ABSTRACT

SMITH, ADAM NELSON. Utilizing Rolled Rye Mulch for Weed Suppression in Organic No-Tillage Soybeans. (Under the direction of J.P. Mueller and S.C. Reberg-Horton).

Rising demand for organic soybeans (*Glycine max* L.) and high price premiums for organic products has stimulated producer interest in organic soybean production. However, organic soybean producers and those making the transition to organic production cite weed management as their biggest limitation. Current weed management practices rely heavily on cultivation. Repeated cultivation is expensive and has negative consequences on soil health. Research is needed to improve organic reduced tillage production. Rye (*Secale cereale* L. cv. Rymin) cover crops were evaluated for weed suppression abilities and effects on soybean yield. Experiments were planted in 2008 and 2009 at three site locations. Rye was planted in the fall of each year and killed at soybean planting with a roller crimper or flail mower, creating a thick weed-suppressing mulch with potential allelopathic properties. The mulch was augmented with one of three additional weed control tactics: pre-emergence corn gluten meal (CGM), post-emergence clove oil, or post-emergence high-residue cultivation. Roll crimped and flail mowed treatments had similar weed suppression abilities at most sites. There were no differences between CGM, clove oil, or cultivation at most sites. Sites with rye biomass above 9,000 kg ha^{-1} of dry matter had sufficient weed control. In Goldsboro 2008, where rye biomass was 10,854 kg ha^{-1} of dry matter, the soybean yield in the rolled rye treatment was not significantly different from the weed-free treatment, yielding at 2,190 and 2,143 kg ha^{-1}, respectively. Likewise, no difference in soybean yields was found in Plymouth 2008 with a rye biomass of 9,256 kg ha^{-1} and yields of 2,694 kg ha^{-1} and 2,809 kg ha^{-1} in the rolled rye and weed-free treatments, respectively. At low rye biomass levels

(4,450- 6,606 kg ha^{-1}), the rolled rye treatment soybean yield was 628- 822 kg ha^{-1} less than the weed-free treatment. High rye biomass levels are critical to the success of this production system. However, high rye biomass was, in some cases, also responsible for soybean lodging severe enough to cause concern with this system.

Utilizing Rolled Rye Mulch for Weed Suppression in Organic No-Tillage Soybeans

by
Adam Smith

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Crop Science

Raleigh, North Carolina

2010

APPROVED BY:

_______________________________ _______________________________
J. Paul Mueller S. Chris Reberg-Horton
Committee Chair Committee Co-Chair

____
Consuelo Arellano

BIOGRAPHY

Adam Smith was born and raised in Wilson, NC. He attended Warren Wilson College and later transferred to University of North Carolina- Asheville to complete a bachelor's degree in Environmental Ecology and Biology. Immediately upon graduating from UNCA, Adam moved to Raleigh and began working with Chris Reberg-Horton and Paul Mueller. He started his master's degree in the fall of 2007. He recently accepted a PhD position with Virginia Tech to continue his work in organic and sustainable agriculture.

During this trajectory as professional student, Adam managed to accomplish other things as well. He met a beautiful, brilliant woman and persuaded her to marry him. He somehow managed to "lose" and "find" himself several times over. He blew precious savings to travel the world. And now, he plans to settle in the Appalachian Mountains, grow a garden, raise a dog, and play the banjo.

ACKNOWLEDGEMENTS

I would like to thank my professors, Chris Reberg-Horton, Paul Mueller, and Consuelo Arellano for their patience, support, and experience. I thank Consuelo for walking me through statistical analysis and having the patience to explain and re-explain what she just did. I thank Paul for helping me create this project and assistantship, and offering sound advice on how to do things. I thank Chris for believing in me and always encouraging creative thinking. I appreciate all the time he spent in the field (weekends, over-nighters, and all). He has been there every step of the way and I greatly value the knowledge and experience that he passed on to me.

I would like to thank other students and staff, namely George Place, Carrie Brinton, William 'Boo' Blount, Aaron Fox, Scottie Wells, Melissa Bell, and Steve Hoyle. George and Carrie have become close friends and I cherish their friendship and all it entails.

I would like to thank my parents for continuing to support me in my endeavors.

I would like to thank my wife for being the amazing woman she is. She is the core of my world and I don't know where I would be without her. I thank her for preserving my sanity and giving me a reason to work so hard.

TABLE OF CONTENTS

LIST OF TABLES

Chapter 1

Chapter 2

LIST OF FIGURES

CHAPTER 1- Weed Management Tactics in Organic No-Tillage Soybean Production

Introduction

The sale of organic products has increased from one billion dollars in 1990 to twenty billion dollars in 2007, making the organic food sector one of the fastest growing markets in the country. In 2006, sales grew 20.9% (OTA, 2008). In North Carolina (NC), organic sales follow similar trends. In 1997, NC had 980 acres in organic production (Wossink and Kuminoff 2002). In 2007, there were 383 organic farms in NC farming 3,021 acres. In addition, 7,775 acres were in the process of being converted to organic production (NC Ag Census 2007). Organic soybean demand for the mid-Atlantic region is not being met and the majority of organic soybeans are being imported from other states (Braswell Milling, personal communication). Conventional soybean prices for 2009 were approximately $10.40/ bushel (USDA 2009), while feed grade organic soybeans were priced at $18.65/bushel (USDA 2009).

Organic producers and those currently making the transition to organic soybean production cite weed management as their most difficult challenge (Walz, 1999). A 19% yield reduction (when compared to a chisel till/ herbicide conventional program) has been reported for organic soybeans, with the majority of that reduction likely due to weed pressure (Cavigelli et al. 2008). Most soybean producers rely on herbicide and transgenic crop technology as their primary tools in weed management programs, both of which are prohibited by USDA organic standards (NOP 2002). Without synthetic herbicides, organic producers must rely on multiple tactics to effectively suppress weeds; this requires a "many little hammers" approach (Liebman and Gallandt 1997). Although organic producers have a variety of weed management tactics available (crop rotations, cover crops, flaming, biocontrol, weed seed predation, allelopathy, smother crops, competition, organic herbicides, and primary and secondary cultivation), frequent cultivation is the core of most organic weed control programs. Intensive cultivation has negative consequences on soil health such as soil erosion (Beale et al. 1955), soil compaction (Raper et al. 2000), decreased soil residue cover (Hargrove 1990), and increased CO_2 release into the atmosphere (Paustian et al. 1998). Intensive cultivation also increases labor and equipment costs (Weersink et al. 1992) and fossil fuel consumption (Hargrove 1990). Conservation tillage agriculture has the potential to alleviate some of the negative consequences of cultivation (Arshad et al. 1990; Six et al. 1999). Reduced tillage in organic systems requires use of tactics such as organic herbicides, high residue cultivation, and allelopathic cover crops.

Rye (*Secale cereale* L.) is a widely used cover crop known for its high biomass levels and allelopathic potential. In no-till systems, the rye can be killed by chemical or mechanical means to create a mulch. The mulches can inhibit weed growth by providing a physical barrier to weeds (Teasdale and Mohler 2000), intercepting light before it reaches weeds (Teasdale and Mohler 1993), and by releasing allelochemicals (Barnes and Putnam 1987). The level of weed suppression depends on the amount of rye mulch, with an exponential relationship between mulch mass and weed emergence (Teasdale and Mohler 2000). Sufficient weed control may be provided for 4 to 16 weeks into the season (Mohler and Teasdale 1993; Weston 1996).

In most cases, rye cover crops are killed with herbicides or by mowing (Weston 1990; Creamer et al. 1995). In organic production, mowing is the main mode of kill for cover crops, but it comes with disadvantages. Most studies show an increased rate of decomposition for mowed mulches (Creamer et al. 1995; Lu et al. 2000), thus reducing the amount of time the residue persists on the soil surface. A recent technology, the roller crimper[1], terminates rye by rolling it down into a mat and crimping the stems without breaking them. This allows for the rye to persist longer on the soil surface by slowing down decomposition rates when compared to mowing (Creamer and Dabney 2002).

The roller crimper is a rolling drum filled with water. Blunted blades are attached to the roller in a chevron design, meant to maximize force against the cover crop without cutting the stems (Rodale 2009). This idea originated in Brazil and Paraguay and is considered a recent technology within the United States. Rolling implements require substantially less energy than a flail-mower (Hunt 1977).

Research has shown that while rye mulch can provide a certain level of weed control, additional weed management measures are sometimes needed (Yenish et al. 1996). Organic herbicides may provide additional weed control. Several of the organic herbicides are based on essential plant oils which are allowed in organic systems due to their low environmental persistence and natural origin (Tworkoski 2002). The phytotoxicity of clove oil[2] via disruption of cell membranes has been demonstrated with many weed species (Bainard et al. 2006; Tworkoski 2002). Tworkoski (2002) also concluded that essential plant oils cause injury by increasing membrane permeability, leading to increased electrolyte leakage.

Clove oil acts as a non-selective "burn-down" herbicide; it can be applied post-emergence using a directed spray. Previous research has shown that at 10-40% concentrations, clove oil can provide significant weed control (Boyd and Brennan 2006). Burning nettle was reduced 90% with 12-61L clove/ ha, while common purslane was reduced 90% with 21-38L clove/ha (Boyd and Brennan 2006). Other research has reported a 10% concentration to provide inconsistent weed control, ranging from 10-40% control (Ferguson 2004). Tworkoski (2002) found 100% injury ratings for johnsongrass, common lambsquarters, and common ragweed at clove oil concentrations of 5 and 10%. Another herbicide available for organic use as a pre-emergent is corn gluten meal[3]. Corn gluten meal has been found to decrease plant survival, shoot length, and root development in 22 weed species (Bingaman and Christians 1995). This option is particularly effective in turf where 95% control of crabgrass is possible at a rate of 582 g m^{-2} (Christians 1993).

