ABSTRACT

WELLS, MICHAEL SCOTT. A Mechanistic Approach to Weed Management in a Cover Crop Mulched System. (Under the direction of Samuel Chris Reberg-Horton and Shuijin Hu.)

Two, 4-site year studies were conducted in North Carolina to evaluate the effects of maize and soybean planting timings after roll-crimping a cover crop mulch, on soil moisture, crop stand, weed pressure and corn and soybean yield. Two, 2-site year studies were conducted in NC and Baltimore, MD to determine the nutritive weed suppressive mechanisms along with decomposition dynamics of cover crop mulches. Two cover crop mixtures were compared; winter pea (P), and AU Early Cover hairy vetch a (V) were both mixed with Wrens Abruzzi rye. Delayed corn planting after roll-kill did not enhance the soil water content; however, at Kinston (2012), the soil water content was 23% greater in the hairy vetch (V) when compared to winter pea (P) and no-till without cover crop mulch treatments. The corn planting date across all 4 site-years did not affect weed biomass; however, weed coverage at Salisbury (2012) was affected by planting date. Cover crop treatments yielded equivalent to their weed-free no-till without cover crop mulch counter parts in 2011; however, despite high biomass production from pea and vetch, in-row weeds did escape control in the CC-H (weedy) treatments, at 3 of the 4 site-years when compared to the CC+H (weed-free) treatments. During the soybean experiment, planting timing included roll-kill/planting and roll-kill/delayed planting where soybean planting occurred either on the same day or approximately two-weeks later, respectively. Soybean row spacing included 76, 38, and 17 cm and all treatments included a weedy check and weed-free treatment. The high rye biomass levels (10,000 kg ha^{-1}) resulted in excellent weed control. Weed coverage was highest in the 76 cm row-space treatment when compared to both the 17 cm and 38 cm row spacing in two of the four site-years. Row spacing also influenced soybean yield; the 38 cm spacing out-yielded the 17 cm and the 76 cm spacing by 3.2% and 12.7%, respectively. Soil volumetric water content was higher in the mulch treatments compared to the no rye checks. Delaying soybean planting lowered soil water evaporation. The increased soil VWC in the rolled-rye treatment did not translate into increased soybean yield. The rolled-rye treatment exhibited significant ($p < 0.01$) increases in soil volumetric water content (VWC) when compared to the no-rye treatment at Goldsboro, Kinston, and Salisbury (2012) with 27.4%, 13.4%, and 29.7%, respectively. Fungal translocation of N from the soil to the surface mulch has been demonstrated in laboratory experiments, but this mechanism has not been documented under field conditions. Translocation of N into surface mulches may play an important role in weed suppression. To assess the presence of fungal mediated N immobilization, the isotope ^{15}N as $(NH_4)_2SO_4$ (99.7 at.) was injected below the soil surface *in situ* at a rate of 1 mg ^{15}N kg^{-1} soil into (4.4 cm depth) buried steel frames (0.58 m^2). N movement was monitored throughout the

season. Treatments received, or did not, receive fungicide every 2-weeks after soybean planting. The cereal rye mulches reduced in N content at both BARC and KINS, at 15 and 50 kg N ha^{-1}. An increase of ^{1}5N atom% access of 10-15% in the cereal rye surface mulch tissue was detected. Only one sampling date showed significant impact of the fungicide treatment. The increase in ^{1}5N atom% excess in the cereal rye mulch supports laboratory observations that soil inorganic N is fungal translocates into surface mulches. At six weeks after soybean planting (averaged over locations), the non-fungicide treatment was 36% greater in ^{15}N concentrations, providing evidence of microbial competition via fungal translocation as a mechanism. Soil extractable inorganic N was reduced by as much as 60% from the initial low of 10 kg N ha^{-1}, where both the soybeans and cereal rye residues sequestered and immobilized considerable amounts of N. These findings support the nutritive weed suppressive mechanism of high biomass cereal rye cover crop mulches during the critical weed free period of soybeans, thereby contributing to the weed suppression of the system.

A Mechanistic Approach to Weed Management in a Cover Crop Mulched System

by
Michael Scott Wells

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Crop Science

Raleigh, North Carolina

2013

APPROVED BY:

David. A. Dickey	Wayne P. Robarge
Jude Maul	Steven B. Mirsky
Samuel Chris Reberg-Horton Co-chair of Advisory Committee	Shuijin Hu Co-chair of Advisory Committee

DEDICATION

I dedicate this body of work to family and friends that supported and believed in me. Without them this body of work would not have been possible.

BIOGRAPHY

The author was born in the Asheville located in the mountains of Western North Carolina. He grew up on a dairy farm on that had been in his family for six generations. Finishing high school at C. A. Erwin, he opened an organic egg business. Before the business had to be shutdown due to his flock becoming sick, he had grown his business to the 2nd largest in the North Carolina. After exiting the egg operation he went to UNC-Asheville where he received a bachelors degree in Mathematics. Continuing on with his education after UNC-Asheville he came to North Carolina State University where he studied Crop Science.

ACKNOWLEDGEMENTS

I would like to thank Chris Reberg-Horton and my committee for their support, guidance, and mentorship. Also I want to express my gratitude to Carrie Brinton for all her help making these projects a success. I want to thank George Place, Adam Smith, and Aaron Fox, and Teshima Brennen for their help and support. Finally, I want to thank my wife Anne Marie Wells for her constant reassurance and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

MAIZE PERFORMANCE AS DETERMINED BY PLANTING DATE IN THE ROTATIONAL NO-TILL/ROLL-KILL LEGUME CEREAL BICULTURAL COVER CROP SYSTEM

1.1 INTRODUCTION

In the United States, the demand for organic corn is on the rise. Between 1997 and 2008, there was a 496% increase in certified organic corn acreage (USDA-ERS, 2013). The increase in production is not surprising given that during most years organic corn sells for twice the going price per bushel as its conventional non-organic counterpart (USDA-AMS, 2013). The operational costs can be similar between organic and conventional corn, however, there is usually a difference in yield between the two systems (Cavigelli et al., 2013). Despite the lower yield potential in organic corn systems, the price premium for certified organic corn allows for a higher profit margin (Cavigelli et al., 2009).

Weed and fertility management are among the greatest challenges associated with organic corn production (Mirsky et al., 2013). Without the reliance on UAN fertilizer and chemical weed control methods, intensive and frequent primary and secondary tillage, in combination with the use of organic nitrogen fertility, are essential to ensure maximum corn yield. Weed

management in organic corn systems relies primarily on frequent and intensive tillage practices, which has the potential to negatively impact the environment. The negative effects associated with intensive tillage, such as reduction in soil organic matter, reduced soil aggregate stability (Stenberg et al., 2000), increased erosion (Holland, 2004), and heightened fuel and labor costs (Ryan, 2010) are well understood, and are among some of the most critical problems associated with organic corn production (Peign et al., 2007).

New mulch-based technologies are being developed and evaluated that have the potential to increase carbon input in low input systems and reduce tillage in organic systems (Delate et al., 2012; Mirsky et al., 2012; Reberg-Horton et al., 2012). A cover crop based approach where roller crimpers make a uniform surface mulch that is no-till planted with corn is one approach that shows potential to enhance cover crop biomass accumulations while improving crop yield (Teasdale et al., 2012). This cover crop-based approach was originally developed in Brazil (Derpsch et al., 1991) and gained interest in the U.S. after the USDA-ARS National Soil Dynamics Laboratory improved on the design, and the Rodale Institute popularized it (Kornecki et al., 2009; Institute, 2012). The roller-crimper is a ground-driven implement designed to terminate near-mature cover crops immediately before the planting of the cash crops (Mirsky et al., 2013; Reberg-Horton et al., 2012; Teasdale et al., 2012; Wells et al., 2013b).

Past research has focused on using cover crop monocultures such as hairy vetch (*Vicia villosa* Roth) with corn and cereal rye (*Secale cereale* L.) utilized with soybeans primarily along with focusing on how these mulched systems impacted nutrient cycling (Mirsky et al., 2011; Teasdale et al., 2012; Wells et al., 2013b). Organic corn production that incorporates the use of mulches has rarely achieved comparable yield to conventional no-till systems (Parr et al., 2011). This has largely been due to the need for high cover crop biomass levels and the lack of an adequate system for cutting/removing cover crop residue in the planting region. Crop populations have been inconsistent resulting in variable crop yields (Delate et al., 2012; Mirsky et al., 2012).

Beyond crop population constraints, lower yield potential of corn in the cover crop-based system can be attributed to several other factors. For one, effective cover crop kill requires most species to be in the reproductive phase of growth. Legumes mature late, which delays corn planting. Furthermore, legumes tend to produce lower biomass levels than cereal covers and degrade faster. As a result, weed control in corn has been inconsistent (Mirsky et al., 2011; Mischler et al., 2010a; Parr et al., 2011; Reberg-Horton et al., 2012). While not addressing crop population and planting date constraints, cover crop mixtures that include both legumes and cereals could improve corn production through greater weed control. For example, the addition of a cereal grain will not hasten the maturation of hairy vetch, but it will increase the biomass potential of the cover crop mix by more than 2000 kg ha^{-1} DM when compared to vetch monocultures (Parr et al., 2011; Reberg-Horton et al., 2012). The increased biomass

potential of mixed cover crops can enhance the weed suppressive ability of the system (Smith et al., 2011; Teasdale and Mohler, 2000).

Soil moisture at planting, is another factor that can negativity impact yield potential. For optimum cover crop termination (i.e. minimal cover crop regrowth), the cover crops must be terminated during the critical growth stages such as: soft dough for cereal rye, and when pods are first seen on the upper five nodes of hairy vetch (Ashford and Reeves, 2003; Mischler et al., 2010a; Reberg-Horton et al., 2012). Delaying cover crop termination until critical maturation can increase soil moisture losses via cover crop transpiration, thereby depleting soil moisture prior to spring cash crop plantings (Price et al., 2009). Davis (2010) reported reduced soil moisture post termination, in roll-killed treatments, when compared to burndown treatments. As a result, he discovered positive correlations between soil moisture after roll-kill and soybean yield.

One mitigation strategy for soil moistures loses is to delay planting after rolling to allow precipitations to partially recharge moisture reserves (Price et al., 2009; Reberg-Horton et al., 2012; Reeves, 1994). One potential negative impact of this approach is the opportunity for weeds to emerge during this delay and become well established before the crop is even planted. The objectives of this study were to determine (i) the impact of delaying planting after roll-kill on soil moisture and subsequent corn performance, (ii) the level of weed control achieved utilizing winter pea/rye and hairy vetch/rye mixtures, as cover crop mulches, in the absents of herbicides and determining how well the best of these treatments yielded relative to standard no-till without mulches.

1.2 MATERIALS AND METHODS

The effect of crop planting timing in relationship to cover crop termination, chemical weed control, and cover crop species and presence on corn performance were tested in a four site-year field experiment conducted at the Center for Environmental Farming Systems in Goldsboro, NC (2011) (35.38291°N, 78.035846°W), Caswell Research Farm in Kinston, NC (2011, and 2012) (35.273206°N, 77.623816°W), and Piedmont Research Station in Salisbury, NC (2012) (35.68503°N, -80.60338 °W). Locations were selected from the North Carolina Department of Agriculture Research Stations that span the broad set of climate, proximity, and soil type to North Carolina corn producers. The soil type in Goldsboro for 2011 was Wickham loamy sand (fine-loamy, mixed, semiactive, thermic Typic Hapludults) with 2 to 6% slope, Kinston for years 2011 and 2012 were Johns loamy sand (fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludults) with 0 to 2% slope and Kenansville loamy sand (loamy, siliceous, subactive, thermic Arenic Hapludults) with 0 to 3% slope, and Salisbury for 2012 was Mecklenburg clay loam (fine, mixed, active, thermic Ultic Haplualfs) with 2 to 8% slope,

moderately eroded.

The experiment used a factorial-structured randomized complete block design with six replicates, with factors consisting of the following: (i) corn-planting date timing after cover crop termination (i.e. same day versus approximately 2-weeks after roll-kill), (ii) with (PRE and POST) or without herbicide weed control (i.e. +H and −H), and cover crop treatments: (iii) no-till without cover crop mulch (NT) (i.e. no cover crop), winter pea (*Pisum sativum* ssp. arvense) (P), and AU Early Cover hairy vetch (*Vicia villosa*) (V) both mixed with Wrens Abruzzi rye (*Secale cereale* L.) Supplemental mineral fertility was provided to eliminate potential limitations of nitrogen from the cover crops and a herbicide treatment was included to establish weed free control plots.

In the fall, the entire field was disked and field cultivated at all site years, prior to planting cover crops to remove any existing vegetation from the prior soybean crop. Lime, phosphorus, and potassium were applied according to soil tests before the cover crop planting in early Fall (Table 2.1). The plot size was four rows wide (76-cm row spacing) by 15-m long. Before planting in the fall (mid-September), all fields were disked with a tandem offset disk and cultivated. Cover crops (winter pea/rye and hairy vetch/rye) were subsequently sown to all treatment combinations including the no-till without cover crop mulch plots (NT+H and NT−H) via grain drill with 13-cm row spacing. The winter pea and AU Early Cover hairy vetch were sown at a rate of 28 and 51 kg ha^{-1}, respectively. Both cover crop treatments were mixed individually with Wrens Abruzzi rye at a rate of 56 kg ha^{-1}. Cover crops were terminated for both NT treatments in February at all four site-years via glyphosate before the cover crops reached 15 cm and had no visible residue by the time of maize planting. In early May (Table 2.1), the cover crop treatments (all plots) were roll-killed (i.e., terminated) with a 3.1 m roller-crimper (I and J Manufacturing, Gap, PA), parallel to cover crop drilling direction. The rye was at soft-dough stage (Feekes 11.2) and the legumes were at early pod set (Hoffman et al., 1993; Mischler et al., 2010a).

Corn planting occurred at both time of cover crop termination (i.e. Early Planting Date) and approximately 2-weeks after termination (i.e. Late Planting Date). Certified organic corn seed (Doeblers N631, 110-d, Jersey Shore, PA) was planted with a no-till planter (John Deere 7200, Moline, IL) parallel to the roller-crimper direction at 81,504 live seed ha^{-1} for Goldsboro (2011) and Kinston (2011 and 2012), and 78,486 live seed ha^{-1} for Salisbury (2012). Additional modifications to the planter were necessary at some locations due to either higher cover crop biomass levels or lodging. At the Kinston and Salisbury sites (2012), sharp row cleaners (Yetter Shark Tooth) were employed to clear mulch ahead of the no-till coulter and v-openers of the planter units. Curvetine closers were also used (2012) to help close the row more effectively.

Crop management included the application of N fertility and herbicide applications. The corn crop received 180 kg-N ha^{-1} consisting of split-applications of 80 kg-N ha^{-1} pre-plant and

100 kg-N ha^{-1} banded 4 weeks after planting (WAP). Having a full factorial of experimental treatments that include plots which receive (+H) or do not receive a post-emergence herbicide (H) allowed us to quantify both the impact of the mulches on weeds as well as determine crop yield loss due to weed competition. The weed-free checks received S-metolachlor plus Atrazine −H(Metal® II AT, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) and Ametryn (Evik® DF, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) or Nicosulfuron (Accent® 75 DF, DuPont, 1007 Market St., Wilimington, DE 19898) as a post-emergent herbicide depending on the weed community. Hand weeding was utilized as needed in addition to herbicide weed control to ensure weed-free conditions throughout the season in the +H plots. The two no-till without cover crop mulch check plots (NT+H, and NT−H) received a glyphosate (Honcho® Plus, Monsanto Company, 800 N Lindbergh BLDV., ST. Louis, MO) burndown at planting thus ensuring weed free conditions at roll-crimping and planting.

Plant and soil measurements collected throughout the season included cover crop biomass production, crop population, percent weed coverage, total weed biomass, percent soil volumetric water content, and corn yield. Following cover crop termination (i.e. same day), cover-crop biomass was harvested on an area basis (0.5 m^2) and dried at 60℃ for 72 hrs to determine dry weight biomass production. Corn population was recorded (4 WAP) in the two center corn rows (6-linear meters total) that were also used to collect yield. Percent weed cover was visually rated across the entire plot for all treatments (12 WAP). Total weed biomass was collected on an area basis and dried at 60℃ for 72 hrs to determine dry weight weed biomass at 12 WAP. Volumetric water content was measured (Fieldscout TDR 300 Soil Moisture Meter, Spectrum Technologies, Plainfield, IL) to a depth of 10 cm for both planting dates at all site-years; however, due to sampling error only the 2012, volumetric water content was reported. Using a small plot combine, corn yield was harvested from 12.2 m of the two center rows in each plot.

To determine the effects of cover crop biomass production, weed coverage and biomass, along with crop populations on corn yield we used a mixed model analysis of variance. Preliminary analysis, across all parameters, showed significant treatment by site-year interactions, therefore, a generalized analysis was not prohibited. Each site-year was analyzed separately using proc MIXED, and within each site-year, treatments were modeled as fixed effects, and blocks as random effects (SAS, 2006). Due to a lack of homogeneous variance for the percent weed cover data, an arcsine of the square root transformation was used on the dependent variable (Steel et al., 1996). For the same reason, total weed biomass data was transformed via the logarithmic transformation (Steel et al., 1996). Transformed means were back-transformed for presentation, and all means were separated using pre-planned contrasts (SAS, 2006; Steel et al., 1996).

1.3 RESULTS AND DISCUSSION

1.3.1 Cover Crop Performance

High levels of cover crop biomass was achieved for both winter pea and hairy vetch rye mixtures across all four site-years (Table 2.2). With the exception of Goldsboro (2011), cover crop biomass production did not vary between the winter pea and hairy vetch treatments (Table 2.2). At Goldsboro (2011), winter pea biomass was significantly higher than hairy vetch producing 8876 and 7781 kg ha-1 dry matter (DM), respectively (Table 2.3). This trend is in agreement with earlier research, where winter pea mixes with rye out-yielded vetch mixed with rye by nearly 2000 kg ha-1 DM (Parr et al., 2011). Biomass production for both of the cover crop treatments, winter pea (P) and hairy vetch (V), were in the suggested range for optimal weed suppression of 8000 kg ha^{-1} (Teasdale et al., 2012; Teasdale and Mohler, 2000).

1.3.2 Soil Moisture and Crop Populations

Cover crop treatments (NT, P and V) significantly impacted VWC across all four sampling events at Kinston (2012), and for the June 4th sampling at Salisbury (2012)(Table 2.3). At Kinston (2012), vetch reported significantly greater VWC when compared to NT and at 3 of the 4 sampling intervals when compared to P (Table 2.3). Unlike the vetch treatment at Kinston (2012), the P did not differ in VWC when compared to the NT treatment (Table 2.3). There was no significant difference between the VWC measured in the P and NT treatments and for both the May 22nd June 4th sampling periods at Salisbury. However, during the June 4th sampling period in Salisbury, V recorded greater VWC than the NT treatment (Table 2.3). The differential effect of pea and vetch on soil moisture could be due to the difference in growth form. While both legumes have a vining habit, hairy vetch is more extreme and virtually every plot had lodged before rolling. The vetch/rye mulch was extraordinarily intertwined and the soil could not be seen after rolling. The pea/rye treatments, however, was more erect where with soil visible after rolling.

Corn populations were generally larger than reported from previous research that utilized heavy mulches (Mischler et al., 2010a; Teasdale et al., 2012). Occasionally stand reduced relative to non-mulched plots was significant; Kinston (2011) at early and late planting dates and Kinston 2012 early planting date (Table 1.4). However, corn populations were not affected by cover crops at the other 2 site-years (Table 1.4). Pea and vetch yield similar corn populations with the exception of the early planting date at Kinston (2011). Vetch/rye plots had lower corn populations there. This site year had the highest biomass and the vetch has been noted for causing more planter problems than other cover crops (Mischler et al., 2010a). Corn planting date affected corn populations at Goldsboro (2011) and Kinston (2012). For example, corn

populations were greater for the early planting date at Goldsboro (2011) whereas the opposite was observed for corn populations during the late planting date at Kinston (2012)(Table 1.4). Across the four site-years, Salisbury populations were least effected by both cover crop and planting date treatments (Table 1.4).

Soil type and conditions, along with available soil moisture, may play an important role in explaining the reductions in crop stands in the mulched plots for Goldsboro (2011) and Kinston (2012) (Table 1.5). One possible explanation for greater corn populations in the early-planted cover crop treatments at Goldsboro (2011) and the late-planted cover crop treatments at Kinston (2012), could be the increased soil VWC (Table 1.4). At Kinston (2012), the soil VWC had declined nearly half from the VWC at the early planting, and was measured below 10% on May 14th (i.e. late planting date for Kinston 2012). The potential drought stress was alleviated by the 1.7 cm rainfall event occurring over the night of the 14th and continuing into the following day. Timely rainfall events alone do not fully explain the fluctuation in corn stand measured in the cover crop treatments.

Soil type at these locations may play an important role in the establishing corn populations. Even with row cleaners mounted ahead of the planter units, there was still an increased frequency of cover crop residues hair-pinned into the seed furrow. Unlike the coarse sandy soil types at Goldsboro and Kinston (2011 and 2012), the clay loam soils at Salisbury provided a firmer planting surface, therefore improving the slicing efficiency of the front coulter and reducing the incidence of hair-pinning (Mirsky et al., 2013). Achieving uniform crop populations are going to continue to be an issue in cover crop-based organic rotational no-till corn and soybean production until planter technology improves residue cutting and seed placement. These findings, along with others, (Mirsky et al., 2013; Reberg-Horton et al., 2012), highlight the need for improved no-till planting technology that can achieve proper seed placement while minimizing disturbance of the cover crop mulch.

1.3.3 Weed Control

Despite weed coverage estimates greater than 60 percent at 3 of the 4 site-years, weed biomass estimates were less than 500 kg ha^{-1} (with exception of Salisbury)(Figure 4.1 and 4.2). Considering the lack of any weed control measure other than the mulch, these weed weights, are low and in the organic context would be considered excellent (Figure 4.1 and 4.2). Cover crop type was important in determining the weed coverage at Goldsboro (2011), Kinston (2011), and Salisbury (2012), and corn planting date had no effect on weed coverage with exception of Salisbury (2012)(Table 1.5). Since planting date had no effect on weed coverage at Goldsboro (2011), Kinston (2011 and 2012), weed coverage estimates for the prior mentioned sites were presented averaged over planting date (Table 1.5)(Figure 4.1). The weed coverage data for Sal-

isbury (2012) was not averaged over planting date due to significant planting date by cover crop type interaction (Table 1.5)(Figure 4.1). Even though, corn planting date was of importance at Salisbury (2012) only, the winter pea without herbicides (P-H) treatment had significantly greater weed coverage estimates than V-H at both Goldsboro (2011) and by the late planting date at Salisbury (2012)(Table 1.5)(Figure 4.1). The lack of a corn planting date effect on weed coverage at 3 of the 4 site-years was surprising. Since the cover crops were terminated on the same day for both early and late corn planting date, it seems plausible that the late planting date plots should have greater incidence of weed coverage giving that the weeds in the late planting date had nearly 2-weeks head start on the corn crop.

Weed biomass production was influenced by cover crop treatments only at Kinston (2011) where the P-HB treatment observed significantly greater weed biomass than the V-HB treatment (Table 1.5)(Figure 4.2). Although not always significant at the $\alpha = 0.05$, P$-$HB treatment reported greater weed biomass estimates for the early planting date at Goldsboro ($p < 0.12$), Kinston (2011; $p < 0.02$), and at the late planting date at Kinston (2012; $p < 0.19$) and Salisbury (2012; $p < 0.17$). The reduced weed suppression in the pea cover crop treatments was surprising since the winter pea + rye treatment produced greater mulch biomass than the vetch (Table 2.1). Two possible explanations for the improved weed control in the vetch treatment could be the documented allelopathic activity of hairy vetch (Fujii, 2001), and already mentioned observed canopy architectural difference observed at planting that lead to less soil shading by the winter pea.

1.3.4 Corn Yield

Corn yield was not generalized over site-years due to significant treatment by site-year interactions; therefore separate analysis for corn yield was performed (Table 1.6). Corn planting date was important in determining corn yield at Kinston (2012) and Salisbury (2012) (Table 1.6), whereas Goldsboro was the only site where cover crop treatment impacted corn yield (Table 1.6). Even though weed biomass estimates were relatively low, weeds did significantly reduced corn yield at 3 of the 4 site-years; however, at Kinston (2011) the CC-H treatments yield statistically equivalent to the CC+H treatments (Table 1.6), which corresponds to the lowest weed coverage and weed biomass of the four site-years (Figure 4.1 and 4.2). Weed-driven yield differential between NT+H and both P-H and V-H treatments was most pronounced for the early planting date at Kinston (2012), and the late planting dates for both Kinston (2012) and Salisbury (2012), with approximately 2000, 1000, and 4000 kg ha^{-1}, respectively, greater corn yield in the NT+H treatments (Table 1.6). With exception to Kinston (2011), and the early planting date at Salisbury (2012), the P-H treatments yielded lower than the NT+H treatments, which was not surprising since P-H, at Goldsboro (2011) and Salisbury (2012), reported greater weed

coverage than the V-H treatment (Figure 4.1)(Figure 4.2).

The significant NT+H versus CC+H contrast that evaluates corn yield potential in the absence of weed pressures was significant at Kinston (2011)(Table 1.6). This finding was not surprising since the NT treatments at Kinston (2011) had greater crop populations for both planting dates when compared to the P and V cover crop treatments (Table 1.4). Since the winter pea + rye (P) and AU Early Cover hairy vetch + rye (V) treatments produced in excess of 7000 kg ha 1 DM, the increased weed pressures in the non-herbicide mulch treatments were not a solely a function of inadequate cover crop biomass production (Teasdale and Mohler, 2000). It is possible, that the in-row proximity of the escaped weeds illustrates the difficulties of no-till planting in high residue mulches. At each location, row cleaners were necessary to ensure proper corn seed placement, resulting in the reduction of mulch over the furrow. This, along with increased soil disturbance, favored small-seeded summer annual weeds.

1.4 CONCLUSION

In summary, cover crop mulches are viable options for organic no-till corn systems. However, our hypothesis that delaying corn planting following cover crop termination would increase soil water content was not supported. Contrary to several study recommendations, delayed planting of corn following the termination of the cover crop had minimal effect on the recharging of the soil moisture in the O nor the A soil horizons. It is possible that gains in soil moisture achieved by delayed planting after a roll-kill event were masked by precipitation events occurring at cover crop termination and cash crop planting. Even though planting on the same day or waiting 2-weeks after cover crop termination had no effect on soil volumetric water content, corn populations were greatly effected by lack of rainfall during the delay in planting period. Timely rainfall events coinciding with planting and roll-kill date are paramount to ensuring optimum corn stand thus illustrating the critical nature of scheduling roll-kill and planting dates that best coincide with precipitation events. Winter pea and hairy vetch mixed with cereal rye are acceptable cover crop mixes for use as roll-killed mulches in conservation tillage corn systems. With exception of hairy vetch at Goldsboro (2011) and winter pea at Salisbury (2012) the cover crop treatments yielded above 8000 kg ha^{-1} DMthe suggested threshold for 80% weed controlacross all 4-site years (Teasdale and Mohler, 2000). During the 2012 growing season, pea and vetch performed equivalently in both corn yields and weed suppression. However in 2011, hairy vetch, despite lower biomass production, did out perform winter pea. Despite high biomass production from pea and vetch, in-row weeds did escape control in the CC-H treatments, at 3 of the 4 site-years when compared to the CC+H treatments. These findings indicate the need of high residue no-till planter innovations that not only minimizes hair-pinning, but also does so with minimal disturbance to the weed suppressive cover crop mulch.

1.5 FIGURE CAPTIONS, TABLES AND FIGURES

1.5.1 Figures

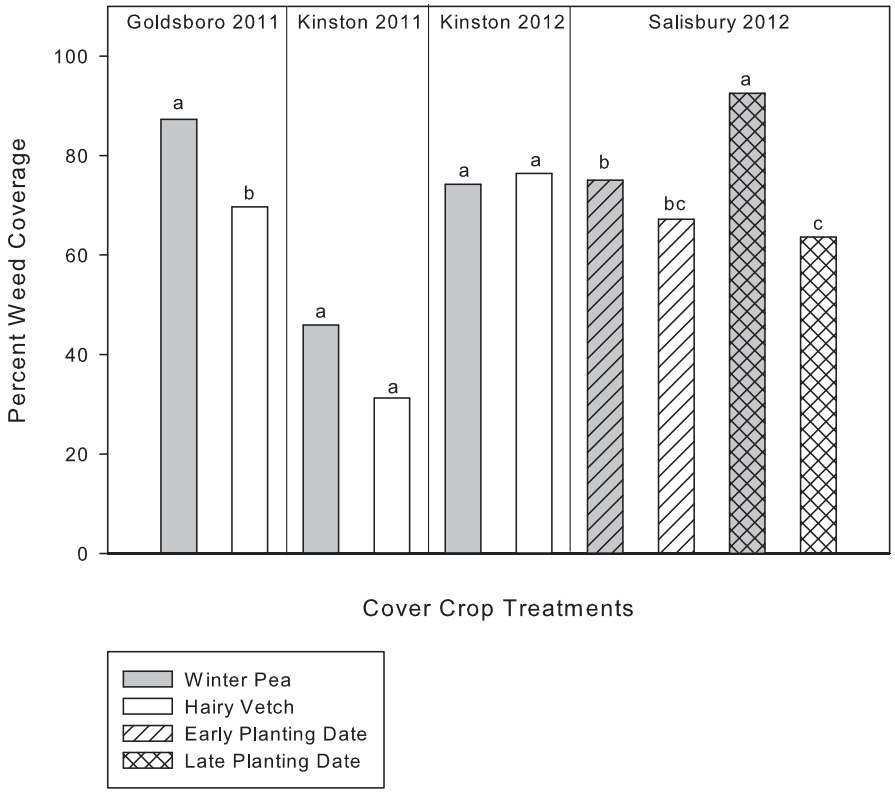

Figure 1.1: Percent weed coverage in winter pea and hairy vetch cover crop treatments for Goldsboro (2011), Kinston (2011-2012), and Salisbury (2012), as influenced by corn planting date and cover crop type. Weed coverage estimates for Goldsboro (2011), and Kinston (2011-2012) are pooled over planting date. Weed-free (NT+H, P+H, and V+H) and weedy check plots (NT-H) are excluded from the analysis. Means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$. North Carolina.

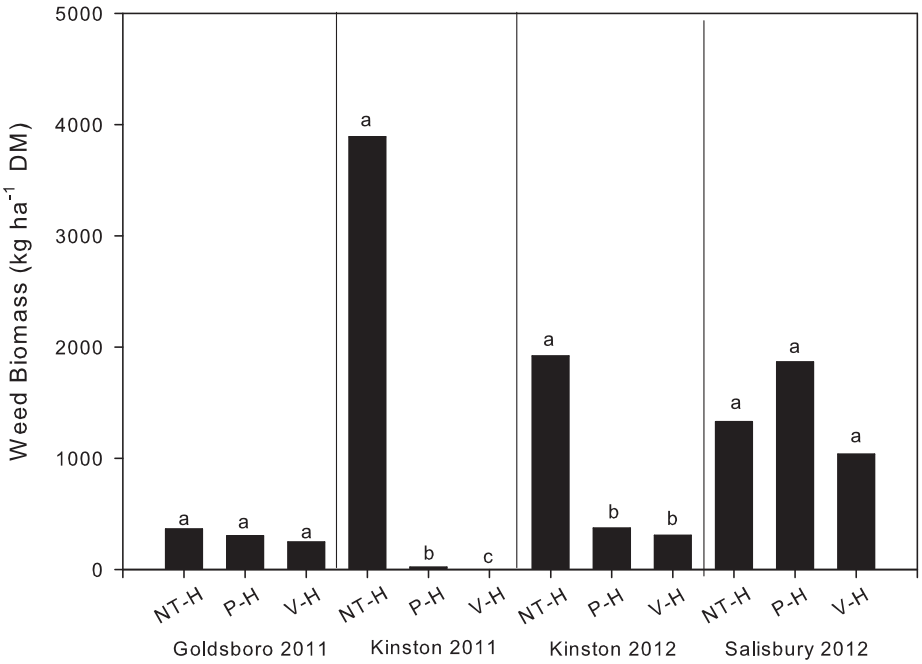

Figure 1.2: Total weed biomass as influenced by site, and cover crop. Data was pooled over planting date within each reported and pooled over planting date for each site-year. Planting date did not significantly affect weed biomass. Weed biomass was collected on an area basis for all treatments by corn growth stage VT. Within site-year treatment means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$. Abbreviations: NT+H, no-till without cover crop mulch with herbicide weed control; P, Winter Pea (*Pisum sativum* ssp. arvense); V, 'AU Early Cover Hairy Vetch (*Vicia villosa* Roth); -H, no herbicide weed control. North Carolina.

1.5.2 Tables

Table 1.1: Planting Dates, Cover Crop Growth Stages, and Percent Control via Roller Crimper at Goldsboro, Kinston and Salisbury, NC (2011-2012).

	Corn Planting Dates		Cover Crop Growth Stage at Termination			Cover Crop Control via Roller Crimper
Site-Year	Early	Late	Rye[a]	Winter Pea[b]	Hairy Vetch[b]	
2011						
Goldsboro	May-2	May-23	11.2	3^{rd}	6^{th}	93%
Kinston	May-3	May-18	11.2	EPS[c]	6^{th}	80%
2012						
Kinston	May-7	May-14	11.2	EPS	EPS	92%
Salisbury	May-21	Jun-2	11.4	$> 5^{th}$	$> 5^{th}$	100%

[a] Rye growth stage taken at roll-kill using the Feekes scale.

[b] Legume cover crop maturity characterized as the lowest node position (from terminal node) where seed pods had formed (Mischler et al., 2010)

[c] Early Pod Set.

Table 1.2: Cover Crop Biomass Production at Roll-kill for Goldsboro, Kinston and Salisbury, NC (2011-2012).

Cover Crop Treatment	Goldsboro 2011	Kinston 2011	Kinston 2012	Salisbury 2012
	——————Biomass (kg ha^{-1} DM)——————			
Winter Pea + Wrens Abruzzi Rye (P)	8876 a[a]	10661 a	9050 a	7192 a
'AU Early Cover' Hairy Vetch + Abruzzi Rye (V)	7781 b	9674 a	8086 a	8117 a

[a] Within columns and main effects, means followed by the same letter are not significantly different based on pre-planned contrast at $p < 0.05$.

Table 1.3: Analysis of variance and mean percent soil volumetric water content for Kinston (2012), and Salisbury (2012), as influenced by corn planting date and cover crop type.

	Kinston 2012				Salisbury 2012	
	7-May	10-May	14-May	1-June	22-May	4-June
Source	ANOVA[a]					
Planting Date (D)	NS	NS	NS	NS	NS	NS
Cover Crop (C)	***	***	**	**	NS	*
D x C	NS	NS	NS	NS	NS	NS
	% Soil Volumetric Water Content[b]					
No-till without Mulch + Herbicide	18.0 b	25.8 b	8.9 ab	18.2 b	25.6 a	25.1 b
Winter Pea (P)	18.5 b	25.8 b	7.8 b	17.8 b	25.5 a	25.7 ab
Hairy Vetch (V)	22.1 a	28.0 a	9.9 a	19.8 a	25.3 a	26.1 a

[a] NS, Non-significant at $\alpha = 0.05$. *, **, and *** represent significance of F tests at $\alpha = 0.05$, 0.01, and 0.001, respectively.

[b] Percent soil volumetric water content was measured across all treatments at a depth of 12 cm for both sites and is displayed by date and treatment. Means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$.

Table 1.4: Analysis of variance and mean corn populations for Goldsboro (2011), Kinston (2011-2012), and Salisbury (2012), as influenced by corn planting date and cover crop type.

