SWEET CORN GERMINATION, GROWTH, AND YIELD AFTER A RYE WINTER COVER CROP

By

TAMARA NICOLE McCLUNG

A Thesis Submitted to the Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Plant Sciences

THE UNIVERSITY OF ARIZONA

D E C E M B E R 2 0 1 3

Approved by:

____

Dr. Dennis T. Ray
Department of Plant Sciences

The University of Arizona Electronic Theses and Dissertations Reproduction and Distribution Rights Form

The UA Campus Repository supports the dissemination and preservation of scholarship produced by University of Arizona faculty, researchers, and students. The University Library, in collaboration with the Honors College, has established a collection in the UA Campus Repository to share, archive, and preserve undergraduate Honors theses.

Theses that are submitted to the UA Campus Repository are available for public view. Submission of your thesis to the Repository provides an opportunity for you to showcase your work to graduate schools and future employers. It also allows for your work to be accessed by others in your discipline, enabling you to contribute to the knowledge base in your field. Your signature on this consent form will determine whether your thesis is included in the repository.

Name (Last, First, Middle)
McClung, Tamara, Nicole

Degree title (eg BA, BS, BSE, BSB, BFA):
BS

Honors area (eg Molecular and Cellular Biology, English, Studio Art):
Plant Sciences

Date thesis submitted to Honors College:
12.9.13

Title of Honors thesis:
Sweet corn germination, growth, and yield after a rye winter cover crop.

The University of Arizona Library Release Agreement

I hereby grant to the University of Arizona Library the nonexclusive worldwide right to reproduce and distribute my dissertation or thesis and abstract (herein, the "licensed materials"), in whole or in part, in any and all media of distribution and in any format in existence now or developed in the future. I represent and warrant to the University of Arizona that the licensed materials are my original work, that I am the sole owner of all rights in and to the licensed materials, and that none of the licensed materials infringe or violate the rights of others. I further represent that I have obtained all necessary rights to permit the University of Arizona Library to reproduce and distribute any nonpublic third party software necessary to access, display, run or print my dissertation or thesis. I acknowledge that University of Arizona Library may elect not to distribute my dissertation or thesis in digital format if, in its reasonable judgment, it believes all such rights have not been secured.

☒ Yes, make my thesis available in the UA Campus Repository!

Student signature: [signature] Date: 12/4 13

Thesis advisor signature: [signature] Date: 12/4/13

☐ No, do not release my thesis to the UA Campus Repository.

Student signature: ____________ Date: ____________

Sweet corn germination, growth, and yield after a rye winter cover crop

Tamara McClung[1]

Work done in conjunction with Joe Shail[2], Thomas Björkman[2], Dennis T. Ray[1]

[1] School of Plant Sciences, University of Arizona, Tucson, AZ 85719

[2] Department of Horticulture, Cornell University, Geneva, NY 14456

Abstract

Cover crops are used to help manage fields when not producing a crop by helping to prevent erosion, add organic matter, improve aggregate stability, suppress weeds, and prevent leaching loss of nitrogen from the soil. Rye winter cover crops are used in New York because they grow late into the fall and resume growth early in the spring and can help scavenge nitrogen from the soil thereby reducing nitrogen leaching loss during spring rains and snowmelts. In a previous study sweet corn fresh weight after a rye winter cover crop was inhibited by 20%. In this study, rye was killed at five different maturity stages to test whether killing the rye earlier in the spring reduces inhibition. The rye was incorporated at the last killing treatment and sweet corn was sown four and six weeks after incorporation. Chlorophyll concentration of the corn was lower in plots that had incorporated more mature rye. Despite these results, germination, fresh weight, or yield of the corn was not reduced by any treatment. Less inhibition by rye was observed this year than previously, and no reduction in inhibition was observed due to killing the rye earlier in the spring.

Sweet corn germination, growth, and yield after a rye winter cover crop

Tamara McClung[1]

Work done in conjunction with Joe Shail[2], Thomas Björkman[2], Dennis T. Ray[1]

[1] School of Plant Sciences, University of Arizona, Tucson, AZ 85719

[2] Department of Horticulture, Cornell University, Geneva, NY 14456

Abstract

Cover crops are used to help manage fields when not producing a crop by helping to prevent erosion, add organic matter, improve aggregate stability, suppress weeds, and prevent leaching loss of nitrogen from the soil. Rye winter cover crops are used in New York because they grow late into the fall and resume growth early in the spring and can help scavenge nitrogen from the soil thereby reducing nitrogen leaching loss during spring rains and snowmelts. In a previous study sweet corn fresh weight after a rye winter cover crop was inhibited by 20%. In this study, rye was killed at five different maturity stages to test whether killing the rye earlier in the spring reduces inhibition. The rye was incorporated at the last killing treatment and sweet corn was sown four and six weeks after incorporation. Chlorophyll concentration of the corn was lower in plots that had incorporated more mature rye. Despite these results, germination, fresh weight, or yield of the corn was not reduced by any treatment. Less inhibition by rye was observed this year than previously, and no reduction in inhibition was observed due to killing the rye earlier in the spring.

1. Introduction

The use of cover crops can provide many benefits to soil health and the health of succeeding crops. They can provide protection from erosion by wind and water, increase the soil capacity for water infiltration, add organic matter to the soil, provide habitat for beneficial organisms (Brady and Weil, 2010), and reduce leaching loss of nitrogen and other nutrients (Björkman and Shail, 2010; Brady and Weil, 2010). Cover crops can also suppress weed growth (Barnes and Putnam, 1983; Clark, 2007) and increase soil aggregate stability (Clark, 2007) and are commonly used in the field at times when it would otherwise lay bare.