The potential advantages of the rolled rye system for organic soybean production have led to a recent proliferation in rolled rye research. Results so far are inconclusive, with adequate weed control provided in some regions (Morse 1994) and insufficient control in others (Reeves et al. 2005). No results have been previously published from the Southeast where climatic conditions favor a much more robust rye cover crop (Snapp et al. 2005), but also provide an environment where rye mulch decomposition rates are expected to be faster. Weed management can also be an even greater concern due to the longer growing season in the Southeast, compared to more northern locations where the use of this system has been more prevalent (Rodale 2009). The objective of this study was to examine how the rolled rye-organic soybean system would perform in the southeastern U.S. in terms of weed control and soybean yield. We also investigated whether auxiliary weed control was needed in the system, either with high residue cultivators or organically approved herbicides. Finally, we tested whether the roller crimper provided enough advantage over flail mowing to justify the investment in a new piece of equipment for producers.

Materials and Methods

Research was conducted in 2008 and 2009 at the Tidewater Research Station near Plymouth, NC, Caswell Research Farm near Kinston, NC, and the Center of Environmental Farming Systems near Goldsboro, NC. The soil type at Tidewater was Portsmouth fine sandy loam (Fine-loamy over sandy or sandy-skeletal, mixed, thermic, Typic Umbraquult). Kinston 2008 soil type was Pocalla loamy sand (Loamy, siliceous, subactive, thermic Arenic Plinthic Paleudults) and 2009 soil type was Johns loamy sand (Coarse-loamy, siliceous, semiactive, thermic Aeric Paleaquults). Goldsboro 2008 and 2009 soil type was Wickham loamy sand (Fine-loamy, mixed, semiactive, thermic Typic Hapludults) with a 0-2% and 2-6% slope, respectively. Plots were 15.2 m long and contained 4 rows spaced 0.76 m apart. A rye (*Secale cereale* L. 'Rymin') cover crop was established at all three locations in the fall (Table 1) of each year using a no-till drill with 15.2 cm spacing between drops at a rate of 134 kg ha^{-1}. Rye was planted perpendicular to proposed soybean planting and rye rolling-crimping patterns in order to maximize light interception and weed suppression.

Prior to planting rye, all fields were disked and field cultivated to remove any existing vegetation. Rye received a 50 to 60 kg N ha^{-1} UAN application in February-March to ensure stand consistency and growth. The Goldsboro 2009 trial was conducted on land in transition to organic production; it received manure compost with a nitrogen equivalent of 56 kg N ha^{-1}. Because maximal rye biomass levels were critical for the objectives of this study, in some cases, such as nitrogen application, the experiment was not conducted under complete organic conditions.

The rye cover crop was terminated at early milk (Feekes growth stage 11) either with a roller crimper or a flail mower. Soybeans "Hutcheson" (*Glycine max* L.), maturity group V, were planted at 370,500 live seed ha^{-1} in mid-May with a Monosem no-till planter[4] in the same direction as the roller crimper and flail mower patterns. Planting dates varied from May 14 to June 3 across sites and locations (Table 1). The Monosem was equipped with trash clearers, fluted discs, and an additional 45 kg of weight on each planter box to ensure penetration of the mulch. The rye was either augmented with pre-emergence organic corn gluten meal herbicide, post-emergence organic clove oil herbicide, high-residue between-row cultivation, or received no additional treatments. All organic weed control treatments were tested against weed-free and weedy check treatments.

Corn gluten meal was applied granularly at soybean planting with a handed pushed Gandy spreader (Gandy Co.)[5]. Openings in the spreader were taped closed to that corn gluten meal was applied in a 17.8 cm band over the soybean row at a rate of 907 kg ha^{-1}. Clove oil was applied 6 weeks after planting (WAP) as a directed under-canopy in-row spray at a rate of 18.7 liters a.i. ha^{-1} (10% concentration). High-residue between-row cultivation was done 6 to 7 WAP using a Sukup cultivator[6] with sweep blades that spanned 55.9cm. Conventional checks were treated 3 WAP with imazethapyr at 74.7g a.i. ha^{-1} and S-metolachlor at 1.91 kg a.i. ha^{-1}. The Goldsboro 2009 location was maintained weed free by regular hand hoeing due to herbicide restrictions at the site.

Measurement were taken for soybean stand counts, soybean height, rye biomass levels, rye biomass decomposition rates, weed control estimates, and soybean yield. Soybean stand counts were taken on a 1 m row in each plot approximately a month after planting at each site. Stand heights were taken on two randomly selected plants per plot at approximately 4 and 8 WAP. Weed control was estimated as percent weed emergence and weed density. Percent weed control was rated visually on a scale of 0-10. At two of the six site locations, weed density was not estimable in August due to high grass weed pressure, thus weed percent coverage was estimated for all plots. Weed density was determined by weed counts of the two middle rows (20.9 m^2). Weed control measurements were taken in July and August. Soybean yield was measured in October or November from 12.2 m of the two center rows in each plot using a small plot combine.

Rye biomass was cut from six 0.5m^2 quadrats and fresh weights were taken at soybean planting. The collected rye biomass was dried at 60° C for 72 hours to quantify percent moisture and to derive total rye biomass for each site location. Rye biomass decomposition rates were measured by collecting litter bags filled with either rolled or flail-mowed rye at two week intervals over the course of the season. Litter bags were made of hundred mesh aluminum screen, sized at 15.2 X 30.4cm, and filled with either flailed rye or rolled rye. Litter bags were prepared and dispersed at soybean planting. Fresh rye weight was measured for each litter bag prior to random positioning throughout plots with a matching type (flailed vs. rolled). Five litter bags were collected every two weeks, dried at 60°C for 72 hours, and weighed to determine percent moisture and percent dry matter loss for each litter bag.

The experimental design was a randomized complete block design with six replicates. A combined analysis was attempted on the six trials, but significant treatment by environment interactions prevented a pooled analysis. Each site was analyzed separately with mean separations generated with Fisher's Protected Least Significant Differences and orthogonal contrasts. Rye decomposition rates were determined using simple linear regression in proc MIXED (SAS 2008).

Results and Discussion

Rye Biomass and Decomposition

Total rye biomass levels varied among locations and years (Figure 1). Goldsboro resulted in the largest difference between years with dry biomass totals of 10,854 kg ha^{-1} for 2008 and 4,450 kg ha^{-1} for 2009. Field compaction was observed in 2009, likely accounting for this difference. These averages are consistent with other research. Ashford and Reeves (2003) averaged 9,725 kg dry rye biomass ha^{-1} in Alabama, while Yenish et al. (1996)

averaged 5,140 and 4,540 kg ha^{-1} in North Carolina. Masiunas et al. (1995) ranged from 3,200 kg ha^{-1} to 11,500 kg ha^{-1}, but averaged (over location and year) at approximately 6,763 kg ha^{-1} in Kentucky, Illinois, and Indiana. Rainfall averages for 2008 for March-May were 9.9cm, 6.7cm, and 7.9cm, where 2009 averages were 8.3cm, 5.8cm, and 7.3cm for Goldsboro, Kinston, and Plymouth, respectively (Table 2). In 2009, the rye cover crop received less rain, which may have reduced rye growth.

Differences in decomposition rates between roll-crimped and flail-mowed rye were not detected (Figure 2). Both mulch types lost approximately 40% of the original biomass over the course of the season to decomposition. Flail mowed legume cover crops have high decomposition rates with major losses of mowed mulches over the course of the season (Creamer and Dabney 2002; Masiunas et al. 1995; Teasdale and Mohler 1993). The slow decomposition of rye, mostly attributed to its high C:N ratio (Ranells and Wagger 1996), permitted flail mowed rye mulch to better persist throughout the season than other flail mowed cover crops. Litter bags have been criticized for not providing a realistic assessment of decomposition rates (Coleman et al. 2004). They can be effective, however, for comparing relative rates of decomposition among different mulch types.

Weed Control

All treatments were applied based on soybean development and the onset of weed emergence (Table 1). The predominant weed species at most site locations was pigweed (*Amaranthus* sp.) with weedy check plots averaging 11-65 plants m^2. At two locations, large crabgrass (*Digitaria sanguinalis* L.) and broadleaf signalgrass (*Urochloa platyphylla* [Munro ex. C. Wright] R.D. Webster) were the dominant species at 40-60 % weed coverage in rye plots.

In 2008, rolled rye plots had significantly less weed density than flail-mowed rye in Goldsboro (Table 3). In 2009, roll-crimped and flail-mowed weed density means were not different for all three sites (Table 3, 4). Rye biomass was 10,852 kg ha^{-1} for Goldsboro 2008, where rolled rye had lower weed density. This suggests a possible relationship between weed control and rye kill mode at high biomass levels (> 10 tons ha^{-1}).

The roller may also provide logistical benefits over the flail-mower. The roller-crimper uses substantially less energy than the flail-mower, thus potentially making the roller-crimper a beneficial long-term investment from an energetics standpoint (Hunt 1977; Kornecki et al. 2009). The roller-crimper also works better at faster tractor speeds, thus reducing time and energy spent in the field, whereas a flail-mower requires a lower tractor speed to effectively mow the cover crop. However, the flail mower may be a more common implement that many producers already own.

The CGM treatment increased weed density at one site when compared to the rye-only treatment (Table 4). When compared to clove oil or cultivation, CGM increased weed density at two sites (Table 4). CGM may have potentially acted as a mid-season N fertilizer for emerging weeds later in the season. CGM contains approximately 10% N by weight and has been shown to provide a sufficient source of N for turf (Christians 1993). Christians (1993) also concluded that CGM acts as a slow release N source. Research has shown that rye's high C: N ratio can lead to N immobilization (Rosecrance et al., 2000). This addition of CGM could have stimulated growth and survival of pigweed seedlings in an N depleted environment, which may increase weed density rather than control weeds in some situations.

Clove oil reduced weed density at one location when compared with the rye-only treatment (Table 4). It was observed that clove oil injured most weed species, but only killed some (data not shown). Tworkoski (2002) found that at 5 and 10% dilution rates, common lambquarters (*Chenopodium album*), johnsongrass (*Sorghum halpense*), and common ragweed (*Ambrosia artemisiifolia*) had 100% injury. Bainard et al. (2006), comparing clove oil response on common lambquarters and redroot pigweed (*Amaranthus retroflexus*), found that pigweed was more susceptible to clove oil due to its lack of epicuticular wax, resulting in a 99% reduction in seedling growth. Yield results did not indicate a beneficial effect of including clove oil in a weed management program. In Plymouth 2009, soybean yields were actually lower in clove treated plots, presumably due to crop injury. More canopy injury had been noted at this location when compared with other sites (data not shown).

