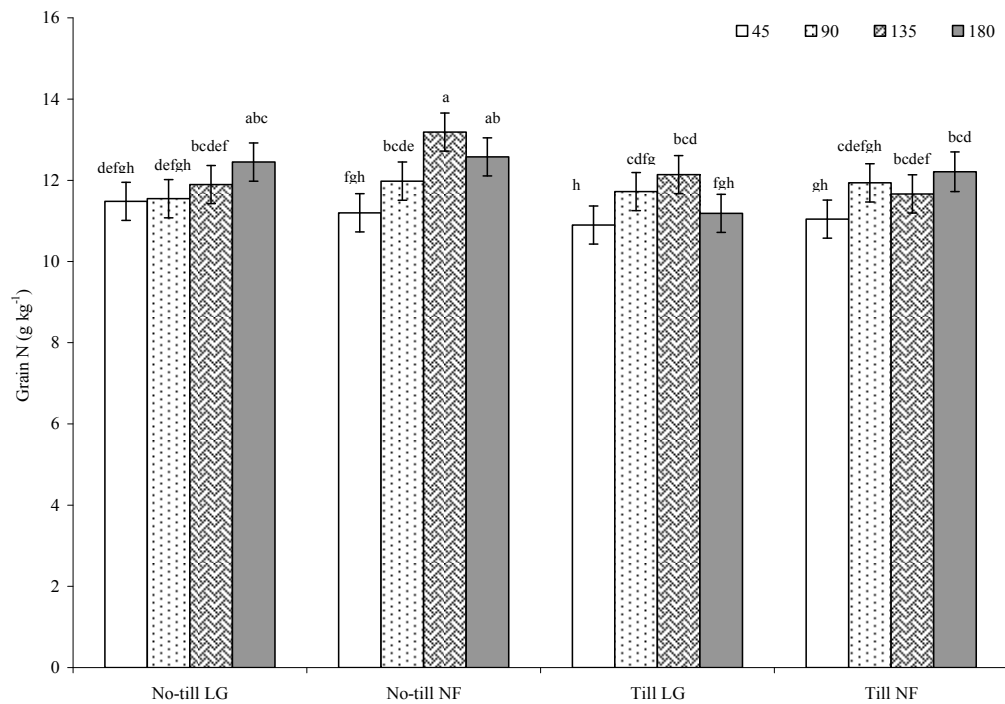


Figure 3.24. Grain N response to tillage, N source and N rate (45, 90, 135, 180 kg N ha⁻¹), UKREC 2008.

UKREC 2009 experimental site

Main effects for UKREC 2009

None of the main effects influenced stand establishment for UKREC 2009 (Table 3.7). Ear leaf N differed for cover crops; plots under hairy vetch had 48% higher ear leaf compared to those under rye (Table 3.7). Tillage also was significantly different; plots that received MP had 23% more ear leaf N than plots that received NT. N sources in this experimental site were not different. The two highest N rates differed significantly in ear leaf N from the two lowest N rates.

Yield was significantly different for cover crops and plots under hairy vetch produced 50% more than plots under rye (Table 3.7). Tillage was not significantly different. N sources were significantly different and NF yielded 10.4% more grain than LG. The N rate effect on yield mirrored the N rate effect on ear leaf N.

Grain N presented significant differences for cover crop where plots under hairy vetch produced 14.5% more grain N than plots under rye (Table 3.7). The type of tillage used was also significant; MP produced 5.6% more grain N than did NT. Neither N source nor N rate significantly influenced grain N.

Interactions for UKREC 2009

In this section only significant interactions will be discussed. The tillage x N rate interaction for stand establishment will not be discussed because the lack of meaningful interpretation (Table 3.8).

Ear leaf N interactions for UKREC 2009

Tillage x N rate

There were pronounced differences between MP and NT observed at 45 and 180 kg N ha⁻¹, but not at the two intermediate rates (Fig. 3.25). At 45 kg N ha⁻¹, MP had 20% more ear leaf N than NT and at 180 kg N ha⁻¹ MP had 29% more ear leaf N than did NT.

Cover crop x N source x N rate

In general, plots under hairy vetch had a higher ear leaf N content than plots under rye (Fig. 3.26). In both rye and vetch there was a response to higher N rates. However, under vetch LG and vetch NF there was a significantly higher response than in the other treatments.

Table 3.7. Corn crop performance under cover crop, tillage, N source and N rate at the UKREC 2009 experimental site.

Main effect	Level	Stand establishment	Ear leaf N	Yield	Grain N
		Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹
Cover crop¹	Hairy vetch	67400	20.77	8.15	10.73
	Rye	69324	13.93	5.42	9.38
		NS ³	**	**	**
Tillage¹	Moldboard plow	69625	18.26	7.08	10.34
	No-till	67100	16.44	6.49	9.78
		NS	†	NS	*
N source²	Louisville				
	Green (LG)	68994	17.06	6.65	10.09
	Nature Safe (NF)	68723	18.16	7.34	10.09
		NS	†	*	NS
N rate²	45 kg N ha⁻¹	69805	16.00b ⁴	5.90b	9.86
	90 kg N ha⁻¹	66694	16.83b	6.08b	10.11
	135 kg N ha⁻¹	68452	18.18a	7.88a	10.24
	180 kg N ha⁻¹	70482	19.43a	8.11a	10.14
		NS	**	**	NS

¹ Analysis for cover crop and tillage including control.

² Analysis for N source and N rate excluding control.

³ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

⁴ N rate means with the same letters are not significantly different (NS).

Table 3.8. Corn crop interactions for cover crop, tillage, N source and N rate at UKREC 2009 experimental site.

	Stand establish.	Ear leaf N	Yield	Grain N
	Plants ha⁻¹	g kg⁻¹	Mg ha⁻¹	g kg⁻¹
Cover crop x tillage¹	NS ³	NS	**	**
Cover crop x N source²	NS	NS	NS	NS
Tillage x N source²	NS	NS	NS	NS
Cover crop x tillage x N source²	NS	NS	NS	NS
Cover crop x N rate²	NS	NS	†	NS
Tillage x N rate²	*	*	NS	NS
Cover crop x tillage x N rate²	NS	NS	NS	NS
N source x N rate²	NS	NS	NS	NS
Cover crop x N source x N rate²	NS	*	NS	NS
Tillage x N source x N rate²	NS	NS	NS	NS
Cover crop x tillage x N source x N rate²	NS	NS	NS	NS

¹ Analysis for cover crop and tillage including control

² Analysis for N source and N rate excluding control

³ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**)

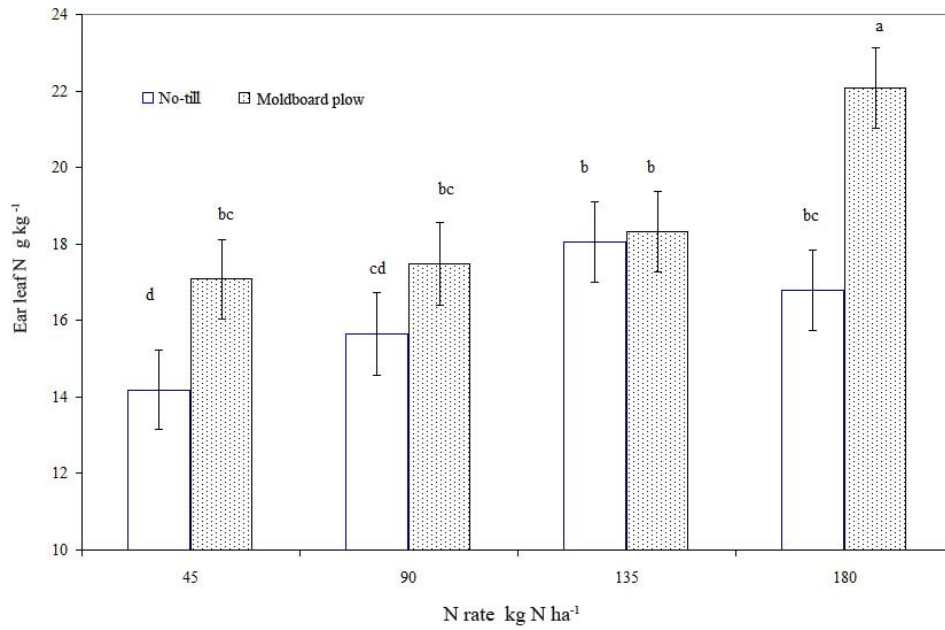


Figure 3.25. Ear leaf N response to tillage and N rate, UKREC 2009.

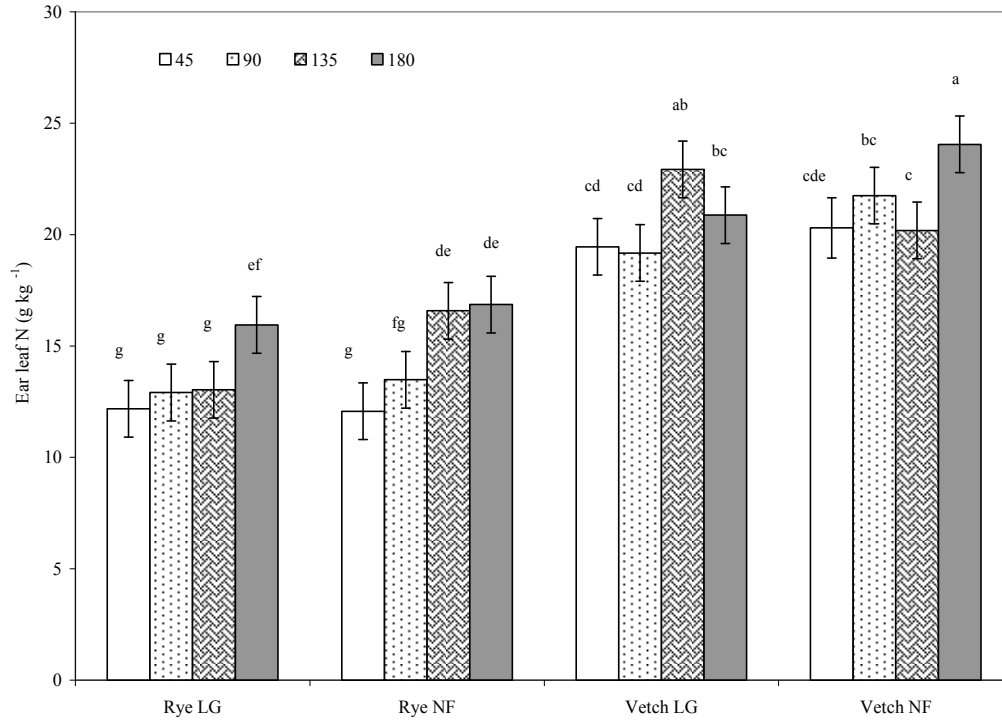


Figure 3.26. Ear leaf N response to cover crop, N source and N rate (45, 90, 135, 180 kg N ha⁻¹), UKREC 2009.

Yield interactions for UKREC 2009

Cover crop x tillage

Moldboard plow hairy vetch produced significantly more yield (39%) than did NT hairy vetch (Fig. 3.27). Meanwhile, the difference between NT and MP rye was not significant.

Cover crop x N rate

Corn following both hairy vetch and rye responded significantly in yield to increases of N rate from 90 to 135 kg ha⁻¹ (Fig. 3.28 a and b). While corn following hairy vetch showed no additional N rate response, corn following rye benefited from a further increase to 180 kg N ha⁻¹. This trend is better depicted in relative yield where plots under rye responded from 60 to 80% by increases of N rate from 90 to 135 kg ha⁻¹ and by another 20% by addition of 180 kg N ha⁻¹.

Grain N interactions for UKREC 2009

Cover crop x Tillage

Grain N of corn following hairy vetch NT was significantly higher than for hairy vetch MP (12.4%). However, corn grain N following by rye was not influenced by tillage (Fig. 3.29).