Source	Goldsboro 2011	Kinston 2011	Kinston 2012	Salisbury 2012
	ANOVA[a]			
Planting Date (D)	***	NS	***	NS
Cover Crop (C)	NS	***	NS	NS
D x C	NS	NS	***	NS
Estimate				
Early Planting Date[b]	69,970 a[c]	64,868 a	64,869 b	74,293 a
Late Planting Date	57,119 b	59,847 a	79,186 a	76,494 a
Early Planting Date	Corn Populations (plants ha^{-1})			
No-till without Mulch	68,170 a[c]	80,868 a	75,346 a	74,124 a
Winter Pea (P)	71,570 a	61,532 b	64,259 b	77,929 a
Hairy Vetch (V)	70,169 a	52,204 c	55,003 b	70,825 a
Late Planting Date				
No-till without Mulch	56,014 a	69,605 a	75,888 a	78,790 a
Winter Pea (P)	56,330 a	56,117 b	77,929 a	75,561 a
Hairy Vetch (V)	59,014 a	53,818 b	83,741 a	75,130 a

[a] NS, Non-significant at $\alpha = 0.05$. *, **, and *** represent significance of F tests at $\alpha = 0.05$, 0.01, and 0.001, respectively.

[b] Early planting date refers to roll-kill of cover crops and planting of corn occurring on the same day. Late planting date refers to corn planting date that occurred (approximately) 2-weeks after roll-kill of the cover crops.

[c] Within columns, and by planting date, means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$.

Table 1.5: Analysis of variance of weed coverage and weed biomass in winter pea and hairy vetch cover crop treatments for Goldsboro (2011), Kinston (2011-2012), and Salisbury (2012), as influenced by corn planting date and cover crop type.

	Goldsboro 2011	Kinston 2011	Kinston 2012	Salisbury 2012
Source	Weed Coverage[a]			
Planting Date (D)	NS[b]	NS	NS	**
Cover Crop (C)	*	$p < 0.08$	NS	***
D x C	NS	NS	NS	***
Source	Weed Biomass[a]			
Planting Date (D)	NS	NS	NS	NS
Cover Crop (C)	NS	**	NS	NS
D x C	NS	NS	NS	NS

[a] Weed-free (NT+H, P+H, and V+H) and weedy check plots (NT−H) were excluded from the analysis

[b] NS, Non-significant at $\alpha = 0.05$. *, **, and *** represent significance of F tests at $\alpha = 0.05$, 0.01, and 0.001, respectively.

Table 1.6: Analysis of variance results of corn yield at Goldsboro (2011), Kinston (2011-2012), and Salisbury (2012), as influenced by corn planting date and cover crop type and presence, and weed control.

	Goldsboro 2011		Kinston 2011		Kinston 2012		Salisbury 2012	
Source	ANOVA[a]							
Planting Date (D)	NS		NS		**		NS	
Cover Crop (C)	*		NS		NS		NS	
Herbicide (H)	**		NS		**		**	
D x H	NS		NS		NS		NS	
D x C	NS		NS		NS		**	
C x H	NS		NS		NS		*	
D x H x C	NS		NS		NS		NS	
Contrast[b]								
NT+H vs. CC+H	NS		*		NS		$p < 0.11$	
CC+H vs. CC−H	**		NS		$p < 0.11$		**	
P−H vs. V−H	*		NS		NS		NS	
	Early[c]	Late	Early	Late	Early	Late	Early	Late
Treatments	Yield (Mg ha^{-1})							
NT+H	5.6 ab	5.5 a	6.1 a	5.4 a	11.0 a	13.3 a	7.7 cd	11.8 ab
NT−H	-	-	-	-	6.6 c	10.2 b	5.6 d	10.9 ab
P+H	5.3 ab	4.1 ab	5.0 a	4.4 a	7.6 bc	12.9 a	14.0 a	12.4 a
P−H	3.1 c	3.3 b	5.3 a	4.9 a	6.8 c	10.3 b	10.1 bc	6.6 c
V+H	6.3 a	5.0 ab	4.8 a	5.2 a	9.2 ab	12.5 ab	12.2 ab	9.1 bc
V−H	4.5 bc	4.5 ab	4.7 a	5.1 a	8.0 bc	11.6 ab	11.2 ab	8.9 bc

[a] NS, Non-significant at $\alpha = 0.05$. *, **, and *** represent significance of F tests at $\alpha = 0.05$, 0.01, and 0.001, respectively.

[b] The contrast NT+H (no-till without mulch cover crop +H) vs. CC+H evaluates the yield potential of the cover crop (CC) treatments absent of weed pressures as represented by NT+H. CC+H vs. CC−H assesses weed driven yield loss in the cover crop treatments. P−H (P, Winter Pea) vs. V−H (V, Hairy Vetch) evaluates the weed suppression performance between the two cover crop treatments void of herbicide weed control.

[c] Early planting date refers to roll-kill of cover crops and planting of corn occurring on the same day. Late planting date refers to corn planting date that occurred (approximately) 2-weeks after roll-kill of the cover crops.

REFERENCES

J. K. Aase and D. L. Tanaka. Soil water evaporation comparisons among tillage practices in the northern great plains. *Soil Science Society of America Journal*, 51(2):436–440, 1987. Irrigation and Drainage.

J. D. Aber and J. M. Melillo. Nitrogen immobilization in decaying hardwood leaf litter as a function of initial nitrogen and lignin content. *Canadian Journal of Botany*, 60(11):2263–2269, 1982. Forestry; Soils and Fertilizers.

R. E. van Acker, C. J. Swanton, and S. F. Weise. The critical period of weed control in soyabean (glycine max (l.) merr.). *Weed Science*, 41(2):194–200, 1993. Weeds; Soyabeans.

D. L. Ashford and D. W. Reeves. Use of a mechanical roller-crimper as an alternative kill method for cover crops. *American journal of alternative agriculture*, 18(1):37–45, 2003. Accession Number: IND43646603 Pagination: p. 37-45. Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

M. H. Beare, R. W. Parmelee, P. F. Hendrix, W. Cheng, D. C. Coleman, and D. A. Crossley. Microbial and faunal interactions and effects on litter nitrogen and decomposition in agroecosystems. *Ecological Monographs*, 62(4):569–591, 1992. Accession Number: 19951908046. Publication Type: Journal Article. Language: English. Number of References: 96 ref. Registry Number: 7727-37-9.

M. H. Beare, P. F. Hendrix, D. C. Coleman, and S. Hu. Influences of mycelial fungi on soil aggregation and organic matter storage in conventional and no-tillage soils. *Applied soil ecology : a section of Agriculture, Ecosystems and Environment*, 5(3):211–219, 1997. soil carbohydrates; sandy clay loam soils; respiration; macroaggregates Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Category Codes: Soil Chemistry and Physics; Soil Cultivation and Cropping Systems; Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH541.5.S6A67 Update Code: 00000000.

E. R. Bernstein, J. L. Posner, D. E. Stoltenberg, and J. L. Hedtcke. Organically managed no-tillage rye-soybean systems: agronomic, economic, and environmental assessment. *Agronomy Journal*, 103(4):1169–1179, 2011. Soyabeans; Wheat, Barley and Triticale Abstracts; Irrigation and Drainage; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers.

Eliana E. Bontti, Ingrid C. Burke, Stephanie Owens, Mark E. Harmon, William J. Parton, Michelle L. Haddix, Seth M. Munson, Joseph P. Decant, Agnieszka Przeszlowska, and Mark A. Gathany. Litter decomposition in grasslands of central north america (us great plains) [electronic resource]. *Global change biology*, 15(5):1356–1363, 2009. root and leaf decomposition; Great Plains (USA); litter decomposition Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Subset: Indexing Branch - NAL NAL Call Number: QC981.8.C5G6323 Update Code: 00000000.

G Bowman. *Steel in the Field: A Farmers' Guide to Weed Mangement Tools.* Sustainable Agriculture Publications, University of Vermont, Burlington, VT, 1997.

P. D. Brooks, J. M. Stark, B. B. McInteer, and T. Preston. Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. *Soil Science Society of America Journal*, 53(6): 1707–1711, 1989. Accession Number: 19901942338. Publication Type: Journal Article. Language: English. Number of References: 21 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

P. L. Brown and D. D. Dickey. Losses of wheat straw residue under simulated field conditions, 1970. Accession Number: CAIN709036937 Pagination: p. 118-121. Language(s): English General Note: Bibliography: p. 121 NAL Call Number: 56.9 SO3 Update Code: 00000000.

J. L. de Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agronomy Journal*, 100(3):704–710, 2008. World Agriculture, Economics and Rural Sociology.

D. Bullock, A. Rayburn, and S. Khan. Soybean yield response to narrow rows is largely due to enhanced early growth. *Crop science*, 38(4):1011–1016, 1998. growth; plant height; determinate and indeterminate habit Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: CRPSAY Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 64.8 C883 Update Code: 00000000.

M. S. Burgess, G. R. Mehuys, and C. A. Madramootoo. Nitrogen dynamics of decomposing corn residue components under three tillage systems. *Soil Science Society of America Journal*, 66 (4):1350–1358, 2002. Soils and Fertilizers.

O. C. Burnside and R. S. Moomaw. Control of weeds in narrow-row soybeans. *Agronomy Journal*, 69(5):793–796, 1977. Weeds; Field Crops.

R. B. Campbell, R. E. Sojka, and D. L. Karlen. Conservation tillage for soybean in the u.s. southeastern coastal plain. *Soil and Tillage Research*, 4(6):531–541, 1984. Agricultural Engineering.

M. A. Cavigelli, B. L. Hima, J. C. Hanson, J. R. Teasdale, A. E. Conklin, and Y. C. Lu. Long-term economic performance of organic and conventional field crops in the mid-atlantic region. *Renewable Agriculture and Food Systems*, 24(2):102–119, 2009. Field Crops; Plant Genetic Resources; Grasslands and Forage; Weeds; World Agriculture, Economics and Rural Sociology; Soyabeans; Soils and Fertilizers; Horticultural Science; Maize.

M. A. Cavigelli, S. B. Mirsky, J. R. Teasdale, J. T. Spargo, and J. Doran. Organic grain cropping systems to enhance ecosystem services. *Renewable Agriculture and Food Systems*, 28(2):145–159, 2013. Conference paper. Language: English. Number of References: 126 ref. Registry Number: 7727-37-9. Subject Subsets: Weeds; Soils and Fertilizers.

K. Chandler, Shrestha Anil, and C. J. Swanton. Weed seed return as influenced by the critical weed-free period and row spacing of no-till glyphosate-resistant soybean. *Canadian Journal of Plant Science*, 81(4):877–880, 2001. Seed Science; Soyabeans; Field Crops; Weeds.

A. J. Clark, A. M. Decker, J. J. Meisinger, and M. S. McIntosh. Kill date of vetch, rye, and a vetch-rye mixture: Ii. soil moisture and corn yield. *Agronomy Journal*, 89(3):434–441, 1997. Maize; Wheat, Barley and Triticale Abstracts.

R. L. Cooper. Response of soybean cultivars to narrow rows and planting rates under weed-free conditions. *Agronomy Journal*, 69(1):89–92, 1977. Field Crops.

W. J. Cox and J. H. Cherney. Growth and yield responses of soybean to row spacing and seeding rate. *Agronomy Journal*, 103(1):123–128, 2011. Field Crops; Soyabeans; World Agriculture, Economics and Rural Sociology.

C. D. Dalley, J. J. Kells, and K. A. Renner. Effect of glyphosate application timing and row spacing on corn (zea mays) and soybean (glycine max) yields. *Weed Technology*, 18(1): 165–176, 2004. Soyabeans; Field Crops; Maize; Weeds.

Adam S. Davis. Cover-crop rollercrimper contributes to weed management in no-till soybean [electronic resource]. *Weed Science*, 58(3):300–309, 2010. Plant Physiology and Biochemistry; Soil Cultivation and Cropping Systems; Plant Production (Field Crops); Soil Fertility, Fertilizers and Manures Subset: Indexing Branch - NAL NAL Call Number: 79.8 W41 Update Code: 00000000.

J.L. De Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agron.J.*, 100(704-710), 2008.

K. Delate, D. Cwach, and C. Chase. Organic no-tillage system effects on soybean, corn and irrigated tomato production and economic performance in iowa, usa. *Renewable Agriculture and Food Systems*, 27(1):49–59, 2012. Soils and Fertilizers; Wheat, Barley and Triticale Abstracts; Maize; Soyabeans; Horticultural Science; World Agriculture, Economics and Rural Sociology.

R. Derpsch, C.H. Roth, N Sidiras, and U Kopke. *Controle da erosao no Parana, Brazil: Sistemas de cobertura do solo, plantio directo e prepare conservacionista do solo.* Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany., 1991.

F. G. Dou, A. L. Wright, and F. M. Hons. Depth distribution of soil organic c and n after long-term soybean cropping in texas. *Soil and Tillage Research*, 94(2):530–536, 2007. Soils and Fertilizers; Soyabeans; Field Crops.

L. H. Fraser and A. D. Hockin. Litter decomposition rates of two grass species along a semi-arid grassland-forest ecocline. *Journal of Arid Environments*, 88:125–129, 2013. Forestry; Grasslands and Forage; Soils and Fertilizers; Plant Genetic Resources; Plant Breeding.

S. D. Frey, E. T. Elliott, K. Paustian, and G. A. Peterson. Fungal translocation as a mechanism for soil nitrogen inputs to surface residue decomposition in a no-tillage agroecosystem. *Soil Biology and Biochemistry*, 32(5):689–698, 2000. Wheat, Barley and Triticale Abstracts.

Yoshiharu Fujii. Screening and future exploitation of allelopathic plants as alternative herbicides with special reference to hairy vetch. *Journal of Crop Production*, 4(2):257, 2001.

M. Gardes and T. D. Bruns. Its primers with enhanced specificity for basidiomycetes - application to the identification of mycorrhizae and rusts. *Molecular Ecology*, 2(2):113–118, 1993. Agricultural Biotechnology.

C. R. Grau, E. S. Oplinger, E. A. Adee, E. A. Hinkens, and M. J. Martinka. Planting date and row width effect on severity of brown stem rot and soybean productivity. *Journal of Production Agriculture*, 7(3):347–351, 1994. Plant Breeding; Soyabeans.

R. Grisso, D. L. Holshouser, and R. M. Pitman. Equipment considerations for no-till soybean seeding, 2009.

J. L. Gunsolus. Mechanical and cultural weed control in corn and soybeans. *American journal of alternative agriculture*, 5(3):114–119, 1990. mechanical methods; yield losses; interrow cultivation Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Plant Production (Field Crops); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

D. B. Harder, C. L. Sprague, and K. A. Renner. Effect of soybean row width and population on weeds, crop yield and economic return. *Weed Technology*, 21(3):744–752, 2007. Soyabeans; World Agriculture, Economics and Rural Sociology.

S. C. Hart and M. K. Firestone. Forest floor-mineral soil interactions in the internal nitrogen cycle of an old-growth forest. *Biogeochemistry*, 12(2):103–127, 1991. Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH345.B564 Update Code: 00000000.

S. C. Hart, J. M. Stark, and E. A. Davidson. *Nitrogen mineralization, immobilization, and nitrification*, pages 985–1018. Soil Science Society of America Inc., Madison, WI, 1994.

L. G. Heatherly and S. R. Spurlock. Yield and economics of traditional and early soybean production system (esps) seedings in the midsouthern united states. *Field Crops Research*, 63(1):35–45, 1999. World Agriculture, Economics and Rural Sociology; Soyabeans.

L. S. Heiffig, G. M. de S. Cmara, L. A. Marques, D. B. Pedroso, and S. M. de S. Piedade. The plasticity of soybean (glycine max (l.) merrill) crop in different spacing arrangements. / plasticidade da cultura da soja (glycine max (l.) merrill) em diferentes arranjos espaciais. *Revista de Agricultura (Piracicaba)*, 84(3):204–219, 2009. Field Crops; Soyabeans.

M. L. Hoffman, E. E. Regnier, and J. Cardina. Weed and corn (zea mays) responses to a hairy vetch (vicia villosa) cover crop. *Weed Technology*, 7(3):594–599, 1993. Weeds; Field Crops; Maize.

E. A. Holland and D. C. Coleman. Litter placement effects on microbial and organic matter dynamics in an agroecosystem. *Ecology*, 62(2):425–433, 1987. Wheat, Barley and Triticale Abstracts.

J. M. Holland. The environmental consequences of adopting conservation tillage in europe: reviewing the evidence. *Agriculture, Ecosystems and Environment*, 103(1):1–25, 2004. Agricultural Entomology; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers; Plant Pathology.

J. P. Huelsenbeck and K. A. Crandall. Phylogeny estimation and hypothesis testing using maximum likelihood. *Annual Review of Ecology and Systematics*, 28:437–466, 1997. Accession Number: 19980103293. Publication Type: Journal Article. Language: English. Number of References: 126 ref. Subject Subsets: Animal Breeding.

E. R. Ingham and D. C. Coleman. Effects of streptomycin, cycloheximide, fungizone, captan, carbofuran, cygon, and pcnb on soil microorganisms. *Microbial Ecology*, 10(4):345–358, 1984. Plant Pathology; Soils and Fertilizers.

E. R. Ingham, C. Cambardella, and D. C. Coleman. Manipulation of bacteria, fungi and protozoa by biocides in lodgepole pine forest soil microcosms: effects on organism interactions and nitrogen mineralization. *Canadian Journal of Soil Science*, 66(2):261–272, 1986. Forestry.

Rodale Institute. No-till revolution, 2012.

III Jaeger, C. H., R. K. Monson, M. C. Fisk, and S. K. Schmidt. Seasonal partitioning of nitrogen by plants and soil microorganisms in an alpine ecosystem. *Ecology*, 80(6):1883–1891, 1999. Accession Number: 19991912029. Publication Type: Journal Article. Language: English. Number of References: 33 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

Ke Jin, S. Sleutel, S. De Neve, D. Gabriels, DianXiong Cai, JiYun Jin, and G. Hofman. Nitrogen and carbon mineralization of surface-applied and incorporated winter wheat and peanut residues. *Biology and Fertility of Soils*, 44(4):661–665, 2008. Soils and Fertilizers; Irrigation and Drainage.

D. R. Keeney and D. W. Nelson. Nitrogen - inorganic forms. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, pages 643–698, 1982. Accession Number: 19841981457. Publication Type: Miscellaneous. Language: English. Number of References: approx. 170 ref. Registry Number: 7727-37-9, 7664-41-7. Subject Subsets: Soils and Fertilizers.

A. Kessavalou, J. H. Qian, T. A. Kettler, J. W. Doran, and W. L. Powers. Bromide and nitrogen-15 tracers of nitrate leaching under irrigated corn in central nebraska [electronic resource]. *Journal of environmental quality*, 25(5):1008–1014, 1996. Soil Biology; Mathematics and Statistics; Soil Chemistry and Physics; Pollution; Irrigation and Drainage Subset: Indexing Branch - NAL NAL Call Number: QH540.J6 Update Code: 00000000.

T. S. Kornecki, F. J. Arriaga, R. L. Raper, and A. J. Price. New roller crimper concepts for mechanical termination of cover crops in conservation agriculture. *Renewable agriculture and food systems*, 24(3):165–173, 2009.

J. T. Lennon, Z. T. Aanderud, B. K. Lehmkuhl, and Jr. Schoolmaster, D. R. Mapping the niche space of soil microorganisms using taxonomy and traits. *Ecology*, 93(8):1867–1879, 2012. Irrigation and Drainage.

L. M. Londono-R, D. Tarkalson, and J. E. Thies. In-field rates of decomposition and microbial communities colonizing residues vary by depth of residue placement and plant part, but not by

crop genotype for residues from two cry1ab bt corn hybrids and their non-transgenic isolines. *Soil Biology and Biochemistry*, 57:349–355, 2013. Soils and Fertilizers; Plant Breeding; Maize; Biocontrol; Field Crops; Agricultural Entomology; Agricultural Biotechnology.

W. G. Lovely, G. C. Weber, and D. W. Staniforth. Effectiveness of the rotary hoe for weed control in soybeans. *Agron.J.*, 50:621–625, 1958.

S. Marinari, A. Lagomarsino, M. C. Moscatelli, A. di Tizio, and E. Campiglia. Soil carbon and nitrogen mineralization kinetics in organic and conventional three-year cropping systems. *Soil and Tillage Research*, 109(2):161–168, 2010. Horticultural Science; Soils and Fertilizers.

M. V. Martnez-Toledo, V. Salmern, B. Rodelas, C. Pozo, and J. Gonzlez-Lpez. Effects of the fungicide captan on some functional groups of soil microflora. *Applied Soil Ecology*, 7(3): 245–255, 1998. Plant Pathology.

R. P. Mathew, Y. C. Feng, L. Githinji, R. Ankumah, and K. S. Balkcom. Impact of no-tillage and conventional tillage systems on soil microbial communities. *Applied and Environmental Soil Science*, 2012:Article ID 548620–Article ID 548620, 2012. Conference paper. Language: English. Number of References: 49 ref. Registry Number: 7440-44-0, 7727-37-9. Subject Subsets: Soils and Fertilizers; Maize; Field Crops.

V. B. Megadi, P. N. Tallur, R. S. Hoskeri, S. I. Mulla, and H. Z. Ninnekar. Biodegradation of pendimethalin by bacillus circulans. *Indian Journal of Biotechnology*, 9(2):173–177, 2010a. Accession Number: 20103171203. Publication Type: Journal Article. Language: English. Number of References: 16 ref. Registry Number: 40487-42-1. Subject Subsets: Weeds.

V. B. Megadi, P. N. Tallur, S. I. Mulla, and H. Z. Ninnekar. Bacterial degradation of fungicide captan. *Journal of Agricultural and Food Chemistry*, 58(24):12863–12868, 2010b. Accession Number: 20113158287. Publication Type: Journal Article. Language: English. Registry Number: 133-06-2. Subject Subsets: Plant Pathology.

J. A. Mickelson and K. A. Renner. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. *Journal of Production Agriculture*, 10(3):431–437, 1997. Soyabeans; Field Crops.

S. B. Mirsky, W. S. Curran, D. M. Mortensen, M. R. Ryan, and D. L. Shumway. Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. *Weed Science*, 59(3):380–389, 2011. Wheat, Barley and Triticale Abstracts; Weeds; Soyabeans.

S. B. Mirsky, M. R. Ryan, W. S. Curran, J. R. Teasdale, J. Maul, J. T. Spargo, J. Moyer, A. M. Grantham, D. Weber, T. R. Way, and G. G. Camargo. Conservation tillage issues: cover crop-based organic rotational no-till grain production in the mid-atlantic region, usa. *Renewable Agriculture and Food Systems*, 27(1):31–40, 2012. Soils and Fertilizers; Field Crops.

S. B. Mirsky, M. R. Ryan, J. R. Teasdale, William S. C., S.C. Reberg-Horton, J. T. Spargo, M. S. Wells, C. L. Keene, and J. W. Moyer. Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the eastern us. *Weed Technology*, 27:193–203, 2013.

Steven B. Mirsky, Matthew R. Ryan, Durland L. Shumway, William S. Curran, and David A. Mortensen. Control of cereal rye with a roller/crimper as influenced by cover crop phenology [electronic resource]. *Agronomy journal*, 101(6):15891596–15891596, 2009. Plant Breeding and Genetics; Plant Production (General); Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: 4 AM34P Update Code: 00000000.

Ruth Mischler, David Wilson, William S. Curran, and Sjoerd W. Duiker. Hairy vetch management for no-till organic corn production [electronic resource]. *Agronomy journal*, 102(1): 355–362, 2010a.

Ruth A. Mischler, Jeffrey A. Hyde, Sjoerd W. Duiker, and William S. Curran. Use of a rolled-rye cover crop for weed suppression in no-till soybeans [electronic resource]. *Weed Technology*, 24(3):253–261, 2010b. Farm Organization and Management (Microeconomics); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: SB610.W39 Update Code: 00000000.

L. N. Mulumba and R. Lal. Mulching effects on selected soil physical properties. *Soil and Tillage Research*, 98(1):106–111, 2008. Soils and Fertilizers.

A. Munawar, R. L. Blevins, W. W. Frye, and M. R. Saul. Tillage and cover crop management for soil water conservation. *Agronomy Journal*, 82(4):773–777, 1990. Wheat, Barley and Triticale Abstracts; Soils and Fertilizers; Irrigation and Drainage; Maize.

K. L. Murphy, J. M. Klopatek, and C. C. Klopatek. The effects of litter quality and climate on decomposition along an elevational gradient. *Ecological Applications*, 8(4):1061–1071, 1998. Forestry.

E. S. Oplinger and B. D. Philbrook. Soybean planting date, row width, and seeding rate response in three tillage systems. *Journal of Production Agriculture*, 5(1):94–99, 1992. Soyabeans.

J. F. Parr and R. I. Papendick. Factors affecting the decomposition of crop residues by microorganisms. *ASA [American Society of Agronomy] Special Publication*, (31):101–129, 1978. Accession Number: 19791950934. Publication Type: Journal Article. Language: English. Number of References: 65 ref. Subject Subsets: Soils and Fertilizers.

M. Parr, J. M. Grossman, S. C. Reberg-Horton, C. Brinton, and C. Crozier. Nitrogen delivery from legume cover crops in no-till organic corn production. *Agronomy journal*, 103(6):1578–1590, 2011. Horticultural Science; Wheat, Barley and Triticale Abstracts; Plant Breeding; Field Crops; Soils and Fertilizers.

P. Pedersen and J. G. Lauer. Corn and soybean response to rotation sequence, row spacing, and tillage system. *Agronomy Journal*, 95(4):965–971, 2003. Field Crops; Maize; Soyabeans.

J. Peign, B. C. Ball, J. Roger-Estrade, and C. David. Is conservation tillage suitable for organic farming? a review. *Soil Use and Management*, 23(2):129–144, 2007. Weeds; Irrigation and Drainage.

G. T. Place, S. C. Reberg-Horton, and M. G. Burton. Effects of preplant and postplant rotary hoe use on weed control, soybean pod position, and soybean yield. *Weed Science*, 57(3): 290–295, 2009. Soyabeans; Weeds.

A. J. Price, F. J. Arriaga, R. L. Raper, K. S. Balkcom, T. S. Komecki, and D. W. Reeves. Comparison of mechanical and chemical winter cereal cover crop termination systems and cotton yield in conservation agriculture. *Journal of Cotton Science*, 13(4):238–245, 2009. Irrigation and Drainage; Weeds; Wheat, Barley and Triticale Abstracts; Field Crops.

A. L. Rathore, A. R. Pal, and K. K. Sahu. Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. *Journal of the Science of Food and Agriculture*, 78(2):149–161, 1998. Field Crops.

S. C. Reberg-Horton, J. D. Burton, D. A. Danehower, G. Y. Ma, D. W. Monks, J. P. Murphy, N. N. Ranells, J. D. Williamson, and N. G. Creamer. Changes over time in the allelochemical content of ten cultivars of rye (secale cereale l.). *Journal of Chemical Ecology*, 31(1):179–193, 2005. Field Crops; Wheat, Barley and Triticale Abstracts; Plant Breeding; Botanical Pesticides; Weeds.

S. C. Reberg-Horton, J. M. Grossman, T. S. Kornecki, A. D. Meijer, A. J. Price, G. T. Place, and T. M. Webster. Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern usa. *Renewable Agriculture and Food Systems*, 27(1):41–48, 2012. Soils and Fertilizers; Maize; Field Crops.

S. Recous, D. Robin, D. Darwis, and B. Mary. Soil inorganic n availability: effect on maize residue decomposition. *Soil Biology and Biochemistry*, 27(12):1529–1538, 1995. Maize.

D. W. Reeves. Cover crops and rotations, 1994 1994.

M. R. Ryan. *Energy usage, greenhouse gases, and multi-tactical weed management in organic rotational no-till cropping systems*. PhD thesis, The Pennsylvania State University, 2010.

F. Salvagiotti, K. G. Cassman, J. E. Specht, D. T. Walters, A. Weiss, and A. Dobermann. Nitrogen uptake, fixation and response to fertilizer n in soybeans: a review. *Field Crops Research*, 108(1):1–13, 2008. World Agriculture, Economics and Rural Sociology; Crop Physiology; Soyabeans.

SAS. *Procedures guide*. Release 9.1.3. SAS Institute, Cary, NC, 2nd edition, 2006.

H. H. Schomberg, J. L. Steiner, and P. W. Unger. Decomposition and nitrogen dynamics of crop residues: residue quality and water effects. *Soil Science Society of America Journal*, 58 (2):372–381, 1994. Wheat, Barley and Triticale Abstracts.

C. M. Schwendener, J. Lehmann, P. B. de Camargo, R. C. C. Luizo, and E. C. M. Fernandes. Nitrogen transfer between high- and low-quality leaves on a nutrient-poor oxisol determined by 15n enrichment. *Soil Biology and Biochemistry*, 37(4):787–794, 2005. Agroforestry; Forestry.

R. M. Shibles and G. C. Weber. Interception of solar radiation and dry matter production by various soybean planting patterns. *Crop Sci.*, 6:55–59, 1966.

B. Shipley and P. A. Keddy. The relationship between relative growth rate and sensitivity to nutrient stress in twenty-eight species of emergent macrophytes. *Journal of ecology*, 76(4): 1101–1110, 1988. stress Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: JECOA Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 450 J829 Update Code: 00000000.

J. Six, S. D. Frey, R. K. Thiet, and K. M. Batten. Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal*, 70(2):555–569, 2006. Accession Number: 20063091201. Publication Type: Journal Article. Language: English. Number of References: many ref. Registry Number: 7440-44-0. Subject Subsets: Soils and Fertilizers.

A. N. Smith, S. Reberg-Horton, G. T. Place, A. D. Meijer, C. Arellano, and J. P. Mueller. Rolled rye mulch for weed suppression in organic no-tillage soybeans. *Weed Science*, 59(2):224–231, 2011. Soils and Fertilizers; Maize; Wheat, Barley and Triticale Abstracts; Soyabeans; Weeds; Animal Nutrition.

J. M. Stark and S. C. Hart. Diffusion technique for preparing salt solutions, kjeldahl digests, and persulfate digests for nitrogen-15 analysis. *Soil Science Society of America. Soil Science Society of America journal*, 60(6):1846–1855, 1996. polytetrafluoroethylene-encased traps; concentration; ratios; recovery Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: SSSJD4 Category Codes: Soil Chemistry and Physics Subset: Indexing Branch - NAL NAL Call Number: 56.9 So3 Update Code: 00000000.

R.G. Steel, J.H. Torrie, and D.A. Dickey. *Principles and procedures of statistics: A biometric approach*. McGraw-Hill, New Your, 3rd edition, 1996.

J. L. Steiner, H. H. Schomberg, P. W. Unger, and J. Cresap. Crop residue decomposition in no-tillage small-grain fields. *Soil Science Society of America Journal*, 63(6):1817–1824, 1999. Accession Number: 20001911086. Publication Type: Journal Article. Language: English. Number of References: 29 ref. Subject Subsets: Soils and Fertilizers.

M. Stenberg, B. Stenberg, and T. Rydberg. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. *Applied Soil Ecology*, 14(2):135–145, 2000. Field Crops; Wheat, Barley and Triticale Abstracts.

D. E. Stott, H. F. Stroo, L. F. Elliott, R. I. Papendick, and P. W. Unger. Wheat residue loss from fields under no-till management. *Soil Science Society of America Journal*, 54(1):92–98, 1990. Wheat, Barley and Triticale Abstracts.

H. F. Stroo, K. L. Bristow, L. F. Elliott, R. I. Papendick, and G. S. Campbell. Predicting rates of wheat residue decomposition. *Soil Science Society of America Journal*, 53(1):91–99, 1989. Wheat, Barley and Triticale Abstracts.

J. R. Teasdale and C. L. Mohler. The quantitative relationship between weed emergence and the physical properties of mulches [electronic resource]. *Weed Science*, 48(3):385–392, 2000.

J. R. Teasdale, S. B. Mirsky, J. T. Spargo, M. A. Cavigelli, and J. E. Maul. Reduced-tillage organic corn production in a hairy vetch cover crop. *Agronomy journal*, 104(3):621–628, 2012. Maize; Weeds.

P. J. Thorburn, M. E. Probert, and F. A. Robertson. Modelling decomposition of sugar cane surface residues with apsim-residue. *Field Crops Research*, 70(3):223–232, 2001. Field Crops; Irrigation and Drainage; Horticultural Science.

P. A. Torres, A. B. Abril, and E. H. Bucher. Microbial succession in litter decomposition in the semi-arid chaco woodland. *Soil Biology and Biochemistry*, 37(1):49–54, 2005. Forestry; Agroforestry.

C. Tu, F. L. Booker, D. M. Watson, X. Chen, T. W. Rufty, W. Shi, and S. J. Hu. Mycorrhizal mediation of plant n acquisition and residue decomposition: impact of mineral n inputs. *Global Change Biology*, 12(5):793–803, 2006. Plant Pathology; Crop Physiology; Grasslands and Forage.

USDA-AMS. Bi-weekly weighted average report for the week ending, 5/12/2012 2013.

USDA-ERS. Certified organic grains. acres of corn, wheat, oats, barley, sorghum, rice, spelt, millet, buckwheat, and rye by state, 1997 and 2000-08., 7/5/2012 2013.

USDA-ERS and C. Greene. Organic production, 2009.

C. Wagner-Riddle, T. J. Gillespie, and C. J. Swanton. Rye cover crop management impact on soil water content, soil temperature and soybean growth. *Canadian Journal of Plant Science*, 74(3):485–495, 1994. Soyabeans; Soils and Fertilizers; Irrigation and Drainage; Wheat, Barley and Triticale Abstracts.

E. R. Walker, A. Mengistu, N. Bellaloui, C. H. Koger, R. K. Roberts, and J. A. Larson. Plant population and row-spacing effects on maturity group iii soybean. *Agronomy Journal*, 102 (3):821–826, 2010. Field Crops; Crop Physiology.

C. R. Weber, R. M. Shibles, and D. E. Byth. Effect of plant population and row spacing on soybean development and production. *Agronomy Journal*, 58:99–102, 1966.

M. S. Wells, S. Reberg-Horton, and C. Brinton. The influence of six-rye cultivars, on weed suppression and organic soybean yield in a roll-killed cover-crop system. *Weed Science*, In Review, 2013a.

M. S. Wells, S. C. Reberg-Horton, A. N. Smith, and J. M. Grossman. The reduction of plant-available nitrogen by cover crop mulches and subsequent effects on soybean performance and weed interference. *Agron.J.*, 105:1-7(2), 2013b.

T. J. White, T. Bruns, S. Lee, and J. W. Talyor. *Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics*, pages 315–322. Acedemic Press, Inc., New York, 1990.

F. H. Yelverton and H. D. Coble. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (glycine max). *Weed Technology*, 5(1):169–174, 1991. Soyabeans.

B. G. Young, J. M. Young, L. C. Gonzini, S. E. Hart, L. M. Wax, and G. Kapusta. Weed management in narrow- and wide-row glyphosate-resistant soybean (glycine max). *Weed Technology*, 15(1):112–121, 2001. Weeds; Field Crops.

Chapter 2

THE EVALUATION OF ROW SPACING AND DELAYED PLANTING DATE ON SOIL MOISTURE CONSERVATION AND YIELD IN A HIGH RESIDUE NO-TILL SOYBEAN SYSTEM

2.1 INTRODUCTION

Weed management in organic soybean production utilizes a multi-faceted approach that relies primarily on cultivation (Place et al., 2009). In order to achieve effective mechanical control of weeds, cultivation must occur several times while weeds are germinating but have not yet emerged (i.e. radical elongation stage). The duration of this control must encompass the critical weed-free period; for soybeans this is 30 days after planting (Bowman, 1997; Gunsolus, 1990; Lovely et al., 1958). These intensive and frequent cultivation events directly degrade soil health resulting in a loss of soil function (Mathew et al., 2012) including; lower soil organic matter, reduced soil aggregate stability (Stenberg et al., 2000), greater erosion and/or risk (Holland, 2004), and increased fuel and labor costs (Mirsky et al., 2012; Ryan, 2010).