High residue cultivation was not significantly different from other treatments at most sites (Table 4). It resulted in better weed control when compared to CGM in Goldsboro 2009, and in Plymouth 2009, high residue cultivation controlled weeds more effectively than the rye-only treatment (Table 4). During the experiment, it was observed that the cultivator pushed the rye from the row middle, exposing the soil and creating an opening for weed germination. However, at two of three sites, August weed counts were not significantly different amongst treatments. The high residue cultivator was used just previous to canopy closure (7 WAP) at all sites. Weeds emerging after cultivation were likely shaded out by the closing soybean canopy. All treatments had significantly better weed control than the weedy check treatment (Table 3).

Few differences were observed among treatments with regard to weed coverage; the only differences were seen between the weedy check treatment vs. all other treatments (Figure 3; Table 3). Goldsboro 2008 (in high rye biomass levels) resulted in a difference between CGM and clove oil, as seen in Figure 3 and Table 3. For weed coverage, all locations were grouped into three rye mulch levels (low, medium, and high). Results suggest that with increasing rye biomass levels, % weed coverage decreases (Figure 3). Rye mulch levels could play a role in weed suppression.

Increasing total rye biomass was found to increase weed suppression. The two sites with the highest biomass, Goldsboro and Plymouth 2008, had biomass values of 10,854 and 9,526 kg ha^{-1}, respectively and resulted in sufficient weed suppression. Teasdale and Mohler (2000) showed that increasing mulch level exponentially decreased weed pressure, concluding that mulch levels greater than 9,000 kg ha^{-1} reduced weed pressure by 90%. Weeds in the soybean row appeared to comprise the majority of weeds in locations with low and medium biomass sites. During soybean planting, the no-till planter created a furrow in the rye and exposed approximately 10 cm of the soil surface, allowing for weeds to be in direct competition with soybeans. The ineffectiveness of CGM and clove oil at controlling in-row weeds suggest this system is inadequate in years where rye growth is limited. Even medium levels of biomass (7-9,000 kg ha^{-1}) could be a problem and foregoing the use of trash clearers may be necessary at medium biomass levels. With high rye biomass, trash clearers do not result in excessive establishment of in-row weeds and a consistent soybean stand would be difficult to achieve without them.

Soybean Yield

The rye-only treatment had an equivalent soybean yield to the weed-free treatment at 4 site locations (Table 5). This is supported by other findings in tomato (Masiunas et al. 1995) and soybean (Moore et al. 1994; Liebl et al. 1992). In Kinston 2008, where rye biomass levels were only 6606 kg ha^{-1}, the weed-free treatment yielded 23% higher than the rye-only treatment (Table 3, 5). In Kinston 2009, rye biomass was higher (8,367 kg ha^{-1}), but the weed-free treatment still yielded 135% higher than the rye-only treatment (Table 3, 5). If the relationship between mulch biomass and weed emergence is one of exponential decay, as suggested by Teasdale and Mohler (2000), then only a 1,000 to 2,000 kg ha^{-1} difference in rye biomass can determine the success or failure of this system in high weed pressure environments, as was the case when comparing Kinston 2009 to Goldsboro 2008.

CGM reduced yield when compared to the clove oil treatments at two site locations (Table 5). Neither clove oil nor CGM was significantly different from the rye-only treatment at most locations. In Plymouth 2009, clove oil treatment yield was 316 kg ha^{-1} less than rye-only treatment yield; this is likely due to clove oil damage to the soybeans. The reduction in yield seen in the CGM treatments correlates to the significant increase in weed density in the same treatment and locations.

Kinston 2009 was the only location where a soybean yield advantage was detected for rolled rye versus flailed rye (Table 3, 5). No difference in weed control density had been detected at this site, suggesting that another mechanism for yield advantage for the rolled rye systems was responsible. Goldsboro 2008 is the site where yield differences between flail-mowed and rolled rye were expected. Despite having 2.5 times fewer weeds, the rolled rye plots had almost identical yield as the flail-mowed plots (Table 3, 5). The weeds that emerged in the flail-mowed plots emerged late, mostly from the between-row area. They were able to grow above the soybean canopy, but were not robust plants. The in-row weeds that developed in lower rye biomass environments were far more robust and would be expected to be more yield damaging.

An important consideration in drawing conclusions from the study is that organic conditions were only maintained at most stations during the soybean production phase. Conventional sites were utilized to permit comparison with conventional weed management (weed-free checks) and for the logistical ease of fertilizing the rye cover crop conventionally. All locations had not previously been under organic management. Research in organic cropping systems has suggested that crops may be more tolerant of weeds in an organically managed field than in a conventionally managed field (Ryan et al. 2009). If crops are more tolerant of weed competition under organic conditions, the roller system may also work at lower rye biomass levels than suggested by these data. Another question is how often organic growers can expect rye growth similar to the high biomass sites in this study. To adopt this system, more attention to the cover crop is required. Inadequate nitrogen or planting too late could severely limit chances of obtaining enough rye biomass. Under current organic practices in North Carolina, the biomass of a rye cover crop could vary widely between farms. Depending on maturity rates and the number of legumes in the rotations, the amount of N available to a cover crop on an organic farm can vary from excessive to deficient (Roberts et al. 2008). Planting dates for this study, mid-November, were fairly late for the region. Planting much earlier, September or October, is possible in fields following corn and may lead to even greater rye biomass than reported in our study (Griggs 2006).

Future research is needed to develop a decision tree to help producers decide when this system will work. Inevitably, some winters will produce less rye biomass than needed for weed suppression. Ideally, others would benefit from a prediction system that could estimate their chance of success in early spring based on rye growth thus far and expected weed pressure for a particular field. Waiting until planting time to decide between no-till and clean-till is too late because rye residue would be too large to incorporate into the soil. More research is also needed to determine whether the system could work with rye biomass levels at 7-9,000 kg ha^{-1}. New organic herbicides are being developed that may be more effective for in-row weed control than those tested here.

Sources of Materials

[1] Roller/Crimper, I&J Manufacturing, 5302 Amish Rd., Gap PA 17527.

[2] Matratec AG, Clawel Specialty Products, 211 West Route 125, Pleasant Plains, IL 62677.

[3] Corn Gluten Meal, Grain Processing Corporation, 1600 Oregon St., Muscatine, Iowa 52761.

[4] Monosem No-Till Planter, Monosem, Inc., 1001 Blake St., Edwardsville, KS 66111.

[5] Gandy Spreader, Gandy Company, 528 Gandrud Rd., Owatonna, MN 55060.

[6] Sukup High-Residue Cultivator, Sukup Manufacturing Company, 1555-255th St., Sheffield, Iowa 50475.

REFERNCES

Arshad, M.A., Schnitzer, M., Anger, D.A., and D.A. Ripmeester. 1990. Effects of till vs no-till on the quality of soil organic matter. Soil Biol. Biochem. 22: 595-599.

Ashford, D.L. and D.W. Reeves. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. American Journal of Alternative Agriculture. 18(1): 37-45.

Bainard, L.D., Isman, M.B., and M.K. Upadhyaya. 2006. Phytotoxicity of clove oil and its primary constituent eugenol and the role of leaf epicuticular wax in the susceptibility to these essential oils. Weed Science. 54: 833-837.

Barnes, J.P. and A.R. Putnam. 1987. Role of benzoxazinones in allelopathy by rye (*Secale cereale* L.). Journal of Chemical Ecology. 13(4): 889-906.

Beale, O.W., Nutt, G.B., and T.C. Peele, 1955. The effects of mulch tillage on runoff, erosion, soil properties, and crop yields. Soil Science Proceedings. 244-247.

Bingaman, B.R. and N.E. Christians. 1995. Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. Hortscience. 30(6): 1256-1259.

Boyd, N.S. and E.B. Brennan. 2006. Burning nettle, common purslane, and rye response to a clove oil herbicide. Weed Technology. 20: 646-650.

Cavigelli, M.A., Teasdale, J.R. and A.E. Conklin. 2008. Long-term agronomic performance of organic and conventional field crops in the mid-atlantic region. Agronomy Journal. 100: 785-794.

Christians, N.E. 1993. The use of corn gluten meal as a natural preemergence weeds control in turf: Chapter 35. International Turfgrass Society Research Journal 7. 284-290.

Coleman, DC. Crossley, D.A., and P.F. Hendrix. 2004. Decomposition and Nutrient Cycling: Chapter 5. In Fundamentals of Soil Ecology (2nd ed.). Elsevier, Inc. Burlington, MA. 187-222.

Creamer, N.G. and S.M. Dabney. 2002. Killing cover crops mechanically: Review of recent literature and assessment of research results. American Journal of Alternative Agriculture. 17(1): 32-40.

Creamer, N.G., Plassman, B., Bennett, M.A., Wood, R.K., Stinner, B.R., and J. Cardina. 1995. A method for mechanically killing cover crops to optimize weed suppression. American Journal of Alternative Agriculture. 10(4): 157-162.

Ferguson, J.J. 2004. Evaluation of organic herbicides. Hortscience. 39: 876.

Griggs, T.C. 2006. Fall and winter spring forage production and quality of winter cereals seeded at three fall dates. Forage and Grazinglands doi: 10.1094/FG-2006-0711-01-RS. Available at http://www.plantmanagementnetwork.org/fg/. Accessed March 9, 2010.

Hargrove, W.L. 1990. Role of conservation tillage in sustainable agriculture. 28-32. In J.P. Mueller and M.G. Wagger (eds.) Proc. Of 1990 South Reg. Cons. Tillage Conference. July 17-26. 1990. North Carolina State University. Raleigh, NC.

Hoyt, G.D. and W.L. Hargrove. 1986. Legume cover crops for improving crop and soil management in the southern United States. Hortscience. 21(3): 397-402.