A rye winter cover crop can provide many benefits to the soil, especially in areas of high rainfall. It has deep roots and a large biomass, adding organic matter into the soil when incorporated (Clark, 2007; Crandall *et al*., 2005). Rye has been identified as a useful winter cover crop in temperate regions due to its ability to germinate at cool temperatures, grow relatively late into the fall, and to resume growth early in the spring (Björkman and Shail, 2010). During times of high rainfall or snowmelt, the fibrous root systems of rye scavenge nitrogen from the soil, helping to prevent it from leaching into agricultural runoff (Brady and Weil, 2010; Clark, 2007; Shipley *et al.,* 1992), making it ideal for use in the northeastern United States (Björkman and Shail, 2010). Reducing nitrogen losses from the soil can help minimize nitrogen inputs for the following crop, however, there have been inconsistent findings on the response of vegetable crops following rye cover crops (Clark *et al.*, 2007; Crandall *et al*., 2005; Thorup-Kristensen and Dresbøll, 2010).

In previous studies, reduced germination, growth, or yield of vegetable crops has been observed following a rye cover crop (Barnes and Putnam 1983; Bollero and Bullock, 1994; Crandall *et al*., 2005; Thorup-Kristensen and Dresbøll, 2010). In an unpublished study performed by Björkman and Shail in 2010, several vegetable crops and sweet corn were grown after wheat, triticale, and rye winter cover crops. The inhibition was measured 30 days after planting as the mean fresh weight of the vegetables and sweet corn following grain winter cover crops subtracted from the mean fresh weight of the same crop grown in bare ground plots. By this measurement, the sweet corn after rye was inhibited by 20%.

The mechanism by which rye inhibits germination or growth is debated (Crandall *et al*., 2005). Barnes and Putnam (1983) found that more mature rye residues were correlated with reduced germination and growth of subsequent crops and suggested that it could be contributed to the action of allelopathic toxins either leached directly from the rye residue or produced as the rye decomposed. Rice *et al*. (2005) observed that the phytotoxicity of rye could not be contributed to one compound alone, and hypothesized that different phytotoxic compounds with different methods of action are produced in rye, changing in concentration as the rye matures. The phytotoxicity of rye contributes to its usefulness as a weed suppressing cover crop (Barnes and Putnam, 1983), but these effects are undesirable for the following vegetable crops.

A rye cover crop can benefit the following crop by diminishing nitrogen losses from the soil by leaching, however the nitrogen in the rye residue must be made available to the following crop at the times when it is needed. The mineralization rate of nitrogen in plant residue depends on the total nitrogen content and the C/N ratio of the residue (Brunn *et al*., 2006; Frankenberger Jr. and Abdelmagid, 1985; Vaughan and Evanylo, 1999), and on the environmental conditions (Vaughan and Evanylo, 1999; Wagger, 1989). As rye matures, the biomass increases and more carbon and nitrogen are incorporated into the plant, with an overall increase in C/N ratio (Crandall *et al*., 2005; Thorup-Kristensen and Dresbøll, 2010; Wagger, 1989). By the time of incorporation, rye biomass will likely have a C/N ratio of greater than 25:1 (Wagger, 1989), the threshold above which nitrogen may be deficient for crop uptake due to microbial competition (Brady and Weil, 2010). Frankenberger Jr. and Abdelmagid (1985) found crop nitrogen deficiency at residue C/N ratios above 19:1.

The objectives of this study were: (1) to assess inhibition, if any, on germination, growth, and yield of sweet corn following a rye winter cover crop; and (2) to determine if the rye maturity when it was killed affected inhibition.

2. Materials and Methods

This study was performed in Geneva, New York at the New York State Agricultural Experiment Station Vegetable Research Farm, where the soil composition is a Honeoye silt loam: a fine-loamy, mixed, active, mesic, Glossic Hapludalf. Rye treatments began in late September 2011.

2.1. Rye killing treatments

Winter rye (*Secale cereale*) was seeded at a rate of 100 lbs/acre by a John Deere no-till drill planter in a treatment area 36.59m east to west and 82.32m north to south. The treatment area was divided into 3.35m x 36.59m strips going east to west in a completely randomized design, and the rye was killed using glyphosate at different stages of maturity according to the Feekes growth stages (Wise, 2011) (Figures 1 and 2). The rye treatment plots were completely randomized, with five repetitions for each of five kill dates (Tables 1 and 2). The strips were killed, five at a time, at Feekes stages 1, 3, 5, 7, and 10, on October 15, April 1, April 15, April 25, and May 1, respectively (Table 2). Plots killed in the fall at Feekes stage 1 acted as fallow plots, having no biomass in the spring. Rye was cut on the kill date with lawn clippers for 1 m^2

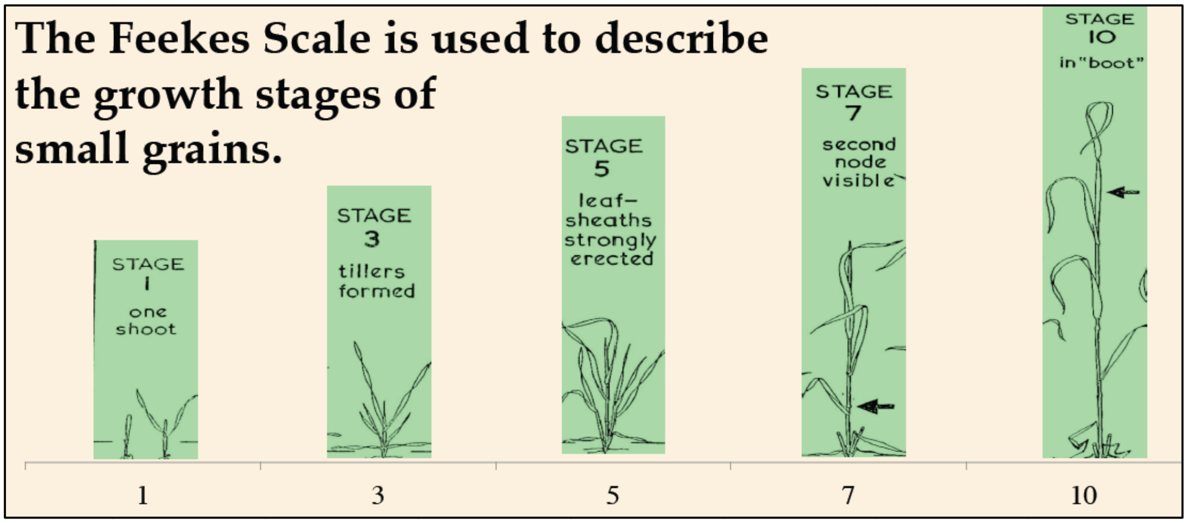

Fig. 1. Feekes stages of maturity at which rye was killed for different treatments ("Growth Stages in Cereals," 1987). Corresponding rye killing times are given in Table 2.