To balance the trade-offs between the need for weed control and soil conservation in organic soybean production, researchers and farmers across the U.S. have been developing a cover crop based approach that allows for no-till planting of soybean through a roll-crimped cereal rye

mulch. This practice has shown promise in many regions of the U.S. (Delate et al., 2012; Mirsky et al., 2013; Wells et al., 2013b). The use of roller-crimpers to manage cover crops was originally developed, and has been in use for many years, in Brazil (Derpsch et al., 1991). However, roller-crimper technology increased in popularity in the US after the USDA-ARS National Soil Dynamics Laboratory improved the design and the Rodale Institute popularized it (Kornecki et al., 2009; Institute, 2012). The roller-crimper, a ground-driven implement, functions to terminate near-mature cover crops before the planting of the cash crops (Davis, 2010; Mirsky et al., 2013; Reberg-Horton et al., 2012). Cover crop mulches have a complex impact on soil moisture. Mulches can reduce soil evaporation (Clark et al., 1997) and increase water infiltration (Munawar et al., 1990). However, cover crops can seriously reduce soil water content during their growth via transpiration, leading to lower soil moisture at planting (Price et al., 2009). Davis (2010) reported reduced soil moisture post termination in roll-killed treatments when compared to burn down treatments, and as a result, he discovered positive correlation between soil moisture after roll-kill and soybean yield. Herbicides enable farmers to terminate their rye earlier, however, organic farmers must rely on the roller-crimper alone for termination. At anthesis, the roller crimper kills approximately 85% of the rye (Mirsky et al., 2009) and greater than 90% by soft-dough (Feekes stage 11.2) stage (Ashford and Reeves, 2003; Mischler et al., 2010b; Reberg-Horton et al., 2012). A delay in cover crop termination extends the duration of transpiration, resulting in greater soil water deficiency at cash crop planting. Therefore, it has been suggested to synchronize planting the cash crop, post cover crop termination, with a precipitation event (Ashford and Reeves, 2003; Price et al., 2009). Another factor that governs water availability is row spacing. Soybeans express a high degree of morphological plasticity, which allows the plant to compensate for different row spacings (Heiffig et al., 2009). While narrow rows (i.e., 38 cm or less) often yield higher than wide rows, the yield advantage is not dramatic (Cox and Cherney, 2011; Pedersen and Lauer, 2003). However, narrow row spacing is thought to make soybeans more vulnerable to late season drought (Walker et al., 2010; Heatherly and Spurlock, 1999). The narrow row spacing also carries important weed control implications for organic farmers. Crop competitiveness over weeds increases as plant density becomes more equidistant through an increase in light interception (De Bruin and Pedersen, 2008; Shibles and Weber, 1966; Weber et al., 1966). However, should physical suppression through a mulch or competition from a soybean crop fail to control weeds, there are no economical options for supplemental control in organic soybean production. With wide row spacing (i.e., 76 cm or greater), high residue cultivation is a supplemental weed control option (Smith et al., 2011; Mirsky et al., 2013). Wider row spacings (38-76 cm) can be carried out with a planter, while narrow row spacings require a drill. While no-till drills have improved greatly over the last decade, they do not have the same number of options for residue management such as double row cleaners (Grisso et al., 2009). Any potential advantage reducing row spacing may have in terms of equidistant plant spacing

can be lost if poor seed to soil contact results in patchy stands. The objectives of this study were to determine basic agronomic recommendations for soybean management in rolled mulch systems. Three row spacings were tested, 76, 38 and 17 cm, to examine their impacts on soil moisture and yield. We also varied the planting date relative to roll-crimping. Same day rolling and planting was compared to a delay between rolling and planting, which was intended to synchronize planting with a precipitation event. Finally, the interactions of these factors with weed management were assessed by including a weed-free check for every treatment combination; thus allowing a direct quantification of yield loss due to weeds for every treatment.

2.2 MATERIAL AND METHODS

Field experiments were conducted at three locations including the Center for Environmental Farming Systems in Goldsboro, NC (2012) (35.38291°N, 78.035846°W), Caswell Research Farm in Kinston, NC (2011, and 2012) (35.273206°N, 77.623816°W), and Piedmont Research Station in Salisbury, NC (2012) (35.68503°N, -80.60338°W). All site-years were managed organically, with two exceptions; the weed-free checks received PRE and POST herbicide weed control, and rye cover crop fertility requirements were met via UAN. The soil type in Goldsboro was a Wickham loamy sand (fine-loamy, mixed, semiactive, thermic Typic Hapludults) with 2 to 6% slope, Kinston was a Johns loamy sand (fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludults) with 0 to 2% slope, Kenansville was a loamy sand (loamy, siliceous, subactive, thermic Arenic Hapludults) with 0 to 3% slope, and Salisbury was a Mecklenburg clay loam (fine, mixed, active, thermic Ultic Haplualfs) with 2 to 8% slope, moderately eroded. The experiment was a complete factorial using a split-plot experimental design with six replicates. Treatment factors consisted of two factors: i) soybean row spacing as the main effects (17 cm, 38 cm and 76 cm); and ii) two factor levels of soybean planting date crossed with two factor levels of herbicide application comprised the sub-plot factors. Planting dates included: Early, which corresponds to soybean planting on the same day as the roll-kill event, and Late, referring to delayed soybean planting approximately 2 weeks after roll-kill. Herbicide application as PRE and POST was used to create a weed-free check plot (+H) contrasting with no herbicide (-H) plots. For all site-years, fields were disked and field cultivated to remove any existing vegetation in the fall prior to cover crop planting. Lime, phosphorus, and potassium were applied according to soil tests before cover crop establishment. To ensure maximum cereal rye biomass, fall (30 kg ha^{-1}) and spring (60 kg ha^{-1}) nitrogen was applied as UAN at three of the four locations where N carryover was minimal due to lack of manure history and soil type. Salisbury 2012 received only 60 kg ha^{-1} of based on N credits from manure carryover. A cereal rye cover crop was drilled (13-cm row spacing at 135 kg ha^{-1}) at all site-years. Redroot pigweed (*Amaranthus retroflexus*) seeds were frost sewn to ensure uniform

weed pressures at three of the four site-years. Frost seeding was not necessary at Salisbury (2012) since their long-term no-till fields have high and uniform pigweed pressures. No-rye weed-free (NR+H) and weedy checks (NR-H) were established to elucidate the combined and independent effects of a cereal rye cover crop and herbicides on weed control and subsequent soybean performance. The no cereal rye check plots were established in early spring for all site-years with a burn down application of glyphosate (Honcho Plus, at 0.85 kg a.i. ha^{-1}, Monsanto Company, 800 N Lindbergh BLDV., ST. Louis, MO). During mid- to late- May, the cover crop was roll-killed at soft-dough (Feekes growth stage 11.2; Zadoks growth stage 85) with a 3.1 m roller-crimper (I and J Manufacturing, Gap, PA) parallel to the cover crop drilling direction (Table 1). Following cover crop termination, a class VI maturity group soybean (Glycine max L. NC Roy) was planted parallel to rolling at 20.7 plants m-1 in the 76 and 38 cm row spacing treatments. The 76 and 38 cm row spacing treatment was achieved with a no-till planter (John Deere, Moline, IL) equipped with Yetter Shark Tooth residue managers (Yetter Profitable Solutions, P.O. Box 358, 109 S. McDonough, Colchester, IL 62326) to assist planting into the rye residue. The 38 cm row spacing treatment was achieved with two passes of the above-described no-till 76 cm row spaced planter. Soybeans were no-till drilled (John Deere, Moline, IL) to implement the 17 cm treatment at 11.8 plants m-1. Planting dates for all three spacings occurred either on the same day as the roll-kill termination of the rye (Table 1) or 14 days later. Before soybean harvest, plot edges were mowed down to 12.2 m to minimize any potential edge effect. Soybean yield data were collected on the interior two (76 cm) and four (38 cm) soybean rows. The 17 cm row spacing (i.e. drilled plots) treatments were harvested according to the width of the plot combine header (152 cm) rows. The primary weed control method consisted of pre-plant burn down of the NR+H and NR-H with glyphosate. In addition to pre-plant burn down of the no-rye weed-free treatments (NR+H) and rolled-rye with herbicide weed control (RC+H) received S-metolachlor as pre-emergent (Metal II, at 1.91 kg a.i. ha^{-1}, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419). In addition to the PRE, imazethapyr (Pursuit, at 74.7g ai ha^{-1}, BASF Corporation, 26 Davis Dr., Research Triangle Park, NC 27709) was applied three weeks after soybean planting (WAP) to achieve POST weed control. In addition to the NR+H and NR-H plots, relative weed pressure at each site-year was assessed via the non-herbicide, non-rye, no-till weedy check plots (i.e. NR-H). Hand-weeding was done in addition to herbicide applications, as needed, to ensure weed free conditions throughout the season in the NR+H and RC+H plots. To quantify the effects of planting date, row spacing, and weeds on soybean performance, we collected an array of plant and soil metrics. Plant metrics included cereal rye biomass, weed cover, soil water content, soybean lodging, and soybean yield. Cover crop biomass was collected on the same day, prior to termination, using 0.5 m2 quadrats and dried at 60°C for 72 hours prior to recording dry weight. Weed cover was visually rated across the entire plot for all treatments at 12 WAP

on a percent basis, with no cover as 0% and complete weed coverage as 100%. In 2012, soil volumetric water content measurements were added to the list of parameters. Volumetric water content (Fieldscout TDR 300 Soil Moisture Meter, Spectrum Technologies, Plainfield, IL) was monitored across all plots at both planting dates (Table 1) to a depth of 10 cm. Prior to soybean harvest, soybean lodging ratings were visually scored for all site-years. The lodging rating scale ranged from no lodging represented as a rating of 0, and extreme lodging where the soybeans were not harvestable rated as a 4. A combined analysis of soybean yield across the four site-years was attempted, but due to large F-values for three-way interaction of herbicide and row spacing with site-year ($p < 0.13$) further investigation to ascertain if treatments were uniform over site-years was required (Table 2). Using the Alterative Log Likelihood Ratio Test to test the reduced model (i.e. the null hypothesis) where site-year does not interact with the treatments versus the full model that includes all site-year by treatment interactions produced a $\chi^2_{1\ df} = 1.1$ with an corresponding p-value of 0.15 thus failing to reject the Null hypothesis (i.e. reduced model) (Huelsenbeck and Crandall, 1997). The failure to reject and the non-significant site-year by treatment interactions provides adequate evidence to generalize soybean yield over the four site-years (Steel et al., 1996). Performing a combined analysis on percent weed coverage, percent volumetric water, and percent soybean emergence data across site-years was not possible due to the significant site-year by treatment interactions (Table 2)(Steel et al., 1996).

All parameters were analyzed using proc MIXED, and treatments were modeled as fixed effects, and blocks and site-years (soybean yield only) were random effects (SAS, 2006). The lack of homogeneous variance associated with the percent weed cover and percent soybean emergence data across all treatments was corrected via the arcsine of the square root of the dependent variable (Steel et al., 1996). Transformed means were back-transformed for presentation, and all means were separated using pre-planned contrasts (SAS, 2006; Steel et al., 1996).

2.3 RESULTS AND DISCUSSION

2.3.1 Cover Crop Performance

High levels of cover crop biomass production were achieved across all four site-years (Figure 4.1). At each location, rye biomass production far exceeded the suggested critical threshold for optimal weed suppression in the southeastern U.S. of 9000 kg ha^{-1} (Smith et al., 2011). Only one of the site years was conducted on a field with a long manuring history. The other site-years were amended with N to mimic the conditions of most organic farms in the region where years of manure application created substantial N carryover. For farms with less history of manure or less N carryover due to soil type, these rye biomass levels are overly high. Due to the low organic matter soils of the southeastern U.S. and warmer soil temperatures, N fertility is critical

in optimizing biomass production. Rye biomass production in the southeastern U.S. has been repeatedly report above 9000 kg ha^{-1} (Reberg-Horton et al., 2012; Wells et al., 2013b,a).

2.3.2 Weed Control

High cereal rye biomass resulted in low weed cover at three of the four site-years, which resulted in minimal impact on soybean performance across all four site-years (Figure 4.2). ANOVA conducted on weed cover and site-year by planting date interaction prevented averaging over site-year (Table 2). Planting date did not affect weed coverage data across all four site-years, however, row spacing did impact weed cover at Goldsboro and Salisbury where lowest weed cover estimates were obtained in the 17 cm row spacing treatments (Figure 4.2). At Kinston (2011), Goldsboro and Salisbury, there was greater weed coverage in the RC-H when compared to the RC+H treatments ($p < 0.05$), where the RC+H plots were weed-free. Weed competitiveness potential, as defined by percent ground cover in the NR-H (i.e. weedy check) plots, were low at Kinston (2011)($\mu = 18.3$, S.E.= 14.1) and Goldsboro (2012) ($\mu = 33.3$, S.E. = 3.6)(Figure 4.2). Salisbury weed cover was the greatest as compared to observations made across all site-years ($\mu = 100$, S.E. = 4.8)(Figure 4.2). The lack of a planting date effect was surprising since the delay in planting was expected to allow weeds to germinate and emerge prior to soybean establishment. At Goldsboro (2012) and Salisbury (2012) weed cover was significantly affected by soybean row spacing, where the 76 cm row spacing had the greatest percent weed coverage when compared to the narrow treatments 38 cm and 17 cm, respectively (Figure 4.3). The observed increase in weed competition with increased row spacing width in heavy residue environments is consistent with what is observed in low residue environments planted in soybeans of similar row spacing (Burnside and Moomaw, 1977; Chandler et al., 2001; Dalley et al., 2004; Harder et al., 2007; Mickelson and Renner, 1997; Young et al., 2001). Yelverton and Coble Yelverton and Coble (1991) reported that narrow row spacing enables soybeans to close canopy faster, thus increasing the photosynthetically active radiation (PAR) absorbed by the soybeans, resulting in the reduction of PAR available to new emerging weed seedlings. Even though the rye biomass at soybean planting was in excess of 10,000 kg ha^{-1} dry matter (Figure 4.2), weeds were present in the roll-killed rye minus herbicide treatments (RC-H) (Figure 4.2). Yetter Shark Tooth residue managers were utilized to ensure proper soybean seed placement during planting along with reducing the hair pinning of the rye in the soybean furrow. The residue managers both cut and move mulch elements from the row in which the crop is planted, allowing light penetration to the soil surface in the 38 and 76 cm row spacing. As a result, weed growth and development was primarily from the within the soybean row compared to between the crop rows.

2.3.3 Soybean Emergence and Lodging

An individual analysis for each site-year was performed for soybean emergence and lodging. Soybean emergence was excellent for the 76 and 38 cm row spacings at all four site-years, where more than 80% of the soybeans planted emerged (Figure 4.3). Row spacing significantly impacted percent emergence at three of the four site-years where greater emergence was observed in both the 76 and 38 row spacings ($p < 0.05$) (Figure 4.3). With exception to Goldsboro, the drilled treatments (i.e. 17 cm spacing) had reduced emergence when compared to the 76 and 38 cm treatments. The no-till drill was ineffective at cutting through 10,000 kg ha^{-1} rye biomass. Even with the assist of hydraulic down force, the coulters failed to effectively cut through the rye, leaving the soybean seed either on the surface of the rye or hair-pinned in the rye mulch. Despite not being able to consistently achieve proper seed placement with the no-till drill, emergence at Goldsboro, and Kinston (2012) to a lesser degree, was better than the other two site years. On the other hand, Goldsboro had nearly 90% emergence of the drilled soybeans (Figure 4.4). One possible explanation for the increased soybean emergence, in lieu of seed placement issues, was the series of precipitation events occurring prior and post planting at Goldsboro and Kinston (2012). Both locations received greater than two cm of precipitation over a five-day period (data not presented). During this time frame, the soybean could have germinated in the mulch layer increasing the overall percent emergence. Soybean lodging was observed at Kinston (2011 and 2012), and Salisbury (2012) (Figure 4.4). At the three site-years where soybean lodging was observed, the no-rye treatments exhibited the lowest incidence of lodging when compared to the roll-rye treatments (Figure 4.4). With exception to Kinston (2011), the no-rye treatments exhibited significantly lower lodging than the rolled-rye treatments where decreasing row spacing resulted in increased prevalence in soybean lodging (Figure 4.5). The phenomenon of soybean lodging in the high residue mulched cover crop system is not fully understood. It is possible that the observed soybean lodging is a consequence of planting soybeans into high residue cover crop mulches. Smith et al. (2011) reported similar lodging of soybeans produced in high residue mulch system where lodging persisted in the roll-killed rye treatments, whereas, no lodging was observed in the no-rye check treatments. It is important to note that even though the soybeans at three out of four site-years did experience lodging, there was no effect on soybean yield; however, harvest time was increased due to the reduction in combine speed necessary to harvest the lodged soybeans.

2.3.4 Soybean Yield and Soil Moisture

Soybean yield analysis was averaged across all four site-years where soybean row spacing was found to significantly ($p < 0.01$) impact yield (Table 2). Even though there was observed weed coverage at all four site-years (Figure 4.2), the weed coverage did not lead to a detectable yield

decline as evident by the equivalent soybean yields between the no-till weed-free check (NR+H) and the 76 cm row spacing (Table 3). At all four site-years, the narrow and intermediate row spacings (17 and 38 cm) out-yielded both the 76 cm RC-H and NR+H treatments (Table 3). The increased yield observed in narrow row soybeans is consistent with non-mulched systems results. Several studies have demonstrated yield increases with narrower row spacing (ranging between 76 to 39.1 cm) (Bruin and Pedersen, 2008; Bullock et al., 1998; Cooper, 1977; Grau et al., 1994; Oplinger and Philbrook, 1992; Weber et al., 1966). Contrary to our hypothesis, no planting date (i.e. Early and Late) effect on soybean yield was detected (Table 3). Previous studies have found lower yields on sandy soil for same-day plantings due to cover crop extraction of soil moisture (Price et al., 2009; Reberg-Horton et al., 2012; Reeves, 1994). The lack of response to planting date on crop performance may be attributed to an unusually wet spring. In 2012 at Goldsboro, Kinston, and Salisbury, the month of May received above average precipitation (Figure 4.5). By the late soybean planting date, nearly three weeks had passed following the roll-kill termination of the rye cover crops and early soybean planting. During this time frame, the roll-killed rye cover crop was fully desiccated, and at all three site-years, the rolled-rye treatments had greater ($p < 0.01$) soil volumetric water content when compared to the no-rye treatments (Figure 3.6). By early June, at the late soybean planting date, monthly precipitation was nearly half of the 30-year average (Figure 4.5). Thick mulches have several mechanisms for increasing soil moisture, including enhanced water infiltration and reduced evaporative stress (Aase and Tanaka, 1987; Wagner-Riddle et al., 1994). Despite the potential of cover crop mulches to deplete early spring water content via transpiration, cover crop mulches can increase moisture conservation throughout the summer and potentially enhance yields during a drought stressed season (Campbell et al., 1984; Clark et al., 1997).

2.4 CONCLUSION

In conclusion, this study demonstrated the utility of a cover crop-based approach to organic rotational no-till soybean production. Our results support our initial hypothesis that a soybean planting date occurring two weeks post-termination of the cereal rye cover crop will mitigate soil moisture loses. Specifically, our work demonstrated that once a soil profile is recharged with water post cover crop termination, a cover crop mulch will conserve soil moisture during the growing season via reduced evaporation. In our case, the improved water retention did not translate into improvements in soybean emergence and yield since the study was conducted during years of adequate summer precipitation. These findings are important during drier seasons, when the gains in soil volumetric water content by the late planting date and continued moisture conservation of roll-killed cover crop mulches could minimize drought severity (Campbell et al., 1984; Clark et al., 1997). Narrowing the soybean row spacing significantly improved

soybean yield and weed control across all site-years. Despite out-yielding the 76 cm row spacing, the narrow, 17 cm row spacing is not recommended for use in the roll-killed rye system due to increased soybean lodging. Since the 38 cm row spacing performed equivalently in soybean yield and weed control of the 17 cm spacing, we recommend the 38 cm row spacing due to reduced incidence of lodging when compared to the 17 cm spacing. This research highlights that during years of average and above average precipitation, delayed planting following the roll-kill termination of cover crop mulches can have no impact on soybean performance. Rye biomass production at roll-kill along with planter technologies that ensures proper soybean seed placement, while minimizing disturbance to the cover crop mulch, is paramount in providing favorable settings for optimal soybean yield in an organic setting. Further research is needed to quantify what mechanisms are responsible for soybean lodging in the high residue mulch systems.

2.5 FIGURE CAPTIONS, TABLES AND FIGURES

2.5.1 Figures

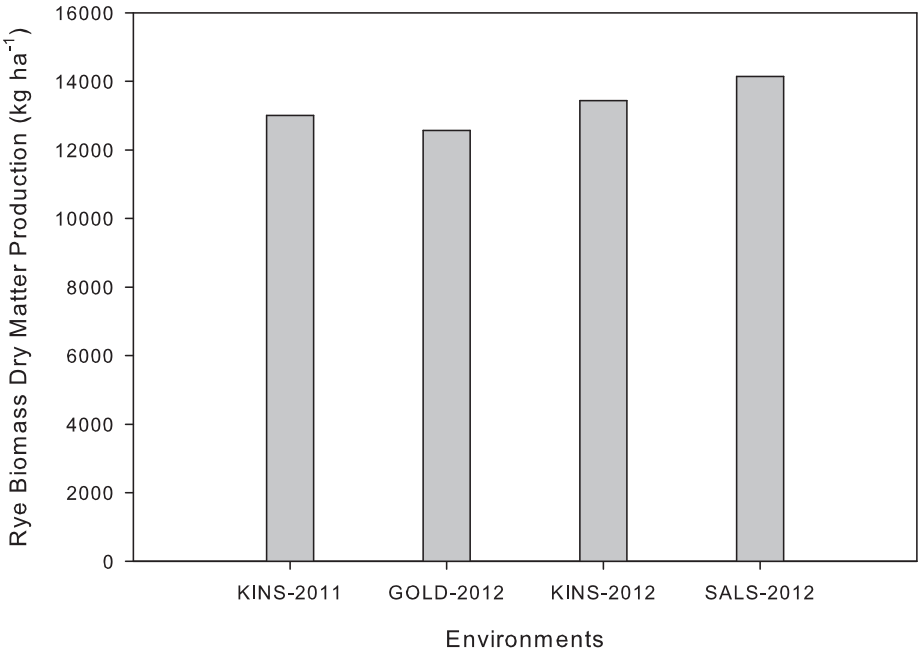

Figure 2.1: Cereal rye cover crop biomass production at Roll-kill for Goldsboro, Kinston and Salisbury, NC (2011-2012). Abbreviations: KINS, Kinston; GOLD, Goldsboro; and SALS, Salisbury. North Carolina.

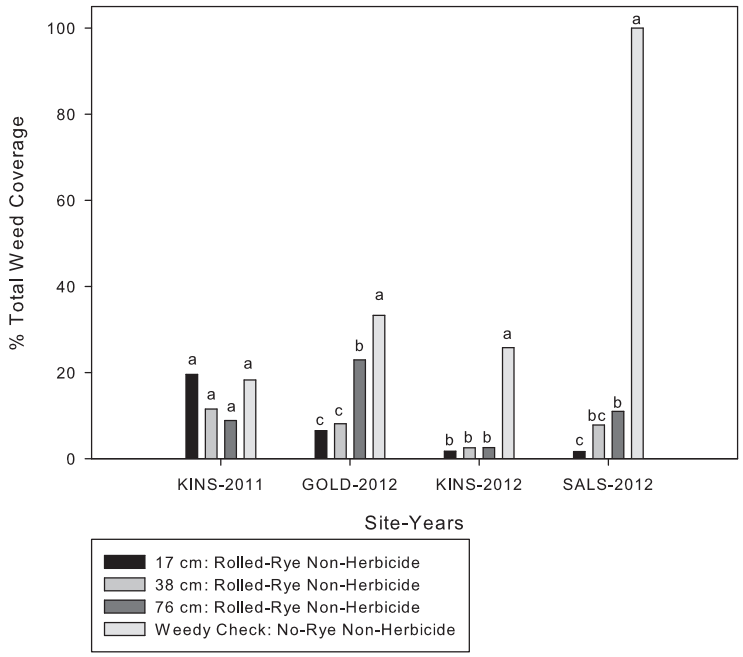

Figure 2.2: Soybean post-canopy closure percent weed coverage analysis for each for each site-year: Kinston (2011 and 2012), Goldsboro (2012), and Salisbury (2012). Data reflects only the non-herbicide treatments averaged over the planting date effects. There was neither significant planting date nor interactions with planting date and soybean row spacing. The weedy check treatments represent a bareground no-till non-herbicide treatments with the purpose of illustrating the relative weed pressures at each site-year. Means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$. Abbreviations: KINS, Kinston; GOLD, Goldsboro; and SALS, Salisbury.

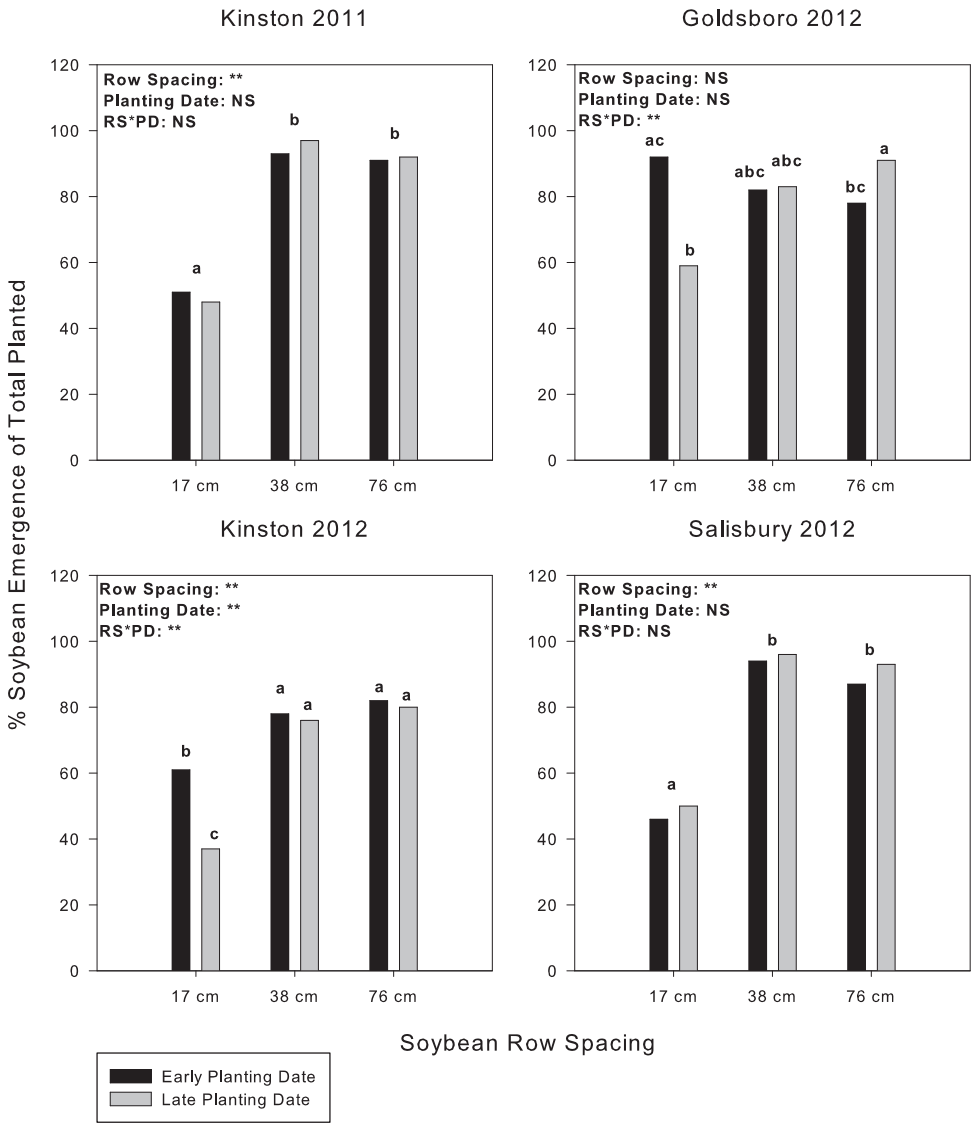

Figure 2.3: Soybean emergence as a percentage of the total planted for each site-year. Means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$.

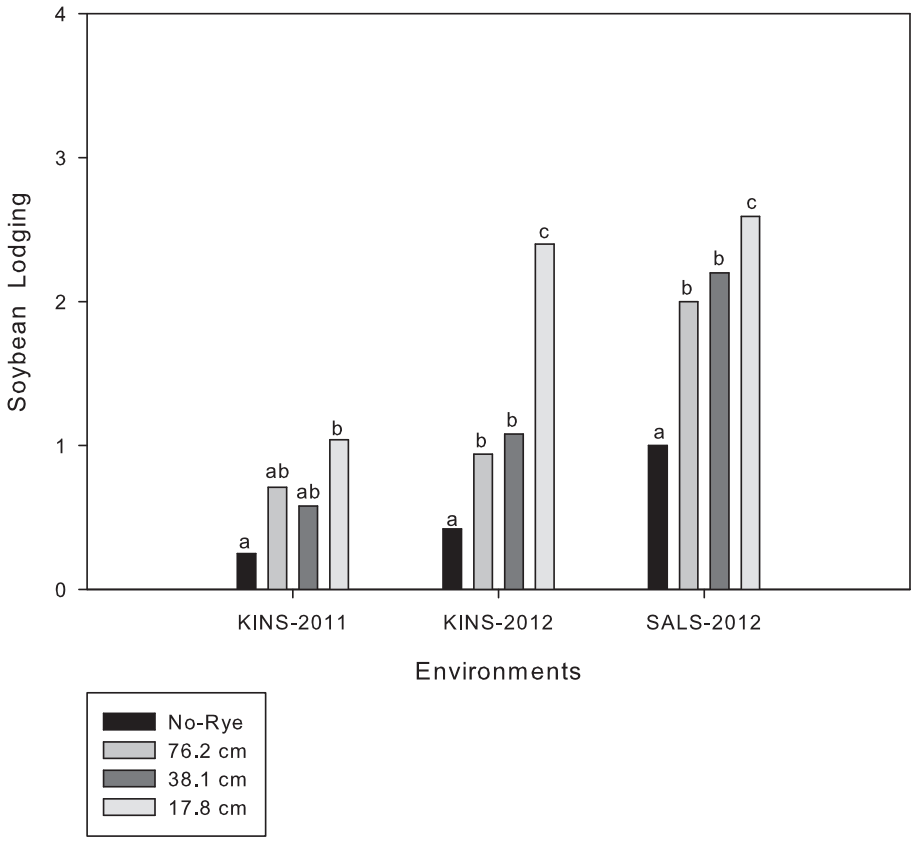

Figure 2.4: Soybean lodging at Kinston, and Salisbury (2011-2012) with no lodging represented by a rating of 0, and not harvestable rated as a 4. There was no observed lodging at Goldsboro (2012). Lodging data was averaged over planting date effects. Means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$. Abbreviations: KINS, Kinston; and SALS, Salisbury. North Carolina.

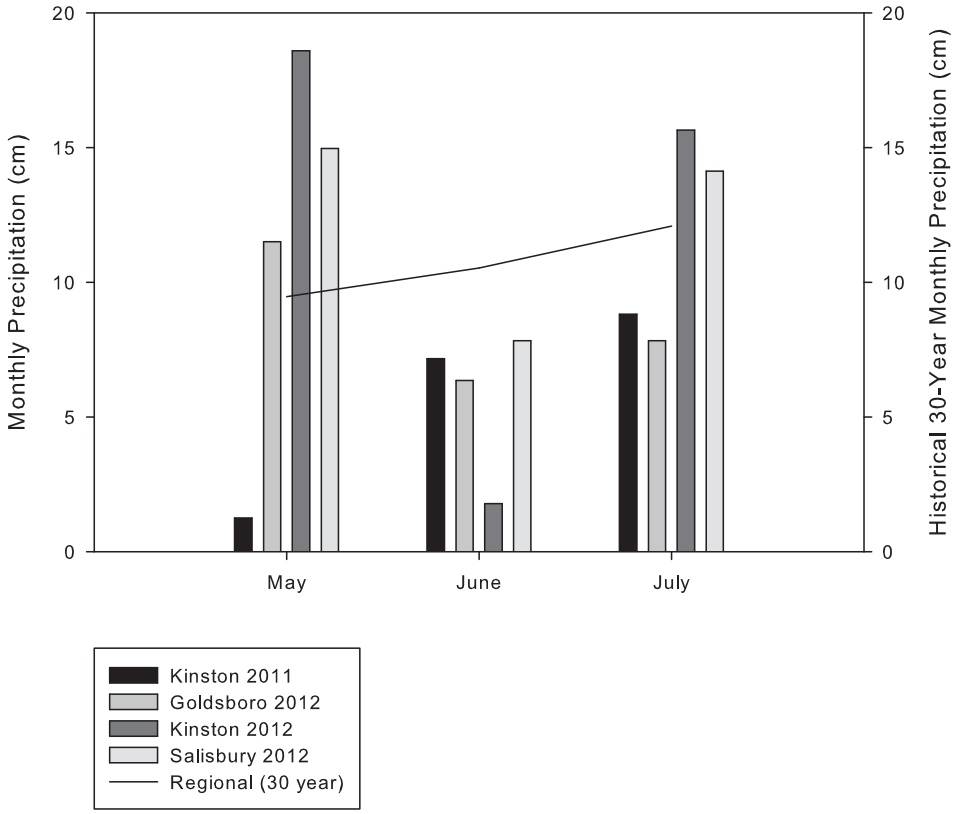

Figure 2.5: Monthly precipitation (cm) and 30-year normal for Goldsboro (2012), Kinston (2011 and 2012), and Salisbury (2012). Weather data provided by the State Climate Office of North Carolina.

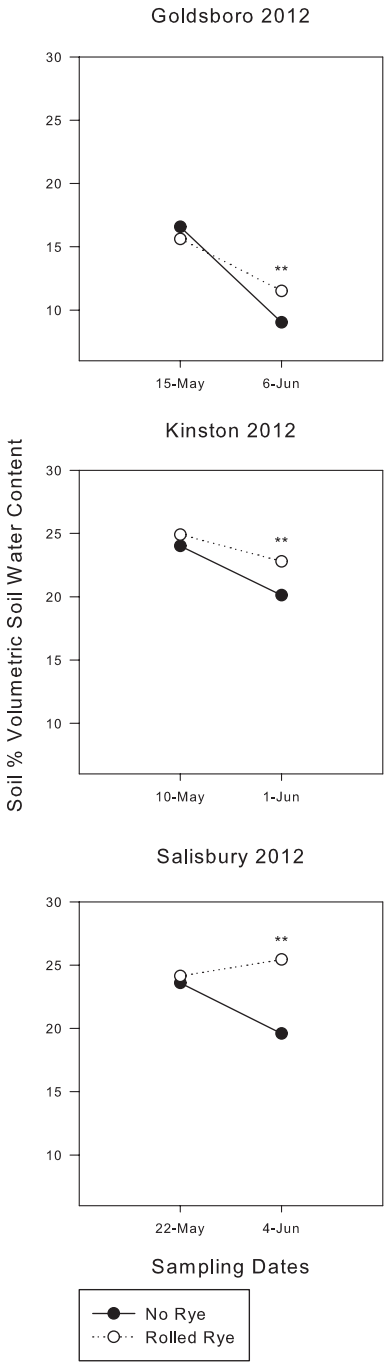

Figure 2.6: Percent soil volumetric water content shown for Kinston, Goldsboro, and Salisbury (2012). Sampling intervals for all three locations correspond to soybean planting dates (i.e. Early and Late). Percent VWC was measured across all treatments at a depth of 12 cm and averaged over planting date effects. * Significant at 0.05 level; ** Significant at 0.01 level.