Hunt, D. 1977. Farm power and machinery management- laboratory manual and workbook. (7th ed., 2nd printing 1979). Iowa State University Press. Ames, IA: 46-47.

Kornecki, T.S., Price, A.J., Raper, R.L., and A.J. Arriaga. 2009. New roller crimper concepts for mechanical termination of cover crops in conservation agriculture. Renewable Agriculture and Food Systems. 24(3): 165-173.

Liebl, R., Simmons, F.W., Wax, L.M., and E.W. Stoller. 1992. Effect of Rye (*Secale cereale*) mulch on weed control and soil moisture in Soybean (*Glycine max*). Weed Technology. 6: 838-846.

Liebman, M. and E. Gallandt. 1997. Many little hammers: ecological approaches for management of crop-weed interactions. 78. In: L.E. Jackson (ed.) Agricultural Ecology. Academic, San Diego, CA.

Lu, Y.C., Watkins, K.B., Teasdale, J.R., and A.A. Adbul-Baki. 2000. Cover crops in sustainable food production. Food Reviews International. 16: 121-157.

Masiunas, J.B., Weston, L.A., and S.C. Weller. 1995. The impact of rye cover crops on weed populations in the tomato cropping system. Weed Science. 43: 318-323.

Mohler, C.L. and J.R. Teasdale. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. Weed Research. 33: 487-499.

Moore, M.J., Gillespie, T.J., and C.J. Swanton. 1994. Effect of cover crop mulches on weed emergence, weed biomass, and soybean (*Glycine max*) development. Weed Technology. 8: 512-518.

Morse, R.D. 2001. No-herbicide, no-till summer broccoli- quantity of rye and hairy vetch mulch on weed suppression and crop yield. Pages 85- 94 in Proccedings of the 24th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Oklahoma City, OK.

National Organic Program (NOP). 2008. National list of allowed and prohibited substances. Website. http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateN&navID=NationalListLinkNOPNationalOrganicProgramHome&rightNav1=NationalListLinkNOPNationalOrganicProgramHome&topNav=&leftNav=&page=NOPNationalList&resultType=&acct=nopgeninfo.

NC Agricultural Census. 2007. Table 48: Organic Agriculture. Website: http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/North_Carolina/st37_1_048_048.pdf.

Organic Trade Association (OTA). 2008. Organic Facts. Website: http://www.ota.com/pics/documents/Mini%20fact%201-08%20confirming.pdf.

Paustian, K., Cole, C.V., Sauerbeck, D., and N. Sampson. 1998. CO2 Mitigation by agriculture: an overview. Climate Change. 41(1): 1480-1573.

Ranells, N.N. and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crops monocultures and bicultures. Agronomy Journal. 88(5): 777-782.

Raper, R.L., Reeves, D.W, Schwal, E.B., and C.H. Burmester. 2000. Reducing soil compaction of Tennessee valley soils in conservation tillage systems. The Journal of Cotton Science. 4: 84-90.

Reddy, K.N. 2001. Effects of cereal and legume cover crops residues on weeds, yield, and net return in soybean (*Glycine max*). Weed Technology. 15: 660-668.

Reeves, D.W., Price, A.J., and M.G. Patterson. 2005. Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton. Weed Technology. 19: 731-736.

Roberts, C.J., Lynch, D.H., Voroney, R.P., Martin, R.C., and S.D. Juurlink. 2008. Nutrient budgets of Ontario organic dairy farms. Canadian Journal of Soil Science. 88(1): 107-114.

Rodale Institute. 2009. No-till revolution. Online: http://www.rodaleinstitute.org/no-till_revolution.

Rosecrance, R.C., McCarty, G.W., Shelton, D.R., and J.R. Teasdale. 2000. Denitrification and N mineralization from hairy vetch (*Vicia villosa* Roth) and rye (*Secale cereale* L.) cover crop monocultures and bicultures. Plant and Soil. 227: 283-290.

Ryan, M.R., Smith, R.G., Mortensen, D.A., Teasdale, J.R., Curran, W.S., Seidel, R., and D.L. Shumway. 2009. Weed-crop competition relationships differ between organic and conventional cropping systems. Weed Research. 49(6): 572-580.

Six, J., Elliott, E.T., and K. Paustian. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Science Society of America Journal. 63: 1350-1358.

Snapp, S.S, Swinton, S.M., Labarta, R., Mutch, D., Black, J.R., Leep, R., Nyiraneza, J., and K. O'Neil. 2005. Evaluating cover crops for benefits, costs, and performance within cropping system niches. Agronomy Journal. 97: 322-332.

Teasdale, J.R. and C.L. Mohler, 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal. 85:673-680.

Teasdale, J.R. and C.L. Mohler. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Science. 48: 385-392.

Tworkoski, T. 2002. Herbicide effects of essential oils. Weed Science. 50: 425-431.

USDA. 2009. NC grain prices. NC Dept of Ag Market News. Online: http://www.ams.usda.gov/mnreports/ra_gr110.txt.

USDA. 2009. National Organic Grain and Feedstuffs. USDA Livestock and Grain Market News. Online: http://www.ams.usda.gov/mnreports/lsbnof.pdf.

Walz, E. 1999. Third biennial national organic farmers' survey, p. 19-47. Organic Farming Research Foundation, Santa Cruz, CA.

Weersink, A., Walker, M., Swanton, C. and J.E. Shaw. 1992. Costs of conventional and conservation tillage systems. Journal of soil and water conservation. 47(4): 328-334.

Weston, L.A. 1990. Cover crop and herbicide influence on row crop seedling establishment in no-tillage culture. Weed Science. 38(2): 166-171.

Weston, L.A. 1996. Utilization of allelopathy for weed management in agroecosystems. Agronomy Journal. 88: 860-866.

Wossink, G.A.A and N. Kuminoff. 2002. Organic Agriculture in North Carolina. North Carolina Cooperative Extension Service: N.C. State Economist. Sept/Oct: 1-4.

Yenish, J.P., Worsham, A.D., and A.C. York. 1996. Cover crops for herbicide replacement in no-tillage corn (*Zea mays*). Weed Technology. 10: 815-821.

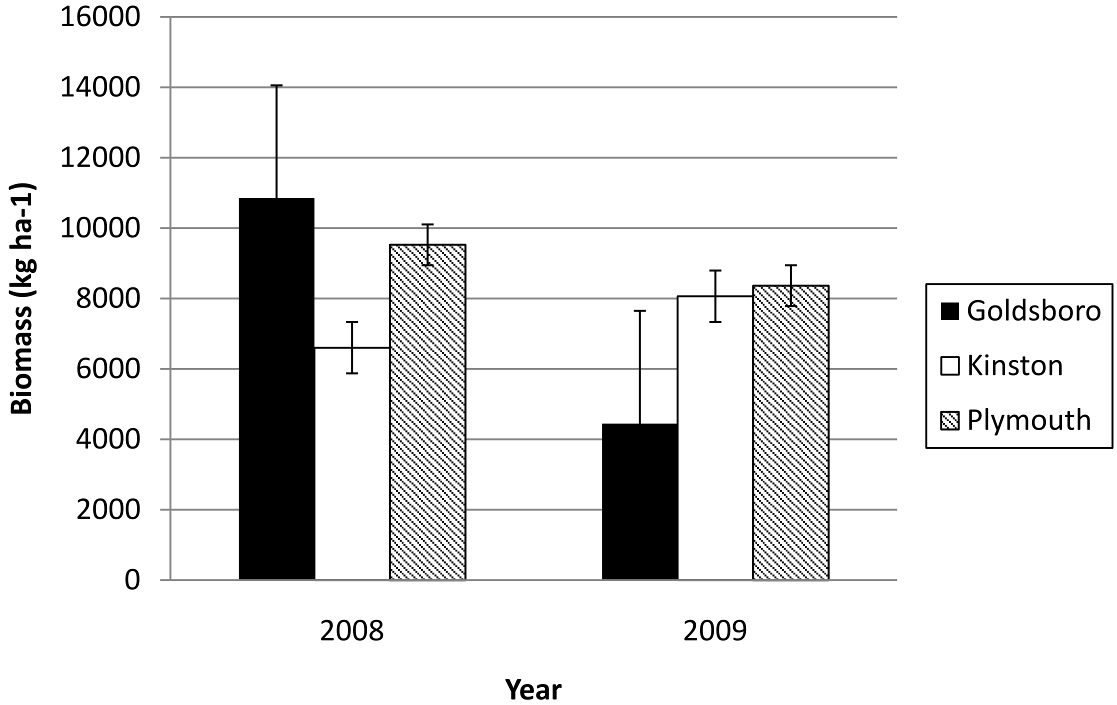


Figure 1: Mean dry rye biomass levels for each site location.