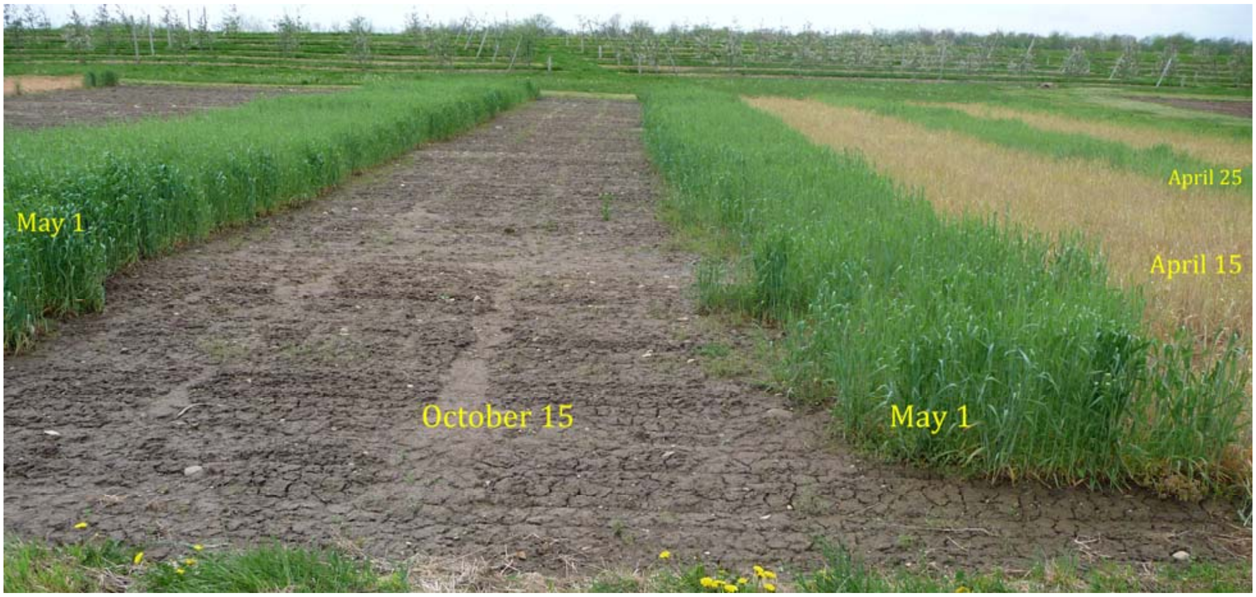

Fig. 2. Rye killing treatments, May 4, 2012, facing west. Plots marked with a date in this figure correspond to plots 4 – 8 (going from right to left in this photo), highlighted in yellow in Table 1. *Photo: Thomas Björkman*

Table 1

Randomized design of field with plot numbers, rye killing dates, and corn planting dates. Green shaded area represents actual field layout, with north at the top. Yellow shaded area corresponds to rye treatments marked with dates, starting with plot #8 on the left, in Figure 2.

Plot #	Rye Kill Date	Corn Planting Dates and Field Layout			
1	Oct 15	June 15	May 31	June 15	May 31
2	April 25	June 15	May 31	June 15	May 31
3	April 15	June 15	May 31	June 15	May 31
4	April 25	June 15	May 31	June 15	May 31
5	April 15	June 15	May 31	June 15	May 31
6	May 1	June 15	May 31	June 15	May 31
7	Oct 15	June 15	May 31	June 15	May 31
8	May 1	June 15	May 31	June 15	May 31
9	April 1	June 15	May 31	June 15	May 31
10	April 1	June 15	May 31	June 15	May 31
11	Oct 15	June 15	May 31	June 15	May 31
12	Oct 15	June 15	May 31	June 15	May 31
13	May 1	June 15	May 31	June 15	May 31
14	April 1	June 15	May 31	June 15	May 31
15	April 15	June 15	May 31	June 15	May 31
16	April 15	June 15	May 31	June 15	May 31
17	May 1	June 15	May 31	June 15	May 31
18	April 15	June 15	May 31	June 15	May 31
19	April 25	June 15	May 31	June 15	May 31
20	April 25	June 15	May 31	June 15	May 31
21	April 25	June 15	May 31	June 15	May 31
22	April 1	June 15	May 31	June 15	May 31
23	May 1	June 15	May 31	June 15	May 31
24	April 1	June 15	May 31	June 15	May 31
25	Oct 15	June 15	May 31	June 15	May 31

Table 2: Rye Kill Dates and Maturity

Feekes stages of maturity of rye, shown in Figure 1, and corresponding killing times.

Feekes Stage	Maturity	Kill Date
1	One shoot	Oct 15, 2011
3	Tillers / green up	April 1, 2012
5	Sheaths erect	April 15, 2012
7	Second node out	April 25, 2012
10	Boot	May 1, 2012

per plot and dried for several days in a 160°F oven, to constant weight. Rye biomass was recorded, and samples were sent to Brookside Lab in New Bremen, OH on May 31, 2012 to test for carbon-to-nitrogen ratios. Rye was incorporated into the soil by conventional tillage at the last killing date.