2.5.2 Tables

Table 2.1: Planting Dates, Cover Crop Growth Stages, and Percent Control via Roller Crimper at Goldsboro, Kinston and Salisbury, NC (2011-2012).

	Soybean Planting Dates		Cover Crop Maturity at Roll-Kill	Cover Crop Control via Roller Crimper
Site-Year	Early[a]	Late	Rye[b]	
2011				
Kinston	May-2	May-23	11.2	100%
2012				
Goldsboro	May-15	Jun-6	11.2	100%
Kinston	May-10	Jun-1	11.2	100%
Salisbury	May-22	Jun-4	11.4	100%

[a] Roll-kill termination of the cover crop occurred once at each location during the 'Early' soybean planting date.

[b] Rye growth stage taken at roll-kill using the Feekes scale.

Table 2.2: Mixed-model analysis of variance generalized over site-years for soybean percent emergence, soybean yield and percent weed coverage.

	% Soybean Emergence of Total Planted[a]	Soybean Yield[b]	% Weed Cover[c]
Source	ANOVA[d]		
Row Spacing (S)	***	**	NS
Planting Date (D)	NS	NS	NS
Herbicide (H)	-	NS	-
S x D	NS	NS	NS
S x H	-	NS	-
D x H	-	$p < 0.11$	-
S x H x D	-	NS	-
Site-Year (Y)	NS	**	**
Y x D	NS	NS	$p < 0.11$
Y x S	$p < 0.07$	NS	*
Y x H	-	NS	-
Y x S x D	**	NS	NS
Y x H x D	-	NS	-
Y x S x H	-	$p < 0.13$	-
Y x S x H x D	-	NS	-

[a] Soybean % emergence of total planted were averaged over Herbicide and Soybean emergence data was $\sin^{-1}(x)^{0.5}$ transformed to meet ANOVA assumptions.

[b] Soybean yield averaged over all four site-years: Kinston (2011 and 2012), Goldsboro (2012), and Salisbury (2012)

[c] The plus herbicide treatments were removed when calculating % Weed Cover and % Weed Coverage data was $\sin^{-1}(x)^{0.5}$ transformed to meet ANOVA assumptions.

[d] NS, Non-significant at $\alpha = 0.05$. *, **, and *** represent significance of F tests at $\alpha = 0.05$, 0.01, and 0.001, respectively.

Table 2.3: A generalized analysis of variance of soybean yield averaged over site-years, planting date, and herbicide for Kinston (2011-2012), Goldsboro (2012), and Salisbury (2012). North Carolina.

	Combined Analysis[a]	Kinston 2011	Goldsboro 2011	Kinston 2012	Salisbury 2012
	-Soybean Yield (kg ha^{-1})-				
Soybean Row Space (cm)	**[b]	-	-	-	-
17	3308 a[c]	2036	1818	3340	4521
38	3292 a	2024	2037	3444	4450
76	2968 b	1806	1680	3101	3955
No-till Weed-Free 76	2957 b	1845	1723	3114	3932
Soybean Planting Date[d]	NS	-	-	-	-
Early	2868	1986	1784	3284	4178
Late	2840	1869	1843	3218	4252

[a] Soybean yield generalized over Kinston (2011 and 2012), Goldsboro (2012) and Salisbury (2012).

[b] NS, not significant at $p < 0.05$; * Significant at $\alpha = 0.05$ level; ** Significant at $\alpha = 0.01$ level.

[c] Means followed by the same letter are not significantly different based on Fishers Protected LSD test at $p < 0.05$.

[d] Roll-Kill and Soybean Planting Date: Early planting date refers to roll-kill of cover crops and planting of soybeans occurring on the same day. Late planting date refers to soybeans planting date that occurred (approximately) 2-weeks after roll-kill of the rye cover crops.

REFERENCES

J. K. Aase and D. L. Tanaka. Soil water evaporation comparisons among tillage practices in the northern great plains. *Soil Science Society of America Journal*, 51(2):436–440, 1987. Irrigation and Drainage.

J. D. Aber and J. M. Melillo. Nitrogen immobilization in decaying hardwood leaf litter as a function of initial nitrogen and lignin content. *Canadian Journal of Botany*, 60(11):2263–2269, 1982. Forestry; Soils and Fertilizers.

R. E. van Acker, C. J. Swanton, and S. F. Weise. The critical period of weed control in soyabean (glycine max (l.) merr.). *Weed Science*, 41(2):194–200, 1993. Weeds; Soyabeans.

D. L. Ashford and D. W. Reeves. Use of a mechanical roller-crimper as an alternative kill method for cover crops. *American journal of alternative agriculture*, 18(1):37–45, 2003. Accession Number: IND43646603 Pagination: p. 37-45. Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

M. H. Beare, R. W. Parmelee, P. F. Hendrix, W. Cheng, D. C. Coleman, and D. A. Crossley. Microbial and faunal interactions and effects on litter nitrogen and decomposition in agroecosystems. *Ecological Monographs*, 62(4):569–591, 1992. Accession Number: 19951908046. Publication Type: Journal Article. Language: English. Number of References: 96 ref. Registry Number: 7727-37-9.

M. H. Beare, P. F. Hendrix, D. C. Coleman, and S. Hu. Influences of mycelial fungi on soil aggregation and organic matter storage in conventional and no-tillage soils. *Applied soil ecology : a section of Agriculture, Ecosystems and Environment*, 5(3):211–219, 1997. soil carbohydrates; sandy clay loam soils; respiration; macroaggregates Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Category Codes: Soil Chemistry and Physics; Soil Cultivation and Cropping Systems; Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH541.5.S6A67 Update Code: 00000000.

E. R. Bernstein, J. L. Posner, D. E. Stoltenberg, and J. L. Hedtcke. Organically managed no-tillage rye-soybean systems: agronomic, economic, and environmental assessment. *Agronomy Journal*, 103(4):1169–1179, 2011. Soyabeans; Wheat, Barley and Triticale Abstracts; Irrigation and Drainage; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers.

Eliana E. Bontti, Ingrid C. Burke, Stephanie Owens, Mark E. Harmon, William J. Parton, Michelle L. Haddix, Seth M. Munson, Joseph P. Decant, Agnieszka Przeszlowska, and Mark A. Gathany. Litter decomposition in grasslands of central north america (us great plains) [electronic resource]. *Global change biology*, 15(5):1356–1363, 2009. root and leaf decomposition; Great Plains (USA); litter decomposition Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Subset: Indexing Branch - NAL NAL Call Number: QC981.8.C5G6323 Update Code: 00000000.

G Bowman. *Steel in the Field: A Farmers' Guide to Weed Mangement Tools.* Sustainable Agriculture Publications, University of Vermont, Burlington, VT, 1997.

P. D. Brooks, J. M. Stark, B. B. McInteer, and T. Preston. Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. *Soil Science Society of America Journal*, 53(6): 1707–1711, 1989. Accession Number: 19901942338. Publication Type: Journal Article. Language: English. Number of References: 21 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

P. L. Brown and D. D. Dickey. Losses of wheat straw residue under simulated field conditions, 1970. Accession Number: CAIN709036937 Pagination: p. 118-121. Language(s): English General Note: Bibliography: p. 121 NAL Call Number: 56.9 SO3 Update Code: 00000000.

J. L. de Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agronomy Journal*, 100(3):704–710, 2008. World Agriculture, Economics and Rural Sociology.

D. Bullock, A. Rayburn, and S. Khan. Soybean yield response to narrow rows is largely due to enhanced early growth. *Crop science*, 38(4):1011–1016, 1998. growth; plant height; determinate and indeterminate habit Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: CRPSAY Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 64.8 C883 Update Code: 00000000.

M. S. Burgess, G. R. Mehuys, and C. A. Madramootoo. Nitrogen dynamics of decomposing corn residue components under three tillage systems. *Soil Science Society of America Journal*, 66 (4):1350–1358, 2002. Soils and Fertilizers.

O. C. Burnside and R. S. Moomaw. Control of weeds in narrow-row soybeans. *Agronomy Journal*, 69(5):793–796, 1977. Weeds; Field Crops.

R. B. Campbell, R. E. Sojka, and D. L. Karlen. Conservation tillage for soybean in the u.s. southeastern coastal plain. *Soil and Tillage Research*, 4(6):531–541, 1984. Agricultural Engineering.

M. A. Cavigelli, B. L. Hima, J. C. Hanson, J. R. Teasdale, A. E. Conklin, and Y. C. Lu. Long-term economic performance of organic and conventional field crops in the mid-atlantic region. *Renewable Agriculture and Food Systems*, 24(2):102–119, 2009. Field Crops; Plant Genetic Resources; Grasslands and Forage; Weeds; World Agriculture, Economics and Rural Sociology; Soyabeans; Soils and Fertilizers; Horticultural Science; Maize.

M. A. Cavigelli, S. B. Mirsky, J. R. Teasdale, J. T. Spargo, and J. Doran. Organic grain cropping systems to enhance ecosystem services. *Renewable Agriculture and Food Systems*, 28(2):145–159, 2013. Conference paper. Language: English. Number of References: 126 ref. Registry Number: 7727-37-9. Subject Subsets: Weeds; Soils and Fertilizers.

K. Chandler, Shrestha Anil, and C. J. Swanton. Weed seed return as influenced by the critical weed-free period and row spacing of no-till glyphosate-resistant soybean. *Canadian Journal of Plant Science*, 81(4):877–880, 2001. Seed Science; Soyabeans; Field Crops; Weeds.

A. J. Clark, A. M. Decker, J. J. Meisinger, and M. S. McIntosh. Kill date of vetch, rye, and a vetch-rye mixture: Ii. soil moisture and corn yield. *Agronomy Journal*, 89(3):434–441, 1997. Maize; Wheat, Barley and Triticale Abstracts.

R. L. Cooper. Response of soybean cultivars to narrow rows and planting rates under weed-free conditions. *Agronomy Journal*, 69(1):89–92, 1977. Field Crops.

W. J. Cox and J. H. Cherney. Growth and yield responses of soybean to row spacing and seeding rate. *Agronomy Journal*, 103(1):123–128, 2011. Field Crops; Soyabeans; World Agriculture, Economics and Rural Sociology.

C. D. Dalley, J. J. Kells, and K. A. Renner. Effect of glyphosate application timing and row spacing on corn (zea mays) and soybean (glycine max) yields. *Weed Technology*, 18(1): 165–176, 2004. Soyabeans; Field Crops; Maize; Weeds.

Adam S. Davis. Cover-crop rollercrimper contributes to weed management in no-till soybean [electronic resource]. *Weed Science*, 58(3):300–309, 2010. Plant Physiology and Biochemistry; Soil Cultivation and Cropping Systems; Plant Production (Field Crops); Soil Fertility, Fertilizers and Manures Subset: Indexing Branch - NAL NAL Call Number: 79.8 W41 Update Code: 00000000.

J.L. De Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agron.J.*, 100(704-710), 2008.

K. Delate, D. Cwach, and C. Chase. Organic no-tillage system effects on soybean, corn and irrigated tomato production and economic performance in iowa, usa. *Renewable Agriculture and Food Systems*, 27(1):49–59, 2012. Soils and Fertilizers; Wheat, Barley and Triticale Abstracts; Maize; Soyabeans; Horticultural Science; World Agriculture, Economics and Rural Sociology.

R. Derpsch, C.H. Roth, N Sidiras, and U Kopke. *Controle da erosao no Parana, Brazil: Sistemas de cobertura do solo, plantio directo e prepare conservacionista do solo.* Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany., 1991.

F. G. Dou, A. L. Wright, and F. M. Hons. Depth distribution of soil organic c and n after long-term soybean cropping in texas. *Soil and Tillage Research*, 94(2):530–536, 2007. Soils and Fertilizers; Soyabeans; Field Crops.

L. H. Fraser and A. D. Hockin. Litter decomposition rates of two grass species along a semi-arid grassland-forest ecocline. *Journal of Arid Environments*, 88:125–129, 2013. Forestry; Grasslands and Forage; Soils and Fertilizers; Plant Genetic Resources; Plant Breeding.

S. D. Frey, E. T. Elliott, K. Paustian, and G. A. Peterson. Fungal translocation as a mechanism for soil nitrogen inputs to surface residue decomposition in a no-tillage agroecosystem. *Soil Biology and Biochemistry*, 32(5):689–698, 2000. Wheat, Barley and Triticale Abstracts.

Yoshiharu Fujii. Screening and future exploitation of allelopathic plants as alternative herbicides with special reference to hairy vetch. *Journal of Crop Production*, 4(2):257, 2001.

M. Gardes and T. D. Bruns. Its primers with enhanced specificity for basidiomycetes - application to the identification of mycorrhizae and rusts. *Molecular Ecology*, 2(2):113–118, 1993. Agricultural Biotechnology.

C. R. Grau, E. S. Oplinger, E. A. Adee, E. A. Hinkens, and M. J. Martinka. Planting date and row width effect on severity of brown stem rot and soybean productivity. *Journal of Production Agriculture*, 7(3):347–351, 1994. Plant Breeding; Soyabeans.

R. Grisso, D. L. Holshouser, and R. M. Pitman. Equipment considerations for no-till soybean seeding, 2009.

J. L. Gunsolus. Mechanical and cultural weed control in corn and soybeans. *American journal of alternative agriculture*, 5(3):114–119, 1990. mechanical methods; yield losses; interrow cultivation Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Plant Production (Field Crops); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

D. B. Harder, C. L. Sprague, and K. A. Renner. Effect of soybean row width and population on weeds, crop yield and economic return. *Weed Technology*, 21(3):744–752, 2007. Soyabeans; World Agriculture, Economics and Rural Sociology.

S. C. Hart and M. K. Firestone. Forest floor-mineral soil interactions in the internal nitrogen cycle of an old-growth forest. *Biogeochemistry*, 12(2):103–127, 1991. Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH345.B564 Update Code: 00000000.

S. C. Hart, J. M. Stark, and E. A. Davidson. *Nitrogen mineralization, immobilization, and nitrification*, pages 985–1018. Soil Science Society of America Inc., Madison, WI, 1994.

L. G. Heatherly and S. R. Spurlock. Yield and economics of traditional and early soybean production system (esps) seedings in the midsouthern united states. *Field Crops Research*, 63(1):35–45, 1999. World Agriculture, Economics and Rural Sociology; Soyabeans.

L. S. Heiffig, G. M. de S. Cmara, L. A. Marques, D. B. Pedroso, and S. M. de S. Piedade. The plasticity of soybean (glycine max (l.) merrill) crop in different spacing arrangements. / plasticidade da cultura da soja (glycine max (l.) merrill) em diferentes arranjos espaciais. *Revista de Agricultura (Piracicaba)*, 84(3):204–219, 2009. Field Crops; Soyabeans.

M. L. Hoffman, E. E. Regnier, and J. Cardina. Weed and corn (zea mays) responses to a hairy vetch (vicia villosa) cover crop. *Weed Technology*, 7(3):594–599, 1993. Weeds; Field Crops; Maize.

E. A. Holland and D. C. Coleman. Litter placement effects on microbial and organic matter dynamics in an agroecosystem. *Ecology*, 62(2):425–433, 1987. Wheat, Barley and Triticale Abstracts.

J. M. Holland. The environmental consequences of adopting conservation tillage in europe: reviewing the evidence. *Agriculture, Ecosystems and Environment*, 103(1):1–25, 2004. Agricultural Entomology; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers; Plant Pathology.

J. P. Huelsenbeck and K. A. Crandall. Phylogeny estimation and hypothesis testing using maximum likelihood. *Annual Review of Ecology and Systematics*, 28:437–466, 1997. Accession Number: 19980103293. Publication Type: Journal Article. Language: English. Number of References: 126 ref. Subject Subsets: Animal Breeding.

E. R. Ingham and D. C. Coleman. Effects of streptomycin, cycloheximide, fungizone, captan, carbofuran, cygon, and pcnb on soil microorganisms. *Microbial Ecology*, 10(4):345–358, 1984. Plant Pathology; Soils and Fertilizers.

E. R. Ingham, C. Cambardella, and D. C. Coleman. Manipulation of bacteria, fungi and protozoa by biocides in lodgepole pine forest soil microcosms: effects on organism interactions and nitrogen mineralization. *Canadian Journal of Soil Science*, 66(2):261–272, 1986. Forestry.

Rodale Institute. No-till revolution, 2012.

III Jaeger, C. H., R. K. Monson, M. C. Fisk, and S. K. Schmidt. Seasonal partitioning of nitrogen by plants and soil microorganisms in an alpine ecosystem. *Ecology*, 80(6):1883–1891, 1999. Accession Number: 19991912029. Publication Type: Journal Article. Language: English. Number of References: 33 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

Ke Jin, S. Sleutel, S. De Neve, D. Gabriels, DianXiong Cai, JiYun Jin, and G. Hofman. Nitrogen and carbon mineralization of surface-applied and incorporated winter wheat and peanut residues. *Biology and Fertility of Soils*, 44(4):661–665, 2008. Soils and Fertilizers; Irrigation and Drainage.

D. R. Keeney and D. W. Nelson. Nitrogen - inorganic forms. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, pages 643–698, 1982. Accession Number: 19841981457. Publication Type: Miscellaneous. Language: English. Number of References: approx. 170 ref. Registry Number: 7727-37-9, 7664-41-7. Subject Subsets: Soils and Fertilizers.

A. Kessavalou, J. H. Qian, T. A. Kettler, J. W. Doran, and W. L. Powers. Bromide and nitrogen-15 tracers of nitrate leaching under irrigated corn in central nebraska [electronic resource]. *Journal of environmental quality*, 25(5):1008–1014, 1996. Soil Biology; Mathematics and Statistics; Soil Chemistry and Physics; Pollution; Irrigation and Drainage Subset: Indexing Branch - NAL NAL Call Number: QH540.J6 Update Code: 00000000.

T. S. Kornecki, F. J. Arriaga, R. L. Raper, and A. J. Price. New roller crimper concepts for mechanical termination of cover crops in conservation agriculture. *Renewable agriculture and food systems*, 24(3):165–173, 2009.

J. T. Lennon, Z. T. Aanderud, B. K. Lehmkuhl, and Jr. Schoolmaster, D. R. Mapping the niche space of soil microorganisms using taxonomy and traits. *Ecology*, 93(8):1867–1879, 2012. Irrigation and Drainage.

L. M. Londono-R, D. Tarkalson, and J. E. Thies. In-field rates of decomposition and microbial communities colonizing residues vary by depth of residue placement and plant part, but not by

crop genotype for residues from two cry1ab bt corn hybrids and their non-transgenic isolines. *Soil Biology and Biochemistry*, 57:349–355, 2013. Soils and Fertilizers; Plant Breeding; Maize; Biocontrol; Field Crops; Agricultural Entomology; Agricultural Biotechnology.

W. G. Lovely, G. C. Weber, and D. W. Staniforth. Effectiveness of the rotary hoe for weed control in soybeans. *Agron.J.*, 50:621–625, 1958.

S. Marinari, A. Lagomarsino, M. C. Moscatelli, A. di Tizio, and E. Campiglia. Soil carbon and nitrogen mineralization kinetics in organic and conventional three-year cropping systems. *Soil and Tillage Research*, 109(2):161–168, 2010. Horticultural Science; Soils and Fertilizers.

M. V. Martnez-Toledo, V. Salmern, B. Rodelas, C. Pozo, and J. Gonzlez-Lpez. Effects of the fungicide captan on some functional groups of soil microflora. *Applied Soil Ecology*, 7(3): 245–255, 1998. Plant Pathology.

R. P. Mathew, Y. C. Feng, L. Githinji, R. Ankumah, and K. S. Balkcom. Impact of no-tillage and conventional tillage systems on soil microbial communities. *Applied and Environmental Soil Science*, 2012:Article ID 548620–Article ID 548620, 2012. Conference paper. Language: English. Number of References: 49 ref. Registry Number: 7440-44-0, 7727-37-9. Subject Subsets: Soils and Fertilizers; Maize; Field Crops.

V. B. Megadi, P. N. Tallur, R. S. Hoskeri, S. I. Mulla, and H. Z. Ninnekar. Biodegradation of pendimethalin by bacillus circulans. *Indian Journal of Biotechnology*, 9(2):173–177, 2010a. Accession Number: 20103171203. Publication Type: Journal Article. Language: English. Number of References: 16 ref. Registry Number: 40487-42-1. Subject Subsets: Weeds.

V. B. Megadi, P. N. Tallur, S. I. Mulla, and H. Z. Ninnekar. Bacterial degradation of fungicide captan. *Journal of Agricultural and Food Chemistry*, 58(24):12863–12868, 2010b. Accession Number: 20113158287. Publication Type: Journal Article. Language: English. Registry Number: 133-06-2. Subject Subsets: Plant Pathology.

J. A. Mickelson and K. A. Renner. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. *Journal of Production Agriculture*, 10(3):431–437, 1997. Soyabeans; Field Crops.

S. B. Mirsky, W. S. Curran, D. M. Mortensen, M. R. Ryan, and D. L. Shumway. Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. *Weed Science*, 59(3):380–389, 2011. Wheat, Barley and Triticale Abstracts; Weeds; Soyabeans.

S. B. Mirsky, M. R. Ryan, W. S. Curran, J. R. Teasdale, J. Maul, J. T. Spargo, J. Moyer, A. M. Grantham, D. Weber, T. R. Way, and G. G. Camargo. Conservation tillage issues: cover crop-based organic rotational no-till grain production in the mid-atlantic region, usa. *Renewable Agriculture and Food Systems*, 27(1):31–40, 2012. Soils and Fertilizers; Field Crops.

S. B. Mirsky, M. R. Ryan, J. R. Teasdale, William S. C., S.C. Reberg-Horton, J. T. Spargo, M. S. Wells, C. L. Keene, and J. W. Moyer. Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the eastern us. *Weed Technology*, 27:193–203, 2013.

Steven B. Mirsky, Matthew R. Ryan, Durland L. Shumway, William S. Curran, and David A. Mortensen. Control of cereal rye with a roller/crimper as influenced by cover crop phenology [electronic resource]. *Agronomy journal*, 101(6):15891596–15891596, 2009. Plant Breeding and Genetics; Plant Production (General); Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: 4 AM34P Update Code: 00000000.

Ruth Mischler, David Wilson, William S. Curran, and Sjoerd W. Duiker. Hairy vetch management for no-till organic corn production [electronic resource]. *Agronomy journal*, 102(1): 355–362, 2010a.

Ruth A. Mischler, Jeffrey A. Hyde, Sjoerd W. Duiker, and William S. Curran. Use of a rolled-rye cover crop for weed suppression in no-till soybeans [electronic resource]. *Weed Technology*, 24(3):253–261, 2010b. Farm Organization and Management (Microeconomics); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: SB610.W39 Update Code: 00000000.

L. N. Mulumba and R. Lal. Mulching effects on selected soil physical properties. *Soil and Tillage Research*, 98(1):106–111, 2008. Soils and Fertilizers.

A. Munawar, R. L. Blevins, W. W. Frye, and M. R. Saul. Tillage and cover crop management for soil water conservation. *Agronomy Journal*, 82(4):773–777, 1990. Wheat, Barley and Triticale Abstracts; Soils and Fertilizers; Irrigation and Drainage; Maize.

K. L. Murphy, J. M. Klopatek, and C. C. Klopatek. The effects of litter quality and climate on decomposition along an elevational gradient. *Ecological Applications*, 8(4):1061–1071, 1998. Forestry.

E. S. Oplinger and B. D. Philbrook. Soybean planting date, row width, and seeding rate response in three tillage systems. *Journal of Production Agriculture*, 5(1):94–99, 1992. Soyabeans.

J. F. Parr and R. I. Papendick. Factors affecting the decomposition of crop residues by microorganisms. *ASA [American Society of Agronomy] Special Publication*, (31):101–129, 1978. Accession Number: 19791950934. Publication Type: Journal Article. Language: English. Number of References: 65 ref. Subject Subsets: Soils and Fertilizers.

M. Parr, J. M. Grossman, S. C. Reberg-Horton, C. Brinton, and C. Crozier. Nitrogen delivery from legume cover crops in no-till organic corn production. *Agronomy journal*, 103(6):1578–1590, 2011. Horticultural Science; Wheat, Barley and Triticale Abstracts; Plant Breeding; Field Crops; Soils and Fertilizers.

P. Pedersen and J. G. Lauer. Corn and soybean response to rotation sequence, row spacing, and tillage system. *Agronomy Journal*, 95(4):965–971, 2003. Field Crops; Maize; Soyabeans.

J. Peign, B. C. Ball, J. Roger-Estrade, and C. David. Is conservation tillage suitable for organic farming? a review. *Soil Use and Management*, 23(2):129–144, 2007. Weeds; Irrigation and Drainage.

G. T. Place, S. C. Reberg-Horton, and M. G. Burton. Effects of preplant and postplant rotary hoe use on weed control, soybean pod position, and soybean yield. *Weed Science*, 57(3): 290–295, 2009. Soyabeans; Weeds.

A. J. Price, F. J. Arriaga, R. L. Raper, K. S. Balkcom, T. S. Komecki, and D. W. Reeves. Comparison of mechanical and chemical winter cereal cover crop termination systems and cotton yield in conservation agriculture. *Journal of Cotton Science*, 13(4):238–245, 2009. Irrigation and Drainage; Weeds; Wheat, Barley and Triticale Abstracts; Field Crops.

A. L. Rathore, A. R. Pal, and K. K. Sahu. Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. *Journal of the Science of Food and Agriculture*, 78(2):149–161, 1998. Field Crops.

S. C. Reberg-Horton, J. D. Burton, D. A. Danehower, G. Y. Ma, D. W. Monks, J. P. Murphy, N. N. Ranells, J. D. Williamson, and N. G. Creamer. Changes over time in the allelochemical content of ten cultivars of rye (secale cereale l.). *Journal of Chemical Ecology*, 31(1):179–193, 2005. Field Crops; Wheat, Barley and Triticale Abstracts; Plant Breeding; Botanical Pesticides; Weeds.

S. C. Reberg-Horton, J. M. Grossman, T. S. Kornecki, A. D. Meijer, A. J. Price, G. T. Place, and T. M. Webster. Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern usa. *Renewable Agriculture and Food Systems*, 27(1):41–48, 2012. Soils and Fertilizers; Maize; Field Crops.

S. Recous, D. Robin, D. Darwis, and B. Mary. Soil inorganic n availability: effect on maize residue decomposition. *Soil Biology and Biochemistry*, 27(12):1529–1538, 1995. Maize.

D. W. Reeves. Cover crops and rotations, 1994 1994.

M. R. Ryan. *Energy usage, greenhouse gases, and multi-tactical weed management in organic rotational no-till cropping systems*. PhD thesis, The Pennsylvania State University, 2010.

F. Salvagiotti, K. G. Cassman, J. E. Specht, D. T. Walters, A. Weiss, and A. Dobermann. Nitrogen uptake, fixation and response to fertilizer n in soybeans: a review. *Field Crops Research*, 108(1):1–13, 2008. World Agriculture, Economics and Rural Sociology; Crop Physiology; Soyabeans.

SAS. *Procedures guide*. Release 9.1.3. SAS Institute, Cary, NC, 2nd edition, 2006.

H. H. Schomberg, J. L. Steiner, and P. W. Unger. Decomposition and nitrogen dynamics of crop residues: residue quality and water effects. *Soil Science Society of America Journal*, 58 (2):372–381, 1994. Wheat, Barley and Triticale Abstracts.

C. M. Schwendener, J. Lehmann, P. B. de Camargo, R. C. C. Luizo, and E. C. M. Fernandes. Nitrogen transfer between high- and low-quality leaves on a nutrient-poor oxisol determined by 15n enrichment. *Soil Biology and Biochemistry*, 37(4):787–794, 2005. Agroforestry; Forestry.

R. M. Shibles and G. C. Weber. Interception of solar radiation and dry matter production by various soybean planting patterns. *Crop Sci.*, 6:55–59, 1966.

B. Shipley and P. A. Keddy. The relationship between relative growth rate and sensitivity to nutrient stress in twenty-eight species of emergent macrophytes. *Journal of ecology*, 76(4): 1101–1110, 1988. stress Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: JECOA Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 450 J829 Update Code: 00000000.

J. Six, S. D. Frey, R. K. Thiet, and K. M. Batten. Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal*, 70(2):555–569, 2006. Accession Number: 20063091201. Publication Type: Journal Article. Language: English. Number of References: many ref. Registry Number: 7440-44-0. Subject Subsets: Soils and Fertilizers.

A. N. Smith, S. Reberg-Horton, G. T. Place, A. D. Meijer, C. Arellano, and J. P. Mueller. Rolled rye mulch for weed suppression in organic no-tillage soybeans. *Weed Science*, 59(2):224–231, 2011. Soils and Fertilizers; Maize; Wheat, Barley and Triticale Abstracts; Soyabeans; Weeds; Animal Nutrition.

J. M. Stark and S. C. Hart. Diffusion technique for preparing salt solutions, kjeldahl digests, and persulfate digests for nitrogen-15 analysis. *Soil Science Society of America. Soil Science Society of America journal*, 60(6):1846–1855, 1996. polytetrafluoroethylene-encased traps; concentration; ratios; recovery Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: SSSJD4 Category Codes: Soil Chemistry and Physics Subset: Indexing Branch - NAL NAL Call Number: 56.9 So3 Update Code: 00000000.

R.G. Steel, J.H. Torrie, and D.A. Dickey. *Principles and procedures of statistics: A biometric approach*. McGraw-Hill, New Your, 3rd edition, 1996.

J. L. Steiner, H. H. Schomberg, P. W. Unger, and J. Cresap. Crop residue decomposition in no-tillage small-grain fields. *Soil Science Society of America Journal*, 63(6):1817–1824, 1999. Accession Number: 20001911086. Publication Type: Journal Article. Language: English. Number of References: 29 ref. Subject Subsets: Soils and Fertilizers.

M. Stenberg, B. Stenberg, and T. Rydberg. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. *Applied Soil Ecology*, 14(2):135–145, 2000. Field Crops; Wheat, Barley and Triticale Abstracts.

D. E. Stott, H. F. Stroo, L. F. Elliott, R. I. Papendick, and P. W. Unger. Wheat residue loss from fields under no-till management. *Soil Science Society of America Journal*, 54(1):92–98, 1990. Wheat, Barley and Triticale Abstracts.

H. F. Stroo, K. L. Bristow, L. F. Elliott, R. I. Papendick, and G. S. Campbell. Predicting rates of wheat residue decomposition. *Soil Science Society of America Journal*, 53(1):91–99, 1989. Wheat, Barley and Triticale Abstracts.

J. R. Teasdale and C. L. Mohler. The quantitative relationship between weed emergence and the physical properties of mulches [electronic resource]. *Weed Science*, 48(3):385–392, 2000.

J. R. Teasdale, S. B. Mirsky, J. T. Spargo, M. A. Cavigelli, and J. E. Maul. Reduced-tillage organic corn production in a hairy vetch cover crop. *Agronomy journal*, 104(3):621–628, 2012. Maize; Weeds.

P. J. Thorburn, M. E. Probert, and F. A. Robertson. Modelling decomposition of sugar cane surface residues with apsim-residue. *Field Crops Research*, 70(3):223–232, 2001. Field Crops; Irrigation and Drainage; Horticultural Science.

P. A. Torres, A. B. Abril, and E. H. Bucher. Microbial succession in litter decomposition in the semi-arid chaco woodland. *Soil Biology and Biochemistry*, 37(1):49–54, 2005. Forestry; Agroforestry.

C. Tu, F. L. Booker, D. M. Watson, X. Chen, T. W. Rufty, W. Shi, and S. J. Hu. Mycorrhizal mediation of plant n acquisition and residue decomposition: impact of mineral n inputs. *Global Change Biology*, 12(5):793–803, 2006. Plant Pathology; Crop Physiology; Grasslands and Forage.

USDA-AMS. Bi-weekly weighted average report for the week ending, 5/12/2012 2013.

USDA-ERS. Certified organic grains. acres of corn, wheat, oats, barley, sorghum, rice, spelt, millet, buckwheat, and rye by state, 1997 and 2000-08., 7/5/2012 2013.

USDA-ERS and C. Greene. Organic production, 2009.

C. Wagner-Riddle, T. J. Gillespie, and C. J. Swanton. Rye cover crop management impact on soil water content, soil temperature and soybean growth. *Canadian Journal of Plant Science*, 74(3):485–495, 1994. Soyabeans; Soils and Fertilizers; Irrigation and Drainage; Wheat, Barley and Triticale Abstracts.

E. R. Walker, A. Mengistu, N. Bellaloui, C. H. Koger, R. K. Roberts, and J. A. Larson. Plant population and row-spacing effects on maturity group iii soybean. *Agronomy Journal*, 102 (3):821–826, 2010. Field Crops; Crop Physiology.

C. R. Weber, R. M. Shibles, and D. E. Byth. Effect of plant population and row spacing on soybean development and production. *Agronomy Journal*, 58:99–102, 1966.

M. S. Wells, S. Reberg-Horton, and C. Brinton. The influence of six-rye cultivars, on weed suppression and organic soybean yield in a roll-killed cover-crop system. *Weed Science*, In Review, 2013a.

M. S. Wells, S. C. Reberg-Horton, A. N. Smith, and J. M. Grossman. The reduction of plant-available nitrogen by cover crop mulches and subsequent effects on soybean performance and weed interference. *Agron.J.*, 105:1-7(2), 2013b.

T. J. White, T. Bruns, S. Lee, and J. W. Talyor. *Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics*, pages 315–322. Acedemic Press, Inc., New York, 1990.

F. H. Yelverton and H. D. Coble. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (glycine max). *Weed Technology*, 5(1):169–174, 1991. Soyabeans.

B. G. Young, J. M. Young, L. C. Gonzini, S. E. Hart, L. M. Wax, and G. Kapusta. Weed management in narrow- and wide-row glyphosate-resistant soybean (glycine max). *Weed Technology*, 15(1):112–121, 2001. Weeds; Field Crops.