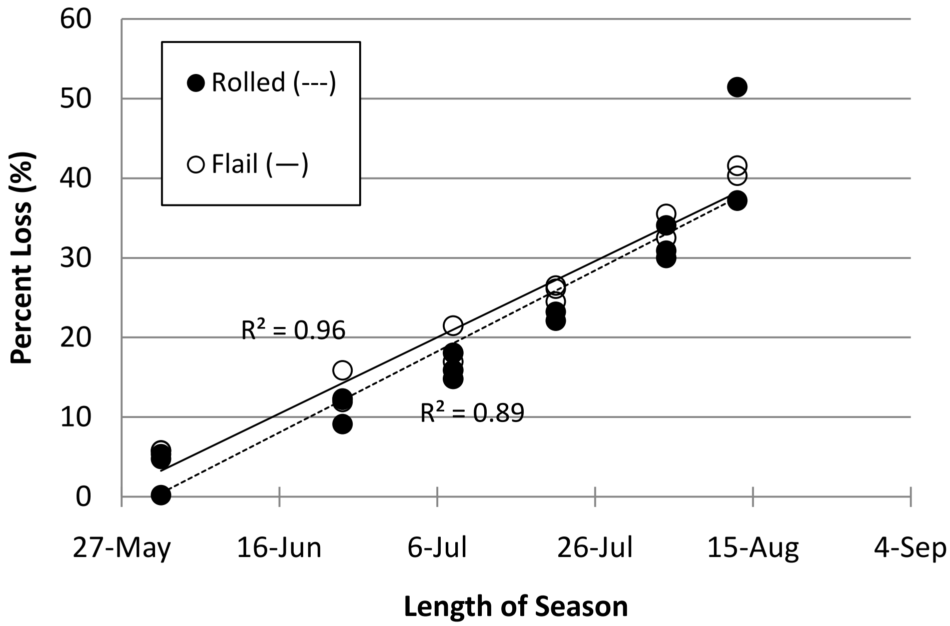
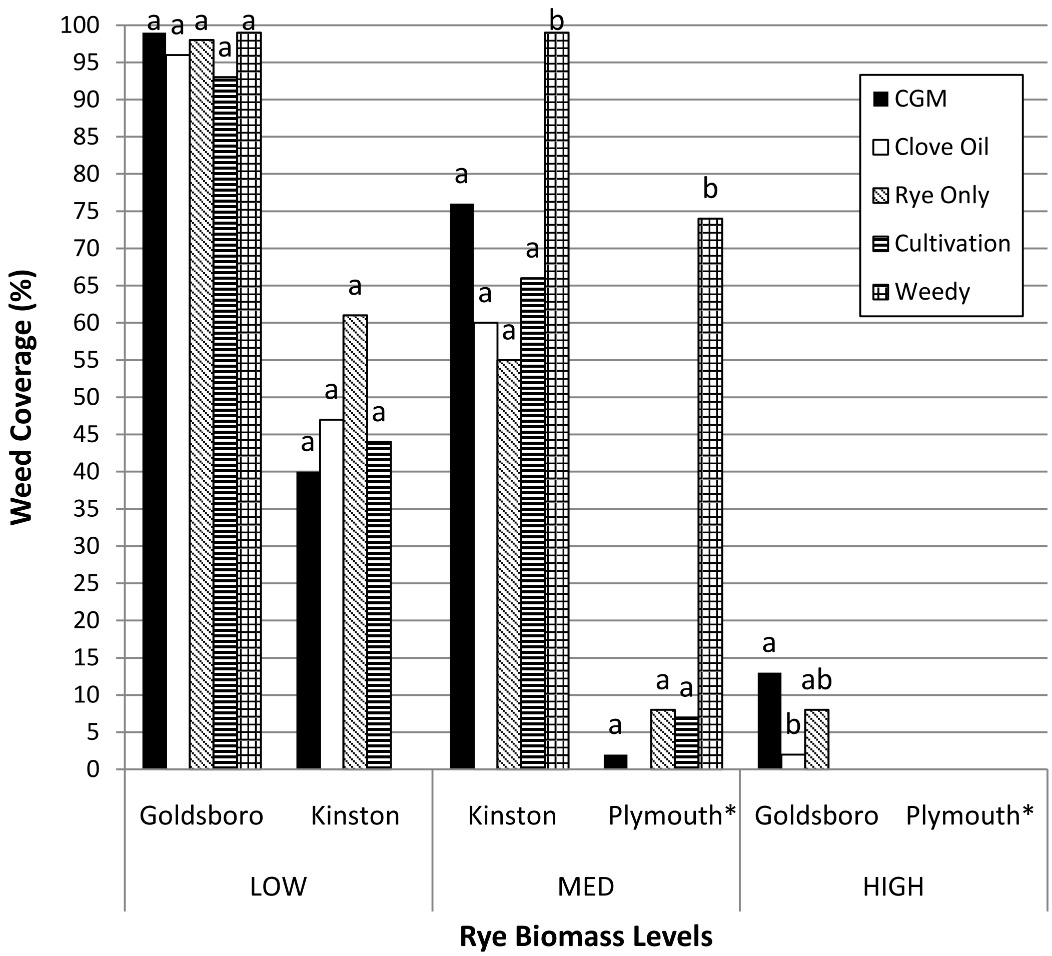


Figure 2: Rye decomposition rates for flail-mowed and rolled-crimped rye, Plymouth NC 2009.



* Denotes locations where some treatments had 0% weed coverage.

Figure 3: Weed management treatment effects on weed coverage. Weed coverage was estimated using visual ratings. Each site location was analyzed separately and LSD letters represent differences within each site location at $P < 0.05$. Site locations were grouped into three qualitative biomass levels: low, medium (med), and high. Goldsboro, under high rye biomass levels, did not receive the cultivation treatment due to drought conditions.

Table 1: Dates for rye and soybean planting and other weed management activities, 2008-2009.[3]

Year/Location	Planting		Rye Kill	CGM	Clove Oil	Cultivation
	Rye	Soybeans				
2008						
Goldsboro	9 Nov[c]	14 May	14 May	14 May	23 June	.
Kinston	2 Nov[c]	26 May	26 May	26 May	17 June	8 July
Plymouth	5 Nov[c]	23 May[b]	23 May	23 May	21 July	.
2009						
Goldsboro	14 Nov[a]	3 June	3 June	3 June	10 July	10 July
Kinston	16 Oct[a]	27 May	27 May	27 May	9 July	9 July
Plymouth	21 Oct[a]	28 May	28 May	28 May	14 July	14 July

[3] Rye kill dates denote when rye was either flail-mowed or rolled-crimped. Corn gluten meal (CGM) was administered at soybean planting because CGM is a pre-emergence organic herbicide. Clove oil was applied when soybeans were approximately V3- V4 growth stages.
[a] Rye for the 2009 season was planted in 2008.
[b] Soybeans were replanted June 18 due to severe drought.
[c] Rye for the 2008 season was planted in 2007.

Table 2: Mean monthly rainfall for all site locations.[3]

Year/ Location	March	April	May	June	July	August	Sept
2008	----------------------------------			cm	------------------------------------		
Goldsboro	10.2	12.2	7.5	6	9.2	15.6	21.5
Plymouth	6	12.9	5	7.2	10.4	2	4.9
Kinston	7.4	7	5.7	3.3	4.5	11.4	17.1
2009							
Goldsboro	11.3	3.1	10.6	8.1	9.4	8.1	3.8
Plymouth	9.8	4.2	8.1	7.4	26.3	20.2	7.7
Kinston	8.7	3	5.9	11.8	10.4	12.7	6.5

[3] Rainfall dates were collected from March to September; March indicated the start of spring rye growth and September represents soybean maturity.

Table 3: Significance of means squares from ANOVA for main effects on soybean yield, weed density, and weed coverage.[a]

	Soybean Yield					Weed Density						Weed Coverage					
	---------kg ha^{-1}-------					----------Count m^{-2}--------						--------------%------------					
	G 08	P 08	K 08	P 09	K 09	G 08	P 08	K 08	G 09	P 09	K 09	G 08	P 08	K 08	G 09	P 09	K 09
Main Effects																	
Mode of Kill (MOK)	NS	.	.	NS	**	**	.	.	NS	NS	NS	*	.	.	NS	NS	NS
Weed Tactics (WT)	NS	NS	NS	**	NS	*	.	.	**	*	NS	NS	NS	NS	NS	NS	NS
WT vs. MOK	**	.	.	NS	NS	NS	.	.	NS	NS	NS	NS	.	.	NS	NS	NS
Contrasts																	
Weed-Free Check vs. ALL	NS	NS	**	NS	**	.	.	.	.	.	.	.	.	.	.	.	.
Weedy Check vs. ALL	.	.	.	.	.	.	.	.	**	**	**	.	.	.	NS	**	**

[a] Mode of kill consisted of flail-mowed and rolled-crimped treatments. Weed tactics consisted of corn gluten meal, clove oil, rye-only, and cultivation treatments. The contrast (Weed-Free Check X ALL) is a comparison of the weed-free check yield means to the average of all weed tactics yield means (WT). The contrast (Weedy Check X ALL) is a comparison of the weedy check weed control to the average of all weed tactics weed control (WT). Each site location is defined by the first letter of the location name, followed by the year (08 or 09).

* Significant at 0.05 level ** Significant at 0.01 level NS- Not significant

Table 4: Rye mode of kill and weed management treatment effects on weed density. The predominant weed species was pigweed (*Amaranthus* sp.). All pigweed plants above the soybean canopy for two data rows were counted (20.9 m^{-2}).[3]

	2008	2009		
Treatment	Goldsboro	Goldsboro	Kinston	Plymouth
	----count m^{-2}----	------------count m^{-2}------------		
Weed Control				
CGM	0.68 a	13 a	1.3 a	0.1 ab
Clove Oil	0.21 b	6.9 b	0.93a	0.05 bc
Rye Only	0.43 ab	7.5 b	1.2 a	0.13 a
Cultivation	.	7.3 b	0.99 a	0.006 c
Weedy Check	.	29[e]	11[e]	0.65[e]
Mode of Kill				
Flail-Mowed	0.63 a	8.6 a	1.1 a	0.08 a
Rolled	0.25 b	8.4 a	1.0 a	0.06 a

[3] Means followed by the same letter for each parameter are not significantly different based on Fisher's Protected LSD test at P<0.05.

[e] Means are different from all treatments at P<0.05.

CGM- corn gluten meal

Table 5: Rye mode of kill and weed management treatment effects on soybean yield.[3]

	2008			2009	
Treatment	Goldsboro	Kinston	Plymouth	Kinston	Plymouth
	----------------kg ha^{-1}--------------			--------kg ha^{-1}-------	
Weed Control					
CGM	1976 a	2681 a	2499 a	1195 a	2460 a
Clove Oil	2345 b	2849 a	2876 b	1114 a	2072 b
Rye Only	2190 ab	2903 a	2694 ab	1112 a	2388 a
Cultivation	.	2611 a	.	1275 a	2570 a
Weed-free Check	2143 ab	3583 b	2809 ab	2616 b	2506 a
Mode of Kill					
Flail-Mowed	2188 a	.	.	1027 a	2360 a
Rolled	2147 a	2761	2690	1321 b	2385 a

[3] Means followed by the same letter for each parameter are not significantly different based on Fisher's Protected LSD test at P<0.05. Two data rows were harvested and weights are reported at 15.5% moisture. All treatments were compared to a weed-free check. Flail-mowed and rolled treatment means are averaged over weed control treatments. Kinston and Plymouth 2008 did not have a flail-mowed treatment.