2.2. Corn planting treatments

Sweet corn (*Zea mays* var. *rugosa* cv. Bodacious) was chosen to follow the rye because of its sensitivity to soil nitrogen levels. Bodacious is a moderately vigorous, disease-resistant hybrid cultivar. The corn was planted on two dates, with two repetitions each, in 9.15m blocks in a north-to-south direction (perpendicular to the rye treatment strips). The four resulting subplots alternated by planting date. The first planting occurred on May 31, 2012, and the second on June 15, 2012. Twelve rows of corn were planted in each of the four subplots, using a Monosem vacuum planter, with 24.13cm in-row spacing and 76.20cm row width. The outer rows of each subplot were guard rows and not used in data collection. There were also recently installed tile drainage lines in the field where the soil had been upturned. Corn occurring in these areas was not used for data collection.

A 10-5-10 fertilizer was applied at a rate of 600 lbs/acre at corn planting, which contributed 60 lbs/acre nitrogen. An additional 30 lbs/acre nitrogen was applied at cultivation when corn was 6-8” tall in the form of 44-0-0 ammonium sulfate.

2.3. Data collection

Samples for pre-sidedress soil nitrate test (PSNT) were taken the just before the first corn planting on May 31, 2012. Four samples were taken from the top six inches of each east-to-west plot, in the center of each of the four corn-planting subplots. Samples were combined for each plot and KNO_3 extractions were performed. Filtered extractions were analyzed for ppm nitrate with a HORIBA C-141 compact ion meter.

Stand counts for germination success were taken for each planting date after seeds sprouted by counting seedlings per 1.45m at the plot centers. Corn fresh weight was measured at forty days after planting for each date. For the fresh weight measurements, eight plants from each subplot (one from each row excepting tile line rows and guard rows) were cut with pruners at ground level and weighed immediately in the field.

Chlorophyll content of the leaves was measured with a Minolta SPAD (single photon avalanche diode) chlorophyll meter when corn was in the V6 stage (vegetative growth stage with the 6^{th} leaf fully expanded with the leaf collar), again taking measurements from eight rows per subplot and recording the averages for each subplot. Readings were taken from the newest leaf with the leaf collar fully exposed, midway between the midrib and the edge of the leaf (Figure 3). Corn yield data was collected in June from $4.18m^2$ per subplot.

2.4. Data analysis

JMP 11 was the software used for statistical analysis. A Tukey Kramer test was used to compare all means for significant differences between rye treatments for the rye biomass, nitrogen content, and C/N ratio at killing time; soil PSNT; and corn germination, early growth, chlorophyll content at the V6 stage, and yield.

Fig. 3. Placement of SPAD meter, between the midrib and the edge of the leaf, for corn chlorophyll measurements.

3. Results

Data for the biomass, C/N ratio, and nitrogen content of the rye when killed is shown in Table 3. All plots differed significantly from each other with respect to biomass of the rye at killing time. The C/N ratios differed significantly between the rye killed at Feekes stage 3 and 5, but all mature-stage rye (Feekes 5, 7, and 10) had C/N ratios of 25:1 or above (Figure 4). Rye nitrogen content at kill date differed significantly between Feekes stage 10 and each of the other treatments, as well as between stage 7 and stage 3 (Figure 6). There were no significant differences between the rye treatments for PSNT (Figure 5).

Corn germination (Table 4, Figure 7), early growth (Table 5, Figure 8) and yield (Table 6, Figure 9) were not significantly affected by the rye treatments.

There was a significant difference in corn chlorophyll content between rye Feekes stage 7 and 1 (Table 7, Figure 10).

Table 3: Rye biomass, rye C/N ratio, rye N content, and soil nitrate-N
Values represent the mean of five repetitions.

Feekes stage	Rye biomass (tons/acre)	Rye C/N ratio	Rye nitrogen content (lbs/acre)	Soil nitrate-N (ppm N)
1	0.08 ± 0.00	0 ± 0	0 ± 0	15.33 ± 2.88
3	0.40 ± 0.09	18.91 ± 1.69	17.17 ± 3.33	16.07 ± 2.67
5	1.12 ± 0.06	28.70 ± 1.03	32.08 ± 1.90	16.60 ± 2.65
7	1.68 ± 0.20	25.70 ± 1.57	56.45 ± 8.71	15.60 ± 2.34
10	2.43 ± 0.11	25.29 ± 2.48	84.28 ± 8.93	14.87 ± 1.92

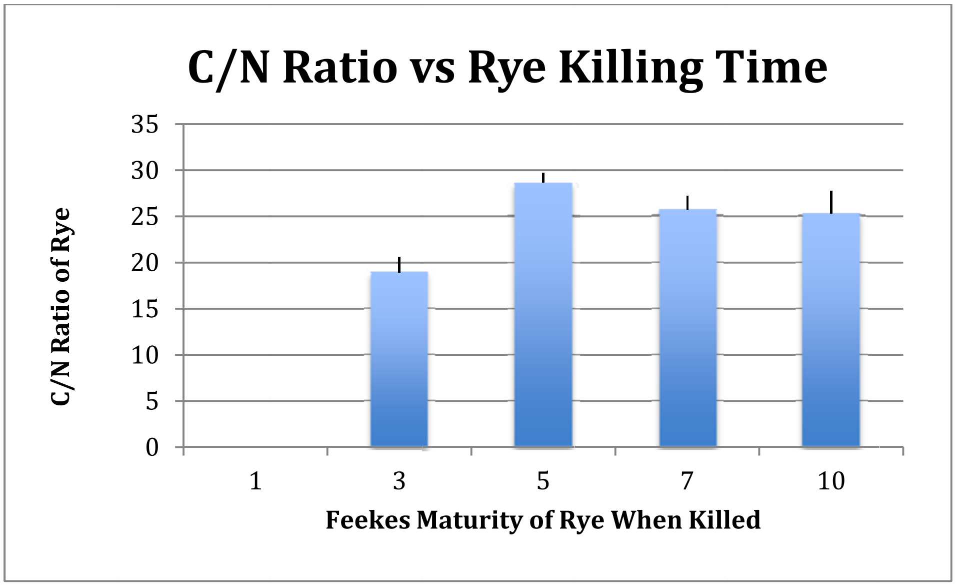

Fig. 4. C/N ratio of rye at killing time. All mature-stage rye (Feekes stages 5, 7, and 10) had C/N ratios over 25:1.