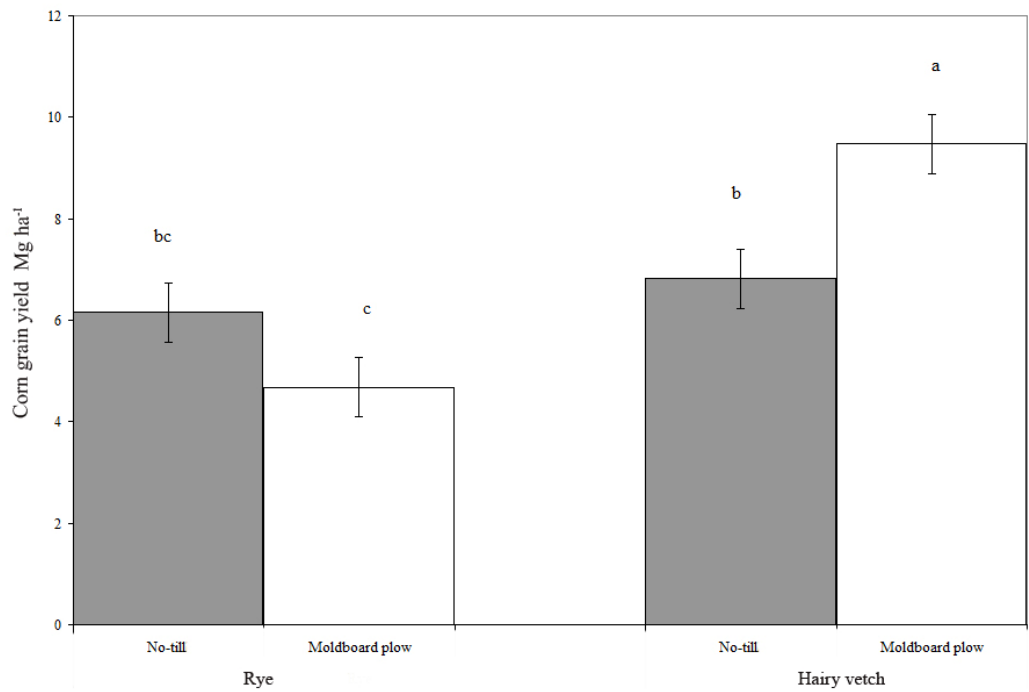


Figure 3.27. Corn grain yield response to cover crop and tillage, UKREC 2009.

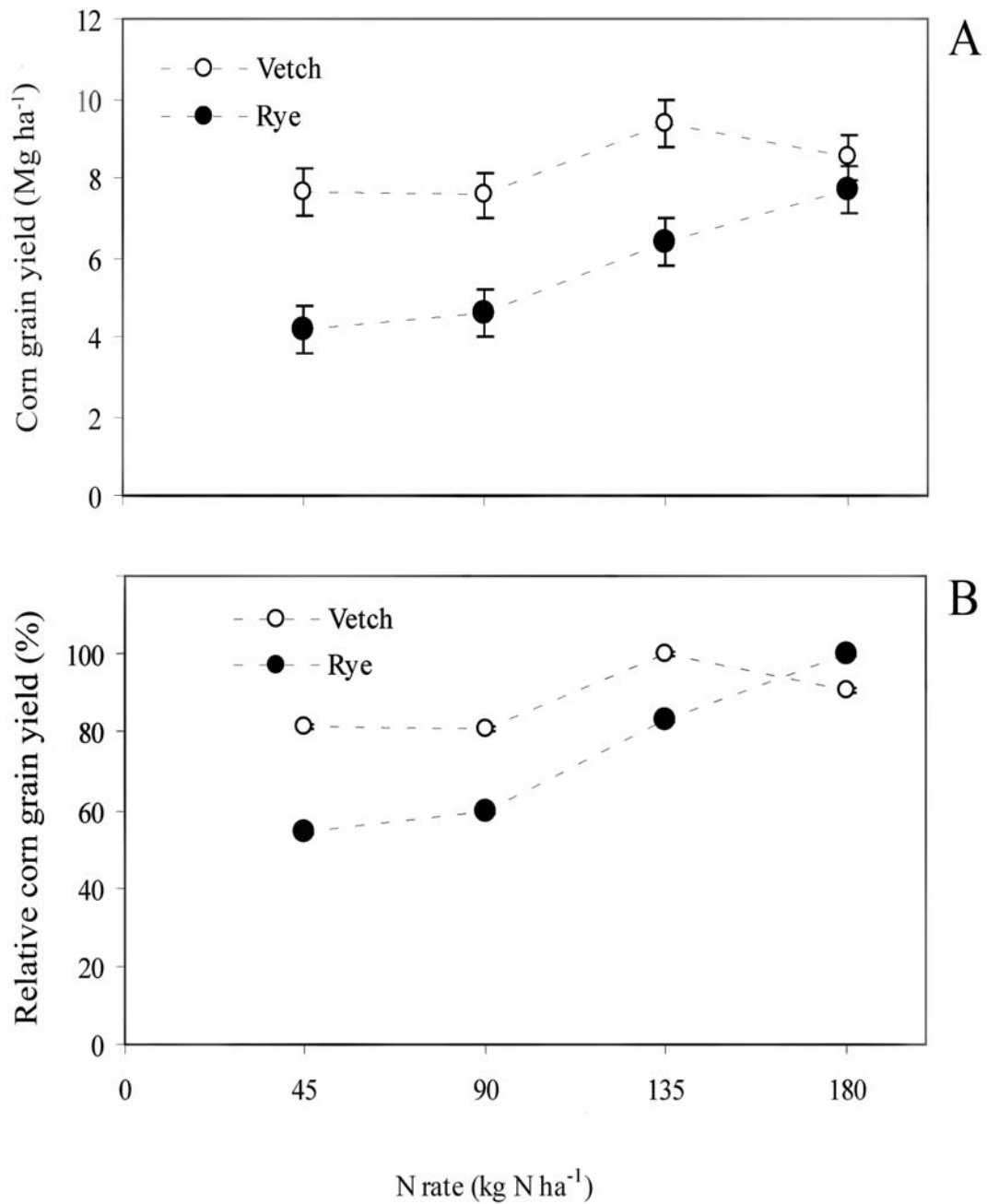


Figure 3.28 a and b. Corn grain yield response to cover crop and N rate (panel A) and relative corn grain yield response to cover crop and N rate, UKREC 2009 (panel B).

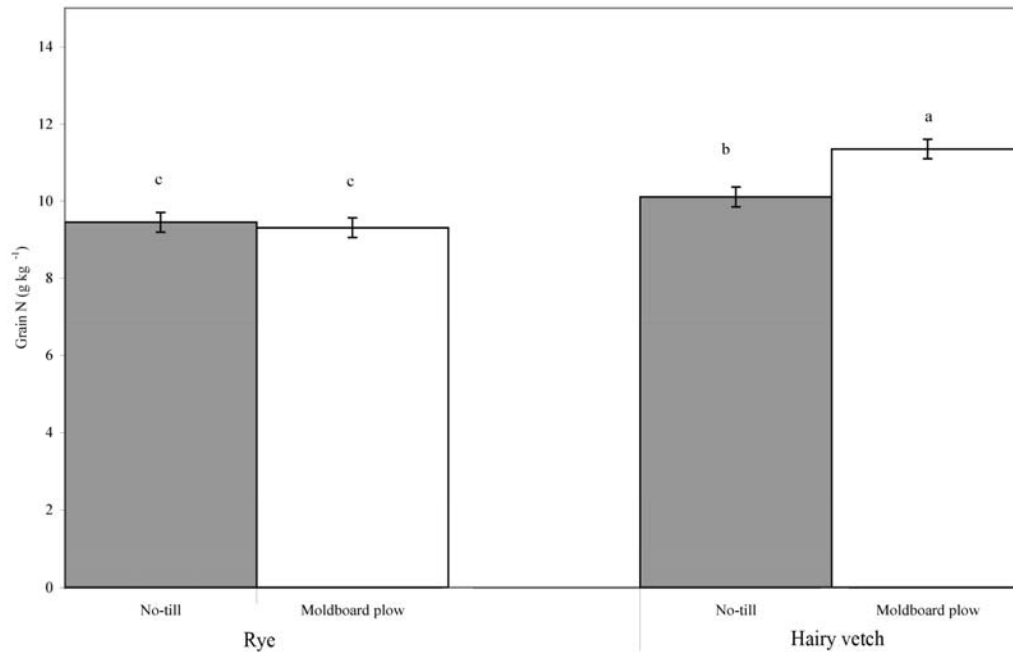


Figure 3.29. Grain N response to cover crop and tillage, UKREC 2009.

Weed responses in Spindletop 2008

Main effects of weed responses for Spindletop 2008

For analysis of weed-related variables, the Nature Safe rates of 0, 90 and 180 kg ha⁻¹ were sampled (Table 3.9). Rye presented significantly higher grass number and grass mass than hairy vetch in Spindletop 2008 (Table 3.10). However, there was no effect of cover crops on broadleaf number or weight. In general, NT was of little value in controlling weeds. No till presented significantly higher broadleaf mass and number. Furthermore, NT presented significantly more grass weight than MP. N rates did not influence any weed responses.

Interactions of weed responses for Spindletop 2008

In this section only significant interactions will be discussed (Table 3.10).

Grass number

Cover crop x tillage

Plots under NT rye produced significantly more grass plants per m² than under rye till and hairy vetch NT and hairy vetch MP (Fig. 3.30). Plants under rye NT produced 165% more grass plants than the average of the other treatments.

Grass weight

Cover crop x Tillage x N rate

There was a significant difference between NT rye with NF 90 and 180 kg N ha⁻¹ vs. all MP hairy vetch treatments. Rye NT produced a significantly higher grass mass compared with the highest rates of hairy vetch NT and with all rates of hairy vetch MP. There were no significant differences in the controls except for hairy vetch MP (Fig. 3.31).

Weed responses in UKREC 2009

Main effects of weed responses for UKREC 2009

There was no effect of cover crop on weed mass or number. However, there was a significant effect of tillage; under MP there was significantly more broadleaf mass than under NT. None of the N treatments affected the weed mass or number (Table 3.11).

Table 3.9. Main effects of cover crop, tillage, Nature Safe N rate (0, 90, 180 kg N ha⁻¹) at Spindletop 2008 and their effects on weed measurements.

		Broadleaf number	Broadleaf weight	Grass number	Grass weight
		number m⁻²	g m⁻²	number m⁻²	g m⁻²
Cover crop	Hairy vetch	13	12.62	7	8.62
	Rye	10	9.74	20	40.88
		NS	NS	*	†
Tillage	Moldboard plow	9	6.38	11	9.76
	No-till	14	18.82	15	36.43
		**	*	NS	†
N rate	control	12	6.91	14	22.80
	NF 90	10	10.91	14	23.20
	NF 180	12	17.79	11	13.04
		NS	NS	NS	NS

¹ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

² N rates are 0, 90 and 180 kg N ha⁻¹ using Nature Safe (NF).

Table 3.10. Interactions for cover crop, tillage, and Nature Safe N rates (0, 90, 180 kg N ha-1) at Spindletop 2008 and their effects on weed measurements.