Chapter 3

A ^{15}N FIELD DEMONSTRATION OF NITROGEN TRANSFER FROM SOIL TO RYE COVER CROP MULCH IN AN ORGANIC SOYBEAN CROPPING SYSTEM

3.1 INTRODUCTION

In order to manage weed pressures, organic soybean production relies on costly and labor-intensive production practices that utilize frequent tillage and cultivation techniques such as blind cultivation, between row cultivation, and expensive low-efficacy organic herbicides. Organic soybean systems that employ intensive cultivation practices can substantially reduce weed driven yield loss (Smith et al., 2011; Reberg-Horton et al., 2012; Wells et al., 2013b). However, these practices come at an environmental and economic cost. Excessive soil cultivation can lead to compaction of the sub-soil layer, increasing water and wind erosion, increasing soil organic matter decomposition, and higher labor and energy inputs (Bernstein et al., 2011). The time, labor, and economic costs of production have prompted interest in reducing tillage in organic soybean production. A cover crop-based approach to producing organic soybeans without tillage is being developed to address the time, labor, and economic costs associated with tillage-based soybean production. In this case, a grass cover crop is rolled-crimped producing a weed suppressive mulch that soybean cash crops are planted into. Coupling a grass cover crop with a legume cash crop (i.e., cereal rye and soybeans) can produce yields equiva-

lent to conventional no-till soybean production (Smith et al., 2011; Reberg-Horton et al., 2012; Mirsky et al., 2013). Current research suggests that the success of this system is dependent on maximizing cover crop biomass production (Smith et al., 2011; Wells et al., 2013b). It is understood that cover crop mulches suppress weeds physically and chemically (Teasdale and Mohler, 2000; Reberg-Horton et al., 2005, 2012). Physically, cover crop mulches provide a restrictive barrier that lowers temperatures and light at the soil surface t, thus inhibiting the germination of small seeded summer annual weed germination and emergence. The chemical controls of cover crop mulches work to suppress the germination of weeds through the release of phytotoxic allelopathic chemicals (Reberg-Horton et al., 2005). To achieve maximum cereal rye biomass production, where N carryover from previous crops is minimal and in lighter textured soil systems, producers rely on N fertility derived from composted manures both prior to fall planting and in the spring before jointing. This is done along with tissue testing to ensure optimal nutrient conditions throughout the growing season. As a result, many of the producers in the Southeast can achieve 9,000[15]0,000 kg ha^{-1} dry matter over the season (Smith et al., 2011; Wells et al., 2013b). While physical factors, and to a far lesser extent allelopathy, appears to be the principal factor driving weed suppression from mulches, nutrient availability may also play an important role. Wells et al., (2013) observed low soil inorganic N levels under a cover crop-based no-till soybean crop; there appeared to be a relationship between weed performance and low soil inorganic N levels. In these systems, not only was the plant available N lower at the beginning of the soybean season; there was a continued suppression of N released throughout the remainder of the season (Wells et al., 2013b). The lower plant available N in this high residue system suggests that nutrient availability may enhance the overall weed control. The nutritive control mechanism, as it refers to suppression induced by low N availability, has not been well studied in roll-crimped cover crop mulched systems (Mirsky et al., 2013; Wells et al., 2013b). However, the effects of incorporating high C/N residues with tillage, and the subsequent microbial N immobilizationa process where N is sequestered by microbes and incorporated into proteins, and other organic N constituentshave been well reviewed (Schomberg et al., 1994; Recous et al., 1995; Burgess et al., 2002; Jin et al., 2008). Although microbial N immobilization in forest systems have been well characterized, research evaluating high C/N cover crop surface residue impacts on N-immobilization are sparse in agricultural systems (Marinari et al., 2010). The transfer of N from the mineral soil to the litter on the forest floor can account for the entire N-immobilization in this layer during the first year of decomposition (Hart and Firestone, 1991). Jaeger et al. (1999) provided further evidence of surface residue driven N-immobilization where microbial N immobilization increased rapidly in September following the addition of newly senesced, high C/N ratio leaf litter. Similar N-immobilization effects were reported when high C/N ratio wheat straw residues (ranging from 40-80:1) were applied to soil surfaces (Holland and Coleman, 1987; Schwendener et al., 2005). The mechanism of N-transfer from soil to sur-

face residues was directly confirmed by (Frey et al., 2000). They demonstrated, in a controlled environment, a 43% reduction in surface soil N immobilization when fungal populations were inhibited by fungicides, along with demonstrating a 52 to 86% reduction of total N transferred from mineral soil to wheat surface residues. Similar N-immobilization effects should be expected in agricultural systems with high C/N surface residues. Determining the extent to which fungal mediated N translocation occurs would help explain the magnitude in which a nutritive weed suppression mechanisms occurs. The objective of this study was to characterize, in-situ, the magnitude of fungal mediated N-transfer from the soil to surface cereal rye cover crop mulch. We hypothesized that fungal mediated N-transfer does occur under field conditions. We expect lower extractable soil inorganic N (i.e. NH_4^+ and NO_3^-) in the presence of a fungicide compared to no fungicide treated soils.

3.2 MATERIALS AND METHODS

3.2.1 Study Location and Soil Properties

In 2010, two independent experiments were conducted at both the Caswell Research Farm (KINS) in Kinston, NC (2011, and 2012) (35.273206°N, 77.623816°W), and USDA-ARS Beltsville Agricultural Research Center (BARC) in Beltsville, MD (39.03269°N, 76.928143°W). The soil type at KINS was Johns loamy sand (fine-loamy over sandy or sandy-skeletal, siliceous, semi-active, thermic Aquic Hapludults) with 0 to 2% slope and Kenansville loamy sand (loamy, siliceous, subactive, thermic Arenic Hapludults) with 0 to 3% slope, and at BARC the soil types were Codorus and Hatboro (mica bearing loamy alluvium), with 0 to 2% slope.

3.2.2 Experimental Design and Macro System Descriptions

The Multiple Injection Study (MIS) was a randomized complete block design, and the Single Injection Study (SIS) was a split-plot design, each with four replicates. In both studies, the two treatments consisted of fungicide (F) and non-fungicide (NF) treatments. Prior to fall drilling of cereal rye (*Secale cereale* 'Rymin' or 'Aroostook'), the entire field, at both locations, was disked and field cultivated to remove any existing vegetation from the previous maize crop. Lime, P, and K were applied according to soil test before cereal rye planting. The cereal rye cover crop was sown during mid-October for all treatments via grain drill on 13-cm row spacing at 134 kg ha1. In the Fall, approximately 30 kg N ha^{-1} of urea ammonium nitrate (UAN) was applied to the cereal rye cover crop to ensure adequate fall tillering and optimal growth in the spring.

The microplots for MIS and SIS consisted of 50, 6.5 mm thick, 0.58 m2 steel boxes. Before the microplots were installed, the cereal rye cover crop was terminated in early June (Feeke's growth stage 11.1 and 11.4 at KINS and BARC, respectively) via a mower conditioner haybine.

The cut cereal rye was removed from the experiment area where it was air-dried for one-week. Following the removal of the cereal rye cover crop, the 50 steel boxes were installed directly into the ryecereal rye cover crop stubble to a depth of 40 cm. Soybeans (Glycine max L. 'Pioneer 95Y40), Maturity Group V, were hand sown at a rate of 370,650 live seed ha^{-1} with 76.2 cm row spacing. Following soybean planting, cereal rye biomass,at 8000 kg ha^{-1} dry matter, was applied to each microplot. The cereal rye biomass was separated over the soybean furrow to ensure maximum soybean emergence and then thinning to 30 plants m^{-1} density. Microplots were managed weed-free throughout the season with broadcast applications of glyphosate.

3.2.3 Single Injection Study

Temporal distribution of N was evaluated in the SIS through one single enrichment of ^{15}N-enriched (NH4)2SO4 solution (99.7 at.%) at a rate of 1 mg ^{15}N kg^{-1} soil injected (4.4 cm depth) at soybean planting (i.e. zero days after planting, DAP) through the rye tissue. Following the enrichment in the SIS, (0 DAP), the cereal rye tissue was collected and assess the level of ^{15}N contamination to the rye tissue during the injection. After the cereal rye biomass was removed, soils were sampled and tested for ^{15}N. Soil, cereal rye, and soybean tissue were sampled at soybean planting, and again four and eight weeks after the initial enrichment.

3.2.4 Multiple Injection Study

Spatial distribution of N was evaluated in the MIS through four injection intervals of ^{15}N-enriched (NH4)2SO4 solution (99.7 at.%) at a rate of 1 mg ^{15}N kg^{-1} soil. Each microplot from MIS received only one application (i.e. injection) of ^{15}N, occurring two weeks before destructive harvesting of all soil and plant parameters. Injections of ^{15}N began at soybean planting, and again every two weeks for an eight-week time frame (i.e. t = 0, 2, 4, and 6). The ^{15}N-enriched (NH4)2SO4 solution was uniformly injected across the entire microplot via a large gauge needle to a depth of 4.4 cm below the soil surface (Figure 3.7). The injection protocol was designed to eliminate ^{15}N contamination to the surface residues. Additional microplots were included in the experimental design to test for ^{15}N contamination to the surface residues via injection.

3.2.5 Fungicide Treatments

Following the soybean planting, cereal rye biomass application, and ^{15}N injection, fungicide and non-fungicide treatments received 3.2 mm of water for each sampling and ^{15}N injection interval for the duration of the study. Captan (50 W wettable powder, 48.9% a.i., 4.6% N) fungicide was broadcasted at a rate of 9 kg ha^{-1}, which was equivalent to 4.4 kg ha^{-1} a.i. to each of the fungicide plots starting at the initial ^{15}N injection and planting of soybeans (i.e. $t = 0$). The fungicide application continued for the next three, two-week intervals for a total

of 17.6 kg ha^{-1} a.i. $microplot^{-1}$. The goals of the fungicide applications were similar to those reported by Frey et al. (2000), to reduce fungal populations while having minimal impacts on non-target organisms (Ingham and Coleman, 1984; Ingham et al., 1986; Beare et al., 1992). Fungicide application rates were chosen to not exceed 1 ppm N, to not perturb the N status in the soil system.

3.2.6 Soil and Plant Measurements

For each sampling interval, the following soil and crop parameters were utilized to monitor for ^{15}N movement: cereal rye mulch residue, soybean plant tissues, and soil extractable inorganic N. Cereal rye biomass and soybean tissues (i.e. whole plant) were collected from the entire microplot and air-dried at 60°C for 72 h. After drying, weights were recorded, plant tissues were finely milled (i.e. ball-ground), and analyzed for total N and C by a PerkinElmer (Norwalk, CT) Model 2400 CHN elemental analyzer (Tu et al., 2006; Wells et al., 2013b). Ball-ground plant tissue was then packed into 9x5 mm tin capsules and sent to the Stable Isotope Facility at University of California, Davis to be analyzed for N isotope ratios using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK). The monitoring of soil inorganic N was conducted by collecting 16, 7.6 cm diameter soil cores at a depth of 10 cm. Bulk density and soil moisture were also collected for each sampling interval. Soil samples were homogenized, wet sieved (2 mm) to remove any plant material and rocks, and placed in cold (4°C) storage for transport. Twenty grams of field moist sieved soils were extracted in 50 ml of 0.5 M K2SO4 and shaken for 30 minutes on an orbital shaker (Hart et al., 1994; Frey et al., 2000). After samples had been shaken, the soil suspension was filtered with filter papers that had been preleached with 100 ml 0.5 M K_2SO_4 (Fisher Scientific Filter Paper Grade Q2), and subsamples were analyzed for ammonium and nitrate on a Quick Chem 8000 Lachat (Keeney and Nelson, 1982). To determine the ^{15}N content in the soil, samples were diffused on to filter paper acid traps according to protocols outlined by Stark and Hart (1996). Diffused samples were transferred to 9x5 mm tin capsule and sent to University of California at Davis to be analyzed for N isotope ratios using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK)(Brooks et al., 1989; Stark and Hart, 1996; Frey et al., 2000).

3.2.7 DNA Extraction and Fungal ITS1 Region Primers Performed on Cereal rye Surface Residues

Metagenomic DNA was extracted from 1 g of dried and ground cereal rye mulch using the PowerPlant DNA Isolation kit (MoBio Laboratories, Solana Beach, CA) according to manufacturers

instructions. DNA concentration was determined using a Nano-drop 2000 spectrophotometer at 260 nm (Thermo Fisher Scientific, Pittsburgh, PA). DNA extracts were diluted to 10 ng μl^{-1} and stored at -20°C for further analyses. The fungal ITS1 region of the nuclear rDNA gene cluster was amplified from metagenomic DNA isolated from the cereal rye mulch using primers ITS1F (5-CTTGGTCATTTAGAGGAAGTAA-3) and ITS4R (5-TCCTCCGCTTATTGATATGC-3) (White et al., 1990; Gardes and Bruns, 1993). Quantitative PCR (qPCR) was carried out on a Stratagene Mx3000p QPCR System (Agilent Technologies, Santa Clara, CA) using SYBR green detection. Each 20 l reaction contained 10 l of 2X SSO Fast EvaGreen Supermix (BioRad Laboratories, Hercules, CA), 400 nM forward primer, 400 nM reverse primer and 50 ng of total template DNA (except for standards and non-template controls). Thermal cycling conditions were as follows: 1 cycle of 98°C for 3 min, 40 cycles of 98°C for 15 seconds, and 65°C for 30 sec, followed by a continuous melting curve of 30 sec at 65°C to 95°C, to assess qPCR product purity. Product specificity was confirmed by agarose gel electrophoresis (1.5% w/v gel containing GelStar). All field samples were run as analytical triplicates in the qPCR step. The mean value of the triplicates were reported as ng of ITS1 fungal gene and plotted against the time course of the experiment.

3.2.8 Statistical Analysis

The two experiments were a randomized complete block design, and split-plot design with four replications. A combined analysis was attempted for both locations, but significant treatment by location interactions prevented pooling soil inorganic N (MIS only) and cereal rye biomass data; however, soil inorganic N (SIS only) and soybean tissue data was pooled over both sites (Steel et al., 1996). All parameters were analyzed using proc MIXED, and treatments were modeled as fixed effects, and blocks and environments as random effects (SAS, 2006). The lack of homogeneous variance associated with soybean tissue and fungal DNA extractions data were corrected via a logarithmic transformation (Steel et al., 1996). Transformed means were back-transformed for presentation, and all means were separated using pre-planned contrasts (Steel et al., 1996; SAS, 2006)

3.3 RESULTS AND DISCUSSION

3.3.1 Cereal rye Surface Residue N Flux

Cereal rye mulch N losses were observed in the MIS over the eight-week duration of the study at Beltsville Agriculture Research Center (BARC), and Caswell Research Station (KINS), totaling 15 and 50 kg N ha^{-1}, respectively. The difference in N losses from the cereal rye surface residue observed at BARC and KINS due to differences in residue quality between BARC and KINS

at the deployment of the study. At BARC, the cereal rye was harvested (i.e. haybined) at the hard kernel stage (Feekes growth stage 11.4), whereas at KINS, the cereal rye was just entering the soft dough stage (Feekes growth stage 11.1). As a result the initial carbon to N ratios of the cereal rye residue were far greater at BARC (70:1) than at KINS (43:1). The lower C:N ratio cereal rye residues at KINS was less resistant to decomposition and released considerably more N to the soil system than the more recalcitrant residues from BARC (Figure 1).

There were no detectable differences in cereal rye tissue N (kg ha^{-1}) between the fungicide and non-fungicide treatments (Figure 1). Contrary to what Frey et al. (2000) observed, there was no significant reduction in decomposition from the fungicide treated cereal rye residues. Both treatments (F and NF) at BARC and KINS lost nearly 41% of their initial biomass, suggesting minimal effect of fungicide in altering decomposition processes in the cereal rye residues. Since the efficacy of the fungicide treatments was minimal, the magnitude of N-immobilization in the cereal rye biomass was calculated (Aber and Melillo, 1982; Frey et al., 2000) to 2.7 and 9.5 kg N ha^{-1}, at BARC and KINS respectively. The reduced N-immobilization observed at BARC and KINS, when compared to the 15 - 18 kg N ha^{-1} N-immobilized as reported by other studies, could be attributed to the increased duration of the their study (i.e. four months greater time frame)(Beare et al., 1992; Frey et al., 2000). The increased duration of pervious studies, along with ensuring the establishment of the fungal hyphal network (achieved by applying wheat straw 36, 125 and 185 days prior to ^{15}N injection and incubation) prior to the ^{15}N injection maximized the observed fungal translocation effect (Beare et al., 1992; Frey et al., 2000).

3.3.2 Upward N-Transfer and Microbial Immobilization

Despite the large N losses from the cereal rye residues, there was also an observed increase of ^{15}N content (kg ha^{-1}) associated with the cereal rye residues. The increase in ^{15}N content indicates bilateral movement of N between the mulch and the mineral soil (Figure 1). By the sixth week after planting, there was a significant increase ($p < 0.01$) of ^{15}N associated with the cereal rye biomass compared to the initial sampling interval at both BARC and KINS, 0.02 and 0.03 kg ^{15}N ha^{-1}, respectively (Figure 1). The fungicide treatments had minimal effect on reducing the ^{15}N enrichment associated with the cereal rye biomass; however, at KINS only, 6 WAP, there was greater ^{15}N concentration detected in the cereal rye residues from non-fungicide treatments ($p < 0.1$) confirming that the fungicides only partially controlled the fungal N transfer (Figure 1, D). Similar trends of increased ^{15}N enrichment in the cereal rye surface residues were observed for both the SIS and the MIS experiments (Figure 2). A combined analysis of ^{15}N atom% excess across site, showed considerable enrichment of ^{15}N in excess of background $\delta^{15}N$ concentrations in the cereal rye residues (Figure 2). It is unlikely that the increase in ^{15}N enrichment in the cereal rye residue was a result of contamination during injection of 15N below the soil surface

or by capillary wicking. Each plot received 0.6 cm of simulated rainfall after injection; cereal rye residues were collected and analyzed for contamination, indicated no enrichment of ^{15}N 0 WAP (Figures 1, B and 2). Even though upward movement of ^{15}N was observed, it is unclear if the N-transfer was primarily mediated via fungal translocation. However in the MIS, 6 WAP, there was evidence of fungal transport of N into the cereal rye surface residues ($p < 0.05$) where the non-fungicide treated plots observed nearly a 36% increase in ^{15}N enrichment above the fungicide (Figure 2, B). Quantification of the fungal ITS1 DNA at both locations was greater in the non-fungicide than the fungicide treated plots, with exception to 8 WAP at Beltsville, and 2, 4 WAP at Kinston (Figure 3). The increase in fungal DNA was greatest in the non-fungicide plots six weeks after planting, which corresponds to the largest N-transfer to the cereal rye residues (Figures 1, 2 and 3). The detection of ITS1 gene signals in the fungicide treatment could have been due to an insufficient application rate of the fungicide. The application rate was lowered to avoid perturbation to the soil N status. We must also consider that the cereal rye mulch is field grown so it may contain both surface dwelling as well as endophytic fungal species that also would be detectable by the qPCR technique used in this study. Studies have reported successful suppression of saprophytic fungi via Captan, while minimizing off-target populations (Ingham and Coleman, 1984; Beare et al., 1992; Frey et al., 2000); However, since Captan contains approximately 4.67% N, the prescribed rates of Captan specified by these studies could perturb the N cycling in low-N environments and may have influenced the degree of N cycling in our microplots. Furthermore, it is plausible that microbes used Captan N and therefore masked the overall magnitude of the fungal translocation of soil derived N to the cereal rye surface residues.

3.3.3 Soybean Contribution to N-Constraints

Unlike many of the studies that evaluate N-transfer from soil to surface residues either in grass or forest ecosystems (**??**), this study evaluated N status associated with high biomass cereal rye cover crop residues in the presence of soybeans. Nitrogen immobilization accounted for approximately 15% of the total N losses from the cereal rye surface mulches, where a relatively large amount of N entered the soil. Even though soybean plants biologically fixed, on average, 50-60% of assimilated N from the air, they remained a considerable sink for soil derived N in the microplots (Figure 4) (Salvagiotti et al., 2008). It is estimated that of the 120 kg N ha^{-1} assimilated by the soybeans throughout the season, approximately 60 kg N ha^{-1} derived from mineralized and residual soil N (Figure 4)(Salvagiotti et al., 2008). Between the six and eight week sampling interval, soybean demand for soil derived N increased by nearly 30%, and during this time frame 0.15 kg ^{15}N ha^{-1} was removed from the soil by the soybeans. This reduced the extractable inorganic soil ^{15}N in the SIS, at Beltsville and Kinston, by approximately 90%

(Figures 4 and 5).

3.3.4 Extractable Inorganic Soil N

Extractable soil inorganic N decreased in the MIS over the eight-week duration at Beltsville (4 kg N ha^{-1}) and after the fourth week at Kinston (6 kg N ha^{-1}) (Figure 5). Fungicide treatments had a limited effect on soil extractable N for all plots, with the exception of the 2-WAP time interval at Beltsville (Figure 6). During the 2-WAP time frame at Beltsville, the non-fungicide treatments had 2 and 0.07 kg ha^{-1} greater extractable soil inorganic N and ^{15}N when compared to the fungicide treated plots (Figure 6; A and C). It is possible that Captan reduced soil extractable inorganic N in the fungicide plots by limiting N-cycling and enhancing bacterial N-immobilization of dissolved organic C originating from both the above ground cereal rye residue and Captan, which contains 36% carbon. Captan has been shown to augment the soil N status by reducing the microbial communities responsible for capturing N, and providing digestible carbon that can be immobilized into the bacterial biomass (Martnez-Toledo et al., 1998; Megadi et al., 2010a,b). There was no separation in soil extractable inorganic N or ^{15}N from the non-fungicide and fungicide treatments during the first two-week time interval at Kinston (Figure 6). Although, at Kinston during 4-WAP there was a 2 and 0.10 kg ha^{-1} increase in extractable soil inorganic N and ^{15}N, respectively (Figure 4). The increase in extractable soil inorganic N during this time frame was a result of nearly 40 kg ha^{-1} N-loss from the cereal rye surface residue (Figure 1). Despite the N losses from the cereal rye, extractable N continued to decreaseexcept for the previously mentioned time interval at Kinstonthroughout the season, and was below 4 and 7 kg N ha^{-1} by 8-WAP (Figure 6, A and B). It is possible that the more than double N losses from the cereal rye at Kinston when compared to Beltsville during the first month of the study acted to mask any negative effects Captan had on both N-cycling and bacterial N immobilization, thereby increasing the extractable soil inorganic N concentrations (Figures 1 and 6). Similar N status was observed via the ^{15}N tracer at both Beltsville and Kinston (Figure 6; C and D). The extractable soil inorganic ^{15}N concentrations in the MIS were far lower than the 1.77 kg ^{15}N ha^{-1} injected. However, soil sampled from the SIS study 2-hours after injection recovered only 0.6 kg ^{15}N ha in the extractable soil N pool (Figure 5, B). It is likely that the remaining 60% of ^{15}N was either quickly immobilized via the intense microbial competition for N in the low N environment, chemical fixation to soil colloids, or leached below the sampling depth (Kessavalou et al., 1996; Dou et al., 2007). Even in the SIS plots where ^{15}N injection occurred at the beginning of the season, the tracer was still high enough to be detected in the soil 4-WAP (Figure 5, B).

3.4 CONCLUSION

In conclusion, this body of work does support our hypothesis of upward movement of N from mineral soil to a high C:N residue cover crop mulch. Although the fungicide effects were small, there was a considerable concentration of N being transported into the cereal rye residue, thereby directly contributing to the reduction of available N in the system. Even though cereal rye residues lost approximately 30% of its initial N, the bulk of the mineralized N did not perturb the extractable soil inorganic N. Our values for extractable soil inorganic N status at both locations were low enough throughout the season to cause considerable N related stress on summer annual weeds such as redroot pigweed (*Amanranthus retroflexus* L.)(Wells et al., 2013b). These results confirm the extreme competition for N and C in high C:N soil systems, and the observed N-immobilization via fungal transport or otherwise is above the N-immobilized (or lost) by the soil microbial community. This study was designed to evaluate the nutritive weed suppressive mechanisms of high biomass cereal rye cover crop mulches during the critical weed free period of soybeans, thus any N-immobilization in the already low N environment can increase the weed suppression of the system (Mirsky et al., 2013; Wells et al., 2013b). Further research is needed to quantify the optimal ratio between increased cereal rye biomass productions and N fertility required to achieve maximum biomass potential.

3.5 FIGURE CAPTIONS, TABLES AND FIGURES

3.5.1 Figures

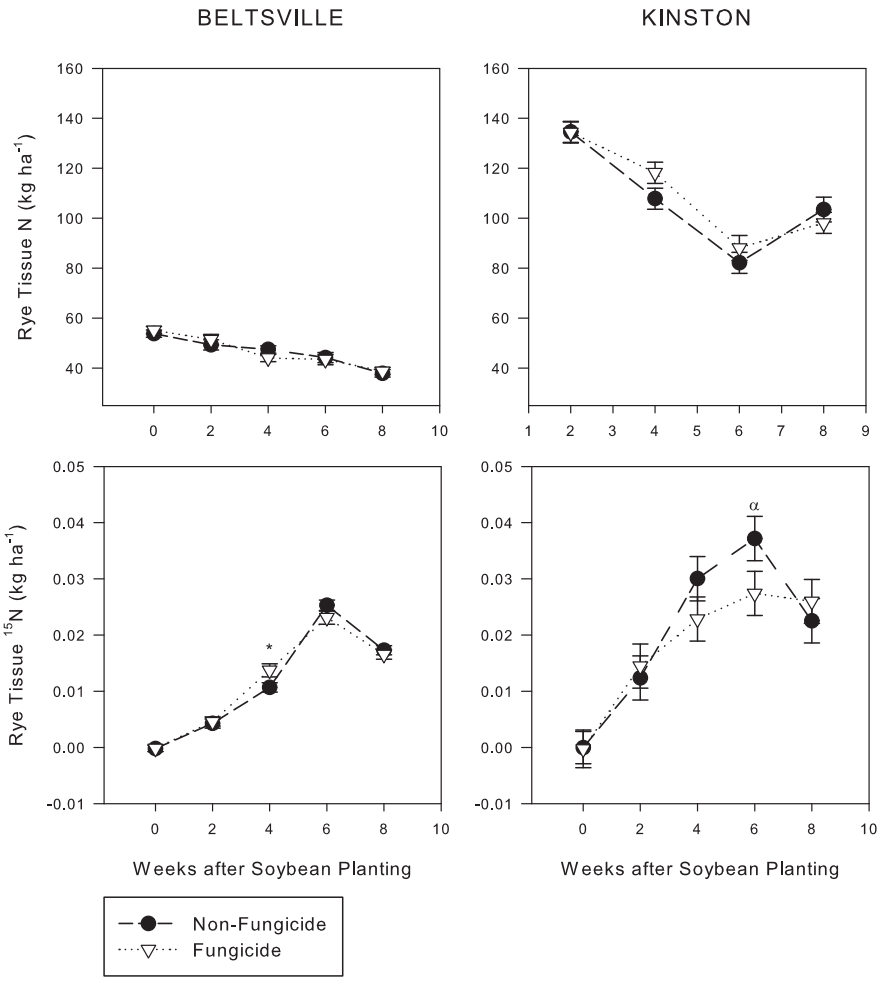

Figure 3.1: Multiple Injection Study: Cereal rye residue tissue N (kg ha^{-1}) (A and B) and 15N (kg ha^{-1}) (C and D) measured from fungicide and non-fungicide cereal rye mulched soybean microplots from Beltsville, MD and Kinston, NC (2010). Error bars indicate $\pm$ 1 standard error. Asterisks and Greek characters indicate significant differences between treatments at a giving time interval as determined by pre-planned contrast ($\alpha : p \leq 0.10$, *: $p \leq 0.05$).

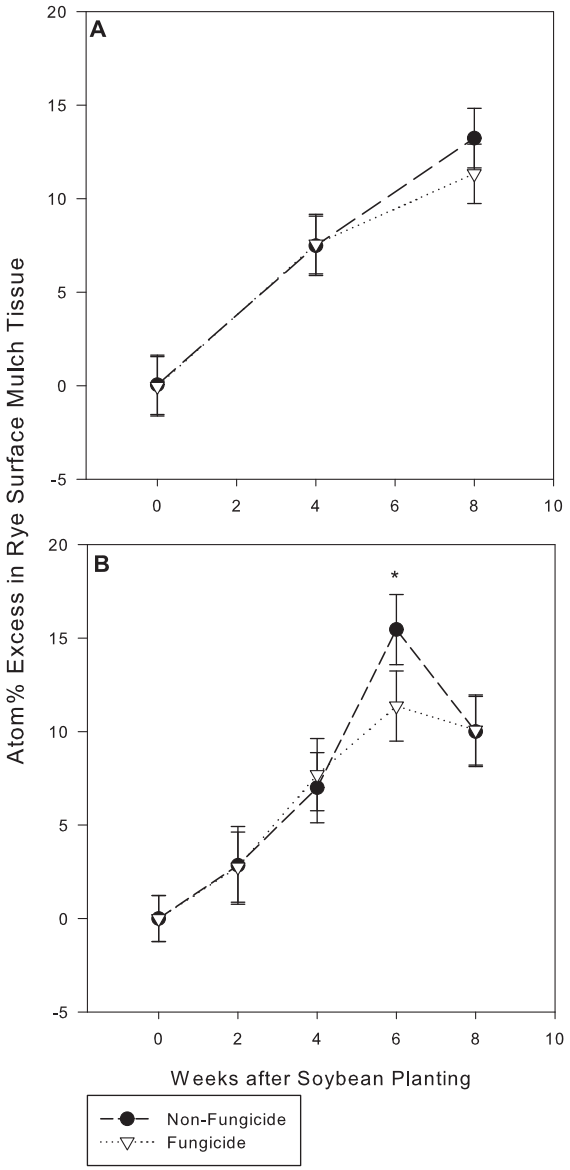

Figure 3.2: Single Injection Study (A, Single Injection Study) and Multiple Injection Study (B, Multiple Injection Study) cereal rye residue tissue atom% excess of ^{15}N measured from fungicide and non-fungicide cereal rye mulched soybean micro-plots from Beltsville, MD and Kinston, NC (2010). Error bars indicate $\pm$ 1 standard error. Asterisks characters indicate significant differences between treatments at a giving time interval as determined by pre-planned contrast (*: $p \leq 0.05$).

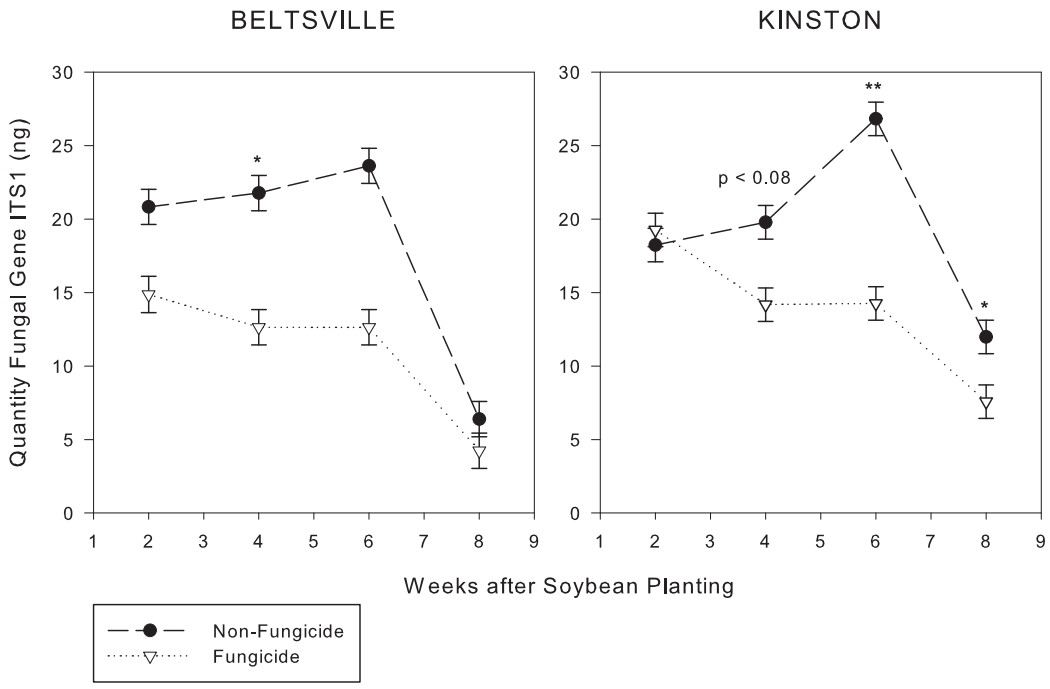

Figure 3.3: Multiple Injection Study: Fungal quanta in cereal rye tissue measured from fungicide and non-fungicide treated cereal rye mulched soybean crop at Beltsville, MD and Kinston, NC (2010).

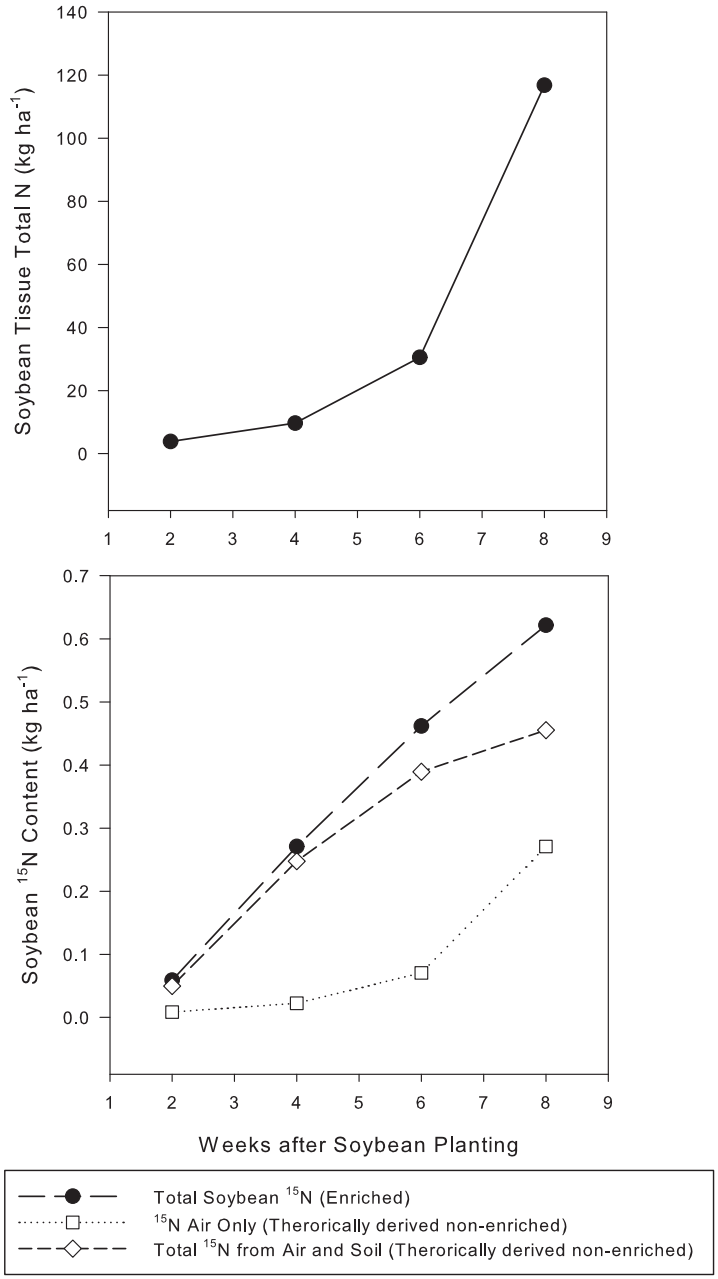

Figure 3.4: Multiple Injection Study: Plant tissue N (A) and ^{15}N (B) concentrations from soybean grown in a cereal rye mulch at Beltsville, MD and Kinston, NC (2010). cereal rye mulched microplots combined for Beltsville, MD and Kinston, NC (2010). Soybean ^{15}N from air only and total ^{15}N from air and soil was derived using widely accepted estimated (Salvagiotti et al., 2008).