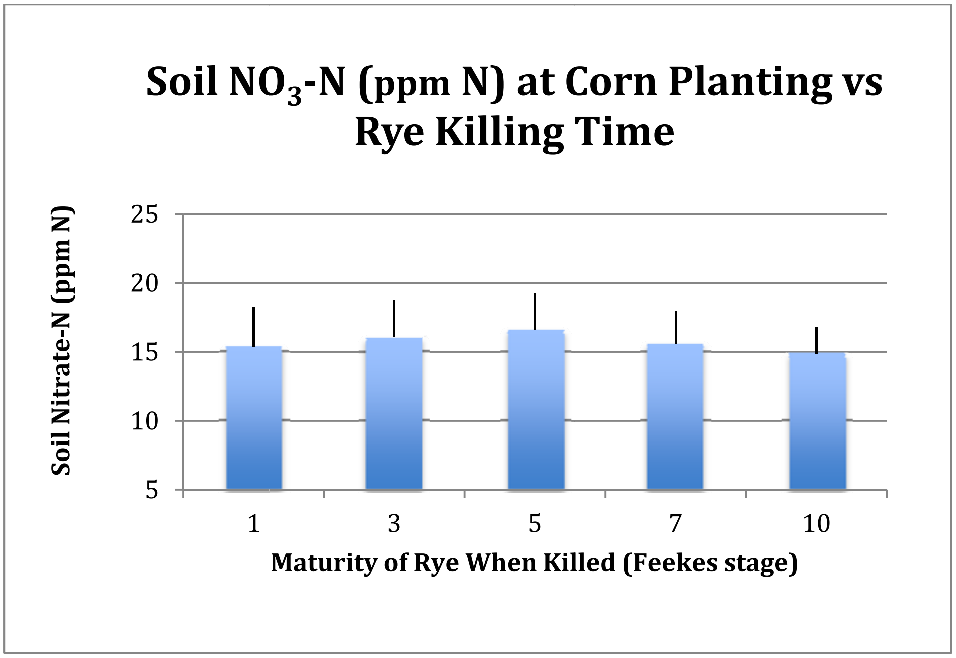

Fig. 5. Pre-sidedress soil nitrate test (PSNT). No significant difference was observed for any treatment.

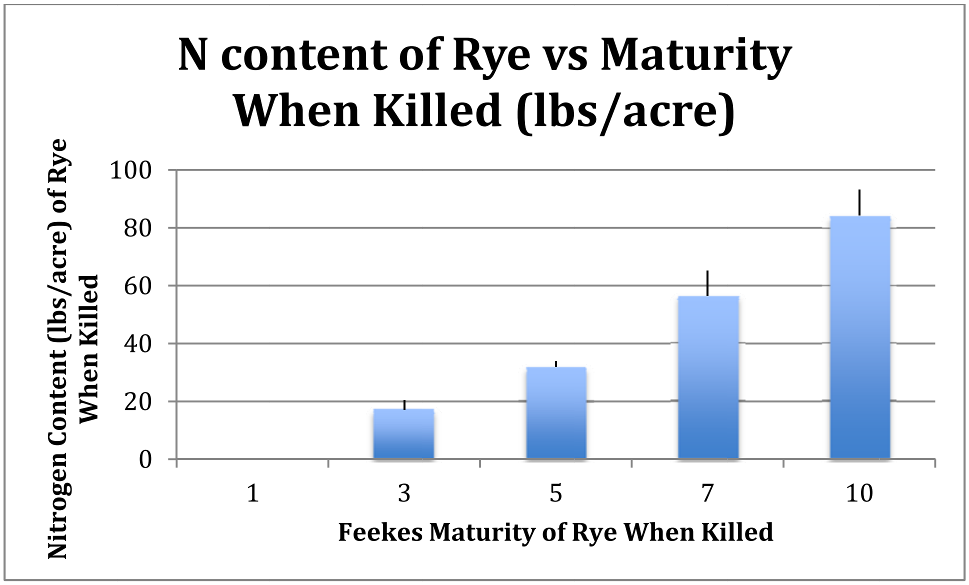

Fig. 6. Rye N content at killing time differed significantly between all treatments, as did rye biomass.

Table 4: Corn stand counts

Stand counts revealed that germination was nearly 100% for all treatments. Values represent the mean of five repetitions.

	Percent Germination	
Feekes stage	Planting 1	Planting 2
1	101.06 $\pm$ 3.68	102.64 $\pm$ 2.37
3	97.90 $\pm$ 1.13	97.90 $\pm$ 4.42
5	102.96 $\pm$ 3.37	103.11 $\pm$ 2.34
7	99.64 $\pm$ 2.05	98.06 $\pm$ 3.51
10	96.16 $\pm$ 2.12	100.27 $\pm$ 1.77