	Broadleaf number	Broadleaf weight	Grass number	Grass weight
	number m⁻²	g m⁻²	number m⁻²	g m⁻²
Cover crop x tillage	NS ¹	NS	†	NS
Cover crop x N rate	NS	NS	NS	NS
Tillage x N rate	NS	NS	NS	NS
Cover crop x tillage x N rate	NS	NS	NS	†

¹Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

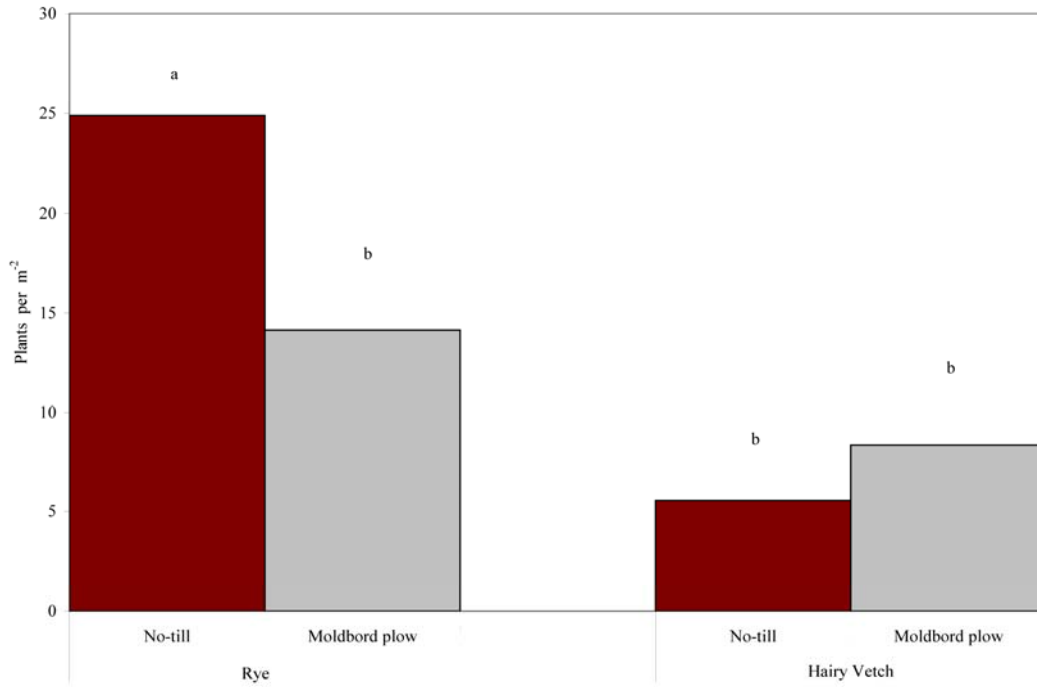


Figure 3.30. Number of grass plants in response to tillage and cover crops for Spindletop 2008.

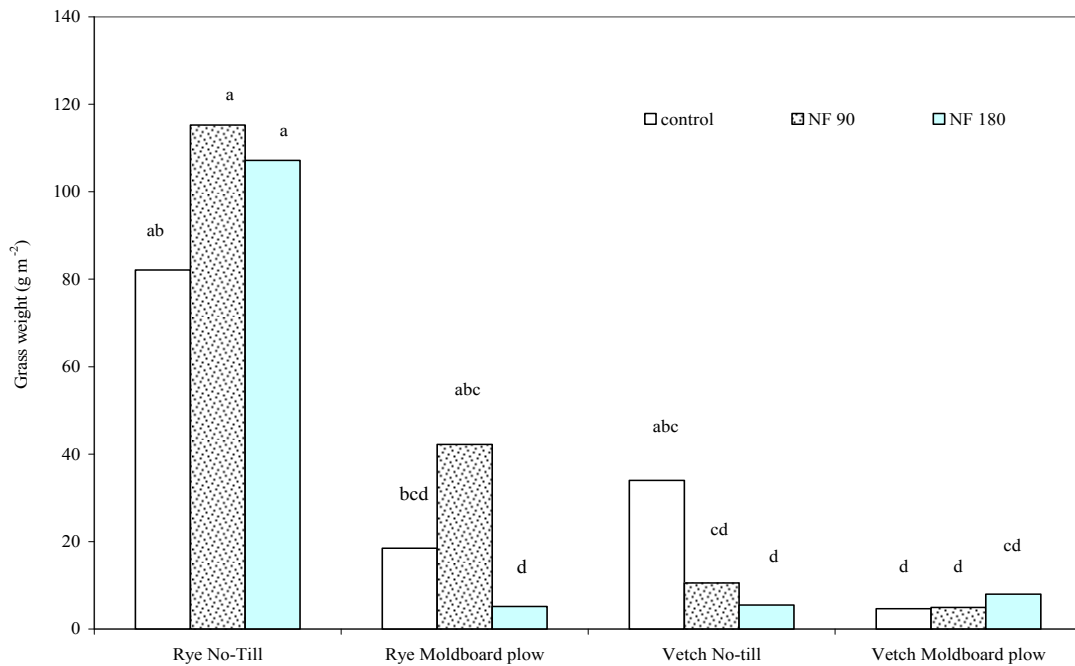


Figure 3.31. Grass number response to cover crops, tillage and N treatments (control, NF 90 kg N ha⁻¹ and NF 180 kg N ha⁻¹) for Spindletop 2008.

Table 3.11. Main effects of cover crop, tillage and Nature Safe N rates (0, 90, 180 kg N ha⁻¹) at UKREC 2009 and their effect on weed measurements.

		Broadleaf number	Broadleaf weight	Grass number	Grass weight
		number m⁻²	g m⁻²	number m⁻²	g m⁻²
Cover crop	Hairy vetch	9	21.6	25	14.8
	Rye	12	17.2	19	11.0
		NS	NS	NS	NS
Tillage	Moldboard plow	12	39.2	26	18.6
	No-till	10	9.2	19	8.7
		NS	*	NS	NS
N rate	Control	9	20.6	26	15.9
	NF 90	10	12.9	18	10.3
	NF 180	13	26.8	23	12.7
		NS	NS	NS	NS

¹Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**). In N rate means within the same letter are not significantly different.

²N rates are 0, 90 and 180 kg N ha⁻¹ using Nature Safe

Interactions of weed responses for UKREC 2009

In this section only significant interactions will be discussed (Table 3.12).

Broadleaf number

Cover crop x Tillage x N rate

There were no differences between rye and hairy vetch treatments under different rates. The only difference arises between rye MP with NF at 180 kg N ha⁻¹ and hairy vetch NT at 180 kg N ha⁻¹. This difference is registered at p=0.0947 so it could be an artifact due to the inherent amount of error (Fig. 3.32).

Table 3.12. Interactions for cover crop, tillage, and Nature Safe N rates (0, 90, 180 kg N ha⁻¹) at UKREC 2009 and their effects on weed measurements.

	Broadleaf number	Broadleaf weight	Grass number	Grass weight
	number m⁻²	g m⁻²	number m⁻²	g m⁻²
Cover crop x tillage	NS	NS	NS	NS
Cover crop x N rate	NS	NS	NS	NS
Tillage x N rate	NS	NS	NS	NS
Cover crop x tillage x N rate	† ¹	NS	NS	NS

¹Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**). In N rate means within the same letter are not significantly different

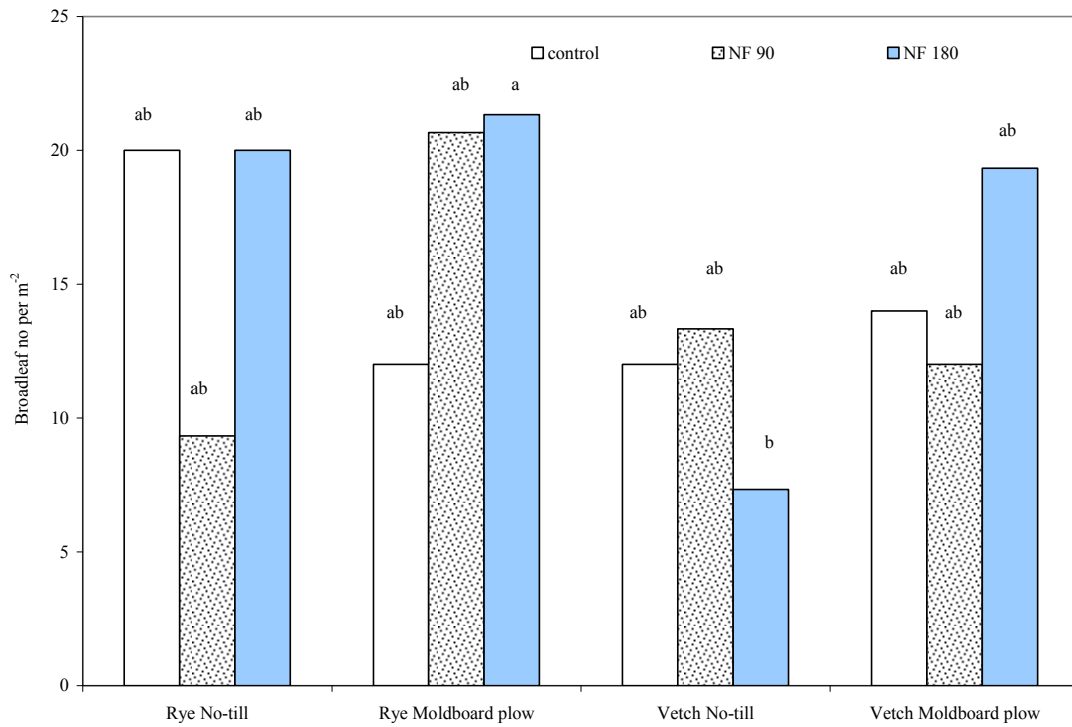


Figure 3.32. Broadleaf number response to cover crop, tillage and N rate (control, NF 90 kg N ha⁻¹ and NF 180 kg N ha⁻¹), UKREC 2009.

Mineralization Experiment Results

NO₃⁻ accumulation

This study was carried out over a period of 56 days using a long term aerobic mineralization procedure as described in Materials and Methods. There were three replications per N source and two methods of fertilizer placement. Fertilizer was either surface applied or thoroughly incorporated into the soil. The curves presented were taken from the average mineralization of the three replications. There was a common control for both N sources.

Louisville green surface applied did not present a divergence of N rate curves (Fig. 3.33). After 21 days, the rates of 90 and 180 kg N ha⁻¹ crossed over and surprisingly 90 kg N ha⁻¹ surpassed 180 kg N ha⁻¹, but there was significant difference at the end of the experiment. The average NO₃⁻ production by the end of the experiment was 18 mg NO₃⁻ kg soil⁻¹ for LG surface applied. When LG was incorporated, there was a higher average production of NO₃⁻ by the end of the experiment (32 mg NO₃⁻ kg soil⁻¹) which was significantly different than surface application (p<0.05) (Fig. 3.33 a and b). When LG was surface applied, NO₃⁻ production did not reach a plateau but when LG was incorporated, it leveled off by 28 days. The control did not reach a plateau but trends slowly trended upward, reaching 10 mg NO₃⁻ kg soil⁻¹ by 56 days. In general, the curves reached a maximum at 28 days after the experiment was initiated. However, the curves for the case of LG surface applied (Fig. 3.33) were more linear and did not seem to level off. Louisville green incorporated produced significantly higher NO₃⁻ kg soil⁻¹ than LG surface applied (p<0.1).

Nature Safe (NF) surface applied presented a synergistic action of NF 180 kg N ha⁻¹ with respect to the other rates of surface applied treatments (p<0.05) (Fig. 3.34 a). Meanwhile, NF 90 kg N ha⁻¹ and NF 45 kg N ha⁻¹ were not statistically different. There was a clear divergence of the curves especially 180 kg N ha⁻¹ NF surface applied with respect to the others. NF surface applied reached a plateau at 28 days in every case. Nature safe incorporated, presented no significant differences depending on the method (Fig. 3.34 a and b) reaching an average of 28.2 mg NO₃⁻ kg soil⁻¹. Nature safe incorporated and surface applied were not significantly different.

Main effects of method of application, N source, N rate at 56 days of aerobic incubation

Method of application was significantly different (p<0.1). With incorporation there was 27% more NO₃⁻ generated after 56 days of aerobic incubation. Neither N source nor N rate differed significantly (Table 3.13).