CGM- corn gluten meal

CHAPTER 2- Inducing Soybean Lodging when Utilizing Mulch for Weed Suppression

Introduction

Organic no-tillage and reduced tillage soybean production are becoming increasingly popular; concerns about soil health and fuel and labor expenses are pushing organic producers to consider whether reducing tillage is a plausible option. In organic soybean production, weed management is cited as producers' most difficult problem (Walz 1999) and cultivation acts as the core of most producers' weed management programs. There are multiple negative consequences associated with frequent cultivation, such as soil erosion (Beale et al. 1955), soil compaction (Raper et al. 2000), decreased soil residue cover (Hargrove 1990), increased CO_2 release (Paustian et al. 1998), increased labor and equipment costs (Weersink et al. 1992), and fuel costs (Hargrove 1990). Reducing or eliminating tillage has the potential to alleviate some of these concerns (Arshad et al. 1990; Six et al. 1999).

The use of cover crops, cover crop mulches, and crop residues have been extensively documented and researched in both organic and conventional agriculture. Cover crops play important roles in reducing soil erosion (Beale et al. 1955), providing weed suppression (Mohler and Teasdale 1993), and improving soil fertility and structure (Beale et al. 1995; Hoyt and Hargrove 1986). Utilizing cover crops in organic no-tillage and reduced tillage production is often critical to the success of the system. Cover crops provide weed and soil management services that otherwise cannot be provided by synthetic herbicides and fertilizers due to USDA organic standards.

Rye (*Secale cereale* L.) cover crop is known for its high biomass levels and allelopathic potential. Its ability to suppress weeds makes it highly favorable in organic conditions where herbicides are prohibited. The use of rye cover crops inhibits weed growth by competing with weeds in early spring (Barnes and Putnam 1983). Additional research has shown that rye mulch provides a physical barrier and light interception, both of which reduce weed pressure (Teasdale and Mohler 1993). Moreover, research has reported that increasing rye mulch mass on the soil surface exponentially decreases weed emergence (Teasdale and Mohler 2000). High rye residue levels have been shown to provide weed suppression 5-16 weeks into the season, while other research found rye to provide sufficient weed control for 4-6 weeks (Mohler and Teasdale 1993; Weston 1996).

Rye is also known for its allelopathic abilities (Barnes and Putman 1983; Barnes and Putnam 1987). Barnes and Putnam (1983) found that rye mulch provides better control of broadleaf weeds when compared to a mulch control (popular excelsior). Barnes and Putnam (1987) attributed rye's allelopathic abilities to two benzoxazinones: DIBOA (2,4-dihydroxy-1,4-(2H)-benzoxazin-3-one) and BOA (2(3H)-benzoxazolinone). Of the two, DIBOA reduced chlorophyll production by 50% in (*Chamydomonas rheinhadrtii* Dangeard) and inhibited the emergence of several weed species.

While high rye biomass levels can provide effective weed control, other research has shown that rye mulch has developmental effects on soybeans. Westgate et al. (2005) found that rye mulch reduced soybean dry matter, light interception, and delayed pod maturity.

Other research has shown reductions in soybean yield when grown in rye mulch (Eckert 1988; Reddy 2001). Moore et al. (1994) found increased soybean branching, nodule formation, and plant leaf area with soybeans grown in rye mulch, when compared to bare plots. Ruffo et al. (2004) did not notice any soybean yield reduction while being grown in rye mulch.

Soybean lodging is another factor of interest in soybean development. Little research has been done relating production practices to soybean lodging. Research has shown that soybean lodging can cause yield loss and has correlated lodging potential with planting dates, row spacing, soybean varieties, and seeding rates (Cooper 1971). Research using wheat stubble mulch noticed more soybean lodging with higher mulch levels (Hovermale et al. 1979). This was attributed to soybean etiolation or having shallower root systems and anchorage failure (Hovermale et al. 1979; Phillips and Young 1973). Yield reductions make soybean lodging a concern. Previous research found that lodging contributed to a 1.3% yield loss per acre, whereas eliminating lodging increased yield potential 13% (Weber and Fehr 1966).

In a previous experiment, severe soybean lodging was documented when grown in rye mulch. In other research, higher amounts of wheat residue have been associated with increased soybean lodging; 2X rates of wheat mulch (1X being straw residue associated with harvest) induced more lodging than the no-mulch control (Hovermale et al. 1979). At 2X rates, the average lodging rating was on a scale of 1-5 (Hovermale et al. 1979). Soybean lodging was considered severe at a rating of 3 or above. Rye cover crop killed at early milk (Feekes growth stage 11) by a roller-crimper or flail-mower is very different from harvested wheat mulch and no research has been done to determine if soybean lodging is induced by rye mulch. With the increase demand for organic soybean (USDA 2008) and the overwhelming challenge of effective weed management, interest in utilizing cover crop residue and allelopathic chemicals (Reberg-Horton 2001) has amplified. More research is needed to determine if rye residue levels and allelopathic chemicals have detrimental developmental effects on crops.

The objective of this research was to determine the relationship between rye mulch levels and soybean lodging. A secondary objective was to determine if allelopathy is a factor in the lodging response.

Materials and Methods

Research was conducted in 2009 at the Center for Environmental Farming Systems near Goldsboro, NC and Caswell Research Station near Kinston, NC. Goldsboro soil type was Wickham loamy sand (Fine-loamy, mixed, semiactive, thermic Typic Hapludults) with 2-6% slope. Kinston soil type was Johns loamy sand (Coarse-loamy, siliceous, semiactive, thermic Aeric Paleaquults). Soybean plot size was four rows (76.2 cm row spacing) by 4.57 meters. There were six replicates per site.

Rye and wheat straw mulch was utilized to determine what levels of mulch induced soybean lodging. Wheat straw was baled and brought in from an off-site location. Wheat straw was used as a less allelopathic check based on previous work showing a dramatic drop in allelochemical content during maturation in small grains (Reberg-Horton, 2005; Burgos et al., 1999). Wheat straw, however, still has active compounds (Wu et al., 2001) and cannot be considered an allelopathic free check. Rye (cv. 'Rymin') was grown on-site; it was planted in the fall of 2008 using a no-till drill with 15.54 cm spacing at a seeding rate of 134 kg ha^{-1}. Prior to planting rye, fields were disked and field cultivated to remove any existing vegetation. At soybean planting in May, the rye cover crop (growth stage: Feekes stage 11) was killed with a hay-mower and raked into two 15.24 m windrows (per replication). "Hutcheson" soybeans (*Glycine max* L.), maturity group V, were planted into bare soil at 370,500 live seed ha^{-1} using a Monosem no-till planter. All mulch treatments were evenly dispersed over the four soybean rows.

For each replicate, the two treatments (rye or wheat straw mulch) were applied at the following rates: 0.5X, 1X, 1.5X, and 2X. In Goldsboro, 1X rates for rye and wheat averaged at 3,365 and 11,513 kg ha^{-1}, respectively. In Kinston, 1X rates for rye and wheat averaged at 6,300 and 10,883 kg ha^{-1}, respectively. These treatments were checked against three weedy plots with no mulch. Both locations received 0.5X and 1X rates; Goldsboro's maximum rate was 1.5X and Kinston's maximum rate was 2X. Both locations ultimately had three rates (rye and wheat) and 3 weedy check plots per replicate.

Mulch rates were determined and dispersed using gross measurement scales. Initial rye rates were determined in linear feet of windrow. Each 15.24 m windrow contained rye biomass from 0.014 hectares. At the 1X rye rate, soybean plots were mulched with 1/9 of the rye biomass from that windrow, approximately 1.7 m. To estimate 0.5X, 1.5X, and 2X rates, the 1.7 m windrow section of rye was halved, increased by 50%, or doubled, respectively. Initial wheat straw rates were based on an estimated 1X rate of 11,208 kg ha^{-1} (dry wheat mulch). Individual wheat straw bales were weighted and averaged, then separated into sections to create the approximate mulch rates. Soybeans in the 1X rate received 1 1/3 bale, equaling approximately 11,185 kg ha^{-1}. The 2X rate received 2 bales per plot, the 1.5 X received 1 1/2 bale, and the 0.5X received 3/4 of a bale. Actual mulch biomass was quantified by taking a 0.5 m^2 quadrat at mulch application for each mulched plot. Collected biomass was dried at 60°C for 72 hours and dry weights were taken.

Mid-season stand counts and weed density data and late-season weed density, weed rating, soybean lodging rating, and soybean yield data were measured. Statistical analysis was completed in SAS [SAS 9.1.3, Cary, NC, 2008]. Weed density, soybean yield, and lodging data were graphed against mulch biomass and their relationship was studied using nonlinear regression (SAS PROC NLIN), with mulch biomass as the continuous independent variable and each response taking the role of dependent variable. Locations were combined and full and reduced models were compared using AIC (Akaike information criterion). The AIC equation is $AIC = n \cdot \ln(SSE/n) + 2k$ and is meant to explain the data with a least number of free parameters, while penalizing for over-fitting the data. When comparing models, the smallest AIC is considered the “best” model because it most closely resembles the “true” model (Beal 2005).

Results and Discussion

Weed Density

The predominant weed species for both locations was pigweed (*Amaranthus* sp.). Goldsboro's weedy check plots had a pigweed density that ranged from 1-9 plants m^2, averaging at 5.4 plants m^2. Kinston's weedy check plots had a pigweed density that ranged from 1-11 plants m^2, averaging at 5.2 plants m^2.