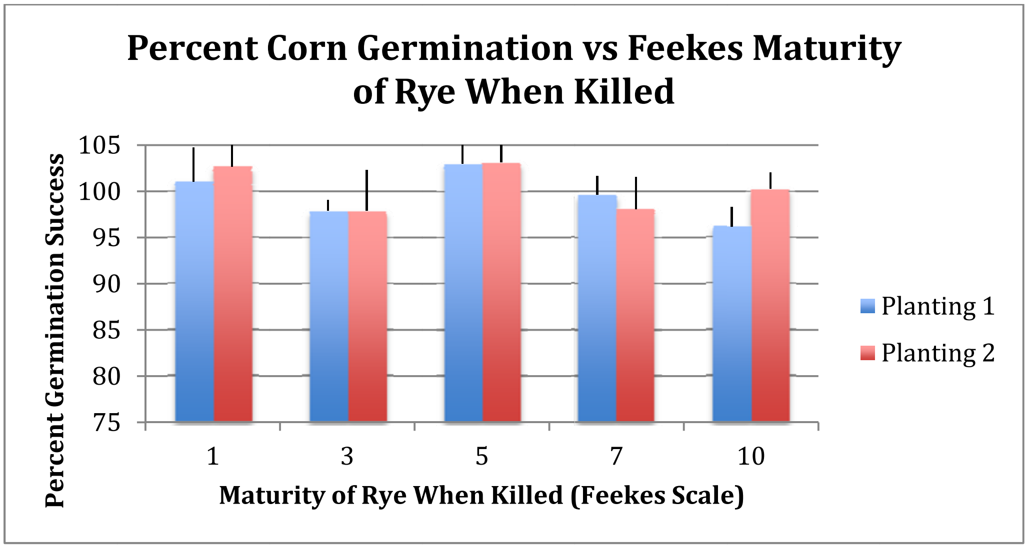

Fig. 7. Corn germination rates were high for all treatments.

Table 5: Early growth

Shoot fresh weight at 40 days. Values represent the mean of five repetitions.

	Planting 1	Planting 2	Both plantings
Feekes stage	Fresh weight corn (kg)	Fresh weight corn (kg)	Fresh weight corn (kg)
1	1.11 $\pm$ 0.12	0.91 $\pm$ 0.11	1.01 $\pm$ 0.09
3	1.20 $\pm$ 0.07	0.91 $\pm$ 0.06	1.05 $\pm$ 0.07
5	1.16 $\pm$ 0.04	1.04 $\pm$ 0.08	1.10 $\pm$ 0.05
7	1.00 $\pm$ 0.08	1.04 $\pm$ 0.05	1.02 $\pm$ 0.04
10	1.17 $\pm$ 0.03	1.04 $\pm$ 0.06	1.10 $\pm$ 0.04

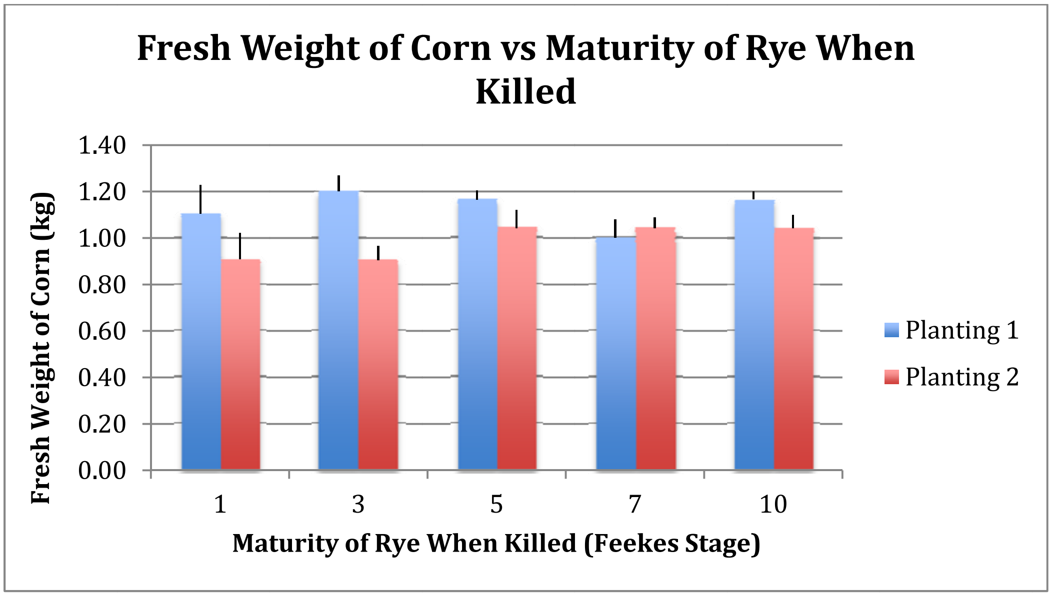

Fig. 8. Early growth of corn measured by shoot fresh weight at 4 weeks. No significant differences were observed between any treatments.

Table 6: Corn yield

Values represent the mean of five repetitions.

	Planting 1	Planting 2	Average of both plantings
Feekes stage	Corn yield (tons/acre)	Corn yield (tons/acre)	Corn yield (tons/acre)
1	8.11 ± 0.38	7.20 ± 0.32	7.65 ± 0.26
3	8.28 ± 0.34	7.56 ± 0.20	7.92 ± 0.21
5	8.15 ± 0.35	7.92 ± 0.21	8.03 ± 0.20
7	7.94 ± 0.29	8.24 ± 0.18	8.09 ± 0.17
10	7.97 ± 0.34	8.03 ± 0.14	8.00 ± 0.18