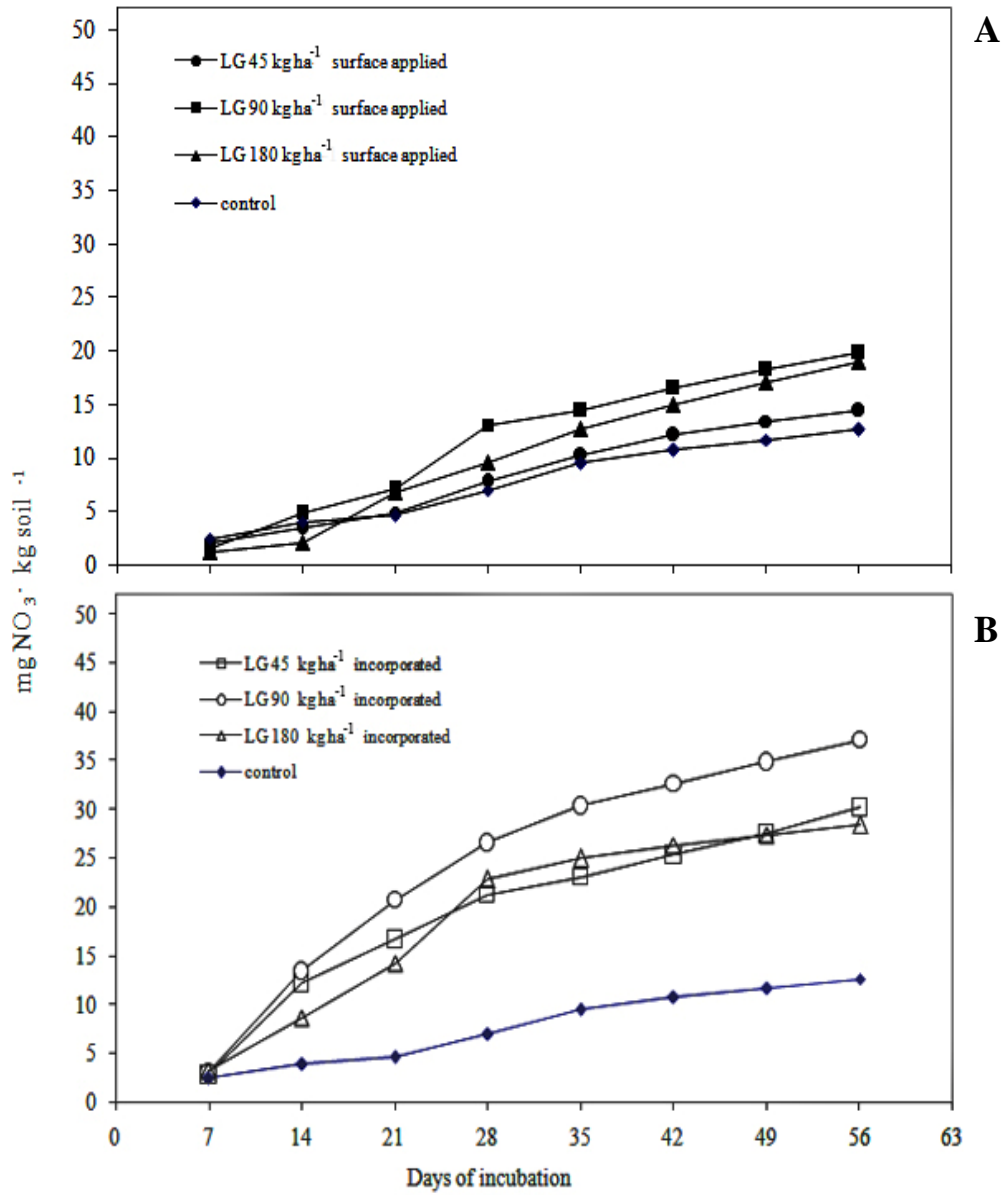


Figure 3.33 a and b. NO_3^- accumulation with surface application for Louisville Green (panel A) and NO_3^- accumulation with incorporation for Louisville Green (panel B).

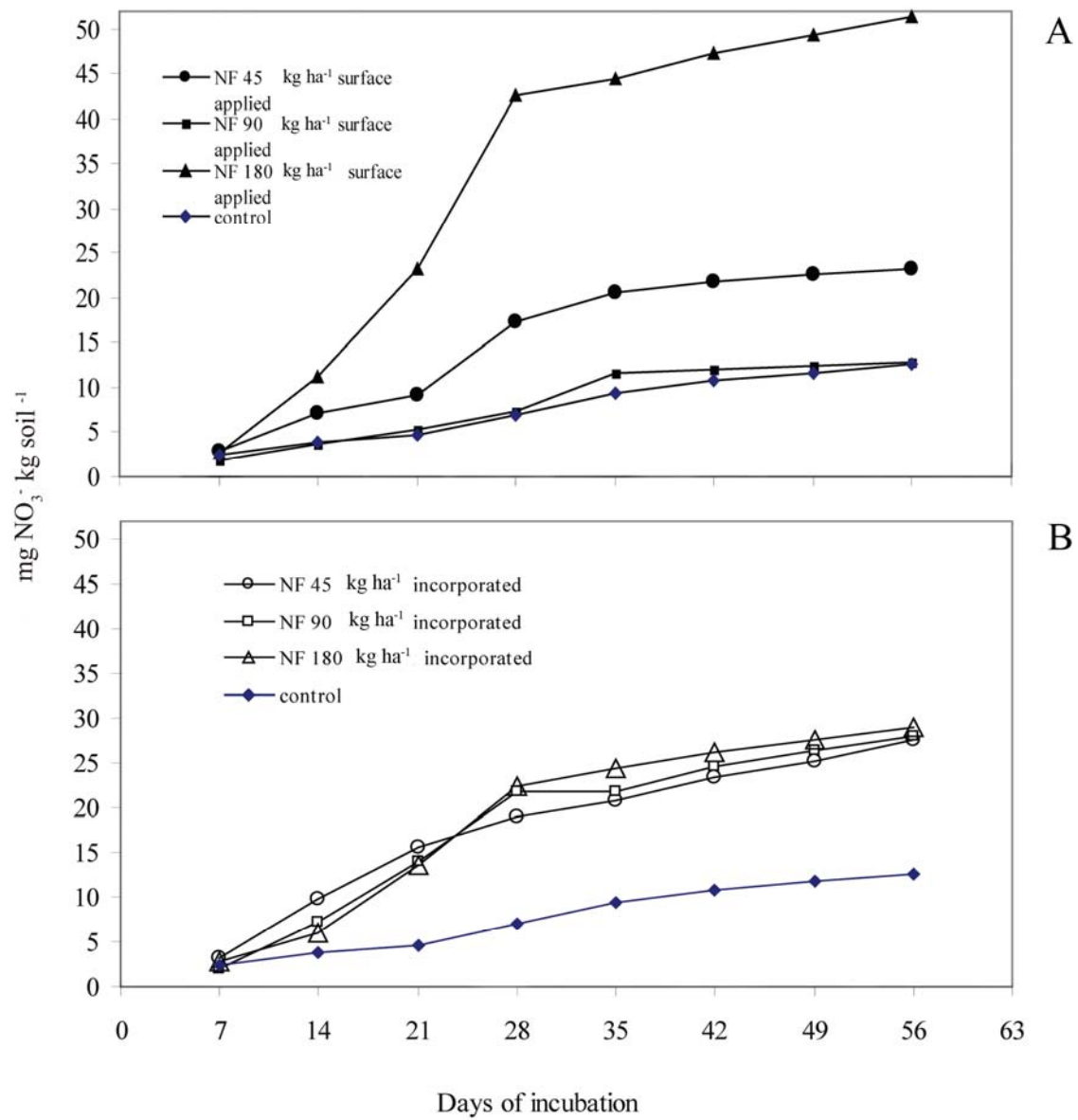


Figure 3.34 a and b. NO_3^- accumulation with surface application for Nature Safe (NF) (panel A) and NO_3^- accumulation with incorporation for Nature Safe (panel B).

Table 3.13. Effect of method of application, N source, N rate on NO₃⁻ accumulation after 56 days of aerobic N mineralization.

Main effect	Level	NO ₃ ⁻ accumulation at	
		56 days	
		mg kg soil ⁻¹	
Method	Surface applied	23.79	
	Incorporated	30.08	
		† ¹	
N source	LG	24.89	
	NF	29.04	
		NS	
Rate	45 kg N ha ⁻¹	23.87	
	90 kg N ha ⁻¹	25.02	
	180 kg N ha ⁻¹	31.92	
		NS	

¹ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**)

Interactions of method of application, N source, and N rate after 56 days of aerobic incubation.

N source x Method

The effect of source and method present a significant interaction ($p < 0.05$) (Table 3.14). There were differences in the method of application depending on the source. Louisville green surface applied and NF surface applied and incorporated were not different but all of these treatments were significantly different than LG incorporated. On average, LG incorporated along with NF surface applied and incorporated generated 26% more NO_3^- than LG surface applied (Fig. 3.35).

N source x rate

There was a significant interaction between N source and rate ($p < 0.05$) where NF 180 kg ha^{-1} generated significantly higher NO_3^- production than the other NF rates and than the other LG rates which averaged 24.3 $\text{mg NO}_3^- \text{ kg soil}^{-1}$. This was mainly caused by the high amount of NO_3^- produced by NF 180 kg ha^{-1} surface applied (Fig. 3.36).

Method x N source x N rate

There was a significant interaction between method x N source and N rate ($p < 0.1$). In this case NF 180 kg ha^{-1} surface applied generated a significantly higher amount of NO_3^- than all other treatments with the exception of LG incorporated 90 kg ha^{-1} that was not different (Fig. 3.37).

NO_3^- k values

The k rates for the mineralization were obtained with the formula: $[A] - [A]_0 = -kt$ since the reaction for every rate was found to be a zero-order process.

Where:

$[A]_0$ = initial NO_3^- concentration

$[A]$ = final NO_3^- concentration

k = rate of NO_3^- accumulation ($\text{mg NO}_3^- \text{ day}^{-1}$)

t = time (days)

This calculation is more fully described in Materials and Methods. When both fertilizer sources were surface applied, they mineralized at an average rate of 0.0792 $\text{mg NO}_3^- \text{ day}^{-1}$ and when they were incorporated, they mineralized at 0.1682 $\text{mg NO}_3^- \text{ day}^{-1}$ which was 112% more.

Table 3.14. Interaction of method of application, N source, N rate on NO₃⁻ accumulation after 56 days of aerobic N mineralization.

Interaction	NO₃⁻ accumulation at 56 days
	mg NO₃⁻ kg soil⁻¹
N source x method	** ¹
N source x N rate	*
N source x method x N rate	†

¹ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**)

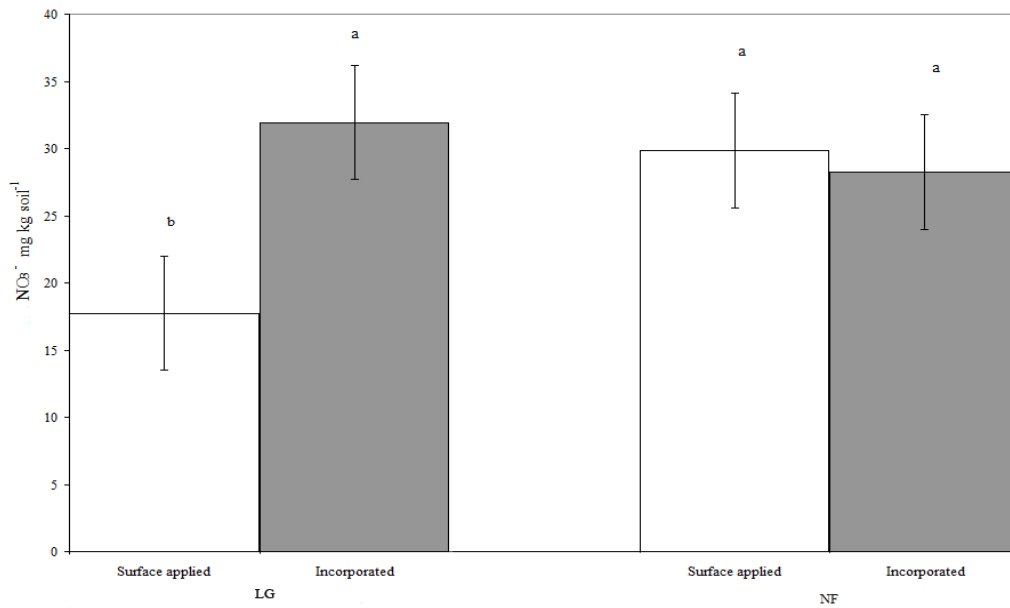


Figure 3.35. N source and application method interaction on NO_3^- accumulation after 56 days of aerobic mineralization.