With increasing mulch biomass, weed density exponentially decreased (Figure 1). The equations $E = (1 + a_1(\text{kg ha}))\exp(-b_1(\text{kg ha}))$ and $E = \exp(-b_3(\text{kg ha}))$ were adapted from Teasdale and Mohler (2000). They found similar results, showing that the physical level of mulch was the determining factor for weed suppression (Teasdale and Mohler 2000). Teasdale and Mohler (2000) averaged weed suppression over 5 different mulch types (including controls) and concluded an exponential drop in weed emergence. At low biomass levels (3,000- 5,000 kg ha^{-1}), there was a slight increase in weed emergence. This could be due to favorable moisture conditions created by the presence of mulch to stimulate weed emergence. Weed increases at low mulch rates have been observed in both vetch and rye cover crops (Mohler and Teasdale 1993).

At approximately 10,000 kg ha^{-1}, the rye and wheat lines intersect, showing a further decrease in weed density with rye mulch (Figure 1). Other research (Teasdale and Mohler 2000) found that all mulching materials fit the same exponential models for weed suppression, concluding that the allelopathic effect was minimal and that physical suppression was the primary mechanism for weed control by mulches. This dataset was best fit by two lines, according to the AIC criterion, though the lines were close (Figure 1, Table 1). A one line model had the same the AIC as the two line model, but the two line model accounted for the initial rise in weed density at low mulch levels and the physical differences in mulch structure. More weeds were present when rye mulch biomass was less than 10,000 kg ha^{-1} and this may be due to subtle physical differences between the mulches. Wheat straw was more chopped, whereas rye was mowed with a hay-mower and consisted of whole stems. Allelochemicals may need to be present in sufficient quantities before having an impact on weed emergence. Wheat straw was assumed to have less active allelopathic activity (Reberg-Horton 2005; Burgos et al. 1999), while rye was assumed to demonstrate additional effects if there were any. The closeness of the two lines concurs with previous research that physical suppression is most likely responsible for weed control.

Soybean Lodging

Soybean lodging was more prominent at high mulch levels (Figure 2). The equation $L = (1+a_1(\text{kg ha}))\exp(-b_1(\text{kg ha}))$ was adapted from Teasdale and Mohler (2000). This dataset was subjected to different one and two line models and compared using AIC criterion (Table 1). A (location X treatment) interaction was not significant and all data was combined. A one line model provided the most parsimonious fit, indicating allelopathic and physical differences between the two mulches had little impact on soybean lodging.

Hovermale et al. (1979) found 2X (not quantified) rates of wheat residue induced soybean lodging at one site location. Increased lodging at high mulch levels could be caused by shallow rooting systems typically found in mulched systems, which can lead to anchorage failure and lodging (Phillips and Young, 1973; Berry et al., 2004).

At approximately 10,000 kg ha^{-1}, lodging ratings plateau at a rating of 4 (Figure 2). This can be attributed to reaching maximum lodging potential for this system. A lodging rate of 3 was deemed the maximal accepted lodging rating; anything higher would likely result in harvest difficulty and yield loss.

Soybean Yield

Soybean yield was collected in Kinston only. Yield increased with increasing mulch levels (Figure 3) with soybean in rye mulch yielding higher than soybean in wheat mulch. Both rye and wheat shared the same model $Y = (1+a_1(\text{kg ha}))\exp(-b_1(\text{kg ha}))$ with a common b_1 coefficient, but separate a_1 coefficients (Teasdale and Mohler, 2000). A one line model had a very close AIC, but the two line accounted for differences in slope and higher yield results with rye mulch. At 10,000 kg ha^{-1}, yield increases plateau and begin to gradually decrease (Figure 3). The yield plateau was likely the result of soybean lodging, which was simultaneously increasing rapidly at these high mulch rates (Figure 2). Moreover, at 10,000 kg ha^{-1}, unacceptable lodging ratings diminish the added weed suppression benefit from rye (Figure 1). Figure 1, along with other research (Teasdale and Mohler, 2000), clearly shows that increasing cover crop biomass levels decrease weed emergence. However, if at these same levels soybean lodging is unacceptable, then a soybean yield advantage due to increased weed suppression in high rye biomass levels is lost.

Future research should address soybean lodging and why it occurs at high rye biomass levels. Other research has shown detrimental effects of rye mulch on soybean development that resulted in yield losses (Westgate et al., 2005, Eckert, 1988; Reddy, 2001), but none associated with soybean lodging. Future research should also address production changes that can be made to reduce soybean lodging. During soybean planting into rye mulch, a furrow is created in the rye by the planter. Increasing the planting furrow may reduce soybean lodging by eliminating the physical barrier of the rye mulch. However, by increasing the furrow, more soil is exposed and allows for more in-row weed emergence to directly compete with the soybean crop. Utilizing rye mulch for weed suppression in organic soybean systems seems promising, but soybean lodging and in-row weed pressure are important issues that need to be addressed before this system is implemented.

REFERENCES

Arshad, M.A., Schnitzer, M., Anger, D.A., and D.A. Ripmeester. 1990. Effects of till vs no-till on the quality of soil organic matter. Soil Biol. Biochem. 22: 595-599.

Barnes, J.P. and A.R. Putnam. 1983. Rye residues contribute weed suppression in no-tillage cropping systems. Journal of Chemical Ecology. 9(8): 1045-1057.

Barnes, J.P. and A.R. Putnam. 1987. Role of benzoxazinones in allelopathy by rye (*Secale cereale* L.). Journal of Chemical Ecology. 13(4): 889-906.

Beale, O.W., Nutt, G.B., and T.C. Peele, 1955. The effects of mulch tillage on runoff, erosion, soil properties, and crop yields. Soil Science Proceedings. 244-247.

Beal, D.J. 2005. Information Criteria Methods in SAS for Multiple Linear Regression Models. SESUG Proceedings. Paper SA05.

Berry, P.M., Sterling, M., Spink, J.H., Baker, C.J., Sylvester-Bradley, R., Mooney, S.J., Tams, A.R., and A.R. Ennos. 2004. Understanding and reducing lodging in cereals. In Advances in Agronomy, Volume 84. (ed. D.L. Sparks). Elsevier, Inc. 217-271.

Burgos, N.R., Talbert, R.E., and J.D. Mattice. 1999. Cultivar and age differences in the production of allelochemicals by Secale cereale. Weed Science. 47: 481-485.

Cooper, R.L. 1971. Influence of early lodging on yield of soybean [*Glycine max* (L.) Merr.]. Agronomy Journal. 63: 449-450.

Cooper, R.L. 1971. Influence of soybean production practices on lodging and seed yield in highly productive environments. Agronomy Journal. 63: 490-492.

Eckert, D.J. 1988. Rye cover crops for no-tillage corn and soybean production. Journal of Production Agriculture. 1: 207-210.

Hargrove, W.L. 1990. Role of conservation tillage in sustainable agriculture. 28-32. In J.P. Mueller and M.G. Wagger (eds.) Proc. Of 1990 South Reg. Cons. Tillage Conference. July 17-26. 1990. North Carolina State University. Raleigh, NC.

Hovermale, C.H., Camper, H.M., and M.W. Alexander. 1979. Effects of small grain stubble height and mulch on no-tillage soybean production. Agronomy Journal. 71: 644-647.

Hoyt, G.D. and W.L. Hargrove. 1986. Legume cover crops for improving crop and soil management in the southern United States. Hortscience. 21(3): 397-402.

Mohler, C.L. and J.R. Teasdale. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. Weed Research. 33: 487-499.

Moore, M.J., Gillespie, T.J., and C.J. Swanton. 1994. Effect of cover crop mulches on weed emergence, weed biomass, and soybean (*Glycine max*) development. Weed Technology. 8: 512-518.

National Organic Program (NOP). 2008. National list of allowed and prohibited substances. Website. http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateN&navID=NationalListLinkNOPNationalOrganicProgramHome&rightNav1=NationalListLinkNOPNationalOrganicProgramHome&topNav=&leftNav=&page=NOPNationalList&resultType=&acct=nopgeninfo.

Paustian, K., Cole, C.V., Sauerbeck, D., and N. Sampson. 1998. CO2 Mitigation by agriculture: an overview. Climate Change. 41(1): 1480-1573.

Phillips, S.H. and H.M. Young, Jr. 1973. No-tillage farming. Reinman Assocation. Milwaukee, Wis. 224 pg.

Raper, R.L., Reeves, D.W, Schwal, E.B., and C.H. Burmester. 2000. Reducing soil compaction of Tennessee valley soils in conservation tillage systems. The Journal of Cotton Science. 4: 84-90.

Reberg-Horton, S.C., Creamer, N.G., Burton, J., Ranells, N., and P.L. Murphy. 2001. Breeding rye (*Secale cereale*) for increased allelopathy. HortScience. 36: 561.

Reddy, K.N. 2001. Effects of cereal and legume cover crop residues on weeds, yield, and net return in soybean (*Glycine max*). Weed Technology. 15: 660-668.

Ruffo, M.L., Bullock, D.G., and G.A. Bollero. 2004. Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. Agronomy Journal. 96: 800-805.

Six, J., Elliott, E.T., and K. Paustian. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Science Society of America Journal. 63: 1350-1358.

Teasdale, J.R. and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal 85: 673-680.

Teasdale, J.R. and C.L. Mohler. 2000. The quantitative relationship between weed emergence and the physical properties of mulches. Weed Science. 48: 385-392.

USDA Economic Research Service. 2008. Organic Production. http://www.ers.usda.goc/data/organic. Accessed Feburary 12, 2010.

Walz, E. 1999. Third biennial national organic farmers' survey, p. 19-47. Organic Farming Research Foundation. Santa Cruz, CA.

Weber, C.R. and W.R. Fehr. 1966. Seed yield losses from lodging and combine harvesting in soybeans. Agronomy Journal. 58: 287-298.

Weersink, A., Walker, M., Swanton, C. and J.E. Shaw. 1992. Costs of conventional and conservation tillage systems. Journal of soil and water conservation. 47(4): 328-334.

Westgate, L.R., Singer, J.W., and K.A. Kohler. 2005. Method and timing of rye control affects soybean development and resource utilization. Agronomy Journal. 97: 806-816.

Weston, L.A. 1996. Utilization of allelopathy for weed management in agroecosystems. Agronomy Journal. 88: 860-866.