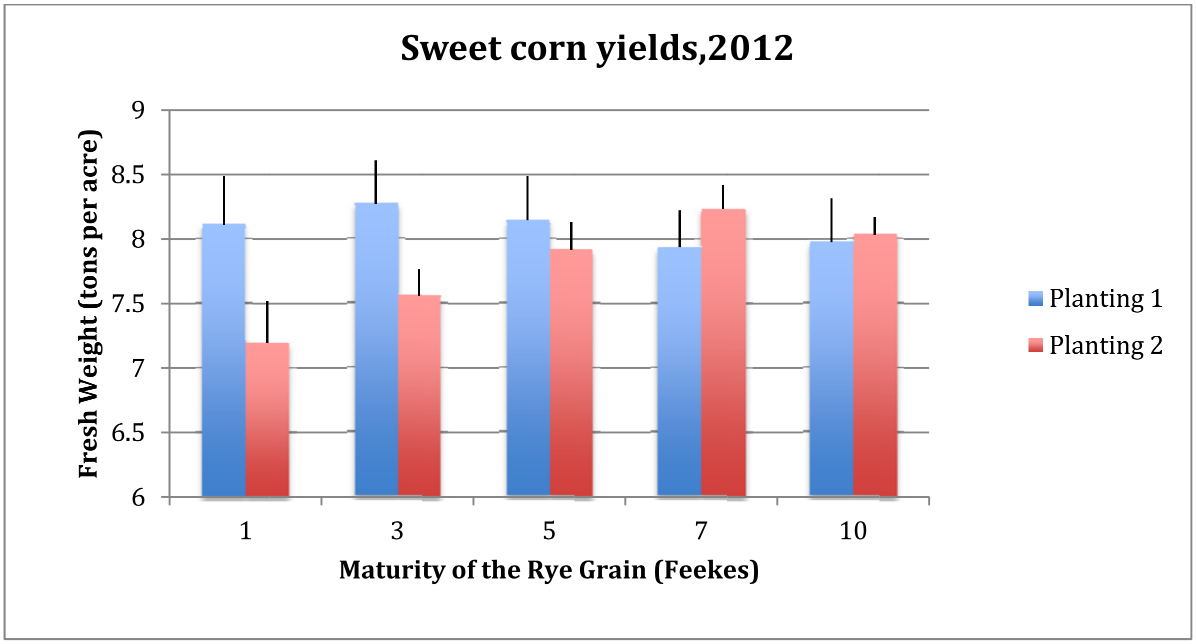

Fig. 9. Corn yield was not observed to differ significantly between treatments.

Table 7: Corn leaf chlorophyll at 40d

Chlorophyll levels in corn leaves in plots where rye was killed at Feekes stage 7 were significantly lower than for any other treatment. Values represent the mean of five repetitions.

	SPAD chlorophyll meter reading	
Feekes stage	Planting 1	Planting 2
1	48.03 $\pm$ 0.46	46.23 $\pm$ 0.69
3	48.08 $\pm$ 0.47	44.26 $\pm$ 1.26
5	46.22 $\pm$ 0.54	44.92 $\pm$ 0.44
7	44.75 $\pm$ 0.78	44.14 $\pm$ 0.29
10	46.07 $\pm$ 0.91	44.80 $\pm$ 0.36

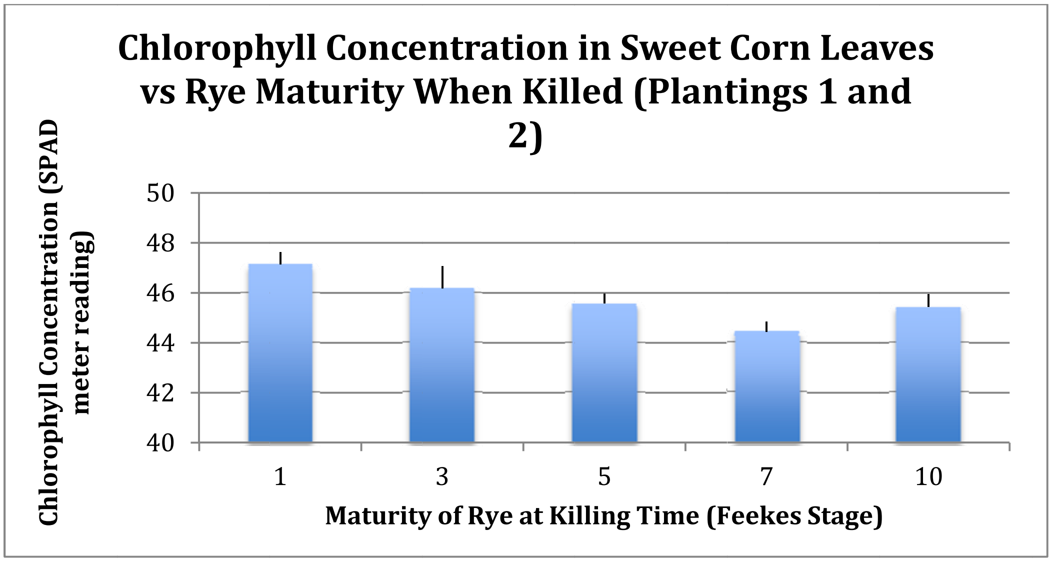

Fig. 10. Corn leaf chlorophyll at the V6 stage was significantly lower in plots where rye had been killed at Feekes stage 7.

4. Discussion

Significant differences were observed between biomass and total nitrogen content of the rye at killing time for all treatments. Nitrogen content was higher in more mature rye, but so was the carbon content, resulting in C/N ratios of over 25:1 for all treatments other than Feekes stage 1 and 3, for which there was no or very little rye biomass incorporated. Despite the high nitrogen content or the high C/N content of the rye, soil nitrate at four weeks after rye incorporation was not affected for any treatment. This indicates that if there was any microbial tie-up of nitrogen in the soil it did not differ depending on the maturity of the rye at killing time. Nitrates could have also been leached from the soil during the weeks between rye incorporation and corn planting.

We also observed a significantly lower corn leaf chlorophyll at the V6 stage in plots where rye was killed at Feekes stage 7 than Feekes stage 1 treatments. Other plots with more mature rye (Feekes stage 5 and 10) at killing time were not observed to have significantly lower corn leaf chlorophyll. Feekes stage 10 treatments had higher chlorophyll than Feekes stage 7 and almost the same as Feekes stage 5 treatments. The corn leaf chlorophyll concentration is correlated with the amount of nitrogen taken up into the leaves, given that nitrogen is a significant component of chlorophyll, largely present in the leaves (Raven *et al.*, 2005). Our results suggest that although there were lower levels of nitrogen in the corn leaves for Feekes stage 7 treatments, whatever nitrogen needed for producing the corn yield was acquired by the harvest date.