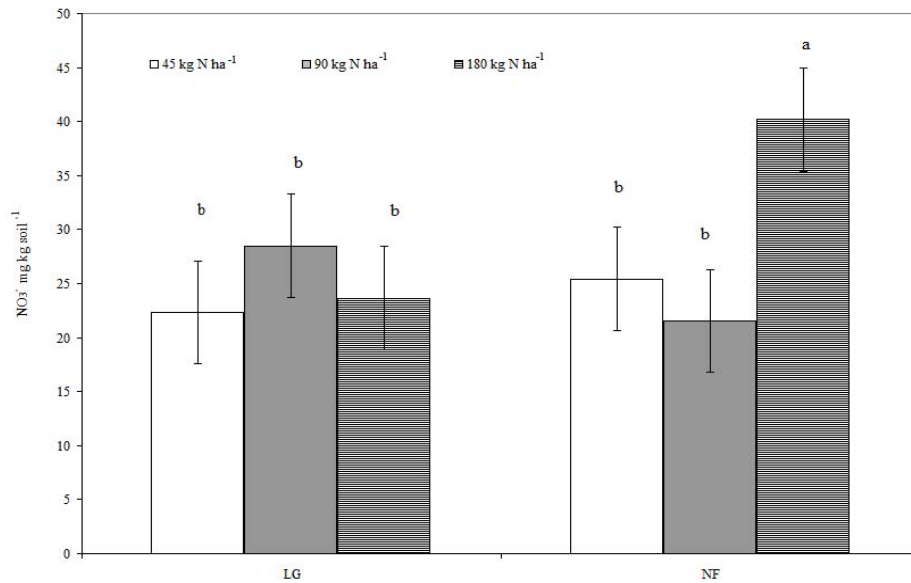


Figure 3.36. N source and N rate interaction on NO_3^- accumulation after 56 days of aerobic mineralization. N sources are averaged across methods of application.

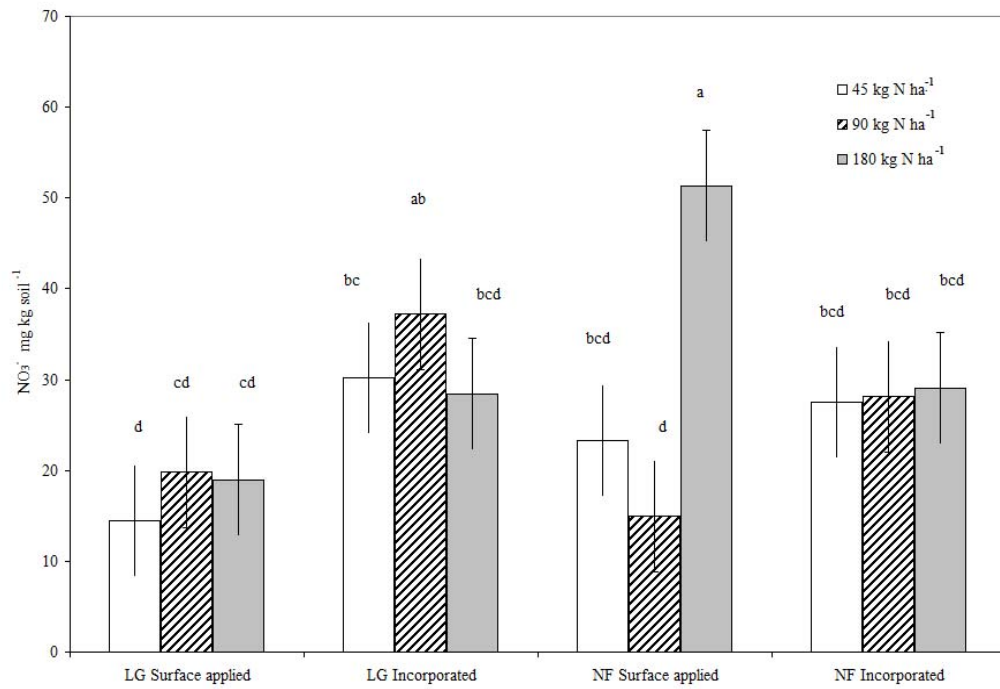


Figure 3.37. Method, N source and N rate interaction on NO₃⁻ accumulation after 56 days of aerobic mineralization.

This difference was also observed in the statistical analysis (Table 3.15) when there was a significant difference in the method of application with incorporation being superior to surface application ($p < 0.1$).

In terms of sources, the reported k values showed that LG mineralized at an average of $0.1195 \text{ mg NO}_3^- \text{ day}^{-1}$ and NF at an average of $0.1279 \text{ mg NO}_3^- \text{ day}^{-1}$ which was corroborated by the statistical analysis (Table 3.15) that showed no significant differences by N source. The highest rates of NF averaged $0.1891 \text{ mg NO}_3^- \text{ day}^{-1}$ which was 55% greater than the highest rate of mineralization with LG at $0.1223 \text{ mg NO}_3^- \text{ day}^{-1}$.

NH₄⁺ accumulation

In general, as occurred with NO_3^- , NH_4^+ reached its maximum values at 28 days of incubation (Fig. 3.38 and 3.39). Louisville Green surface applied showed divergence of N rates (Fig. 3.38a). However, the statistical analysis at the end of the incubation did not detect an interaction for N source depending on either method and rate (Table 3.16). This was also true for LG incorporated. The average NH_4^+ production with LG surface applied was $0.697 \text{ mg NH}_4^+ \text{ mg soil}^{-1}$ and for LG incorporated was $0.767 \text{ mg NH}_4^+ \text{ mg soil}^{-1}$. The amounts were not statistically different (Fig. 3.38). NF surface applied presented differences at the end of the incubation based on method of application. NF surface applied presented higher NH_4^+ production compared with incorporation. The average production of NH_4^+ with NF surface applied was 52% more than the NH_4^+ production when NF was incorporated (Fig 3.39).

Main effects of method of application, N source, N rate after 56 days of aerobic incubation

Method of application was not different but N source was significantly different with LG producing 36% more NH_4^+ than NF ($p < 0.05$). Moreover, N rates were different and there was an increasing production of NH_4^+ as more N was applied (Table 3.16).

Interactions of method of application, N source, and N rate after 56 days of aerobic incubation.

There was only one significant interaction in this case: method x N source (Table 3.17).

Method x N source

There were differences depending on method of application and N source. Nature safe incorporated was different than the other treatments ($p < 0.05$) (Fig. 3.40).

Table 3.15. k values for NO₃⁻ production with two N sources with two methods of application.

Method	N source	N rate	k average	standard error
		kg ha⁻¹	mg NO₃⁻ day⁻¹	
Surface applied	LG	45	0.0467	0.0109
		90	0.0968	0.0301
		180	0.0738	0.0421
Surface applied	NF	45	0.0744	0.0193
		90	0.0149	0.0098
		180	0.1688	0.0342
Incorporated	LG	45	0.1269	0.0412
		90	0.2019	0.0670
		180	0.1709	0.0682
Incorporated	NF	45	0.1799	0.0518
		90	0.1200	0.0444
		180	0.2095	0.0159

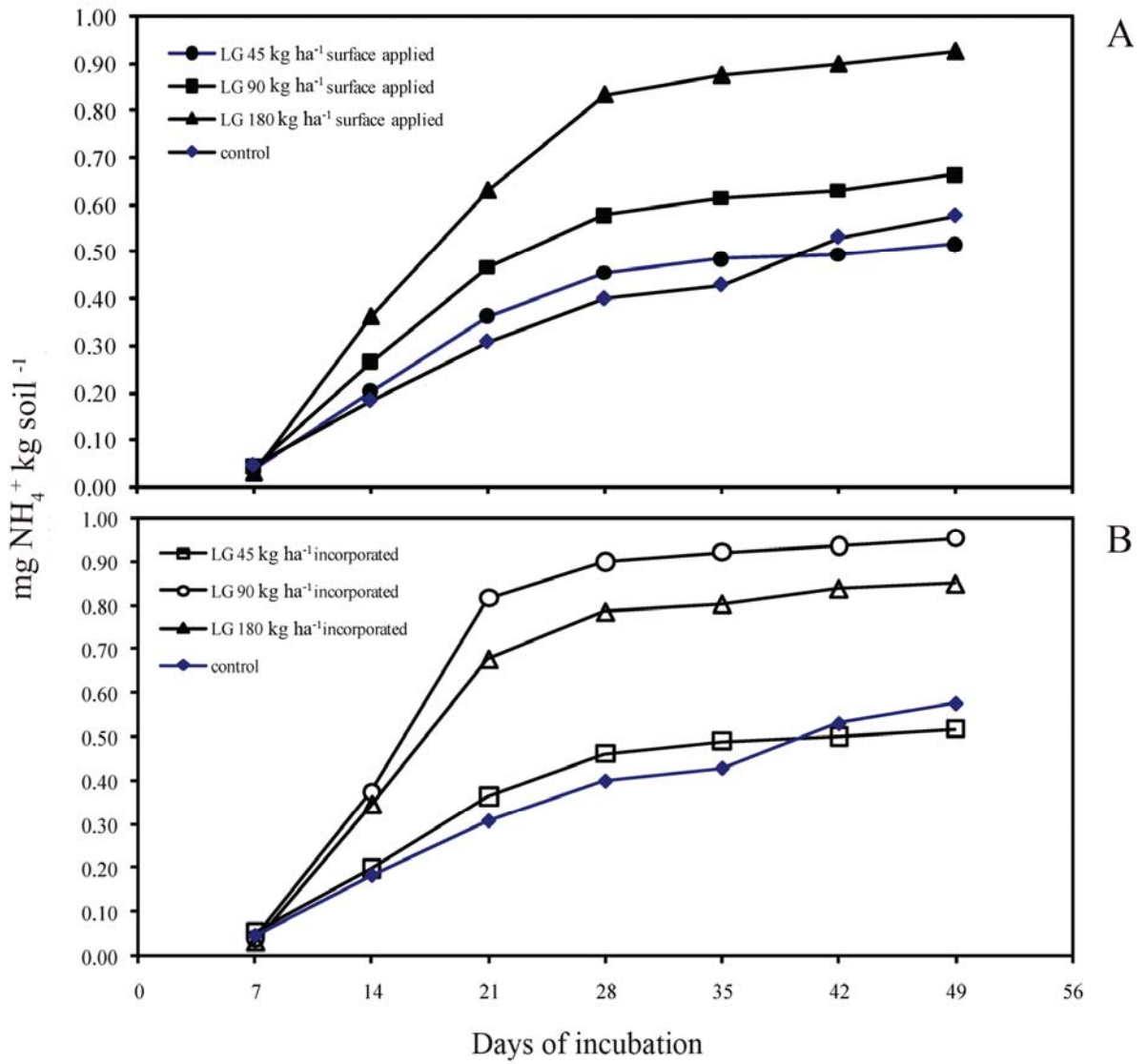


Figure 3.38 a and b. NH_4^+ accumulation with surface application for Louisville Green (panel A) and NH_4^+ accumulation with incorporation for Louisville Green (panel B).