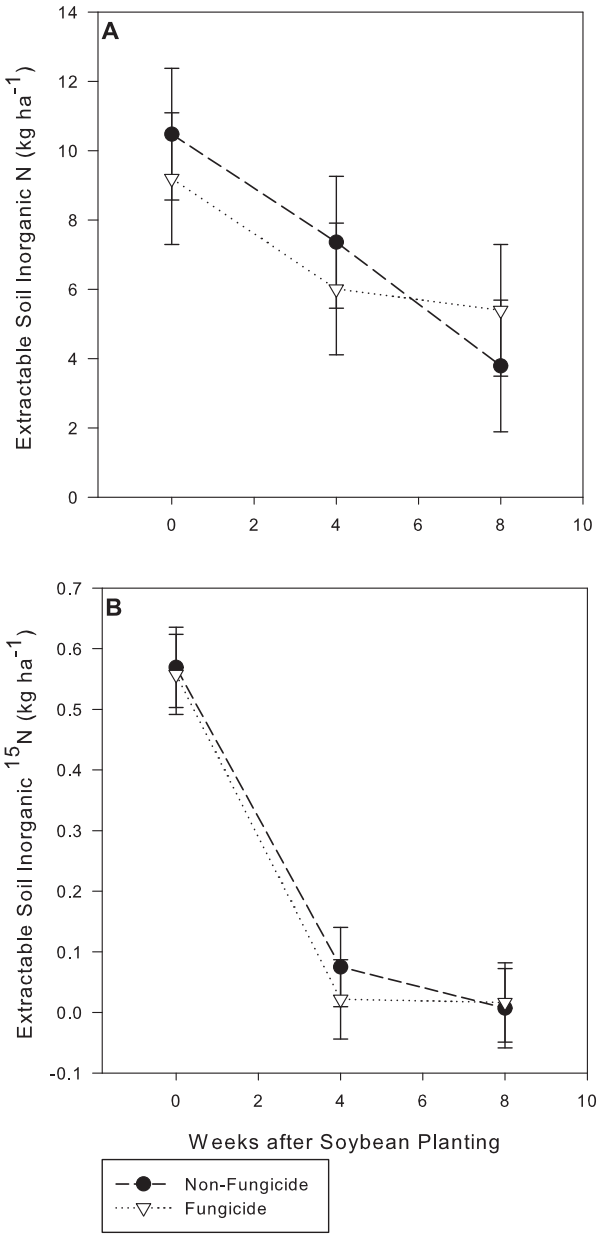

Figure 3.5: Single injection Study: Extractable soil inorganic N (A) and ^{15}N (B) measured from fungicide and non-fungicide treated soil under a cereal rye mulched soybean crop at Beltsville, MD and Kinston, NC (2010). Error bars indicate $\pm$ 1 standard error. Asterisks indicate significant differences between treatments at a giving time interval as determined by pre-planned contrast ($^{*}p \leq 0.05$, $^{**}p \leq 0.01$).

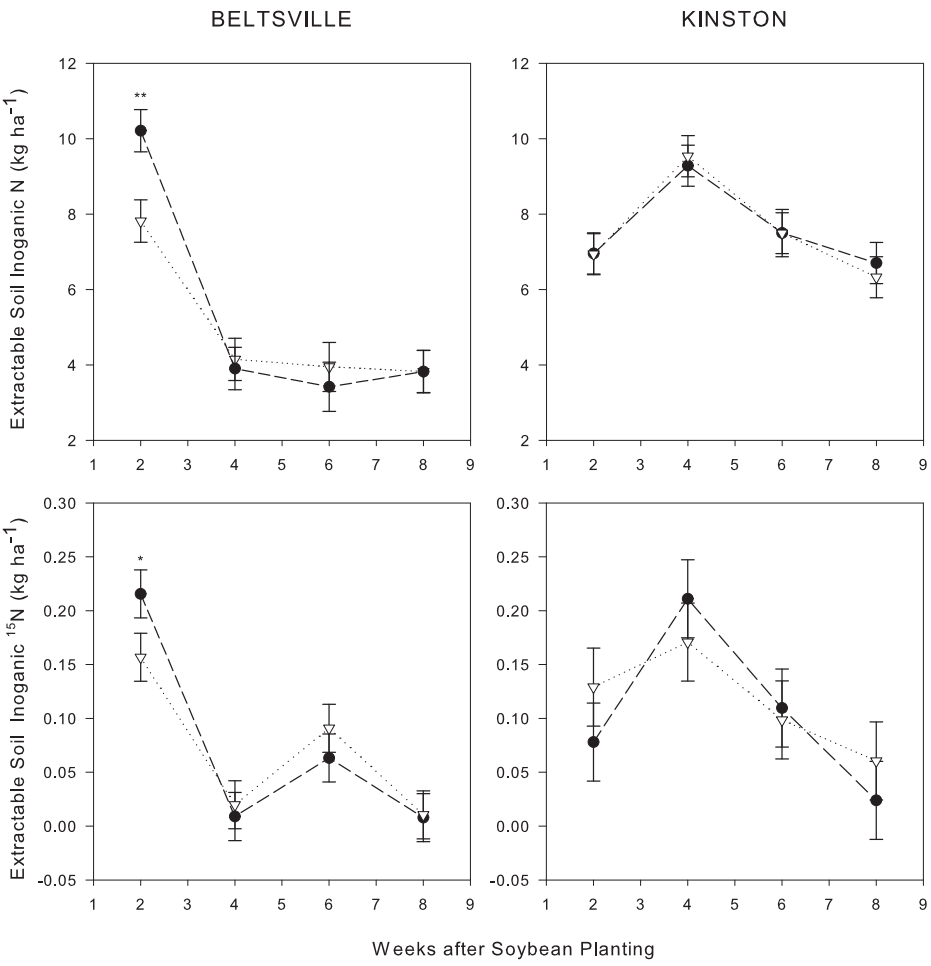

Figure 3.6: Multiple Injection Study: Extractable soil inorganic N (A and B) and ^{15}N (C and D) measured from fungicide and non-fungicide treated soil under a cereal rye mulched soybean crop at Beltsville, MD and Kinston, NC (2010). Error bars indicate $\pm$ 1 standard error. Asterisks indicate significant differences between treatments at a giving time interval as determined by pre-planned contrast ($^*p \leq 0.05$, $^{**}p \leq 0.01$).

Figure 3.7: Injection of $^{15}(NH_4)_2SO_4$ (99.7 at.) 4.4 cm below soil surface for both the Multiple and Single Injection Studies.

REFERENCES

J. K. Aase and D. L. Tanaka. Soil water evaporation comparisons among tillage practices in the northern great plains. *Soil Science Society of America Journal*, 51(2):436–440, 1987. Irrigation and Drainage.

J. D. Aber and J. M. Melillo. Nitrogen immobilization in decaying hardwood leaf litter as a function of initial nitrogen and lignin content. *Canadian Journal of Botany*, 60(11):2263–2269, 1982. Forestry; Soils and Fertilizers.

R. E. van Acker, C. J. Swanton, and S. F. Weise. The critical period of weed control in soyabean (glycine max (l.) merr.). *Weed Science*, 41(2):194–200, 1993. Weeds; Soyabeans.

D. L. Ashford and D. W. Reeves. Use of a mechanical roller-crimper as an alternative kill method for cover crops. *American journal of alternative agriculture*, 18(1):37–45, 2003. Accession Number: IND43646603 Pagination: p. 37-45. Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

M. H. Beare, R. W. Parmelee, P. F. Hendrix, W. Cheng, D. C. Coleman, and D. A. Crossley. Microbial and faunal interactions and effects on litter nitrogen and decomposition in agroecosystems. *Ecological Monographs*, 62(4):569–591, 1992. Accession Number: 19951908046. Publication Type: Journal Article. Language: English. Number of References: 96 ref. Registry Number: 7727-37-9.

M. H. Beare, P. F. Hendrix, D. C. Coleman, and S. Hu. Influences of mycelial fungi on soil aggregation and organic matter storage in conventional and no-tillage soils. *Applied soil ecology : a section of Agriculture, Ecosystems and Environment*, 5(3):211–219, 1997. soil carbohydrates; sandy clay loam soils; respiration; macroaggregates Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Category Codes: Soil Chemistry and Physics; Soil Cultivation and Cropping Systems; Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH541.5.S6A67 Update Code: 00000000.

E. R. Bernstein, J. L. Posner, D. E. Stoltenberg, and J. L. Hedtcke. Organically managed no-tillage rye-soybean systems: agronomic, economic, and environmental assessment. *Agronomy Journal*, 103(4):1169–1179, 2011. Soyabeans; Wheat, Barley and Triticale Abstracts; Irrigation and Drainage; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers.

Eliana E. Bontti, Ingrid C. Burke, Stephanie Owens, Mark E. Harmon, William J. Parton, Michelle L. Haddix, Seth M. Munson, Joseph P. Decant, Agnieszka Przeszlowska, and Mark A. Gathany. Litter decomposition in grasslands of central north america (us great plains) [electronic resource]. *Global change biology*, 15(5):1356–1363, 2009. root and leaf decomposition; Great Plains (USA); litter decomposition Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Subset: Indexing Branch - NAL NAL Call Number: QC981.8.C5G6323 Update Code: 00000000.

G Bowman. *Steel in the Field: A Farmers' Guide to Weed Mangement Tools.* Sustainable Agriculture Publications, University of Vermont, Burlington, VT, 1997.

P. D. Brooks, J. M. Stark, B. B. McInteer, and T. Preston. Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. *Soil Science Society of America Journal*, 53(6): 1707–1711, 1989. Accession Number: 19901942338. Publication Type: Journal Article. Language: English. Number of References: 21 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

P. L. Brown and D. D. Dickey. Losses of wheat straw residue under simulated field conditions, 1970. Accession Number: CAIN709036937 Pagination: p. 118-121. Language(s): English General Note: Bibliography: p. 121 NAL Call Number: 56.9 SO3 Update Code: 00000000.

J. L. de Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agronomy Journal*, 100(3):704–710, 2008. World Agriculture, Economics and Rural Sociology.

D. Bullock, A. Rayburn, and S. Khan. Soybean yield response to narrow rows is largely due to enhanced early growth. *Crop science*, 38(4):1011–1016, 1998. growth; plant height; determinate and indeterminate habit Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: CRPSAY Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 64.8 C883 Update Code: 00000000.

M. S. Burgess, G. R. Mehuys, and C. A. Madramootoo. Nitrogen dynamics of decomposing corn residue components under three tillage systems. *Soil Science Society of America Journal*, 66 (4):1350–1358, 2002. Soils and Fertilizers.

O. C. Burnside and R. S. Moomaw. Control of weeds in narrow-row soybeans. *Agronomy Journal*, 69(5):793–796, 1977. Weeds; Field Crops.

R. B. Campbell, R. E. Sojka, and D. L. Karlen. Conservation tillage for soybean in the u.s. southeastern coastal plain. *Soil and Tillage Research*, 4(6):531–541, 1984. Agricultural Engineering.

M. A. Cavigelli, B. L. Hima, J. C. Hanson, J. R. Teasdale, A. E. Conklin, and Y. C. Lu. Long-term economic performance of organic and conventional field crops in the mid-atlantic region. *Renewable Agriculture and Food Systems*, 24(2):102–119, 2009. Field Crops; Plant Genetic Resources; Grasslands and Forage; Weeds; World Agriculture, Economics and Rural Sociology; Soyabeans; Soils and Fertilizers; Horticultural Science; Maize.

M. A. Cavigelli, S. B. Mirsky, J. R. Teasdale, J. T. Spargo, and J. Doran. Organic grain cropping systems to enhance ecosystem services. *Renewable Agriculture and Food Systems*, 28(2):145–159, 2013. Conference paper. Language: English. Number of References: 126 ref. Registry Number: 7727-37-9. Subject Subsets: Weeds; Soils and Fertilizers.

K. Chandler, Shrestha Anil, and C. J. Swanton. Weed seed return as influenced by the critical weed-free period and row spacing of no-till glyphosate-resistant soybean. *Canadian Journal of Plant Science*, 81(4):877–880, 2001. Seed Science; Soyabeans; Field Crops; Weeds.

A. J. Clark, A. M. Decker, J. J. Meisinger, and M. S. McIntosh. Kill date of vetch, rye, and a vetch-rye mixture: Ii. soil moisture and corn yield. *Agronomy Journal*, 89(3):434–441, 1997. Maize; Wheat, Barley and Triticale Abstracts.

R. L. Cooper. Response of soybean cultivars to narrow rows and planting rates under weed-free conditions. *Agronomy Journal*, 69(1):89–92, 1977. Field Crops.

W. J. Cox and J. H. Cherney. Growth and yield responses of soybean to row spacing and seeding rate. *Agronomy Journal*, 103(1):123–128, 2011. Field Crops; Soyabeans; World Agriculture, Economics and Rural Sociology.

C. D. Dalley, J. J. Kells, and K. A. Renner. Effect of glyphosate application timing and row spacing on corn (zea mays) and soybean (glycine max) yields. *Weed Technology*, 18(1): 165–176, 2004. Soyabeans; Field Crops; Maize; Weeds.

Adam S. Davis. Cover-crop rollercrimper contributes to weed management in no-till soybean [electronic resource]. *Weed Science*, 58(3):300–309, 2010. Plant Physiology and Biochemistry; Soil Cultivation and Cropping Systems; Plant Production (Field Crops); Soil Fertility, Fertilizers and Manures Subset: Indexing Branch - NAL NAL Call Number: 79.8 W41 Update Code: 00000000.

J.L. De Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agron.J.*, 100(704-710), 2008.

K. Delate, D. Cwach, and C. Chase. Organic no-tillage system effects on soybean, corn and irrigated tomato production and economic performance in iowa, usa. *Renewable Agriculture and Food Systems*, 27(1):49–59, 2012. Soils and Fertilizers; Wheat, Barley and Triticale Abstracts; Maize; Soyabeans; Horticultural Science; World Agriculture, Economics and Rural Sociology.

R. Derpsch, C.H. Roth, N Sidiras, and U Kopke. *Controle da erosao no Parana, Brazil: Sistemas de cobertura do solo, plantio directo e prepare conservacionista do solo.* Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany., 1991.

F. G. Dou, A. L. Wright, and F. M. Hons. Depth distribution of soil organic c and n after long-term soybean cropping in texas. *Soil and Tillage Research*, 94(2):530–536, 2007. Soils and Fertilizers; Soyabeans; Field Crops.

L. H. Fraser and A. D. Hockin. Litter decomposition rates of two grass species along a semi-arid grassland-forest ecocline. *Journal of Arid Environments*, 88:125–129, 2013. Forestry; Grasslands and Forage; Soils and Fertilizers; Plant Genetic Resources; Plant Breeding.

S. D. Frey, E. T. Elliott, K. Paustian, and G. A. Peterson. Fungal translocation as a mechanism for soil nitrogen inputs to surface residue decomposition in a no-tillage agroecosystem. *Soil Biology and Biochemistry*, 32(5):689–698, 2000. Wheat, Barley and Triticale Abstracts.

Yoshiharu Fujii. Screening and future exploitation of allelopathic plants as alternative herbicides with special reference to hairy vetch. *Journal of Crop Production*, 4(2):257, 2001.

M. Gardes and T. D. Bruns. Its primers with enhanced specificity for basidiomycetes - application to the identification of mycorrhizae and rusts. *Molecular Ecology*, 2(2):113–118, 1993. Agricultural Biotechnology.

C. R. Grau, E. S. Oplinger, E. A. Adee, E. A. Hinkens, and M. J. Martinka. Planting date and row width effect on severity of brown stem rot and soybean productivity. *Journal of Production Agriculture*, 7(3):347–351, 1994. Plant Breeding; Soyabeans.

R. Grisso, D. L. Holshouser, and R. M. Pitman. Equipment considerations for no-till soybean seeding, 2009.

J. L. Gunsolus. Mechanical and cultural weed control in corn and soybeans. *American journal of alternative agriculture*, 5(3):114–119, 1990. mechanical methods; yield losses; interrow cultivation Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Plant Production (Field Crops); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

D. B. Harder, C. L. Sprague, and K. A. Renner. Effect of soybean row width and population on weeds, crop yield and economic return. *Weed Technology*, 21(3):744–752, 2007. Soyabeans; World Agriculture, Economics and Rural Sociology.

S. C. Hart and M. K. Firestone. Forest floor-mineral soil interactions in the internal nitrogen cycle of an old-growth forest. *Biogeochemistry*, 12(2):103–127, 1991. Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH345.B564 Update Code: 00000000.

S. C. Hart, J. M. Stark, and E. A. Davidson. *Nitrogen mineralization, immobilization, and nitrification*, pages 985–1018. Soil Science Society of America Inc., Madison, WI, 1994.

L. G. Heatherly and S. R. Spurlock. Yield and economics of traditional and early soybean production system (esps) seedings in the midsouthern united states. *Field Crops Research*, 63(1):35–45, 1999. World Agriculture, Economics and Rural Sociology; Soyabeans.

L. S. Heiffig, G. M. de S. Cmara, L. A. Marques, D. B. Pedroso, and S. M. de S. Piedade. The plasticity of soybean (glycine max (l.) merrill) crop in different spacing arrangements. / plasticidade da cultura da soja (glycine max (l.) merrill) em diferentes arranjos espaciais. *Revista de Agricultura (Piracicaba)*, 84(3):204–219, 2009. Field Crops; Soyabeans.

M. L. Hoffman, E. E. Regnier, and J. Cardina. Weed and corn (zea mays) responses to a hairy vetch (vicia villosa) cover crop. *Weed Technology*, 7(3):594–599, 1993. Weeds; Field Crops; Maize.

E. A. Holland and D. C. Coleman. Litter placement effects on microbial and organic matter dynamics in an agroecosystem. *Ecology*, 62(2):425–433, 1987. Wheat, Barley and Triticale Abstracts.

J. M. Holland. The environmental consequences of adopting conservation tillage in europe: reviewing the evidence. *Agriculture, Ecosystems and Environment*, 103(1):1–25, 2004. Agricultural Entomology; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers; Plant Pathology.

J. P. Huelsenbeck and K. A. Crandall. Phylogeny estimation and hypothesis testing using maximum likelihood. *Annual Review of Ecology and Systematics*, 28:437–466, 1997. Accession Number: 19980103293. Publication Type: Journal Article. Language: English. Number of References: 126 ref. Subject Subsets: Animal Breeding.

E. R. Ingham and D. C. Coleman. Effects of streptomycin, cycloheximide, fungizone, captan, carbofuran, cygon, and pcnb on soil microorganisms. *Microbial Ecology*, 10(4):345–358, 1984. Plant Pathology; Soils and Fertilizers.

E. R. Ingham, C. Cambardella, and D. C. Coleman. Manipulation of bacteria, fungi and protozoa by biocides in lodgepole pine forest soil microcosms: effects on organism interactions and nitrogen mineralization. *Canadian Journal of Soil Science*, 66(2):261–272, 1986. Forestry.

Rodale Institute. No-till revolution, 2012.

III Jaeger, C. H., R. K. Monson, M. C. Fisk, and S. K. Schmidt. Seasonal partitioning of nitrogen by plants and soil microorganisms in an alpine ecosystem. *Ecology*, 80(6):1883–1891, 1999. Accession Number: 19991912029. Publication Type: Journal Article. Language: English. Number of References: 33 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

Ke Jin, S. Sleutel, S. De Neve, D. Gabriels, DianXiong Cai, JiYun Jin, and G. Hofman. Nitrogen and carbon mineralization of surface-applied and incorporated winter wheat and peanut residues. *Biology and Fertility of Soils*, 44(4):661–665, 2008. Soils and Fertilizers; Irrigation and Drainage.

D. R. Keeney and D. W. Nelson. Nitrogen - inorganic forms. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, pages 643–698, 1982. Accession Number: 19841981457. Publication Type: Miscellaneous. Language: English. Number of References: approx. 170 ref. Registry Number: 7727-37-9, 7664-41-7. Subject Subsets: Soils and Fertilizers.

A. Kessavalou, J. H. Qian, T. A. Kettler, J. W. Doran, and W. L. Powers. Bromide and nitrogen-15 tracers of nitrate leaching under irrigated corn in central nebraska [electronic resource]. *Journal of environmental quality*, 25(5):1008–1014, 1996. Soil Biology; Mathematics and Statistics; Soil Chemistry and Physics; Pollution; Irrigation and Drainage Subset: Indexing Branch - NAL NAL Call Number: QH540.J6 Update Code: 00000000.

T. S. Kornecki, F. J. Arriaga, R. L. Raper, and A. J. Price. New roller crimper concepts for mechanical termination of cover crops in conservation agriculture. *Renewable agriculture and food systems*, 24(3):165–173, 2009.

J. T. Lennon, Z. T. Aanderud, B. K. Lehmkuhl, and Jr. Schoolmaster, D. R. Mapping the niche space of soil microorganisms using taxonomy and traits. *Ecology*, 93(8):1867–1879, 2012. Irrigation and Drainage.

L. M. Londono-R, D. Tarkalson, and J. E. Thies. In-field rates of decomposition and microbial communities colonizing residues vary by depth of residue placement and plant part, but not by

crop genotype for residues from two cry1ab bt corn hybrids and their non-transgenic isolines. *Soil Biology and Biochemistry*, 57:349–355, 2013. Soils and Fertilizers; Plant Breeding; Maize; Biocontrol; Field Crops; Agricultural Entomology; Agricultural Biotechnology.

W. G. Lovely, G. C. Weber, and D. W. Staniforth. Effectiveness of the rotary hoe for weed control in soybeans. *Agron.J.*, 50:621–625, 1958.

S. Marinari, A. Lagomarsino, M. C. Moscatelli, A. di Tizio, and E. Campiglia. Soil carbon and nitrogen mineralization kinetics in organic and conventional three-year cropping systems. *Soil and Tillage Research*, 109(2):161–168, 2010. Horticultural Science; Soils and Fertilizers.

M. V. Martnez-Toledo, V. Salmern, B. Rodelas, C. Pozo, and J. Gonzlez-Lpez. Effects of the fungicide captan on some functional groups of soil microflora. *Applied Soil Ecology*, 7(3): 245–255, 1998. Plant Pathology.

R. P. Mathew, Y. C. Feng, L. Githinji, R. Ankumah, and K. S. Balkcom. Impact of no-tillage and conventional tillage systems on soil microbial communities. *Applied and Environmental Soil Science*, 2012:Article ID 548620–Article ID 548620, 2012. Conference paper. Language: English. Number of References: 49 ref. Registry Number: 7440-44-0, 7727-37-9. Subject Subsets: Soils and Fertilizers; Maize; Field Crops.

V. B. Megadi, P. N. Tallur, R. S. Hoskeri, S. I. Mulla, and H. Z. Ninnekar. Biodegradation of pendimethalin by bacillus circulans. *Indian Journal of Biotechnology*, 9(2):173–177, 2010a. Accession Number: 20103171203. Publication Type: Journal Article. Language: English. Number of References: 16 ref. Registry Number: 40487-42-1. Subject Subsets: Weeds.

V. B. Megadi, P. N. Tallur, S. I. Mulla, and H. Z. Ninnekar. Bacterial degradation of fungicide captan. *Journal of Agricultural and Food Chemistry*, 58(24):12863–12868, 2010b. Accession Number: 20113158287. Publication Type: Journal Article. Language: English. Registry Number: 133-06-2. Subject Subsets: Plant Pathology.

J. A. Mickelson and K. A. Renner. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. *Journal of Production Agriculture*, 10(3):431–437, 1997. Soyabeans; Field Crops.

S. B. Mirsky, W. S. Curran, D. M. Mortensen, M. R. Ryan, and D. L. Shumway. Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. *Weed Science*, 59(3):380–389, 2011. Wheat, Barley and Triticale Abstracts; Weeds; Soyabeans.

S. B. Mirsky, M. R. Ryan, W. S. Curran, J. R. Teasdale, J. Maul, J. T. Spargo, J. Moyer, A. M. Grantham, D. Weber, T. R. Way, and G. G. Camargo. Conservation tillage issues: cover crop-based organic rotational no-till grain production in the mid-atlantic region, usa. *Renewable Agriculture and Food Systems*, 27(1):31–40, 2012. Soils and Fertilizers; Field Crops.

S. B. Mirsky, M. R. Ryan, J. R. Teasdale, William S. C., S.C. Reberg-Horton, J. T. Spargo, M. S. Wells, C. L. Keene, and J. W. Moyer. Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the eastern us. *Weed Technology*, 27:193–203, 2013.

Steven B. Mirsky, Matthew R. Ryan, Durland L. Shumway, William S. Curran, and David A. Mortensen. Control of cereal rye with a roller/crimper as influenced by cover crop phenology [electronic resource]. *Agronomy journal*, 101(6):15891596–15891596, 2009. Plant Breeding and Genetics; Plant Production (General); Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: 4 AM34P Update Code: 00000000.

Ruth Mischler, David Wilson, William S. Curran, and Sjoerd W. Duiker. Hairy vetch management for no-till organic corn production [electronic resource]. *Agronomy journal*, 102(1): 355–362, 2010a.

Ruth A. Mischler, Jeffrey A. Hyde, Sjoerd W. Duiker, and William S. Curran. Use of a rolled-rye cover crop for weed suppression in no-till soybeans [electronic resource]. *Weed Technology*, 24(3):253–261, 2010b. Farm Organization and Management (Microeconomics); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: SB610.W39 Update Code: 00000000.

L. N. Mulumba and R. Lal. Mulching effects on selected soil physical properties. *Soil and Tillage Research*, 98(1):106–111, 2008. Soils and Fertilizers.

A. Munawar, R. L. Blevins, W. W. Frye, and M. R. Saul. Tillage and cover crop management for soil water conservation. *Agronomy Journal*, 82(4):773–777, 1990. Wheat, Barley and Triticale Abstracts; Soils and Fertilizers; Irrigation and Drainage; Maize.

K. L. Murphy, J. M. Klopatek, and C. C. Klopatek. The effects of litter quality and climate on decomposition along an elevational gradient. *Ecological Applications*, 8(4):1061–1071, 1998. Forestry.

E. S. Oplinger and B. D. Philbrook. Soybean planting date, row width, and seeding rate response in three tillage systems. *Journal of Production Agriculture*, 5(1):94–99, 1992. Soyabeans.

J. F. Parr and R. I. Papendick. Factors affecting the decomposition of crop residues by microorganisms. *ASA [American Society of Agronomy] Special Publication*, (31):101–129, 1978. Accession Number: 19791950934. Publication Type: Journal Article. Language: English. Number of References: 65 ref. Subject Subsets: Soils and Fertilizers.

M. Parr, J. M. Grossman, S. C. Reberg-Horton, C. Brinton, and C. Crozier. Nitrogen delivery from legume cover crops in no-till organic corn production. *Agronomy journal*, 103(6):1578–1590, 2011. Horticultural Science; Wheat, Barley and Triticale Abstracts; Plant Breeding; Field Crops; Soils and Fertilizers.

P. Pedersen and J. G. Lauer. Corn and soybean response to rotation sequence, row spacing, and tillage system. *Agronomy Journal*, 95(4):965–971, 2003. Field Crops; Maize; Soyabeans.

J. Peign, B. C. Ball, J. Roger-Estrade, and C. David. Is conservation tillage suitable for organic farming? a review. *Soil Use and Management*, 23(2):129–144, 2007. Weeds; Irrigation and Drainage.

G. T. Place, S. C. Reberg-Horton, and M. G. Burton. Effects of preplant and postplant rotary hoe use on weed control, soybean pod position, and soybean yield. *Weed Science*, 57(3): 290–295, 2009. Soyabeans; Weeds.

A. J. Price, F. J. Arriaga, R. L. Raper, K. S. Balkcom, T. S. Komecki, and D. W. Reeves. Comparison of mechanical and chemical winter cereal cover crop termination systems and cotton yield in conservation agriculture. *Journal of Cotton Science*, 13(4):238–245, 2009. Irrigation and Drainage; Weeds; Wheat, Barley and Triticale Abstracts; Field Crops.

A. L. Rathore, A. R. Pal, and K. K. Sahu. Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. *Journal of the Science of Food and Agriculture*, 78(2):149–161, 1998. Field Crops.

S. C. Reberg-Horton, J. D. Burton, D. A. Danehower, G. Y. Ma, D. W. Monks, J. P. Murphy, N. N. Ranells, J. D. Williamson, and N. G. Creamer. Changes over time in the allelochemical content of ten cultivars of rye (secale cereale l.). *Journal of Chemical Ecology*, 31(1):179–193, 2005. Field Crops; Wheat, Barley and Triticale Abstracts; Plant Breeding; Botanical Pesticides; Weeds.

S. C. Reberg-Horton, J. M. Grossman, T. S. Kornecki, A. D. Meijer, A. J. Price, G. T. Place, and T. M. Webster. Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern usa. *Renewable Agriculture and Food Systems*, 27(1):41–48, 2012. Soils and Fertilizers; Maize; Field Crops.

S. Recous, D. Robin, D. Darwis, and B. Mary. Soil inorganic n availability: effect on maize residue decomposition. *Soil Biology and Biochemistry*, 27(12):1529–1538, 1995. Maize.

D. W. Reeves. Cover crops and rotations, 1994 1994.

M. R. Ryan. *Energy usage, greenhouse gases, and multi-tactical weed management in organic rotational no-till cropping systems*. PhD thesis, The Pennsylvania State University, 2010.

F. Salvagiotti, K. G. Cassman, J. E. Specht, D. T. Walters, A. Weiss, and A. Dobermann. Nitrogen uptake, fixation and response to fertilizer n in soybeans: a review. *Field Crops Research*, 108(1):1–13, 2008. World Agriculture, Economics and Rural Sociology; Crop Physiology; Soyabeans.

SAS. *Procedures guide*. Release 9.1.3. SAS Institute, Cary, NC, 2nd edition, 2006.

H. H. Schomberg, J. L. Steiner, and P. W. Unger. Decomposition and nitrogen dynamics of crop residues: residue quality and water effects. *Soil Science Society of America Journal*, 58 (2):372–381, 1994. Wheat, Barley and Triticale Abstracts.

C. M. Schwendener, J. Lehmann, P. B. de Camargo, R. C. C. Luizo, and E. C. M. Fernandes. Nitrogen transfer between high- and low-quality leaves on a nutrient-poor oxisol determined by 15n enrichment. *Soil Biology and Biochemistry*, 37(4):787–794, 2005. Agroforestry; Forestry.

R. M. Shibles and G. C. Weber. Interception of solar radiation and dry matter production by various soybean planting patterns. *Crop Sci.*, 6:55–59, 1966.

B. Shipley and P. A. Keddy. The relationship between relative growth rate and sensitivity to nutrient stress in twenty-eight species of emergent macrophytes. *Journal of ecology*, 76(4): 1101–1110, 1988. stress Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: JECOA Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 450 J829 Update Code: 00000000.

J. Six, S. D. Frey, R. K. Thiet, and K. M. Batten. Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal*, 70(2):555–569, 2006. Accession Number: 20063091201. Publication Type: Journal Article. Language: English. Number of References: many ref. Registry Number: 7440-44-0. Subject Subsets: Soils and Fertilizers.

A. N. Smith, S. Reberg-Horton, G. T. Place, A. D. Meijer, C. Arellano, and J. P. Mueller. Rolled rye mulch for weed suppression in organic no-tillage soybeans. *Weed Science*, 59(2):224–231, 2011. Soils and Fertilizers; Maize; Wheat, Barley and Triticale Abstracts; Soyabeans; Weeds; Animal Nutrition.

J. M. Stark and S. C. Hart. Diffusion technique for preparing salt solutions, kjeldahl digests, and persulfate digests for nitrogen-15 analysis. *Soil Science Society of America. Soil Science Society of America journal*, 60(6):1846–1855, 1996. polytetrafluoroethylene-encased traps; concentration; ratios; recovery Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: SSSJD4 Category Codes: Soil Chemistry and Physics Subset: Indexing Branch - NAL NAL Call Number: 56.9 So3 Update Code: 00000000.

R.G. Steel, J.H. Torrie, and D.A. Dickey. *Principles and procedures of statistics: A biometric approach*. McGraw-Hill, New Your, 3rd edition, 1996.

J. L. Steiner, H. H. Schomberg, P. W. Unger, and J. Cresap. Crop residue decomposition in no-tillage small-grain fields. *Soil Science Society of America Journal*, 63(6):1817–1824, 1999. Accession Number: 20001911086. Publication Type: Journal Article. Language: English. Number of References: 29 ref. Subject Subsets: Soils and Fertilizers.

M. Stenberg, B. Stenberg, and T. Rydberg. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. *Applied Soil Ecology*, 14(2):135–145, 2000. Field Crops; Wheat, Barley and Triticale Abstracts.

D. E. Stott, H. F. Stroo, L. F. Elliott, R. I. Papendick, and P. W. Unger. Wheat residue loss from fields under no-till management. *Soil Science Society of America Journal*, 54(1):92–98, 1990. Wheat, Barley and Triticale Abstracts.

H. F. Stroo, K. L. Bristow, L. F. Elliott, R. I. Papendick, and G. S. Campbell. Predicting rates of wheat residue decomposition. *Soil Science Society of America Journal*, 53(1):91–99, 1989. Wheat, Barley and Triticale Abstracts.

J. R. Teasdale and C. L. Mohler. The quantitative relationship between weed emergence and the physical properties of mulches [electronic resource]. *Weed Science*, 48(3):385–392, 2000.

J. R. Teasdale, S. B. Mirsky, J. T. Spargo, M. A. Cavigelli, and J. E. Maul. Reduced-tillage organic corn production in a hairy vetch cover crop. *Agronomy journal*, 104(3):621–628, 2012. Maize; Weeds.

P. J. Thorburn, M. E. Probert, and F. A. Robertson. Modelling decomposition of sugar cane surface residues with apsim-residue. *Field Crops Research*, 70(3):223–232, 2001. Field Crops; Irrigation and Drainage; Horticultural Science.

P. A. Torres, A. B. Abril, and E. H. Bucher. Microbial succession in litter decomposition in the semi-arid chaco woodland. *Soil Biology and Biochemistry*, 37(1):49–54, 2005. Forestry; Agroforestry.

C. Tu, F. L. Booker, D. M. Watson, X. Chen, T. W. Rufty, W. Shi, and S. J. Hu. Mycorrhizal mediation of plant n acquisition and residue decomposition: impact of mineral n inputs. *Global Change Biology*, 12(5):793–803, 2006. Plant Pathology; Crop Physiology; Grasslands and Forage.

USDA-AMS. Bi-weekly weighted average report for the week ending, 5/12/2012 2013.

USDA-ERS. Certified organic grains. acres of corn, wheat, oats, barley, sorghum, rice, spelt, millet, buckwheat, and rye by state, 1997 and 2000-08., 7/5/2012 2013.

USDA-ERS and C. Greene. Organic production, 2009.

C. Wagner-Riddle, T. J. Gillespie, and C. J. Swanton. Rye cover crop management impact on soil water content, soil temperature and soybean growth. *Canadian Journal of Plant Science*, 74(3):485–495, 1994. Soyabeans; Soils and Fertilizers; Irrigation and Drainage; Wheat, Barley and Triticale Abstracts.

E. R. Walker, A. Mengistu, N. Bellaloui, C. H. Koger, R. K. Roberts, and J. A. Larson. Plant population and row-spacing effects on maturity group iii soybean. *Agronomy Journal*, 102 (3):821–826, 2010. Field Crops; Crop Physiology.

C. R. Weber, R. M. Shibles, and D. E. Byth. Effect of plant population and row spacing on soybean development and production. *Agronomy Journal*, 58:99–102, 1966.

M. S. Wells, S. Reberg-Horton, and C. Brinton. The influence of six-rye cultivars, on weed suppression and organic soybean yield in a roll-killed cover-crop system. *Weed Science*, In Review, 2013a.

M. S. Wells, S. C. Reberg-Horton, A. N. Smith, and J. M. Grossman. The reduction of plant-available nitrogen by cover crop mulches and subsequent effects on soybean performance and weed interference. *Agron.J.*, 105:1-7(2), 2013b.

T. J. White, T. Bruns, S. Lee, and J. W. Talyor. *Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics*, pages 315–322. Acedemic Press, Inc., New York, 1990.

F. H. Yelverton and H. D. Coble. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (glycine max). *Weed Technology*, 5(1):169–174, 1991. Soyabeans.

B. G. Young, J. M. Young, L. C. Gonzini, S. E. Hart, L. M. Wax, and G. Kapusta. Weed management in narrow- and wide-row glyphosate-resistant soybean (glycine max). *Weed Technology*, 15(1):112–121, 2001. Weeds; Field Crops.

Chapter 4

A RESPONSE SURFACE STUDY TO DETERMINE THE RELATIONSHIP OF NITROGEN IMMOBILIZATION TO VARYING RYE SURFACE RESIDUE RATES IN A MULCHED SYSTEM

4.1 INTRODUCTION

It is not surprising that the demand for organic soybeans for both feedstock and human consumption has continuously grown over the past decade. The increase in demand for organic soybean products has driven the commodity to near record prices, and in many cases organic soybeans sell for twice that of their conventional counterpart (USDA-ERS and Greene, 2009). Even with increase commodity prices, there is considerably higher operational cost in organic soybean production associated primarily with weed management. These operational costs have the potential to reduce the economic and environmental sustainability of the production system.