Wu, H., Haig, T., Pratley, J., Lemerle, D., and M. An. 2001. Allelochemicals in wheat (Triticum aestivum L.): Variation of phenolic acids in shoot tissues. Journal of Chemical Ecology. 27(1): 125-135.

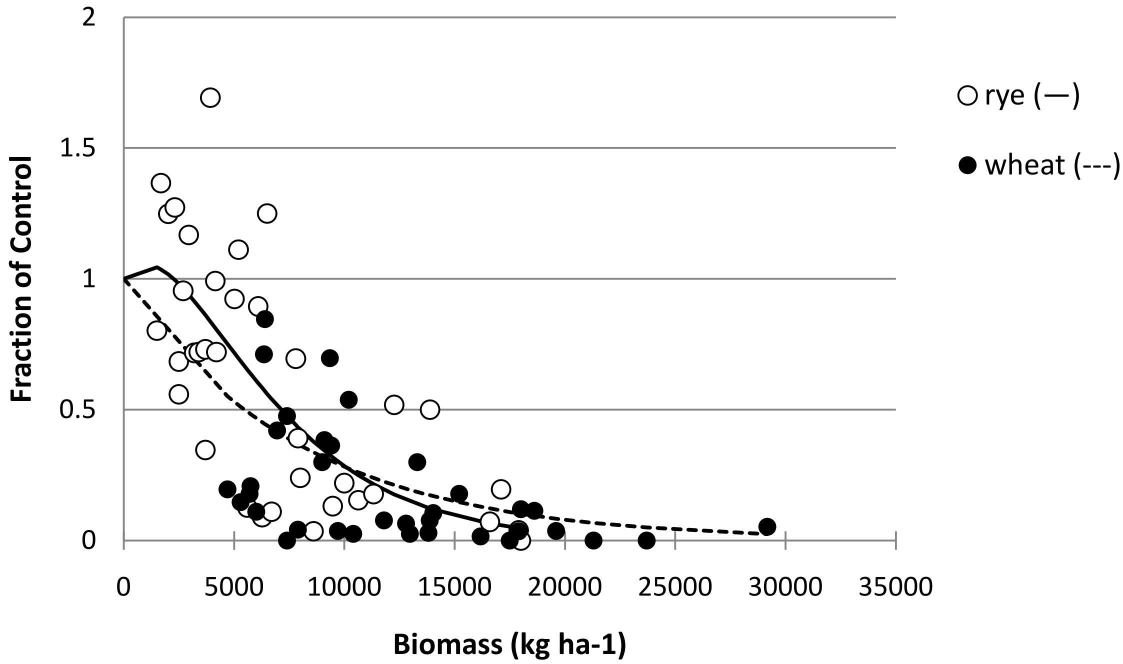


Figure 1: Weed emergence response to increasing cover crop biomass. Emergence was determined by dividing an individual plot's total weed count by the average weed count for weedy check plots; the weedy check averages were separated by block. The rye model is $E = (1 + a_1(\text{kg ha}))\exp(-b_1(\text{kg ha}))$. The wheat model is $E = \exp(-b_3(\text{kg ha}))$. The rye model accounts for the initial increase in weed emergence at lower biomass levels. The wheat model is the standard exponential decay model.

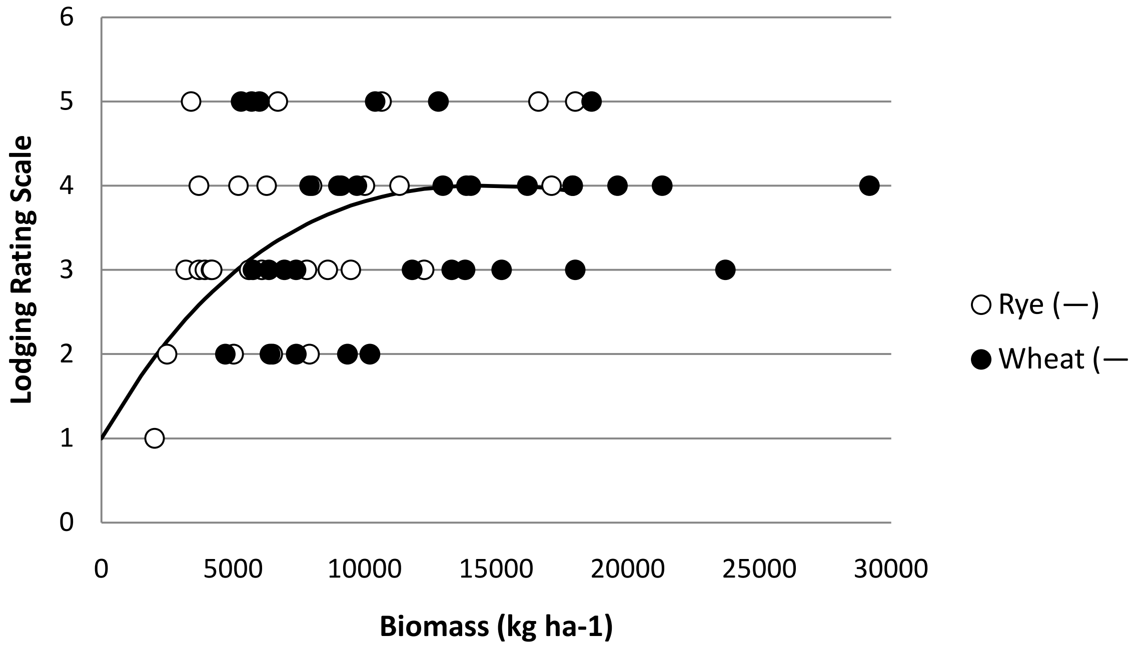


Figure 2: Soybean lodging response to increasing cover crop biomass. Lodging was determined on a (1-5) rating scale, with 1 being completely erect and 5 being completely prostrate. The rye and wheat model is $L = (1+a_1(\text{kg ha}))\exp(-b_1(\text{kg ha}))$.

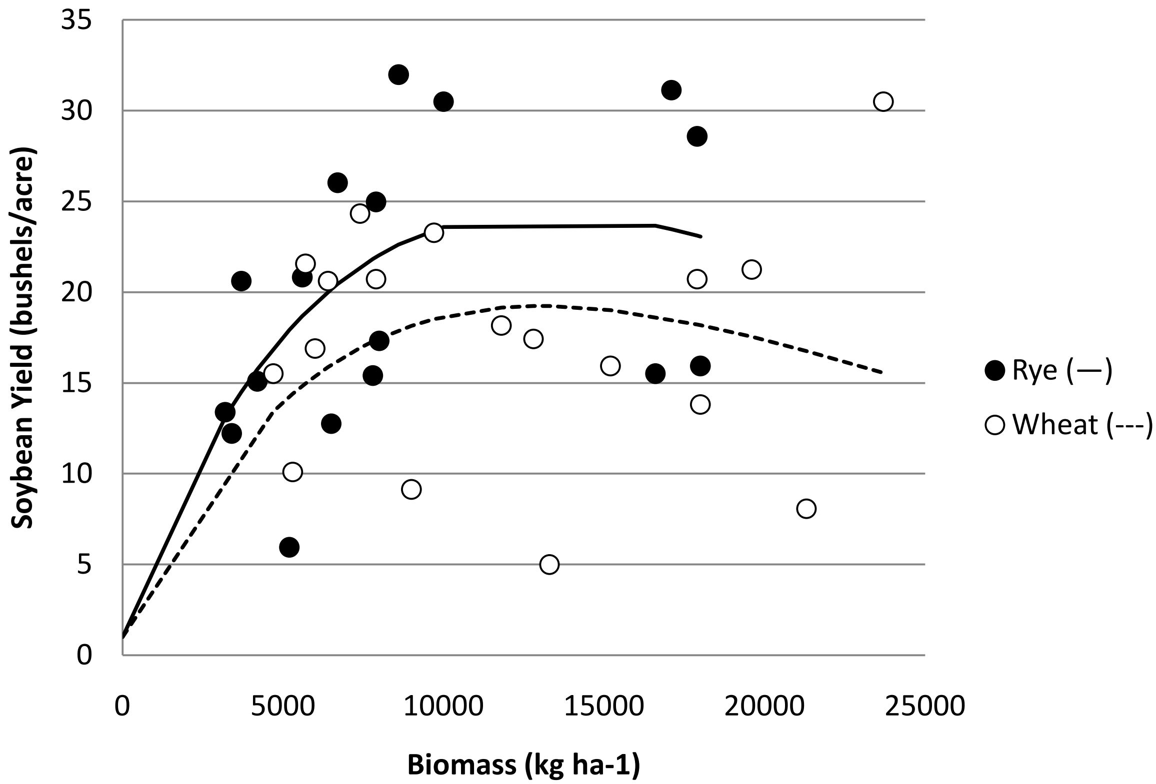


Figure 3: Soybean yield response to increasing cover crop biomass. The model for both rye and wheat was $Y = (1+a_1(\text{kg ha}))\exp(-b_1(\text{kg ha}))$. Curves share a common b_1 coefficient and separate a_1 coefficients.

Table 1: Akaike information criterion (AIC) testing was used to determine the best fit for the data. Combined weed emergence, soybean lodging, and soybean yield (Kinston only) data were compared in response to rye (R) and wheat (W) treatments. Model equations were adapted from Teasdale and Mohler (2000). The number of curves is representative of whether R and W treatments were combined or held separate: 1 curve- R and W combined, 2 curves- R and W separate.

Model	# of curves	------------------------------ AIC ------------------------------		
		Weed Emergence	Soybean Lodging	Soybean Yield
Eq. 5 (W); Eq. 6(R)	2	-151.4	.	.
Eq. 5	1	-151.4	104.9	251.5
Eq. 5	2	-150.5	99.7	250.3
Eq. 6	1	-150.5	48.7	208.8
Eq. 6	2	.	52.1	210.6
Eq. 6 *	2	.	50.1	208.7

I: Dependent Variable

Equation 5: $I = \exp(-b_3(\text{kg ha}))$

Equation 6: $I = (1 + a_1(\text{kg ha}))\exp(-b_1(\text{kg ha}))$

* Common b_1 coefficient and separate a_1 coefficients