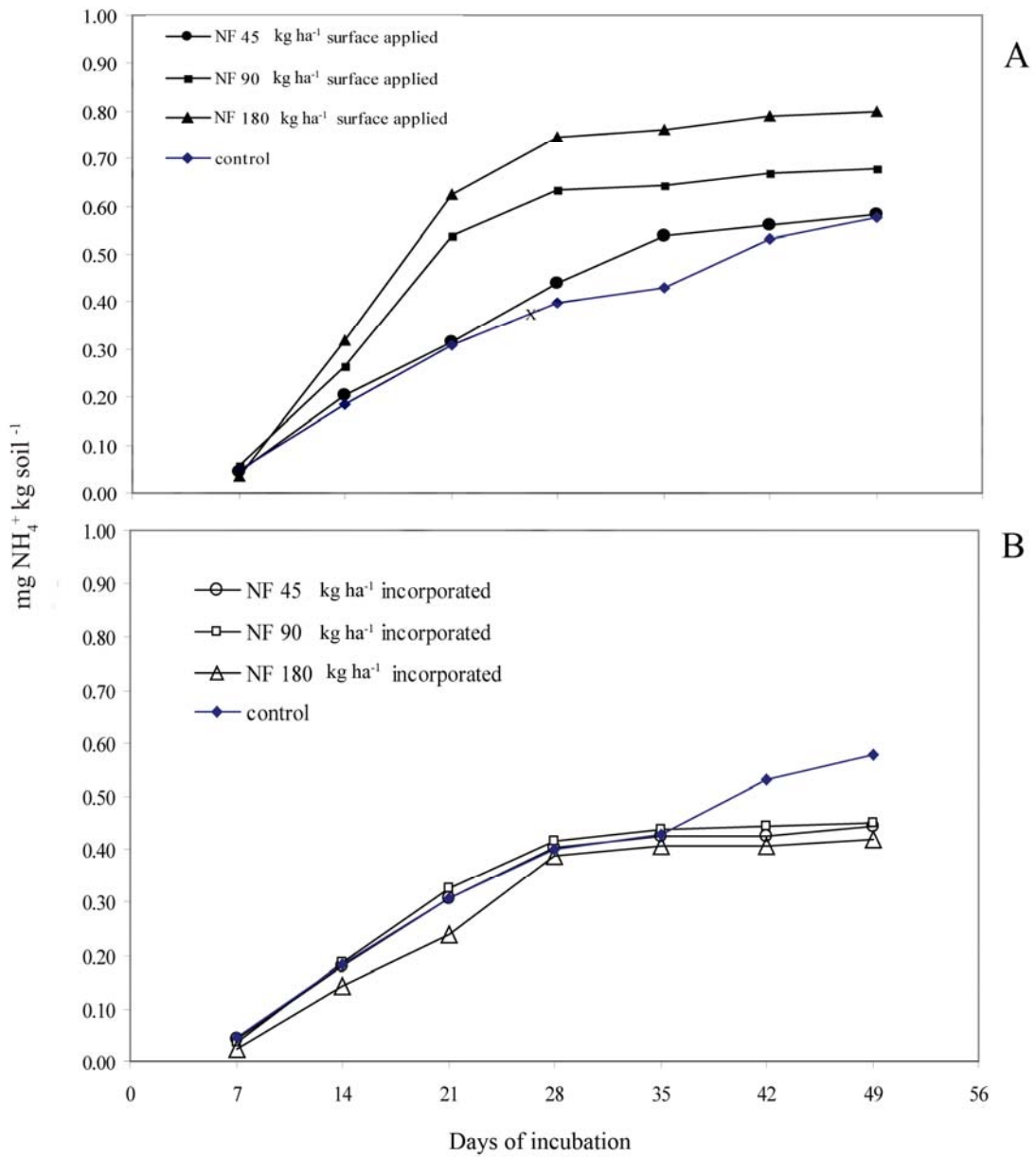


Figure 3.39 a and b. NH_4^+ accumulation with surface application for Nature Safe (panel A) and NH_4^+ accumulation with incorporation for Nature Safe (panel B).

Table 3.16. Effect of method of application, N source, N rate on NH_4^+ accumulation after 56 days of aerobic N mineralization.

Main effect	Level	NH_4^+ accumulation at 49 days
		mg NH_4^+ kg soil ⁻¹
Method	Surface applied	0.6782
	Incorporated	0.6016
		NS ¹
N source	LG	0.7426
	NF	0.5472
		*
N rate	45 kg N ha ⁻¹	0.5145
	90 kg N ha ⁻¹	0.6684
	180 kg N ha ⁻¹	0.7478
		*

¹ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**).

Table 3.17. Interaction of method of application, N source, N rate on NH_4^+ accumulation after 56 days of aerobic N mineralization.

	NH_4^+ accumulation at 56 days
Interaction	Mg kg soil⁺¹
Method X N source	*¹
N source x N rate	NS
Method x N source x N rate	NS

¹ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**)

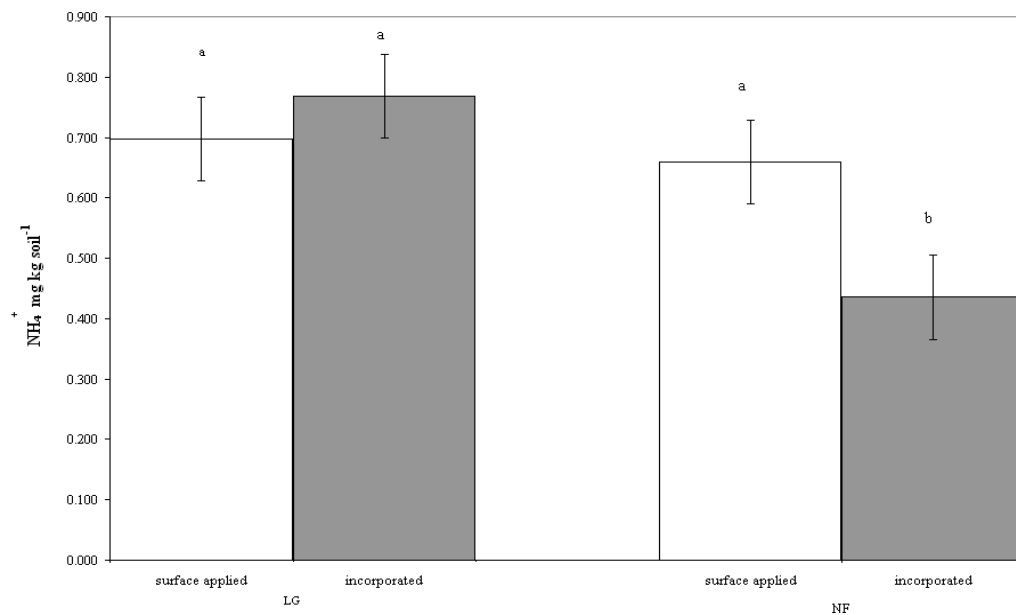


Figure 3.40. Method and N source effect for NH_4^+ accumulation after 56 days of aerobic mineralization.

NH₄⁺ k values

The k rates for the mineralization were calculated in similar fashion than for NO₃⁻ k values. See Materials and Methods for more details. When LG and NF were surface applied or incorporated mineralization occurred at an average rate of 0.0041 mg NH₄⁺ day⁻¹ and the method of application was not statistically different. In terms of sources, the reported k values showed that LG mineralized at an average of 0.0048 mg NH₄⁺ day⁻¹ and NF at an average of 0.0034 mg NH₄⁺ day⁻¹. Louisville green mineralized 41% more than NF which was corroborated by the statistical analysis (Table 3.18).

Table 3.18. k values for NH₄⁺ production with two N sources with two methods of application.

Method	N source	N rate	k average	standard error
		kg ha⁻¹	mg NH₄⁺ day⁻¹	
Surface applied	LG	45	0.0016	0.0007
		90	0.0033	0.0028
		180	0.0073	0.0060
Surface applied	NF	45	0.0019	0.0012
		90	0.0035	0.0030
		180	0.0071	0.0027
Incorporated	LG	45	0.0025	0.0009
		90	0.0089	0.0008
		180	0.0054	0.0006
Incorporated	NF	45	0.0013	0.0005
		90	0.0058	0.0014
		180	0.0006	0.0004

Chapter Four: Discussion

Cover crops

There were significant differences in cover crop biomass and C content for all three experimental sites considered in this study. Moreover, there were also species differences in biomass, N content, C/N ratio and C content (Table 3.2). Species differences in C content were related to biomass differences and were dependent upon experimental site. The interaction between experimental site x cover crop was explained by weather-induced variation in rye biomass, with UKREC 2008 exceeding Spindletop 2008 which in turn exceeded UKREC 2009. On the other hand, hairy vetch biomass did not significantly differ between Spindletop 2008 and UKREC 2008 (UKREC 2009 was lower than Spindletop 2008). Moreover, C content followed the same pattern (Fig. 3.9 and Fig. 3.11). Such differences in biomass and C content can be explained by the weather conditions for the three experimental sites during the cover crop growing season. A combination of low temperature (2 °C below normal) and low precipitation during March (46 mm below normal) in UKREC CC 2008-2009 season caused lower cover crop biomass accumulation. This cover crop season corresponded with the corn site UKREC 2009 (Fig. 3.2 and 3.4). The cover crop seasons UKREC CC 2007-2008 and Spindletop CC 2007-2008 were characterized by high precipitation during March and April and comparatively milder temperatures (Fig. 3.1 and 3.3). Crandall et al. (2005) noticed a decrease in hairy vetch and rye biomass accumulation due to lack of precipitation during March and April which can be critical for biomass accumulation.

There were no significant differences in N concentration and N content between sites (Table 3.2); however, there were the expected cover crop differences by species. The average biomass amount for the three experimental sites was 4.34 Mg ha⁻¹ for hairy vetch and 9.50 Mg ha⁻¹ for rye. Hairy vetch contained 142 kg N ha⁻¹ and rye 60 kg N ha⁻¹ by the time of corn planting; that is 2.36 times more N content in hairy vetch than in rye. This result is explained by the higher N concentration. The lower N content of rye, despite the fact that it had more biomass, was related to the lower N concentration (6.5 g N kg⁻¹ in rye compared to 32 g N kg⁻¹ in hairy vetch). Ebelhar et al. (1984), who conducted research on Spindletop from 1980 to 1981, found higher ranges of biomass and N content for hairy vetch than for rye. In their case, hairy vetch accumulated 5.1 Mg ha⁻¹ with a N content of 209 kg ha⁻¹ whereas rye accumulated 3.4 Mg ha⁻¹ with a N content of 36 kg ha⁻¹; thus, hairy vetch contained 5.8 times more N than rye (Ebelhar et

al., 1984). This might be explained by the larger biomass and N concentration (40 g kg^{-1}) for hairy vetch and a much lower rye biomass that the researchers found compared with our study. In their case, rye was killed in mid May and in our case rye was killed in early June leaving more time for biomass accumulation for both cover crops. In Maryland, Mitchell and Teel (1977), reported high rye biomass (4.5 Mg ha^{-1}) and even higher biomass with a mixture of hairy vetch and rye (7.9 Mg ha^{-1}) that produced 46 kg N ha^{-1} for rye and 158 kg N ha^{-1} for the mixture. On the other hand, Hargrove (1986) tested rye and hairy vetch for three years (1981-1983) and did not find statistical differences in cover crop biomass production with 4.03 and 4.25 Mg ha^{-1} for rye and hairy vetch, respectively. However, there were differences in the N content, in favor of hairy vetch (153 kg N ha^{-1}) compared with rye (38 kg N ha^{-1}) (Hargrove, 1986).

The initial N content in biomass and C/N in biomass determines the possible mineralization or immobilization of the N that enters in the system for the next crop. The C/N ratio is a key factor influencing the rate of decomposition and N release by the cover crop (Clark et al., 1994; Ruffo and Bollero, 2003). In our case, C/N did not differ significantly among experimental sites (Table 3.2). However, there was a significant difference depending on species; rye had a C/N of 71:1 and vetch 14:1. There was no site x cover crop interaction for C/N, so the observed differences were attributable to species differences. In our study, rye was killed at corn planting in early June which contributed to increase the ratio due to more time for biomass and C accumulation. A C/N ratio of 25:1 is recognized as the dividing line between mineralization and immobilization and when the C/N ratio of residues added to the soil is >30 then net immobilization will occur whereas a ratio of less than 20 will produce a release of mineral N (Havlin et al., 1999). In our experiment, a net mineralization for the hairy vetch residue was expected and net immobilization for rye residue would be expected.

In Maryland, Clark et al. (1994), studied the C/N changes when rye and hairy vetch were early killed (late March or early April) or late killed (late April or early May) and found results similar to ours in their Coastal Plain location. When hairy vetch and rye were late killed, they had C/N ratios of 15:1 and 67:1 ratios respectively. Moreover, the dry matter accumulation was also closer to what we found with 7.1 Mg ha^{-1} for rye and 5.2 Mg ha^{-1} for hairy vetch. However, when rye and hairy vetch were combined in mixtures the C/N ratio was less than 25:1. Moreover, they found that rye and hairy vetch N concentration decreased from early planting to late planting (Clark et al., 1994). The importance of rye as cover crop however, is not as N source but more as “N recycler” due to its extensive root system that can scavenge residual inorganic N that otherwise will be leached to ground water. Thus, rye could be an important tool for

“environmental services” due to increasing public concern toward a more sustainable agriculture (Crandall et al., 2005; Miguez and Bollero, 2006). Another important aspect of using rye is soil conservation especially when used in a no-till system as it can reduce erosion (Blevins et al., 1990; Mitchell and Teel, 1977).