Germination rates for sweet corn were higher than expected, possibly due to extra seed being dispensed as the tractor went over bumps in the field. The high germination rates we observed gave no indication that any allelopathic compounds that may have been present in the rye or produced during rye decomposition were inhibitive to germination.

Despite any differences in rye biomass, rye nitrogen, rye C/N content, or corn leaf chlorophyll, no significant inhibition of sweet corn germination, early growth, or yield was observed by any rye treatment.

Although our findings did not support previous findings of the inhibitory effects of a rye cover crop on the following sweet corn crop (Barnes and Putnam 1983; Bollero and Bullock, 1994; Crandall *et al*., 2005; Thorup-Kristensen and Dresbøll, 2010), there is reason to believe that a longer-term study may reveal different results. Studies have found that although a winter rye cover crop did not increase immediately available inorganic soil nitrogen, it did increase nitrogen in soil organic matter over the long term (Kuo *et al.,* 1997; Sainju *et al.,* 2002), and in a subsequent study was shown to be of benefit to corn crops due to the organic nitrogen accumulation in the soil (Kuo and Jellum, 2000).

5. Conclusion

We did not observe rye to have an effect on corn germination, growth, or yield, as some others have reported. We also did not observe the rye maturity at killing time to have an effect on soil nitrate levels at corn planting time. The mechanism by which a rye winter cover crop may cause inhibition of a succeeding corn crop was not tested for, but our results do not indicate any allelopathic effects on corn germination. The C/N ratios were high for all mature-stage rye, suggesting that microbial tie-up of nitrates in the soil may be problematic for growers; however, this did not affect the corn crop differentially between treatments in this study.

This study was one year long. Other studies have shown that rye cover crops have the ability to benefit corn crop growth over the long-term due to accumulation of organic nitrogen in the soil. Mechanisms by which rye cover crops promote or inhibit the growth of succeeding vegetable or grain crops may be elucidated by more long-term study.

References

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

Björkman, T.; Shail, J.W. (2010). Cornell cover crop guide for rye. Cornell University. 2pp. Ver. 1. 101029.

Bollero, G.A.; Bullock, D.G. (1994). Cover cropping systems for the Central Corn Belt. *Journal of Production Agriculture*. *7*, 55–58.

Brady, N.C.; Weil, R.R. (2010). *Elements of the Nature and Properties of Soils*. New Jersey: Prentice Hall, 462-464.

Bruun, S.; Luxøi, J.; Magid, J.; de Neergaard, A.; Jensen, L.S. (2006). A nitrogen mineralization model based on relationships for gross mineralization and immobilization. *Soil Biology and Biochemistry*. *38*(9), 2712-2721.

Clark, A. (ed.). (2007). *Managing Cover Crops Profitably*. Maryland: Sustainable Agriculture Research and Education.

Clark, A.J.; Decker, A.M.; Meisinger, J.J.; McIntosh, M.S. (1997). Kill Date of Vetch, Rye and a Vetch-Rye Mixture: I. Cover Crop and Corn Nitrogen. *Agron. J*. *89*, 427-434.

Crandall, S.M.; Ruffo, M.L.; Bollero, G.A. (2005). Cropping system and nitrogen dynamics under a cereal winter cover crop preceding corn. *Plant and Soil*, *268*, 209-219.

"Growth Stages in Cereals." (1957). Cornell Field Crops and Soils Handbook. *Cornell Cooperative Extension*.

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

Haynes, C.; Everhart, E.; Jauron, R. (n.d.). Iowa State University Horticulture Guide: Home Gardening. Cooperative Extension Service Iowa State University of Science and Technology, Ames, Iowa.

Kuo, S. and Jellum, E.J. (2000). Long-term winter cover cropping effects on corn (*Zea mays* L.) production and soil nitrogen availability. *Biol Fertil Soils*, *31*, 470-477.

Kuo, S.; Sainju, U.M.; Jellum, E.J. (1997). Winter cover cropping influence on nitrogen in soil. *Soil Sci. Soc. Am. J. 61*, 1392-1399.

Large, E.C. (1954). Growth stages in cereals. *Plant Pathol*. *3*, 128-129.

"New York Soils." (N.d.). Technical Resources. Natural Resource Conservation Service.

Raven, P.H.; Evert, R.F.; Eichhorn, S.E. (2005). *Biology of Plants*. New York: W.H. Freeman and Company.

Rice, C.P.; Park, Y.B.; Adam, F.; Abdul-Baki, A.A.; Teasdale, J.R. (2005). Hydroxamic acid content and toxicity of rye at selected growth stages. *Journal of Chemical Ecology*.

Sainju, U.M.; Singh, B.P.; Whitehead, W.F. (2002). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Gerogia, USA. *Soil and tillage research*, *63*(3-4), 167-179.

Shipley, P.R., Meisinger, J.J. and Decker, A.M. (1992). Conserving residual corn fertilizer nitrogen with winter cover crops. *Agronomy Journal*, *84*, 869–876.

Thorup-Kristensen, K.; Dresboll, D.B. (2010). Incorporation time of nitrogen catch crop influences the N effect for the succeeding crop. *Soil Use and Management*, *26*(1), 27-35.

Vaughan, J.D.; Evanylo, J.K. (1999). Soil nitrogen dynamics in winter cover crop systems. *Communications in Soil Science and Plant Analysis*, *30*(1-2), 31-52.

Wagger, M.G. (1989). Time of dessication effects on plant composition and subsequent nitrogen release from several winter annual crops. *Agronomy Journal*, *81*, 236-241.

Wise, J.; Johnson, B.; Mansfield, C.; Krupke, C. (2011). Managing Wheat by Growth Stage. Purdue University Agriculture Extension, West Lafayette, IN.