Weed management in organic soybeans is achieved via a multi-tactic approach utilizing various forms of frequent and intensive cultivation events. Excessive soil cultivation can lead to compaction of the sub-soil layer, increasing water and wind erosion, and increasing soil organic matter decomposition along with elevated energy consumption and labor costs associated with organic soybean production (Bernstein et al., 2011). The increased disturbance to the soil system

can enhance soil degradation resulting in a lost of ecosystem services such as decreased soil aggregate formation (Beare et al., 1997), which could contribute to a loss of soil C sequestration (Six et al., 2006).

One emerging technology that has the potential to increase the sustainability of current organic soybean productions systems is the use of weed suppressive roller-crimped cover crop mulches. The roller-crimper, a ground-driven implement, functions to terminate near-mature cover crops before the no-till planting of the cash crops (Ashford and Reeves, 2003; Reberg-Horton et al., 2012; Wells et al., 2013b). Several studies have demonstrated the effectiveness of cover crop mulch as related to decreased weed crop interference thus increasing the crop productivity of the system (Mirsky et al., 2013; Reberg-Horton et al., 2012; Wells et al., 2013b). The idea and implementation of roller-crimped cover crops paired with annual row crops is not new. The technology necessary to roll-kill the cover crops was originally developed, and has been in use for many years year, in Brazil (Derpsch et al., 1991). This technology recently gain popularity in the US after USDA-ARS National Soil Dynamics Laboratory improved the roller-crimper design and the Rodale Institute popularized it (Kornecki et al., 2009; Institute, 2012).

The primary mechanisms behind the weed suppressive attributes of roller-crimped (i.e. roll-killed) cover crop mulches are both physical and chemical in nature, where physically, cover crop mulches provide a restrictive barrier that augments the soil/surface (i.e. soil moisture and light) microclimate thus inhabiting weed seed germination (Teasdale and Mohler, 2000). Chemically, cover crop mulches suppress weeds through the release of phytotoxic allelopathic chemicals (Reberg-Horton et al., 2005). Both of the above-mentioned mechanisms require sufficient cover crop biomass production to achieve optimum weed suppression. In the case of organic soybean production, 8000-9000 kg ha^{-1} rye dry matter biomass has been reported as minimal thresholds for acceptable weed control in the eastern US (Mirsky et al., 2013; Reberg-Horton et al., 2012).

Despite the physical and chemical mechanisms for weed suppression in roll-killed mulches, recent research suggests that a third mechanism may play an important role in reducing weed/crop interference. Reduced plant available nitrogen (i.e. extractable soil inorganic N) and subsequent N stress in summer annual broadleaves (*Amaranthus Retroflexus* L.), was reported in organic soybean system that utilized roll-killed mulches (Wells et al., 2013b). The lower plant available nitrogen in high residue system suggests that nutrient availability may contribute and enhance the overall weed control of the system.

The idea of a nutritive control mechanism (i.e. N limitation) has not been well reviewed in the cover crop surface mulch context. There is however, a sizable body of literature describing the effects of incorporating high C:N ratio residues into the soil system and the subsequent increase in N immobilization (Burgess et al., 2002; Jin et al., 2008; Recous et al., 1995; Schomberg et al., 1994). The concept of N limitation associated with high C:N ratio surface mulches is not

fully characterized in agriculture setting; however, in forestry systems, N transfer from the soil surface accounted for the entire N-immobilization in the forest litter layer during the first year of decomposition (Hart and Firestone, 1991). Analogous N-immobilization effects were reported when wheat straw residues (ranging from 40-80:1) were applied to soil surfaces (Holland and Coleman, 1987; Schwendener et al., 2005) and fungal translocation of soil N to the surface residues was confirmed as one of the modes of N-transfer (Frey et al., 2000).

Recent research in N dynamic associated with high biomass cover crop mulches have confirmed N-transfer from the soil to the above ground residue, and provide partial confirmation of Frey (2000) fungal translocation mechanisms. However optimal rate of rye biomass that maximized N immobilization have not been established, or determined if the N immobilization event had a measurable response on the escaped weeds in the system. We hypothesize that increased cover crop mulch rates will influence greater immobilization of nitrogen into surface residues thereby limiting plant available nitrogen throughout the soil profile, resulting in increased N stress in the summer annual broadleaves. The objective of this study was to establish the optimal rye residue mulch rates that maximize N immobilization, and determine the N deficit response to the subsequent escaped pigweeds.

4.2 MATERIALS AND METHODS

4.2.1 Study Location and Soil Properties

In 2011, a two site-year experiments was conducted at the Center for Environmental Farming Systems in Goldsboro (GOLD), NC (35.3829°N, 78.035846°W), and USDA-ARS Beltsville Agricultural Research Center (BARC) in Beltsville, MD (39.03269°N, 76.928143°W). The soil type in Goldsboro for 2011 was Wickham loamy sand (fine-loamy, mixed, semiactive, thermic Typic Hapludults) with 2 to 6% slope, and at BARC the soil types were Codorus and Hatboro (mica bearing loamy alluvium), with 0 to 2% slope.

4.2.2 Experimental Design and Macro System Descriptions

Treatments consisted of six rye rates crossed with seven 2-week time intervals without replication for a total of 42 treatment combinations before adding several control treatments to the factorial design. Increased numbers of levels were considered more important for the purpose of response surface modeling than replication of treatment combinations. The time factor is not a repeated measure in this study since each plot was randomly assigned a time at which it would be sampled and each experimental unit was sampled only once. Mulch rates consisted of 0,2000, 5000, 8000, 12000, and 15000 kg ha^{-1} of dry matter. Sample times consisted of 0, 14, 30, 42, 56, 70, and 84 days after planting (Picture 1). Two sets of control plots were added to

the factorial treatments and sampled at each time interval. One control was a plot where rye was grown over the winter. The above ground growth was clipped at the surface and removed before soybean planting. This roots only control was intended to quantify N relations in the absence of surface residue but with roots included. The second control was a bare-ground plot where neither rye roots nor shoots were present. These plots had been maintained in a fallow state through the use of herbicides beginning several months prior to soybean planting. Prior to fall drilling of rye (*Secale cereale* 'Wheeler'), the entire field, at both locations, was disked and field cultivated to remove any existing vegetation from the prior maize crop at Beltsville, and the clover perianal hay crop at Goldsboro. Lime, P, and K were applied according to soil test before rye planting. Rye was sown during mid-October to all treatments via grain drill with 13-cm spacing between rows as a cover crop at a rate of 134 kg ha1. Approximately 30 kg N ha^{-1} was applied to the study as urea ammonium nitrate (UAN) in the fall to the rye crop to ensure adequate N availability for early growth of the rye cover crop. The microcosms (i.e. micro-plots) consisted of a 42, 6.5 mm thick, 0.58 m^2 steel boxes. Before the micro-plots were installed, the rye cover crop was terminated in early June (Feekes growth stage 11.1 or Zadoks growth stage 85) via a mower conditioner haybine. The mowed rye was removed from the experiment area where it was air-dried for one-week. Following the removal of the rye cover crop, the 42 micro-plots boxes were installed directly into the rye cover crop stubble to a depth of 40 cm. To assess ^{15}N contamination to rye surface mulch after injection, rye tissue was collected and evaluated for percent enrichment of ^{15}N. Soybeans (Glycene max L. NC Roy), Maturity Group VI, were hand sown at a rate of 370,650 live seed ha^{-1} with 72.6 cm row spacing. In addition to planting soybeans, pigweeds (*Amaranthus retroflexus* L.) were sown at two symmetric distances (10.2 and 20.3 cm) on either side of the soybeans. After the soybeans and pigweed had been sown, ^{15}N-enriched (NH4)2SO4 solution (99.7 at.%) at a rate of 2 mg ^{15}N per kg soil was uniformly injected using a large gauge needles approximately 5 cm below the soil surface at soybean planting (i.e. zero days after planting, DAP). Following injection of ^{15}N, rye biomass rates according to the prescribed rate was applied to each micro-plot. The rye biomass was separated over the soybean and pigweed furrow to ensure a uniform soybean and pigweed stand. Pigweeds were thin to 8 plants per micro-plot to ensure uniform growth. With exception of the pigweed, the micro-plots were managed weed-free throughout the season by carefully clipping and removing any escaped weeds. Irrigation of 1.27 cm was applied to each micro-plot box weekly for the first five-weeks, afterwards irrigation was administered at a rate of 1.27 cm per micro-plot on an as needed basis.

4.2.3 Parameter Assessments

For each sampling interval, the following soil and crop parameters were used to monitor for ^{15}N movement: rye mulch residue, soybean plant tissues, pigweed tissue, soil extractable inorganic N, and total soil N. Rye surface mulch, soybean and pigweed tissue were collected from the entire micro-plot and air-dried at 60°C for 72 h. After drying, weights were recorded; plant tissues were finely milled (i.e. ball-ground), and analyzed for total N and C by a PerkinElmer (Norwalk, CT) Model 2400 CHN elemental analyzer (Tu et al., 2006). Ball-ground plant tissue was also packed into 9x5 mm tin capsules and sent to Stable Isotope Facility at University of California at Davis to be analyzed for N isotope ratios using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK).

The monitoring of soil inorganic N was achieved via the collecting of 16, 7.6 cm diameter cores at a depth of 10 cm. Bulk density and soil moisture were also collected for each sampling interval. Soil samples were homogenized, wet sieved (2 mm) to remove any plant material and rocks, and placed in cold (4°C) storage for transport. Twenty grams of field moist sieved soils were extracted in 50 ml of 0.5 M K2SO4 and shaken for 30 minutes on an orbital shaker (Frey et al., 2000; Hart et al., 1994). After samples had been shaken, the soil suspension was filtered with filter papers that had been preleached with 100 ml 0.5 M K_2SO_4 (Fisher Scientific Filter Paper Grade Q2), and subsamples were analyzed for ammonium and nitrate on a Quick Chem 8000 Lachat (Keeney and Nelson, 1982). To determine the ^{15}N content in the soil, samples were diffused and the filter paper acid traps containing the diffused N were sent to University of California at Davis to be analyzed for N isotope ratios using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK)(Brooks et al., 1989; Frey et al., 2000; Stark and Hart, 1996).

4.2.4 Statistical Analysis

Model fitting for the data was conducted utilizing exponential growth and decay equations in proc NLIN environment (SAS, 2006). Rye biomass decomposition and rye nitrogen loss were modeled across all rye rates with the following exponential decay equation.

$$y = (P + sP * rate) * e^{(-k*DAP)} \tag{4.1}$$

Whereas rye ^{15}N content and soil extractable inorganic N were modeled as quadratic functions (n 2) where non-significant terms were kept in the model. Total N from soybeans and pigweeds (both 10 and 20 cm) were model using exponential growth functions in proc NLIN environment

(SAS, 2006).

$$y = (P + sP * rate) * e^{((k+sk*rate)*DAP)} \tag{4.2}$$

Where P = initial pool size, sP = the slope P, k = decay constant, and DAP = days after soybean planting. Rye ^{15}N content and soil extractable inorganic N was modeled as quadratic functions ($n \leq 2$) where non-significant terms were kept in the model. Total N from soybeans and pigweeds (both 10 and 20 cm) were model using exponential growth functions in proc NLIN environment (SAS, 2006). All data is presented as modeled responses.

4.3 RESULTS AND DISCUSSION

4.3.1 Rye Surface Residue Decomposition

Rye residue decomposition rates, with exception of the 2000 kg ha^{-1} rye biomass rate, were approximately constant ($k \approx 0.03$) at BARC (Figure 1). However, rye decomposition dynamics were more variable at GOLD with a quadratic relationship ($r^2 = 0.98$) observed for k as a function of increasing rye residue rate (Figure 1). The modeled decay rates k for GOLD increased from $k = 0.01$ for the 2000 kg ha^{-1} rye residue rate to the maximum of $k = 0.05$ observed for 10,000 kg ha^{-1} rye biomass rate (Figure 1). As a result of increasing rye residue decay rates k observed at GOLD translated into enhanced decomposition was in the heavier (i.e. $15,000 > 12,000 > \cdots >$ 2000 kg ha^{-1}) rye surface mulch rates (Figure 2). Even though both locations experiences non-constants rye biomass decomposition, at Goldsboro there was greater increase in rye decomposition rate associated with ascending rye rates, whereas at BARC, with exception to the 2000 kg ha^{-1} rye surface mulch rate, there was less observer separation in rye decomposition rates when compared to similar rye surface mulch rates at Goldsboro (Figure 1 and 2). Giving the body of literature indicating that residue decomposition is inversely related to increasing residue rates (Brown and Dickey, 1970; Parr and Papendick, 1978; Stroo et al., 1989; Stott et al., 1990; Steiner et al., 1999; Thorburn et al., 2001), the observed greater rye decomposition proportional to the greater initial rye surface mulch rate is paradoxical. The increased rye decomposition (Figure 1 and 2) at GOLD, proportional to increasing rye surface residue rates, can be explained through the augmentation of the soil surface microclimate and the corresponding enhancement of the soil fauna, and micro-arthropods associated with decomposition. Micro-arthropods are essential in early biomass decomposition, where through fragmentation; they increase the surface area of the detritus thereby enhancing microbial colonization (Londono-R et al., 2013). It is possible that the paradoxical decomposition observed at GOLD and to a lesser degree at BARC could be explained by improvements to the environmental conditions that increased decomposition of rye surface residues through ensuring bioavailability of essentially resource and providing microclimates and edaphic conditions that

optimize decomposition (Londono-R et al., 2013). Conservation of soil moisture is one of the many advantages of farming systems that utilize mulches (Mulumba and Lal, 2008), where even a partial covering of the soil with residues can increase soil moisture storage content (Rathore et al., 1998). Several studies have identified that available soil moisture exerts significant controls on decomposition rates (Fraser and Hockin, 2013), and moisture, not temperature was reported as the dominant climatic control on decomposition (Murphy et al., 1998; Torres et al., 2005; Bontti et al., 2009). Mulumba and Lal (2008) reported that wheat mulches ranging from 0 to 16 Mg ha^{-1} had an logarithmic effect on field capacity moisture where no gain in soil moisture retention was observed above 10 Mg ha^{-1}. It is possible, especially at Goldsboro that the increased decomposition for the 8000, 12,000, and 15,000 kg ha^{-1} rye residue rates, was a result of differential dry down of the surface mulch after the irrigation events. In the higher rye residue rates, microclimates conditions conducive for decomposition could have remained optimal for an increased period in the 12,000 and 15,000 kg ha^{-1} rye residue rates, whereas, rates less than or equal to 8000 kg ha^{-1} experienced hasten decline in soil moisture (i.e. logarithmic decline) thereby diminishing the time frame for decomposition.

4.3.2 Rye Surface Residue Nitrogen Status

Total N content of the rye mulch declined across all rye residue rates at BARC and GOLD (with exception of the 2000 and 5000 kg ha^{-1} rye residue rates) (Figure 2) where the 15,000 kg ha^{-1} rye residue rates experienced the largest N losses totaling 25 and 19 kg N ha^{-1}, respectively (Figure 2). However, at Goldsboro, the 12,000 and 15,000 kg ha^{-1} residue rates experienced greater N losses when compared to the lower residue rates (Figure 2). The rapid loss of N from the rye was surprising, since prior to this study, rye cover crop mulches had not been considered as N sources (i.e. rye C:N ratio ¿ 50:1) to the system especially during the first month of decomposition, which corresponds to the critical weed-free period in soybeans (Acker et al., 1993).

Despite the total N losses across all residue rates and BARC, and the 8000, 12,000 and 15,000 kg ha^{-1} at GOLD, there still was a detectable enrichment of ^{15}N in the all rye residue ranging from the maximums of 0.04 and 0.03 kg ^{15}N ha^{-1}, respectively indicating N transfer from the detritusphere to the rye surface mulch (Figure 3). This translocation of N from the soil to the surface was greatest in the 12,000 and 15,000 kg ha^{-1} rates at BARC, and the 8000 and 12,000 kg ha^{-1} rates at GOLD (Figure 3). The amount of N both loss from the rye residue (Figure 2) and N transferred into the rye from the detritusphere (Figure 3), demonstrates the bi-directional movement of N in the system and could offer explanation to why soil extractable inorganic N from rye mulched plots previously measured by Wells et al (2013) remained relatively unchanged throughout the season.

ha^{-1}Studies have reported a net N immobilization of 18 20 kg N ha^{-1} for rye loading rates of 2500 and 4500 kg ha^{-1} DM which consequently had reduce N mineralizing potential when compared to the greater biomass rates utilized in this study (Beare et al., 1992; Frey et al., 2000). Frey et al., (2000) described the mechanism of upward enrichment of total N into surface mulches as fungal translocation. It is possible that rye residue rates above 8000 kg ha^{-1} are experiencing greater N mineralizing and leaching as a result of greater bacterial and micro-arthropod driven decomposition associated with increase moisture conservation. Rye rates 8000 kg ha^{-1} and below, could experience moisture limitation along with other abiotic stressors earlier than the heavier rye rates, thus fungal decomposition of available carbon would be enhanced since fungi are less sensitive moisture limited environments than bacteria (Lennon et al., 2012); greater N-immobilization would be observed under these conditions.

4.3.3 Extractable Soil Inorganic Nitrogen and Plant Response

Extractable soil inorganic N declined throughout the season at BARC and GOLD approximately to 6 and 4 kg N ha^{-1} by the end of the season (Figure 4). Contrasting the extractable soil inorganic N losses observed between the rye residue rates, the 'No Rye Check' at GOLD was the only treatment that observed an increase in extractable soil inorganic N (Figure 4). This increase in N could be a response to increased soil temperatures compared to the other rye residue rates thereby enhancing N mineralization.

At BARC the soil extractable N losses were similar across all rye residue rates, whereas the greatest concentration of soil N among the rye residue rates was observed in the 12,000 and 15,000 kg ha^{-1} (Figure 4). The 8,000 kg ha^{-1} rye residue rate had the lowest extractable soil inorganic N concentrations at GOLD when compared the other rye residue rates. Given the amount of extractable soil N concentrations in the No Rye Check, the effect rye residues on extractable soil N was most pronounced at GOLD where the greatest upward fungal translocation of N was observed in the 8,000 kg ha^{-1} rye residue (Figure 3), and resulting in the lowest extractable soil inorganic N concentrations observed in the 8000 kg ha^{-1} rye residue rate (Figure 4). This finding demonstrates the N suppressive nature of cover crop mulches on extractable N. Even though there was minimal effect of individual rye residue rates on extractable soil inorganic N at BARC, the extractable soil inorganic N pool did decreased to approximately 5 kg N ha^{-1}, and was within the range of N-limitation to negatively influence summer annual broadleaves such as pigweed at both BARC and GOLD (Wells et al., 2013b).

Pigweed tissue N averaged over locations measured 10 and 20 cm from the soybean row was lowering for all the rye residue rates including the Rye Roots Only than the No Rye Check treatments (Figure 5). By the end of the study (84 DAP), the No Rye Check treatments for the 10 and 20 cm had approximately 4 and 2.5 times greater tissue N than the rye residue

treatments (Figure 5). Even thought the 10 cm pigweeds exhibited overall lower tissue N across all treatments when compared to the 20 cm pigweeds, there was an observable effect of rye residue rate on pigweed tissue N. The differences of pigweed tissue N were less pronounced in the 20 cm pigweeds (Figure 5).

In the 10 cm pigweeds, the lowest tissue N was measured in the 15,000 kg ha^{-1} rye residue rate, following the 12,000 and 8000 kg ha^{-1} rye residue rates (Figure 5). This is not surprising since the greatest fungal transfer ^{15}N to the rye resides was observed at both BARC and GOLD in the rates 8000 kg ha^{-1} and greater (Figure 3). The rye residue that experiences the lowest transfer for ^{15}N, the 2000 kg ha^{-1} rye residue rate, corresponded to pigweeds with the greatest tissue N content (Figure 3 and 5). Species such as pigweed, which experience increased growth rates in N rich environments, can be the most sensitive to suboptimal extractable inorganic N concentrations (Shipley and Keddy, 1988). Similar N stress in pigweeds was demonstrated by Wells et al. (2013), where they establish that pigweeds grown in roll-killed rye residues of 7000 8000 kg ha^{-1} had C:N ratios as high as 40:1 after eight weeks after planting compared to the 10:1 C:N ratios observed in plots free of rye residues. The N-immobilization effect of rye surface residues on pigweed N assimilation (10 cm) is most evident in the 'Rye Roots Only' treatment. This treatment was managed similar to the other rye residue treatment with exception of receiving about ground biomass; however, in the absence of rye surface residues, this treatment negatively influence pigweed tissue N during the first 40 DAP as well as the 8000 kg ha^{-1} rate (Figure 5). Since the 'Rye Roots Only' treatment did not have receive surface residue or the possible mineralized DON as observed by the N losses from the other rye residue rates, demonstrates, at least in the 10 cm pigweeds, N losses from the rye residues are not sufficient to influence the growth and N assimilation of the pigweeds that are placed in close proximity of the soybean row. It is highly possible that the bulk of N-immobilization is driven by the rye roots and is occurring in the O and A soil horizons. The lower pigweed tissue N observed in the 10 cm pigweeds illustrates the intense composition for available resources in the proximity of the soybeans.

Soybean tissue N at BARC showed improvements (i.e. great N assimilation) among all of the residue rates when compared to both the No Rye Check and the 'Rye Roots Only' treatment where the 12,000 and 15,000 kg ha^{-1} rye residue rates corresponded to soybeans with the greatest N content 40 DAP (Figure 6). Soybeans from the 'No Rye Check' at BARC, 50 DAP, had the lowest tissue N content when compared to the other treatments. The lower soybean N content in the 'No Rye Check' is most likely the result of lower extractable soil inorganic N observed through out the season at BARC (Figure 4).

At GOLD, there were marginal differences in soybean tissue N between the rye residue treatments (Figure 6). Despite the increased in extractable soil inorganic N observed in the 'No Rye Check' treatment (Figure 4), there was no observed effect on the soybean tissue N. The

overall effect of the rye residues on soybean tissue N observed at BARC and GOLD support the resilience of legume cash crops in N limited environments.

4.4 CONCLUSION

In summary, this body of work does provide evidence of a third nutritive weed control mechanism in high residue mulched systems. Rye residue rate did influence the amount of ^{15}N translocate to the surface residues where the greatest upward movement observed in rates 8000 kg ha^{-1} and above. The increased N transfer from the to detritusphere to both the surface mulch and possible the rye roots did negatively impact pigweed tissue status in proximity of the soybean row. However, marginal effects to soybean tissue N was observed under the varying rye residue rates.

Along with shedding light to some of the mechanism driving nutrient limitations in mulched systems, rye residue decomposition dynamics depending on initial biomass rates was surprising. It is possible that the greater residue rates are shielded from harmful biotic and abiotic events thereby increasing decomposition through improving the micro-climates through out the mulch layer and at the detritusphere.

Future research is needed to quantify the increased decomposition proportional to rye surface rates. Detailed measurements and characterizations of the biota along with monitoring the microclimate in these mulched environments are critical to improving our understanding of the complex relationship and intense competition for available resource in high biomass mulched environments.

4.5 FIGURE CAPTIONS, TABLES AND FIGURES

4.5.1 Figures

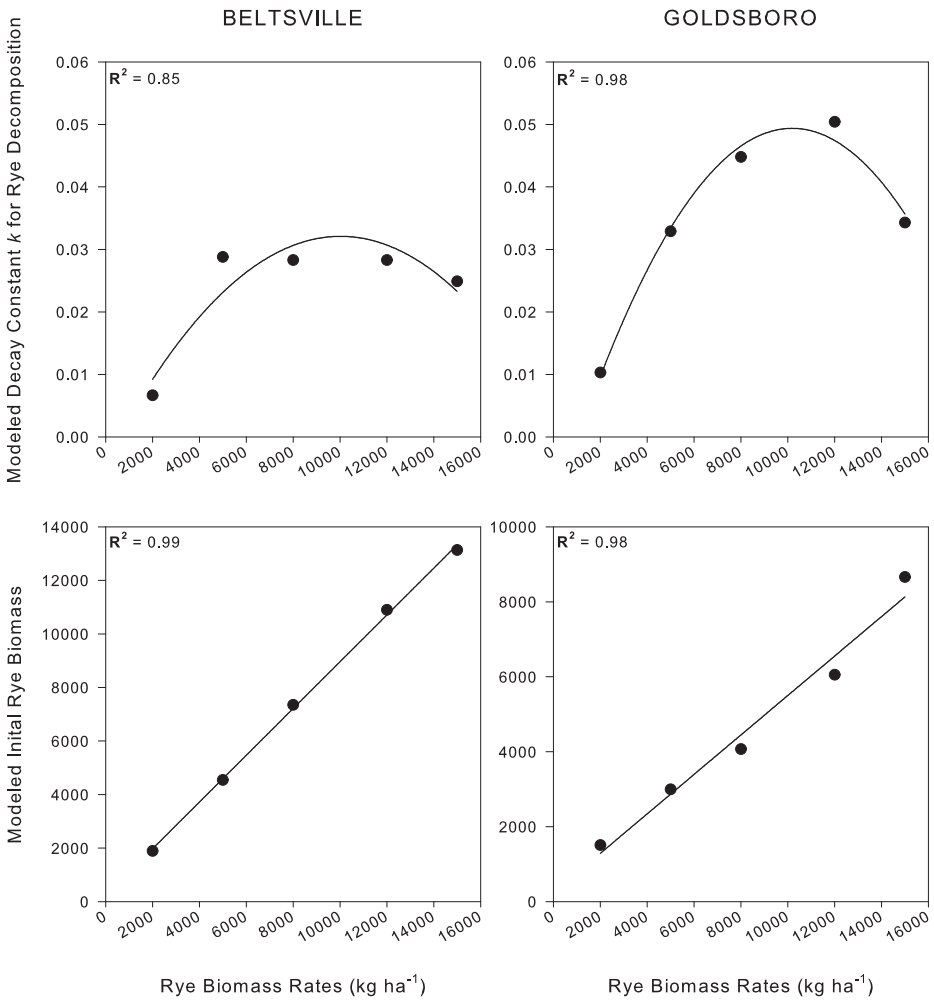

Figure 4.1: Rye decomposition modeling parameters: Decay constant k and initial rye biomass pool size p rye residue rates for Beltsville, MD and Goldsboro, NC (2011).

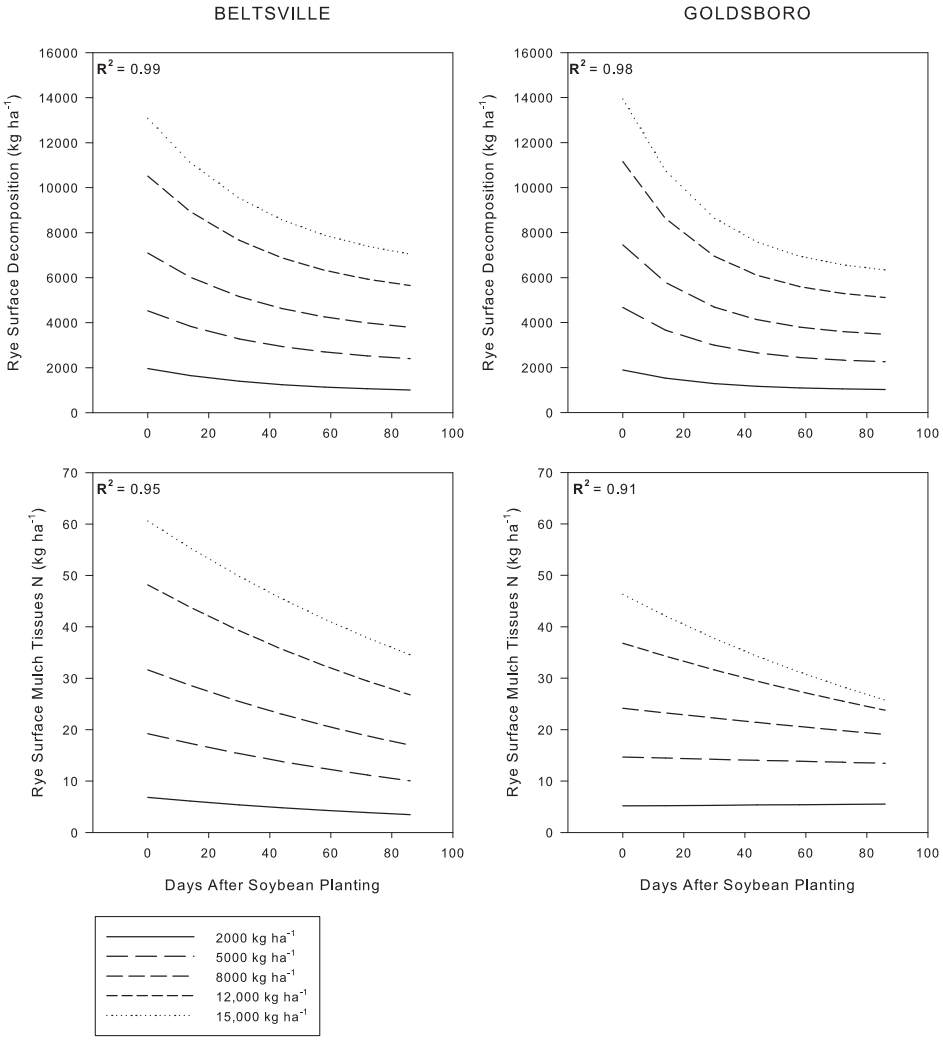

Figure 4.2: Predicated exponential decomposition and nitrogen losses for rye mulch rates at Beltsville, MD and Goldsboro, NC.

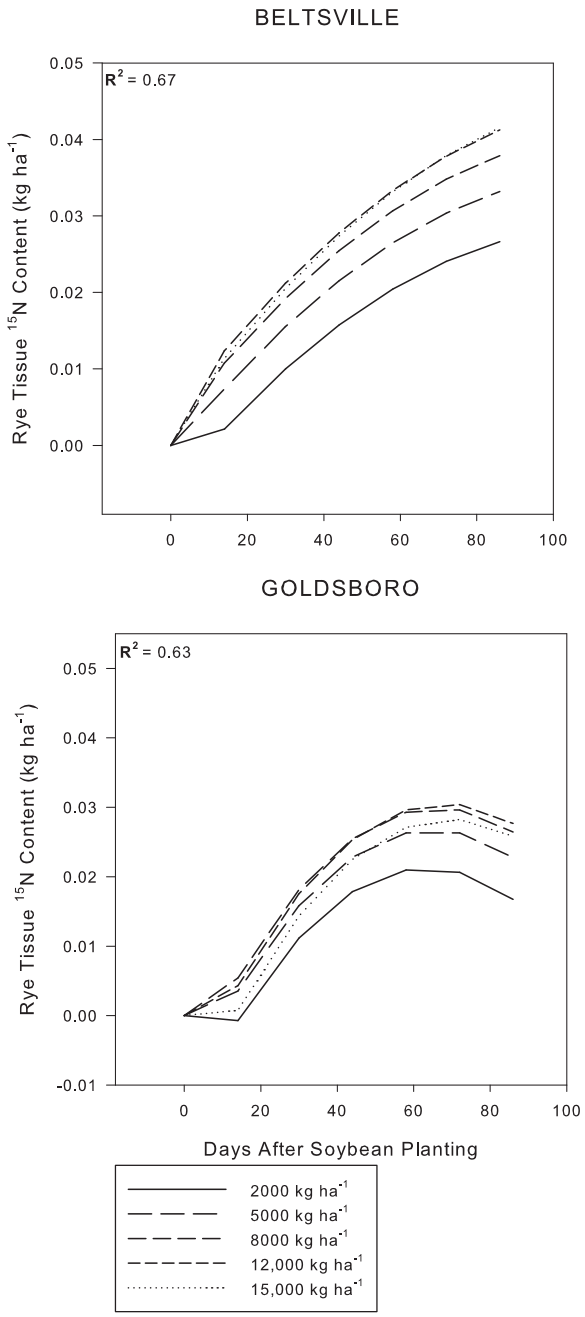

Figure 4.3: Modeled ^{15}N concentrations in rye surface mulch for Beltsville, MD and Goldsboro, NC (2011).

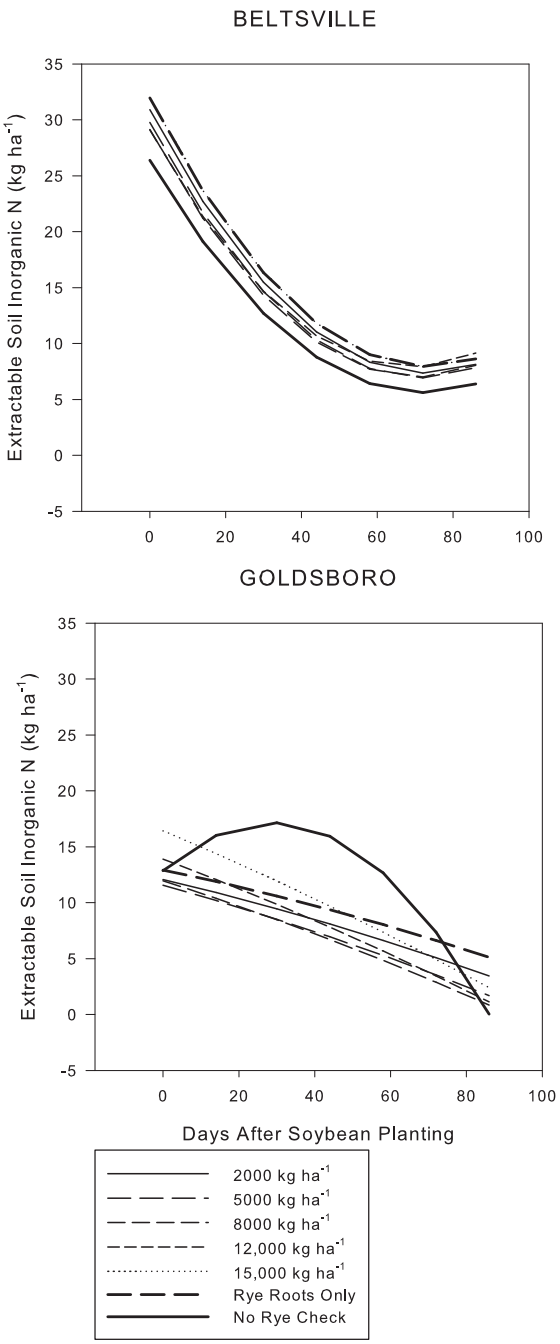

Figure 4.4: Extractable soil inorganic N monitored over six rye surface mulch rates including a Rye Roots Only rate and the No Rye Check for Beltsville, MD ($R^2 = 0.784$) and Goldsboro, NC ($R^2 = 0.56$). The Rye Roots Only treatment received zero rye surface mulch.