Weed effects

Weed presence was affected by tillage in two experimental sites Spindletop 2008 and UKREC 2009 (Table 4.1). In Spindletop 2008, there was a significant interaction for cover crop x tillage and cover crop x tillage x N rate; in both cases, there was a significantly higher presence of grasses under rye no-till. In UKREC 2009, there were more weeds under MP which was the opposite of Spindletop 2008. The weeds in this case corresponded to broadleaf weight (g m^{-2}) but all the other variables measured were not significant (Table 4.1). Delate and Cambardella (2004) found that a combination of grass weeds (plants m^{-2}) and lower plant populations affected organic corn yields in one out of four years of their experiment.

By the fourth year of their experiment there were significantly more broadleaf weeds in the organic rotation; however, no yield influence was detected and organic treatments had greater yields compared with conventional treatments (Delate and Cambardella, 2004). In general, studies that use cover crops as no-till strategy report better weed control under no-till compared with conventional till (Ateh and Doll, 1996; Mischler et al., 2010; Teasdale et al., 2007). Ateh and Doll (1996) reported better weed control with high seeding rates of rye (112 kg ha^{-1}) which generated more biomass. Teasdale et al. (2007) reported that best weed control was accomplished for corn production with no-till and herbicides with an average of 5% soil cover by weeds across 9 years of their study. Moreover, no-till was the best treatment for corn yield over 9 years (Teasdale et al., 2007). Mischler et al. (2010) reported that hairy vetch used as mulch was effective in controlling weeds compared to no-cover control. There were reductions in weed biomass of 31, 93 and 94% in three experimental sites when using the roller crimper with no herbicide application (Mischler et al., 2010). In our case, rye no-till did not provide good weed control in one of our experimental sites (Spindletop 2008). The effect on yield, however was better explained by the dry conditions for Spindletop 2008 (57 and 68 mm below normal during July and August) that specially affected rye no-till yields (only 0.95 Mg ha^{-1}). Some grasses escaped the manual weed control that was carried out before R1 and thrived under the dry conditions, also contributing to low yields. Surprisingly, UKREC 2009 yields were higher under moldboard plow even though there were significantly more broadleaf weed biomass under this treatment (Table 3.11).

Table 4.1. Effects and interactions of cover crop, tillage and Nature Safe N rate (0, 90, 180 kg N ha⁻¹) on weed measurements at Spindletop 2008 and UKREC 2009.

	Spindletop 2008				UKREC 2009			
	Broadleaf number	Broadleaf weight	Grass number	Grass weight	Broadleaf number	Broadleaf weight	Grass number	Grass weight
	number m ⁻²	g m ⁻²	number m ⁻²	g m ⁻²	number m ⁻²	g m ⁻²	number m ⁻²	g m ⁻²
Cover crop	NS ¹	NS	*	†	NS	NS	NS	NS
Tillage	**	*	NS	†	NS	*	NS	NS
NF rate²	NS	NS	NS	NS	NS	NS	NS	NS
Cover crop x tillage	NS	NS	†	NS	NS	NS	NS	NS
Cover crop x N treatment	NS	NS	NS	NS	NS	NS	NS	NS
Tillage x N treatment	NS	NS	NS	NS	NS	NS	NS	NS
Cover crop x tillage x N treatment	NS	NS	NS	†	†	NS	NS	NS

¹ Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**). In N rate means within the same letter are not significantly different.

² N rates are 0, 90 and 180 kg N ha⁻¹ using Nature Safe

N sources and mineralization experiment

Louisville Green (LG) and Nature Safe (NF) are organic N sources recently introduced to Kentucky so scientific information about these N sources is scarce. In order to learn more about these N sources a long term aerobic incubation was conducted during May 2009 in a Maury silt loam. Our results indicated that both LG and NF mineralized mostly as NO_3^- with relatively little coming off as NH_4^+ . Total inorganic N production was 25.63 mg kg^{-1} of soil for LG and 29.59 mg kg^{-1} of soil for NF. In the case of LG about 2.88% was NH_4^+ ; for NF, NH_4^+ content was about 1.85%. In general, the mineralization reached a maximum at 28 days after application where it reached a maximum and stayed nearly constant until the end of our incubation (56 days). Method of application seemed to influence N release with incorporation generating more NO_3^- than surface application (Fig. 3.35). The kinetic model, $[A] - [A]_0 = -kt$ used in this study supports that mineralization of the pure N sources (minus the N production at 0 kg N ha^{-1}) is a zero order reaction process.

The results of our experiment show that when fertilizer sources were surface applied, they mineralized at an average rate of 0.0802 mg inorganic N day^{-1} (0.0792 mg $\text{NO}_3^- \text{day}^{-1} + 0.0041 \text{ mg NH}_4^+ \text{day}^{-1}$) and when they were incorporated, they mineralized at 0.1723 mg N day^{-1} (0.1682 mg $\text{NO}_3^- \text{day}^{-1} + 0.0041 \text{ mg NH}_4^+ \text{day}^{-1}$). In terms of sources, the reported k values show that LG mineralized at an average of 0.1243 mg N day^{-1} (0.1195 mg $\text{NO}_3^- \text{day}^{-1} + 0.0048 \text{ mg NH}_4^+ \text{day}^{-1}$) and NF at an average of 0.1313 mg N day^{-1} (0.1279 mg $\text{NO}_3^- \text{day}^{-1} + 0.0034 \text{ mg NH}_4^+ \text{day}^{-1}$). Stanford and Smith (1972) estimated the rate constants of 39 soils from the following soil orders: Entisols, Alfisols, Aridisols, Ultisols and Mollisols. Their soils were not amended with fertilizer or plant residue. The authors estimated an k value based on incubation periods of 0 to 30 weeks and found that pooling 29 soils gave an weighted average k of 0.054 g N per week. The average k value for Alfisols was 0.0578 g N per week. The values in our experiment were much higher which could be attributable to the increasing mineralization of the organic N from LG or NF.

Based on our results, incorporation of NF will generate about twice as inorganic N mg per day as will LG surface applied (Fig. 3.35), but the amount of inorganic N generated by the two sources will be not much different (Table 3.13). In general, both sources reach maximum at 28 days after the initial fertilizer application. Growth stage V6 is the period where N uptake rapidly increases and is the period where N application is recommended if it was not performed at planting (Iowa State University Extension Service, 1993). In our case V6 occurred in Spindletop 2008 about 22 days after planting (that is July 4) and in UKREC 2008 and UKREC 2009 around

19 days after planting (June 21 and June 20, respectively). Since the sources reached a plateau of inorganic N release at 28 days after application, it would appear to be more appropriate by the time of planting.

Crop variables

Stand establishment

Stand establishment did not present interactions in any of the three experimental sites. The influence of cover crops, tillage, N source and N rates were not significant for UKREC 2008 and UKREC 2009 but were significant for some main effects in Spindletop 2008. Cover crops and tillage had effects on stand establishment in Spindletop 2008 in which there were significantly less plants under rye than hairy vetch ($p < 0.1$) and significantly less plants under NT than under MP (< 0.01). However, there was no interaction between cover crops and tillage. This might be due to an effect of NT planting into high residue rye that created poorer conditions for corn emergence (Table 4.2). Previous studies (Eckert, 1988; Mitchell and Teel, 1977; Utomo et al., 1990) suggested that the amount and thickness of the rye residue under no-tillage practices can cause significantly lower corn stands which by the end of the corn growing season could influence yield. Mehdi et al. (1999) concluded that residue hindered corn emergence and delayed maturity but yields were not affected. Thus, the high amount of rye residue might have contributed to lower stand counts under no-till in Spindletop 2008. The effect of the residue was observed just in one out of three experimental sites. There was no effect of any treatment on stand establishment for UKREC 2008 and UKREC 2009 which could be due to better contact of the seed with the soil. Furthermore, significantly higher stand counts under MP ($p < 0.05$) might have contributed to higher yields for MP treatments regardless of cover crop in Spindletop 2008.

Ear leaf N

Ear leaf N significantly increased under hairy vetch compared with rye in all three experimental sites. Moreover, this increase was related to an increase in yield in two out of three experimental sites followed by an increase in grain N in all three experimental sites (Table 4.2). In Spindletop 2008, ear leaf N was affected by the interaction of tillage x N source x N rate. There was an increase in ear leaf N with increasing N rates showing a step-wise reaction under MP NF [with the highest rate (180 kg N ha^{-1})]. Ear leaf N was also affected by the interaction cover crop x tillage x N rate (Fig. 3.13) in which hairy vetch regardless of the tillage and N rate provided an average of 22 g N kg^{-1} .

Table 4.2. Main effects and interactions of cover crops, tillage, N source and N rate on corn responses in three experimental sites.

	Spindletop 2008				UKREC 2008				UKREC 2009			
	SE¹	ELN	Y	GN	SE	ELN	Y	GN	SE	ELN	Y	GN
	Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹	Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹	Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹
Cover crop	† ²	**	NS	**	NS	**	**	**	NS	**	**	**
Tillage	**	†	**	NS	NS	NS	NS	NS	NS	†	NS	*
N source	NS	†	NS	NS	NS	*	†	†	NS	†	*	NS
N rate³	NS	**	†	**	NS	†	†	**	NS	**	**	NS
Cover crop x tillage	NS	**	*	*	NS	NS	*	NS	NS	NS	**	**
Cover crop x N source	NS	NS	NS	NS	NS	†	NS	†	NS	NS	NS	NS
Tillage x N source	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cover crop x tillage x N source	NS	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS

¹SE: stand establishment; ELN: Ear leaf N; Y: Yield; GN: Grain N

²Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**). In N rate means within the same letter are not significantly different.

Table 4.2. (continue)

	Spindletop 2008				UKREC 2008				UKREC 2009			
	SE ¹	ELN	Y	GN	SE	ELN	Y	GN	SE	ELN	Y	GN
	Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹	Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹	Plants ha ⁻¹	g kg ⁻¹	Mg ha ⁻¹	g kg ⁻¹
Cover crop x N rate	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	†	NS
Tillage x N rate	NS	NS	†	NS	NS	NS	NS	NS	*	*	NS	NS
Cover crop x tillage x N rate	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N source x N rate	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cover crop x N source x rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
Tillage x N source x N rate	NS	*	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
Cover crop x tillage x N source x N rate	NS	NS	NS	NS	NS	NS	†	NS	NS	NS	NS	NS

¹SE: stand establishment; ELN: Ear leaf N; Y: Yield; GN: Grain N

²Means within a column are not significant (NS), significant at the 0.1 probability level (†), significant at the 0.05 probability level (*) or significant at the 0.01 probability level (**). In N rate means within the same letter are not significantly different.

In UKREC 2008, ear leaf N was affected by the interaction cover crop x N source in which regardless of the source ear leaf N under hairy vetch was superior to rye but rye NF was superior than rye LG (Fig. 3.20). In UKREC 2009, ear leaf N was affected by the interaction tillage x N rate in which the combination MP 180 kg N ha⁻¹ produced a significantly higher level of ear leaf N. The superior effect of NF on ear leaf N can be explained by the mineralization experiment in which NF surface applied at 180 kg N ha⁻¹ produced significantly more NO₃⁻ than NF incorporated and than LG surface applied and incorporated. The only exception was LG 90 kg N ha⁻¹ incorporated which was not different (Fig. 3.37).

The beneficial effects for corn after hairy vetch have been widely reported (Blevins et al., 1990; Czapar et al., 2002; Ebelhar et al., 1984; Hargrove, 1986; Utomo et al., 1990) mainly due to a rotation effect and a significant increase of inorganic N compared with fallow or rye. For instance, Ebelhar et al. (1984) conducted research on cover crops in Spindletop during 1977 through 1981 and found that with no-till hairy vetch was able to increase the levels of inorganic N in soil from a steady state of 10 mg inorganic N kg⁻¹ (NO₃⁻ + NH₄⁺) before planting to around 40 mg N kg⁻¹ 18 DAP and around 25 mg N kg⁻¹ 37 DAP without any addition of fertilizer. When 100 kg N ha⁻¹ were added, the amount of inorganic N doubled 18 DAP and steadily decreased to around 20 mg N kg 37 DAP. Moreover, the authors found that there was a high correlation ($r^2=0.84$) between different rates of fertilizer NH₄NO₃ + legume cover crop N content (Ebelhar et al., 1984). Czapar et al. (2002) reported higher SPAD meter readings with hairy vetch grown in bands along with corn and killed with herbicides 1 or 2 weeks after planting compared with broadcasted hairy vetch killed at planting (due to more N available for plants). In their case, fertilizer N was not applied (Czapar et al., 2002). Miguez and Bollero (2006) determined ear leaf N status using a SPAD meter to measure chlorophyll meter readings (CMR) around corn stage R1. Corn was subjected to no-till practices and cover crops. They reported that CMR were lower at 0 kg N ha⁻¹ after hairy vetch compared to hairy vetch-rye. Rye alone had the lowest readings compared with the other two treatments ($p<0.05$). However after the application of 90 kg N ha⁻¹, CMR increased for all treatments and at 180 kg N ha⁻¹ there were no significant differences between the three treatments. The negative effects of rye in this case were attributed to immobilization even though C/N ratios were lower than 17 due to the fact that rye was killed two weeks prior to planting corn, the hairy vetch-rye mixture was killed 1 week prior to planting corn and hairy vetch alone was killed at planting. The authors mentioned that the below ground biomass that they did not measure could have contributed to the immobilization of N. Most of the negative effects of rye and rye + hairy vetch mixture were overcome by the application of 90

kg N ha⁻¹ in the form of ammonium sulfate (21-0-0) (Miguez and Bollero, 2006). Our results were different mainly due to the fact that cover crops were allowed to grow until the time of planting. At this time, hairy vetch averaged across experimental sites had a C/N of 14:1 and rye 71:1 so immobilization was expected for rye; this is supported by comparatively lower ear leaf N, grain N and yields. In the case of Spindletop 2008, V6 occurred about 22 days after planting. V6 occurred around June 21 for UKREC 2008 and UKREC 2009 that is 19 days after planting. When rye was incorporated there was more N available for the plant and since mineralization reached maximum around 28 days (Fig. 3.33, 3.34, 3.38 and 3.39), there were some N available at V6 that escaped from immobilization. Another experiment could test different killing times of rye and rye-legume mixtures and organic N source in Kentucky that would allow us to obtain lower C/N ratios and “escape” from the detrimental effects of immobilization. Crandall et al. (2005) tested different rye and hairy vetch killing timings and found that killing rye two weeks prior to corn planting and killing hairy vetch at planting were the best treatments in terms of corn yield. They recommended not to delay rye kill beyond a week prior to planting. The worst treatment combination in their case was applying all N fertilizer at V6 and killing rye at planting (Crandall et al., 2005).

Corn grain yields

Corn yields were affected by the main effects of cover crop in two out of three experimental sites in favor of hairy vetch and affected by tillage in one out of three experimental sites in favor of MP (Table 4.2). Yields were also affected by N source in two out three experimental sites and N rate was significant for all three experimental sites. There was a consistent cover crop x tillage interaction for the three experimental sites ($p < 0.05$).

Hairy vetch MP was the best treatment in the 3 experimental sites followed by hairy vetch no-till in two out of three sites. The average yields obtained with hairy vetch MP treatment were 2.7 Mg ha⁻¹, 7.8 Mg ha⁻¹ and 9.5 Mg ha⁻¹ for Spindletop 2008, UKREC 2008 and UKREC 2009, respectively. The low overall yields obtained in Spindletop 2008 were mainly explained to weather conditions instead of the treatment effects. Conditions were dry for Spindletop 2008 during July and August 2008 (57 and 68 mm below normal, respectively). Considering that R1, a critical stage for yield determination (Miguez and Bollero, 2006), occurred around August 10, water stress appears to have been the primary yield-limiting factor. The UKREC 2008 experimental site was also dry during August (72 mm below normal) but a combination of sufficient rain during July and the fact that R1 occurred around July 27 caused no noticeable water stress. In the case of UKREC 2009, R1 occurred around July 29 in a season without water

deficit. The ear leaf N sufficiency range recommended by the University of Kentucky ranges from 28 to 40 mg kg⁻¹ (UK Cooperative Extension Service, 2007). Thus, in our case the yields obtained under hairy vetch with ear leaf N levels of 21.70, 25.73 and 20.77 g kg⁻¹ for Spindletop 2007, UKREC 2008 and UKREC 2009, respectively were 2.4, 7.9 and 8.1 Mg ha⁻¹ for Spindletop 2007, UKREC 2008 and UKREC 2009, respectively. Our yields were slightly lower than the 2008 and 2009 statewide average for conventional corn production in Kentucky of 8.55 and 10.4 Mg ha⁻¹, respectively (USDA NASS, 2010).

The consistency of this interaction in favor of hairy vetch moldboard plow is in agreement with other authors. Utomo et al. (1990) worked at Spindletop during 1984 and 1985. They incorporated rye and hairy vetch 1 or 2 days previous to planting corn by moldboard plowing and disking and found higher yields without N fertilizer were obtained under conventional tillage than with no-till. The authors attributed this to a rapid release of N from the accumulated SOM, since these soils were managed under no-till the 7 previous years and the cover crops were incorporated. The authors examined total C and N contents and found that there were significantly lower contents of total C and N under conventional tillage but higher levels of inorganic N 6 weeks after plowing (Utomo et al., 1990). Varco et al. (1993) working at Spindletop during 1984 and 1985 followed the decomposition of hairy vetch with labeled N¹⁵. The incorporation of this labeled residue allowed the authors to detect a rapid release of inorganic N which in turn produced greater N availability for corn in the next cycle compared with hairy vetch no-till (Varco et al., 1993). In our study, the higher biomass and N content in plots under hairy vetch MP confirmed these findings. In all three experimental sites hairy vetch had higher ear leaf N and grain N and in two out of three experimental sites registered an increase in yield (Table 4.2). Ear leaf N levels of hairy vetch were significantly higher than rye regardless of tillage.

No-till hairy vetch was able to improve N nutrition measured by ear leaf N in Spindletop 2008 (Fig. 3.13), and was the best treatment for yield for UKREC 2008 (Fig. 3.21) and hairy vetch regardless of tillage was able to maintain and increase yields in UKREC 2009 (Fig. 3.27). These results agree with Hargrove (1986), Ebelhar et al. (1984), and Mitchell and Teel (1977) that found increasing response to N fertilizer under no-till for rye but less response with hairy vetch.

Hargrove (1986) compared different legumes against rye and fallow (corn residue) in no-till practices. He found that sorghum yields following legumes averaged 3.91 Mg ha⁻¹ at any N rate (including 0 kg N ha⁻¹). Meanwhile, it was necessary to apply 112 kg N ha⁻¹ under rye or

fallow to obtain similar yields (Hargrove, 1986). Ebelhar et al. (1984) found that the fertilizer replacement value for no-till corn under hairy vetch compared with rye was about 90 to 100 kg N ha⁻¹. Moreover, in five years of their experiment there was an increase of yields year by year with hairy vetch and 100 kg N ha⁻¹ but not with 0 kg ha⁻¹ and fallow or rye and in the latter case, there was a consistent decrease in yields indicating a likely soil fertility effect (Ebelhar et al., 1984). Mitchell and Teel (1977) found that corn yields with hairy vetch at 0 kg ha⁻¹ equated the yields obtained with rye and oats and 112 kg N ha⁻¹ (Mitchell and Teel, 1977). Our study shows improvement in N nutrition by the use of hairy vetch benefitted as well from increasing rates of organic N in all three experimental sites.

Grain N

For Spindletop 2008, the interactions of cover crop x tillage and cover crop x N rate produced significantly higher levels of grain N under hairy vetch regardless of the tillage or N rate. There was an increase in grain N with rye and NF fertilizer (Fig. 3.18 and 3.19). Under hairy vetch, grain N averaged 14.6 g kg⁻¹ which was significantly higher than 10.9 g kg⁻¹ with rye. In UKREC 2008, grain N was affected by tillage x N source x N rate. Mostly this effect was explained by a greater response at the higher rates of NF regardless of the tillage system (Fig. 3.24). In UKREC 2009 the only interaction that affected grain N was cover crop x tillage in which hairy vetch MP was superior to the other treatments (Fig. 3.29). Grain N was affected by cover crop in favor of hairy vetch in all the three experimental sites. Moreover, there was an effect of N rate in two out of three site years with the highest rates producing significantly higher grain N levels. Grain N levels for all the treatments were between 10.0 and 14.6 g kg⁻¹ for the three experimental sites. Mehdi et al. (1999) mentioned that grain N measured under the Kjeldahl method indicated a range from 10 to 25 g kg⁻¹ for grain content at maturity (Mehdi et al., 1999). Our grain N levels were within this range.

Chapter Five: Conclusions

The cover crops in this study accumulated a biomass of 4.3 Mg ha⁻¹ of hairy vetch and 9.5 Mg ha⁻¹ of rye. This biomass contained 142 kg N ha⁻¹ for hairy vetch and 60 kg N ha⁻¹ for rye (about 2.4 more N content in vetch). The C/N was 14:1 of vetch and 71:1 for rye; under these conditions, net mineralization would be expected for vetch and net immobilization for rye. In fact, the combination of rye and no-till produced lower yields, lower ear leaf N and lower grain N across all three experimental sites so this combination should be avoided for organic corn production, especially if rye is killed at planting. No-till rye was not effective in controlling grass weeds in the dry season of Spindletop 2008 but there were significantly fewer weeds under no-till in UKREC 2009 compared with moldboard plow. The significantly higher presence of grassy weeds on rye no-till could have contributed as well to the lower yields in this treatment. In UKREC 2009 higher broadleaf weeds under moldboard plow treatments did not seem to influence yields.

The method of application of the N sources seems to influence N release from the organic N sources [Nature Safe (NF) and Louisville Green (LG)] with incorporation generating about 1.25 times more inorganic N compared with surface applied. In general, both sources reached maximum by 28 days after application. Inorganic N production was 25.63 mg kg⁻¹ of soil for LG which represented about 50 kg N ha⁻¹ and 29.59 mg kg⁻¹ of soil for NF which represented 60 kg N ha⁻¹. Application of these sources should be made at or near planting in order to match N supply with corn needs due to the pattern of mineralization of the sources.

There was a significantly higher amount of N produced by NF at 180 kg N ha⁻¹ when it was surface applied compared with other source and rate combinations. NF was also better in improving ear leaf N compared with LG in two out three experimental sites. In general, there was little benefit of increasing ear leaf N with N rates after vetch but there was significant increase in ear leaf N after rye. This study shows that across three experimental sites ear leaf N and grain N increased under hairy vetch compared with rye. The use of hairy vetch with moldboard plowing resulted in the best combination of treatments for this study across the 3 experimental sites. The yields obtained with hairy vetch MP treatment were 2.7 Mg ha⁻¹, 7.8 Mg ha⁻¹ and 9.5 Mg ha⁻¹ for Spindletop 2008, UKREC 2008 and UKREC 2009, respectively. The lower yield in Spindletop 2008 can be explained by water stress that occurred around R1.

It was possible to grow corn organically with relative high yields in two out of three experimental sites with the vetch and moldboard plow combination (average 8.65 Mg ha⁻¹). No-

till treatments using the roller crimper did not yield as high as we expected. The combination rye no-till produced the lowest yields across the three locations, but with a sharp difference depending on the experimental site; for instance, in Spindletop 2008 the average was 0.95 Mg ha^{-1} whereas in UKREC 2008 and 2009 the average was 5.8 Mg ha^{-1} . These differences in rye-no till treatments could be mainly attributed to climatic factors that affected corn during R1. The second highest treatment across experimental sites was hairy vetch no-till with big differences depending on the site; Spindletop 2008 averaged 2.03 Mg ha^{-1} whereas in UKREC 2008 and 2009 averaged 7.4 Mg ha^{-1} . In 2008 and 2009, the statewide yield average was 8.55 and 10.4 Mg ha^{-1} , respectively and our yields using moldboard plow vetch approached conventional yields. The favorable conditions of 2009 resulted in record high corn yields for the state of Kentucky. Organic corn production maybe is more risky during dry seasons, especially if drought stress occurs during R1. Further research may be needed to evaluate different rye-vetch combinations with different amounts of N that allow to use rye more effectively by reducing the C/N ratio and “escaping” from the detrimental effects of N immobilization.

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