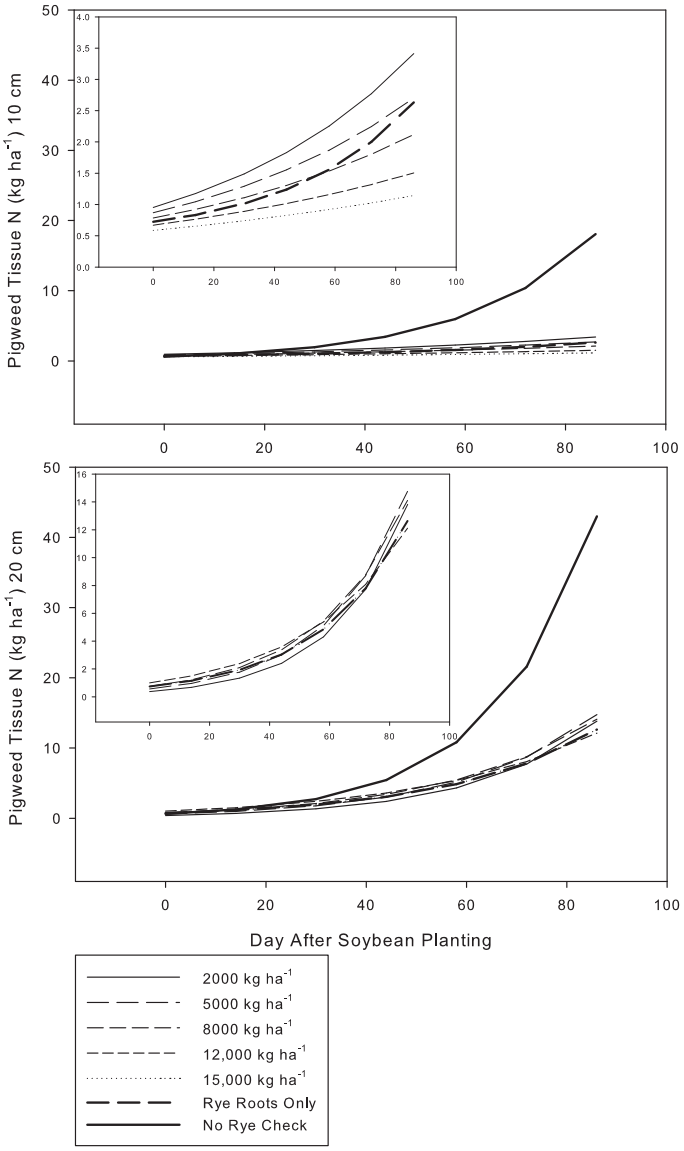

Figure 4.5: Modeled pigweed (*Amaranthus retroflexus* L.), tissue N averaged over Beltsville, MD and Goldsboro, NC for pigweeds harvested 10 ($r^2 = 0.30$) and 20 ($r^2 = 0.83$) cm away from the soybean row.

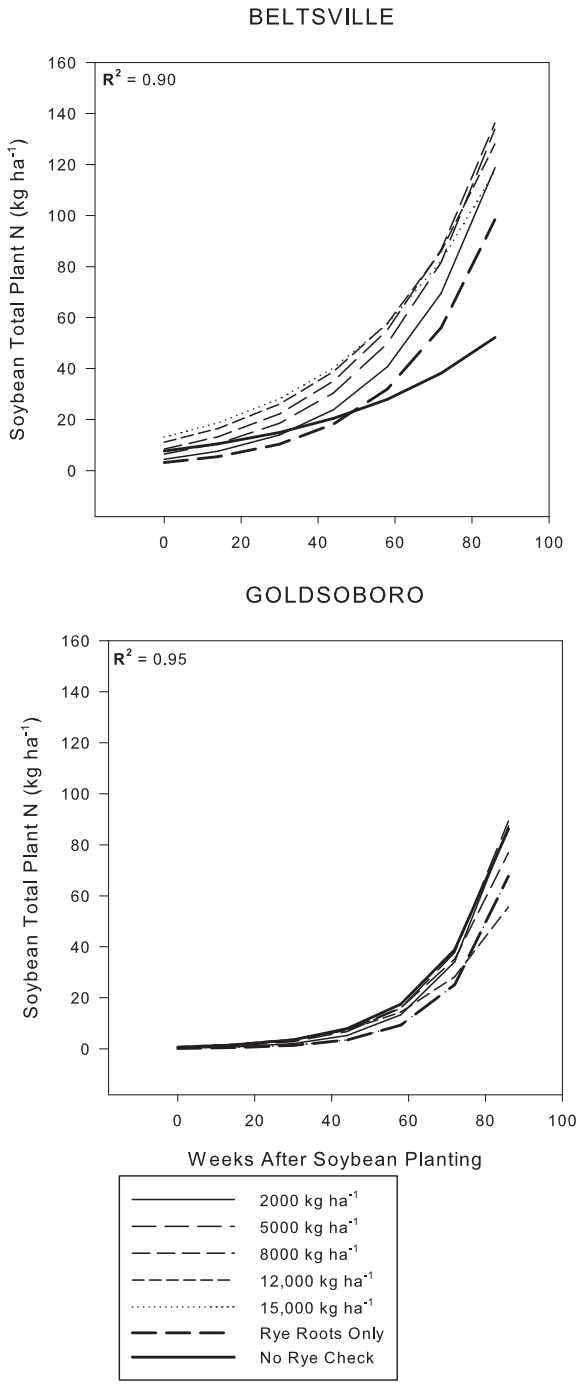

Figure 4.6: Modeled soybean (*Glycene max* L. NC Roy) tissue N as affected by rye surface mulch rates averaged over Beltsville, MD and Goldsboro, NC. The Rye Roots Only treatment received zero rye surface mulch.

REFERENCES

J. K. Aase and D. L. Tanaka. Soil water evaporation comparisons among tillage practices in the northern great plains. *Soil Science Society of America Journal*, 51(2):436–440, 1987. Irrigation and Drainage.

J. D. Aber and J. M. Melillo. Nitrogen immobilization in decaying hardwood leaf litter as a function of initial nitrogen and lignin content. *Canadian Journal of Botany*, 60(11):2263–2269, 1982. Forestry; Soils and Fertilizers.

R. E. van Acker, C. J. Swanton, and S. F. Weise. The critical period of weed control in soyabean (glycine max (l.) merr.). *Weed Science*, 41(2):194–200, 1993. Weeds; Soyabeans.

D. L. Ashford and D. W. Reeves. Use of a mechanical roller-crimper as an alternative kill method for cover crops. *American journal of alternative agriculture*, 18(1):37–45, 2003. Accession Number: IND43646603 Pagination: p. 37-45. Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

M. H. Beare, R. W. Parmelee, P. F. Hendrix, W. Cheng, D. C. Coleman, and D. A. Crossley. Microbial and faunal interactions and effects on litter nitrogen and decomposition in agroecosystems. *Ecological Monographs*, 62(4):569–591, 1992. Accession Number: 19951908046. Publication Type: Journal Article. Language: English. Number of References: 96 ref. Registry Number: 7727-37-9.

M. H. Beare, P. F. Hendrix, D. C. Coleman, and S. Hu. Influences of mycelial fungi on soil aggregation and organic matter storage in conventional and no-tillage soils. *Applied soil ecology : a section of Agriculture, Ecosystems and Environment*, 5(3):211–219, 1997. soil carbohydrates; sandy clay loam soils; respiration; macroaggregates Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Category Codes: Soil Chemistry and Physics; Soil Cultivation and Cropping Systems; Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH541.5.S6A67 Update Code: 00000000.

E. R. Bernstein, J. L. Posner, D. E. Stoltenberg, and J. L. Hedtcke. Organically managed no-tillage rye-soybean systems: agronomic, economic, and environmental assessment. *Agronomy Journal*, 103(4):1169–1179, 2011. Soyabeans; Wheat, Barley and Triticale Abstracts; Irrigation and Drainage; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers.

Eliana E. Bontti, Ingrid C. Burke, Stephanie Owens, Mark E. Harmon, William J. Parton, Michelle L. Haddix, Seth M. Munson, Joseph P. Decant, Agnieszka Przeszlowska, and Mark A. Gathany. Litter decomposition in grasslands of central north america (us great plains) [electronic resource]. *Global change biology*, 15(5):1356–1363, 2009. root and leaf decomposition; Great Plains (USA); litter decomposition Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Genre: Internet resource Subset: Indexing Branch - NAL NAL Call Number: QC981.8.C5G6323 Update Code: 00000000.

G Bowman. *Steel in the Field: A Farmers' Guide to Weed Mangement Tools.* Sustainable Agriculture Publications, University of Vermont, Burlington, VT, 1997.

P. D. Brooks, J. M. Stark, B. B. McInteer, and T. Preston. Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. *Soil Science Society of America Journal*, 53(6): 1707–1711, 1989. Accession Number: 19901942338. Publication Type: Journal Article. Language: English. Number of References: 21 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

P. L. Brown and D. D. Dickey. Losses of wheat straw residue under simulated field conditions, 1970. Accession Number: CAIN709036937 Pagination: p. 118-121. Language(s): English General Note: Bibliography: p. 121 NAL Call Number: 56.9 SO3 Update Code: 00000000.

J. L. de Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agronomy Journal*, 100(3):704–710, 2008. World Agriculture, Economics and Rural Sociology.

D. Bullock, A. Rayburn, and S. Khan. Soybean yield response to narrow rows is largely due to enhanced early growth. *Crop science*, 38(4):1011–1016, 1998. growth; plant height; determinate and indeterminate habit Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: CRPSAY Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 64.8 C883 Update Code: 00000000.

M. S. Burgess, G. R. Mehuys, and C. A. Madramootoo. Nitrogen dynamics of decomposing corn residue components under three tillage systems. *Soil Science Society of America Journal*, 66 (4):1350–1358, 2002. Soils and Fertilizers.

O. C. Burnside and R. S. Moomaw. Control of weeds in narrow-row soybeans. *Agronomy Journal*, 69(5):793–796, 1977. Weeds; Field Crops.

R. B. Campbell, R. E. Sojka, and D. L. Karlen. Conservation tillage for soybean in the u.s. southeastern coastal plain. *Soil and Tillage Research*, 4(6):531–541, 1984. Agricultural Engineering.

M. A. Cavigelli, B. L. Hima, J. C. Hanson, J. R. Teasdale, A. E. Conklin, and Y. C. Lu. Long-term economic performance of organic and conventional field crops in the mid-atlantic region. *Renewable Agriculture and Food Systems*, 24(2):102–119, 2009. Field Crops; Plant Genetic Resources; Grasslands and Forage; Weeds; World Agriculture, Economics and Rural Sociology; Soyabeans; Soils and Fertilizers; Horticultural Science; Maize.

M. A. Cavigelli, S. B. Mirsky, J. R. Teasdale, J. T. Spargo, and J. Doran. Organic grain cropping systems to enhance ecosystem services. *Renewable Agriculture and Food Systems*, 28(2):145–159, 2013. Conference paper. Language: English. Number of References: 126 ref. Registry Number: 7727-37-9. Subject Subsets: Weeds; Soils and Fertilizers.

K. Chandler, Shrestha Anil, and C. J. Swanton. Weed seed return as influenced by the critical weed-free period and row spacing of no-till glyphosate-resistant soybean. *Canadian Journal of Plant Science*, 81(4):877–880, 2001. Seed Science; Soyabeans; Field Crops; Weeds.

A. J. Clark, A. M. Decker, J. J. Meisinger, and M. S. McIntosh. Kill date of vetch, rye, and a vetch-rye mixture: Ii. soil moisture and corn yield. *Agronomy Journal*, 89(3):434–441, 1997. Maize; Wheat, Barley and Triticale Abstracts.

R. L. Cooper. Response of soybean cultivars to narrow rows and planting rates under weed-free conditions. *Agronomy Journal*, 69(1):89–92, 1977. Field Crops.

W. J. Cox and J. H. Cherney. Growth and yield responses of soybean to row spacing and seeding rate. *Agronomy Journal*, 103(1):123–128, 2011. Field Crops; Soyabeans; World Agriculture, Economics and Rural Sociology.

C. D. Dalley, J. J. Kells, and K. A. Renner. Effect of glyphosate application timing and row spacing on corn (zea mays) and soybean (glycine max) yields. *Weed Technology*, 18(1): 165–176, 2004. Soyabeans; Field Crops; Maize; Weeds.

Adam S. Davis. Cover-crop rollercrimper contributes to weed management in no-till soybean [electronic resource]. *Weed Science*, 58(3):300–309, 2010. Plant Physiology and Biochemistry; Soil Cultivation and Cropping Systems; Plant Production (Field Crops); Soil Fertility, Fertilizers and Manures Subset: Indexing Branch - NAL NAL Call Number: 79.8 W41 Update Code: 00000000.

J.L. De Bruin and P. Pedersen. Effect of row spacing and seeding rate on soybean yield. *Agron.J.*, 100(704-710), 2008.

K. Delate, D. Cwach, and C. Chase. Organic no-tillage system effects on soybean, corn and irrigated tomato production and economic performance in iowa, usa. *Renewable Agriculture and Food Systems*, 27(1):49–59, 2012. Soils and Fertilizers; Wheat, Barley and Triticale Abstracts; Maize; Soyabeans; Horticultural Science; World Agriculture, Economics and Rural Sociology.

R. Derpsch, C.H. Roth, N Sidiras, and U Kopke. *Controle da erosao no Parana, Brazil: Sistemas de cobertura do solo, plantio directo e prepare conservacionista do solo.* Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany., 1991.

F. G. Dou, A. L. Wright, and F. M. Hons. Depth distribution of soil organic c and n after long-term soybean cropping in texas. *Soil and Tillage Research*, 94(2):530–536, 2007. Soils and Fertilizers; Soyabeans; Field Crops.

L. H. Fraser and A. D. Hockin. Litter decomposition rates of two grass species along a semi-arid grassland-forest ecocline. *Journal of Arid Environments*, 88:125–129, 2013. Forestry; Grasslands and Forage; Soils and Fertilizers; Plant Genetic Resources; Plant Breeding.

S. D. Frey, E. T. Elliott, K. Paustian, and G. A. Peterson. Fungal translocation as a mechanism for soil nitrogen inputs to surface residue decomposition in a no-tillage agroecosystem. *Soil Biology and Biochemistry*, 32(5):689–698, 2000. Wheat, Barley and Triticale Abstracts.

Yoshiharu Fujii. Screening and future exploitation of allelopathic plants as alternative herbicides with special reference to hairy vetch. *Journal of Crop Production*, 4(2):257, 2001.

M. Gardes and T. D. Bruns. Its primers with enhanced specificity for basidiomycetes - application to the identification of mycorrhizae and rusts. *Molecular Ecology*, 2(2):113–118, 1993. Agricultural Biotechnology.

C. R. Grau, E. S. Oplinger, E. A. Adee, E. A. Hinkens, and M. J. Martinka. Planting date and row width effect on severity of brown stem rot and soybean productivity. *Journal of Production Agriculture*, 7(3):347–351, 1994. Plant Breeding; Soyabeans.

R. Grisso, D. L. Holshouser, and R. M. Pitman. Equipment considerations for no-till soybean seeding, 2009.

J. L. Gunsolus. Mechanical and cultural weed control in corn and soybeans. *American journal of alternative agriculture*, 5(3):114–119, 1990. mechanical methods; yield losses; interrow cultivation Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Category Codes: Plant Production (Field Crops); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: S605.5.A43 Update Code: 00000000.

D. B. Harder, C. L. Sprague, and K. A. Renner. Effect of soybean row width and population on weeds, crop yield and economic return. *Weed Technology*, 21(3):744–752, 2007. Soyabeans; World Agriculture, Economics and Rural Sociology.

S. C. Hart and M. K. Firestone. Forest floor-mineral soil interactions in the internal nitrogen cycle of an old-growth forest. *Biogeochemistry*, 12(2):103–127, 1991. Soil Biology Subset: Indexing Branch - NAL NAL Call Number: QH345.B564 Update Code: 00000000.

S. C. Hart, J. M. Stark, and E. A. Davidson. *Nitrogen mineralization, immobilization, and nitrification*, pages 985–1018. Soil Science Society of America Inc., Madison, WI, 1994.

L. G. Heatherly and S. R. Spurlock. Yield and economics of traditional and early soybean production system (esps) seedings in the midsouthern united states. *Field Crops Research*, 63(1):35–45, 1999. World Agriculture, Economics and Rural Sociology; Soyabeans.

L. S. Heiffig, G. M. de S. Cmara, L. A. Marques, D. B. Pedroso, and S. M. de S. Piedade. The plasticity of soybean (glycine max (l.) merrill) crop in different spacing arrangements. / plasticidade da cultura da soja (glycine max (l.) merrill) em diferentes arranjos espaciais. *Revista de Agricultura (Piracicaba)*, 84(3):204–219, 2009. Field Crops; Soyabeans.

M. L. Hoffman, E. E. Regnier, and J. Cardina. Weed and corn (zea mays) responses to a hairy vetch (vicia villosa) cover crop. *Weed Technology*, 7(3):594–599, 1993. Weeds; Field Crops; Maize.

E. A. Holland and D. C. Coleman. Litter placement effects on microbial and organic matter dynamics in an agroecosystem. *Ecology*, 62(2):425–433, 1987. Wheat, Barley and Triticale Abstracts.

J. M. Holland. The environmental consequences of adopting conservation tillage in europe: reviewing the evidence. *Agriculture, Ecosystems and Environment*, 103(1):1–25, 2004. Agricultural Entomology; World Agriculture, Economics and Rural Sociology; Soils and Fertilizers; Plant Pathology.

J. P. Huelsenbeck and K. A. Crandall. Phylogeny estimation and hypothesis testing using maximum likelihood. *Annual Review of Ecology and Systematics*, 28:437–466, 1997. Accession Number: 19980103293. Publication Type: Journal Article. Language: English. Number of References: 126 ref. Subject Subsets: Animal Breeding.

E. R. Ingham and D. C. Coleman. Effects of streptomycin, cycloheximide, fungizone, captan, carbofuran, cygon, and pcnb on soil microorganisms. *Microbial Ecology*, 10(4):345–358, 1984. Plant Pathology; Soils and Fertilizers.

E. R. Ingham, C. Cambardella, and D. C. Coleman. Manipulation of bacteria, fungi and protozoa by biocides in lodgepole pine forest soil microcosms: effects on organism interactions and nitrogen mineralization. *Canadian Journal of Soil Science*, 66(2):261–272, 1986. Forestry.

Rodale Institute. No-till revolution, 2012.

III Jaeger, C. H., R. K. Monson, M. C. Fisk, and S. K. Schmidt. Seasonal partitioning of nitrogen by plants and soil microorganisms in an alpine ecosystem. *Ecology*, 80(6):1883–1891, 1999. Accession Number: 19991912029. Publication Type: Journal Article. Language: English. Number of References: 33 ref. Registry Number: 7727-37-9. Subject Subsets: Soils and Fertilizers.

Ke Jin, S. Sleutel, S. De Neve, D. Gabriels, DianXiong Cai, JiYun Jin, and G. Hofman. Nitrogen and carbon mineralization of surface-applied and incorporated winter wheat and peanut residues. *Biology and Fertility of Soils*, 44(4):661–665, 2008. Soils and Fertilizers; Irrigation and Drainage.

D. R. Keeney and D. W. Nelson. Nitrogen - inorganic forms. *Methods of soil analysis. Part 2. Chemical and microbiological properties*, pages 643–698, 1982. Accession Number: 19841981457. Publication Type: Miscellaneous. Language: English. Number of References: approx. 170 ref. Registry Number: 7727-37-9, 7664-41-7. Subject Subsets: Soils and Fertilizers.

A. Kessavalou, J. H. Qian, T. A. Kettler, J. W. Doran, and W. L. Powers. Bromide and nitrogen-15 tracers of nitrate leaching under irrigated corn in central nebraska [electronic resource]. *Journal of environmental quality*, 25(5):1008–1014, 1996. Soil Biology; Mathematics and Statistics; Soil Chemistry and Physics; Pollution; Irrigation and Drainage Subset: Indexing Branch - NAL NAL Call Number: QH540.J6 Update Code: 00000000.

T. S. Kornecki, F. J. Arriaga, R. L. Raper, and A. J. Price. New roller crimper concepts for mechanical termination of cover crops in conservation agriculture. *Renewable agriculture and food systems*, 24(3):165–173, 2009.

J. T. Lennon, Z. T. Aanderud, B. K. Lehmkuhl, and Jr. Schoolmaster, D. R. Mapping the niche space of soil microorganisms using taxonomy and traits. *Ecology*, 93(8):1867–1879, 2012. Irrigation and Drainage.

L. M. Londono-R, D. Tarkalson, and J. E. Thies. In-field rates of decomposition and microbial communities colonizing residues vary by depth of residue placement and plant part, but not by

crop genotype for residues from two cry1ab bt corn hybrids and their non-transgenic isolines. *Soil Biology and Biochemistry*, 57:349–355, 2013. Soils and Fertilizers; Plant Breeding; Maize; Biocontrol; Field Crops; Agricultural Entomology; Agricultural Biotechnology.

W. G. Lovely, G. C. Weber, and D. W. Staniforth. Effectiveness of the rotary hoe for weed control in soybeans. *Agron.J.*, 50:621–625, 1958.

S. Marinari, A. Lagomarsino, M. C. Moscatelli, A. di Tizio, and E. Campiglia. Soil carbon and nitrogen mineralization kinetics in organic and conventional three-year cropping systems. *Soil and Tillage Research*, 109(2):161–168, 2010. Horticultural Science; Soils and Fertilizers.

M. V. Martnez-Toledo, V. Salmern, B. Rodelas, C. Pozo, and J. Gonzlez-Lpez. Effects of the fungicide captan on some functional groups of soil microflora. *Applied Soil Ecology*, 7(3): 245–255, 1998. Plant Pathology.

R. P. Mathew, Y. C. Feng, L. Githinji, R. Ankumah, and K. S. Balkcom. Impact of no-tillage and conventional tillage systems on soil microbial communities. *Applied and Environmental Soil Science*, 2012:Article ID 548620–Article ID 548620, 2012. Conference paper. Language: English. Number of References: 49 ref. Registry Number: 7440-44-0, 7727-37-9. Subject Subsets: Soils and Fertilizers; Maize; Field Crops.

V. B. Megadi, P. N. Tallur, R. S. Hoskeri, S. I. Mulla, and H. Z. Ninnekar. Biodegradation of pendimethalin by bacillus circulans. *Indian Journal of Biotechnology*, 9(2):173–177, 2010a. Accession Number: 20103171203. Publication Type: Journal Article. Language: English. Number of References: 16 ref. Registry Number: 40487-42-1. Subject Subsets: Weeds.

V. B. Megadi, P. N. Tallur, S. I. Mulla, and H. Z. Ninnekar. Bacterial degradation of fungicide captan. *Journal of Agricultural and Food Chemistry*, 58(24):12863–12868, 2010b. Accession Number: 20113158287. Publication Type: Journal Article. Language: English. Registry Number: 133-06-2. Subject Subsets: Plant Pathology.

J. A. Mickelson and K. A. Renner. Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. *Journal of Production Agriculture*, 10(3):431–437, 1997. Soyabeans; Field Crops.

S. B. Mirsky, W. S. Curran, D. M. Mortensen, M. R. Ryan, and D. L. Shumway. Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. *Weed Science*, 59(3):380–389, 2011. Wheat, Barley and Triticale Abstracts; Weeds; Soyabeans.

S. B. Mirsky, M. R. Ryan, W. S. Curran, J. R. Teasdale, J. Maul, J. T. Spargo, J. Moyer, A. M. Grantham, D. Weber, T. R. Way, and G. G. Camargo. Conservation tillage issues: cover crop-based organic rotational no-till grain production in the mid-atlantic region, usa. *Renewable Agriculture and Food Systems*, 27(1):31–40, 2012. Soils and Fertilizers; Field Crops.

S. B. Mirsky, M. R. Ryan, J. R. Teasdale, William S. C., S.C. Reberg-Horton, J. T. Spargo, M. S. Wells, C. L. Keene, and J. W. Moyer. Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the eastern us. *Weed Technology*, 27:193–203, 2013.

Steven B. Mirsky, Matthew R. Ryan, Durland L. Shumway, William S. Curran, and David A. Mortensen. Control of cereal rye with a roller/crimper as influenced by cover crop phenology [electronic resource]. *Agronomy journal*, 101(6):15891596–15891596, 2009. Plant Breeding and Genetics; Plant Production (General); Soil Cultivation and Cropping Systems Subset: Indexing Branch - NAL NAL Call Number: 4 AM34P Update Code: 00000000.

Ruth Mischler, David Wilson, William S. Curran, and Sjoerd W. Duiker. Hairy vetch management for no-till organic corn production [electronic resource]. *Agronomy journal*, 102(1): 355–362, 2010a.

Ruth A. Mischler, Jeffrey A. Hyde, Sjoerd W. Duiker, and William S. Curran. Use of a rolled-rye cover crop for weed suppression in no-till soybeans [electronic resource]. *Weed Technology*, 24(3):253–261, 2010b. Farm Organization and Management (Microeconomics); Weeds and Other Noxious Plants Subset: Indexing Branch - NAL NAL Call Number: SB610.W39 Update Code: 00000000.

L. N. Mulumba and R. Lal. Mulching effects on selected soil physical properties. *Soil and Tillage Research*, 98(1):106–111, 2008. Soils and Fertilizers.

A. Munawar, R. L. Blevins, W. W. Frye, and M. R. Saul. Tillage and cover crop management for soil water conservation. *Agronomy Journal*, 82(4):773–777, 1990. Wheat, Barley and Triticale Abstracts; Soils and Fertilizers; Irrigation and Drainage; Maize.

K. L. Murphy, J. M. Klopatek, and C. C. Klopatek. The effects of litter quality and climate on decomposition along an elevational gradient. *Ecological Applications*, 8(4):1061–1071, 1998. Forestry.

E. S. Oplinger and B. D. Philbrook. Soybean planting date, row width, and seeding rate response in three tillage systems. *Journal of Production Agriculture*, 5(1):94–99, 1992. Soyabeans.

J. F. Parr and R. I. Papendick. Factors affecting the decomposition of crop residues by microorganisms. *ASA [American Society of Agronomy] Special Publication*, (31):101–129, 1978. Accession Number: 19791950934. Publication Type: Journal Article. Language: English. Number of References: 65 ref. Subject Subsets: Soils and Fertilizers.

M. Parr, J. M. Grossman, S. C. Reberg-Horton, C. Brinton, and C. Crozier. Nitrogen delivery from legume cover crops in no-till organic corn production. *Agronomy journal*, 103(6):1578–1590, 2011. Horticultural Science; Wheat, Barley and Triticale Abstracts; Plant Breeding; Field Crops; Soils and Fertilizers.

P. Pedersen and J. G. Lauer. Corn and soybean response to rotation sequence, row spacing, and tillage system. *Agronomy Journal*, 95(4):965–971, 2003. Field Crops; Maize; Soyabeans.

J. Peign, B. C. Ball, J. Roger-Estrade, and C. David. Is conservation tillage suitable for organic farming? a review. *Soil Use and Management*, 23(2):129–144, 2007. Weeds; Irrigation and Drainage.

G. T. Place, S. C. Reberg-Horton, and M. G. Burton. Effects of preplant and postplant rotary hoe use on weed control, soybean pod position, and soybean yield. *Weed Science*, 57(3): 290–295, 2009. Soyabeans; Weeds.

A. J. Price, F. J. Arriaga, R. L. Raper, K. S. Balkcom, T. S. Komecki, and D. W. Reeves. Comparison of mechanical and chemical winter cereal cover crop termination systems and cotton yield in conservation agriculture. *Journal of Cotton Science*, 13(4):238–245, 2009. Irrigation and Drainage; Weeds; Wheat, Barley and Triticale Abstracts; Field Crops.

A. L. Rathore, A. R. Pal, and K. K. Sahu. Tillage and mulching effects on water use, root growth and yield of rainfed mustard and chickpea grown after lowland rice. *Journal of the Science of Food and Agriculture*, 78(2):149–161, 1998. Field Crops.

S. C. Reberg-Horton, J. D. Burton, D. A. Danehower, G. Y. Ma, D. W. Monks, J. P. Murphy, N. N. Ranells, J. D. Williamson, and N. G. Creamer. Changes over time in the allelochemical content of ten cultivars of rye (secale cereale l.). *Journal of Chemical Ecology*, 31(1):179–193, 2005. Field Crops; Wheat, Barley and Triticale Abstracts; Plant Breeding; Botanical Pesticides; Weeds.

S. C. Reberg-Horton, J. M. Grossman, T. S. Kornecki, A. D. Meijer, A. J. Price, G. T. Place, and T. M. Webster. Utilizing cover crop mulches to reduce tillage in organic systems in the southeastern usa. *Renewable Agriculture and Food Systems*, 27(1):41–48, 2012. Soils and Fertilizers; Maize; Field Crops.

S. Recous, D. Robin, D. Darwis, and B. Mary. Soil inorganic n availability: effect on maize residue decomposition. *Soil Biology and Biochemistry*, 27(12):1529–1538, 1995. Maize.

D. W. Reeves. Cover crops and rotations, 1994 1994.

M. R. Ryan. *Energy usage, greenhouse gases, and multi-tactical weed management in organic rotational no-till cropping systems*. PhD thesis, The Pennsylvania State University, 2010.

F. Salvagiotti, K. G. Cassman, J. E. Specht, D. T. Walters, A. Weiss, and A. Dobermann. Nitrogen uptake, fixation and response to fertilizer n in soybeans: a review. *Field Crops Research*, 108(1):1–13, 2008. World Agriculture, Economics and Rural Sociology; Crop Physiology; Soyabeans.

SAS. *Procedures guide*. Release 9.1.3. SAS Institute, Cary, NC, 2nd edition, 2006.

H. H. Schomberg, J. L. Steiner, and P. W. Unger. Decomposition and nitrogen dynamics of crop residues: residue quality and water effects. *Soil Science Society of America Journal*, 58 (2):372–381, 1994. Wheat, Barley and Triticale Abstracts.

C. M. Schwendener, J. Lehmann, P. B. de Camargo, R. C. C. Luizo, and E. C. M. Fernandes. Nitrogen transfer between high- and low-quality leaves on a nutrient-poor oxisol determined by 15n enrichment. *Soil Biology and Biochemistry*, 37(4):787–794, 2005. Agroforestry; Forestry.

R. M. Shibles and G. C. Weber. Interception of solar radiation and dry matter production by various soybean planting patterns. *Crop Sci.*, 6:55–59, 1966.

B. Shipley and P. A. Keddy. The relationship between relative growth rate and sensitivity to nutrient stress in twenty-eight species of emergent macrophytes. *Journal of ecology*, 76(4): 1101–1110, 1988. stress Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: JECOA Category Codes: Plant Physiology and Biochemistry Subset: Indexing Branch - NAL NAL Call Number: 450 J829 Update Code: 00000000.

J. Six, S. D. Frey, R. K. Thiet, and K. M. Batten. Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal*, 70(2):555–569, 2006. Accession Number: 20063091201. Publication Type: Journal Article. Language: English. Number of References: many ref. Registry Number: 7440-44-0. Subject Subsets: Soils and Fertilizers.

A. N. Smith, S. Reberg-Horton, G. T. Place, A. D. Meijer, C. Arellano, and J. P. Mueller. Rolled rye mulch for weed suppression in organic no-tillage soybeans. *Weed Science*, 59(2):224–231, 2011. Soils and Fertilizers; Maize; Wheat, Barley and Triticale Abstracts; Soyabeans; Weeds; Animal Nutrition.

J. M. Stark and S. C. Hart. Diffusion technique for preparing salt solutions, kjeldahl digests, and persulfate digests for nitrogen-15 analysis. *Soil Science Society of America. Soil Science Society of America journal*, 60(6):1846–1855, 1996. polytetrafluoroethylene-encased traps; concentration; ratios; recovery Publicaton Type: Journal Article Language(s): English Bibliography Statement: Includes references Coden: SSSJD4 Category Codes: Soil Chemistry and Physics Subset: Indexing Branch - NAL NAL Call Number: 56.9 So3 Update Code: 00000000.

R.G. Steel, J.H. Torrie, and D.A. Dickey. *Principles and procedures of statistics: A biometric approach*. McGraw-Hill, New Your, 3rd edition, 1996.

J. L. Steiner, H. H. Schomberg, P. W. Unger, and J. Cresap. Crop residue decomposition in no-tillage small-grain fields. *Soil Science Society of America Journal*, 63(6):1817–1824, 1999. Accession Number: 20001911086. Publication Type: Journal Article. Language: English. Number of References: 29 ref. Subject Subsets: Soils and Fertilizers.

M. Stenberg, B. Stenberg, and T. Rydberg. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. *Applied Soil Ecology*, 14(2):135–145, 2000. Field Crops; Wheat, Barley and Triticale Abstracts.

D. E. Stott, H. F. Stroo, L. F. Elliott, R. I. Papendick, and P. W. Unger. Wheat residue loss from fields under no-till management. *Soil Science Society of America Journal*, 54(1):92–98, 1990. Wheat, Barley and Triticale Abstracts.

H. F. Stroo, K. L. Bristow, L. F. Elliott, R. I. Papendick, and G. S. Campbell. Predicting rates of wheat residue decomposition. *Soil Science Society of America Journal*, 53(1):91–99, 1989. Wheat, Barley and Triticale Abstracts.

J. R. Teasdale and C. L. Mohler. The quantitative relationship between weed emergence and the physical properties of mulches [electronic resource]. *Weed Science*, 48(3):385–392, 2000.

J. R. Teasdale, S. B. Mirsky, J. T. Spargo, M. A. Cavigelli, and J. E. Maul. Reduced-tillage organic corn production in a hairy vetch cover crop. *Agronomy journal*, 104(3):621–628, 2012. Maize; Weeds.

P. J. Thorburn, M. E. Probert, and F. A. Robertson. Modelling decomposition of sugar cane surface residues with apsim-residue. *Field Crops Research*, 70(3):223–232, 2001. Field Crops; Irrigation and Drainage; Horticultural Science.

P. A. Torres, A. B. Abril, and E. H. Bucher. Microbial succession in litter decomposition in the semi-arid chaco woodland. *Soil Biology and Biochemistry*, 37(1):49–54, 2005. Forestry; Agroforestry.

C. Tu, F. L. Booker, D. M. Watson, X. Chen, T. W. Rufty, W. Shi, and S. J. Hu. Mycorrhizal mediation of plant n acquisition and residue decomposition: impact of mineral n inputs. *Global Change Biology*, 12(5):793–803, 2006. Plant Pathology; Crop Physiology; Grasslands and Forage.

USDA-AMS. Bi-weekly weighted average report for the week ending, 5/12/2012 2013.

USDA-ERS. Certified organic grains. acres of corn, wheat, oats, barley, sorghum, rice, spelt, millet, buckwheat, and rye by state, 1997 and 2000-08., 7/5/2012 2013.

USDA-ERS and C. Greene. Organic production, 2009.

C. Wagner-Riddle, T. J. Gillespie, and C. J. Swanton. Rye cover crop management impact on soil water content, soil temperature and soybean growth. *Canadian Journal of Plant Science*, 74(3):485–495, 1994. Soyabeans; Soils and Fertilizers; Irrigation and Drainage; Wheat, Barley and Triticale Abstracts.

E. R. Walker, A. Mengistu, N. Bellaloui, C. H. Koger, R. K. Roberts, and J. A. Larson. Plant population and row-spacing effects on maturity group iii soybean. *Agronomy Journal*, 102 (3):821–826, 2010. Field Crops; Crop Physiology.

C. R. Weber, R. M. Shibles, and D. E. Byth. Effect of plant population and row spacing on soybean development and production. *Agronomy Journal*, 58:99–102, 1966.

M. S. Wells, S. Reberg-Horton, and C. Brinton. The influence of six-rye cultivars, on weed suppression and organic soybean yield in a roll-killed cover-crop system. *Weed Science*, In Review, 2013a.

M. S. Wells, S. C. Reberg-Horton, A. N. Smith, and J. M. Grossman. The reduction of plant-available nitrogen by cover crop mulches and subsequent effects on soybean performance and weed interference. *Agron.J.*, 105:1-7(2), 2013b.

T. J. White, T. Bruns, S. Lee, and J. W. Talyor. *Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics*, pages 315–322. Acedemic Press, Inc., New York, 1990.

F. H. Yelverton and H. D. Coble. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (glycine max). *Weed Technology*, 5(1):169–174, 1991. Soyabeans.

B. G. Young, J. M. Young, L. C. Gonzini, S. E. Hart, L. M. Wax, and G. Kapusta. Weed management in narrow- and wide-row glyphosate-resistant soybean (glycine max). *Weed Technology*, 15(1):112–121, 2001. Weeds; Field Crops.