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2014

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Field Ecology Fall 2014
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Abstract

Some of the most challenging problems and pressing issues for today's conventional farmers involve nutrient leaching, soil erosion, land degradation, biodiversity loss, and increasing costs of synthetic fertilizers. These issues can be prevented or at least minimized by the implementation of cover crops into farmers' cropping systems. However, there has not been extensive research on the best ways to incorporate cover crops into cash crop systems while minimizing negative effects and costs. This study aimed to extend this research by examining four different methods in which cover crops can be interseeded into a corn crop for a farm in southeastern, MN. On June 25, 2014, the first three treatments were broadcast seeded with a forage radish, annual rye grass, and white clover cover crop mix. The first 48 rows were broadcast seeded and then cultivated (ISTC). The second 48 rows were broadcast seeded and no tillage was done (ISNT). The third 48 rows were cultivated prior to broadcast seeding (ISCP). The fourth treatment was aerial seeded with a forage radish and winter cereal rye mix on August 12, 2014. The remaining corn field was untreated and used as a control. Cover crop stand density and corn yield were measured for each treatment, as was soil, which was collected and analyzed for percent moisture, organic matter, bulk density, nitrates, and ammonium concentrations. After analysis of the 4 treatments and the control, corn yields and soil properties revealed no significant differences among the five groups. the four treatments, aerially seeding resulted in a significantly higher forage radish density per square foot (p-value: <.001). Overall, the different methods didn't show many significant differences in yield, stand density, and soil properties, but strengths and weaknesses of each method assessed, as s cost of each method.

Based o th analyss, suggestions for interseeding cover crops into corn are presented for Midwest conventional farmers.

Introduction

Agriculture today is receiving much criticism because of its negative environmental impacts, especially its contribution to climate change and its effects on water resources. In the Midwest, the majority of conventional grain farmers rely heavily on synthetic fertilizers and deep tillage to obtain maximum yields. Runoff of soil and nitrogen fertilizer as a result of these practices has contributed to the contamination of many ground and surface water sources, including the "dead zone" in the Gulf of Mexico (Tonitto et al. 2006). Even so, with the spike of grain prices between 2008 and 2012, many farmers applied excessive fertilizer to try to maximize profit, which lead to unused fertilizer being left in the soil and available for leaching. In 2003, the National Research Council (BANR/NRC 2003) reported that the cost of excess fertilizerfertilizer inputs that exceeded the amount that crops could use was $2.5 billion per year (Pimental et al, 2005). Since then, synthetic fertilizer prices have continued to rise, and farmers have continued to add excessive amounts to get the most production out of their land in order to help offset increasing land, machinery, and fuel costs. However, many farmers are beginning to realize that these conventional practices are not sustainable for their land. Besides that, with the recent decline in corn prices, many don't want to pay for the expensive synthetic fertilizers. Cover crops are a growing field of interest in today's agriculturebecause not only can they be a source of organic fertilizer, they also benefit farms by improving soil and water health, preventing erosion, suppressing weeds, increasing biodiversity, and reducing input costs (Lu et al. 2000).

Cover crops include all herbaceous plants that are grown in an agricultural field for purposes previously mentioned. Generally, cover crops are not harvested; rather, they are usually incorporated back into the soil for optimum nutrient additions. Often, a cover crop will be a mix of legumes, grasses, and non-legume broadleaves so that a variety of benefits may be gained. For example, a mix might include the legume hairy vetch for nitrogen fixation, annual ryegrass as a soil builder, and oilseed radish for a weed suppressor. Due to the wide range of cover crop species, mixes can be designed and implemented to meet land However, many farmers are still skeptical. Perceived risks and complexity of cover-crop-based systems have kept many from their initial adoption and long term use (Scholberg et al. 2010). Since today's agriculture is economically driven, a major loss in soil productivity or crop yields due to a failed cover crop plan could be devastating for a farm. Proper implementation of cover crops is essential to avoid undesired crop effects. Uchino et al. (2009) determined that the timing of cover crop seeding had a significant effect on the cash crop growth and subsequent yields. Cover crops planted before or at the same time as the cash crop (either corn or beans) resulted in significant decreases in yields compared to cover crops sown after the establishment of the cash crop. They determined that competition for nutrients between the cover and cash crops was amplified by the earlier establishment of the cover crop compared to the establishment of the main crop. Since then, there has been little research done on how to most efficiently interseed cover crops after the cash crop is established. Our study aimed to address this issue by examining four different methods of interseeding cover crops into an established corn field in southeast

Minnesota. The main objectives of the study were to determine the following: does interseeding cover crops into an established corn field result in decreased corn yields (yield drag) do different interseeding methods result in significant differences in corn yields, cover crop stand density, and soil properties (due to differences in cover crop productivity different interseeding methods in terms of cost efficiency.

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Methods

This experiment was conducted on a farm just southeast of Faribault, MN. A large field (>60 acres) was planted with the same variety of corn in the spring of 2014. The field was then split into 5 plots. The first plot was left untreated and was used as the control. The next 3 plots were approximately 10 acres each and were interseeded with a mix of annual rye (*Secale cereal*), tillage radish (*Raphanus sativus*), and Dutch white clover (*Trifolium repens)* at rates of 46 lbs/acre, 16 lbs/acre, and 9 lbs/ acre, respectively. On June 25th, a tall-wheeled tractor spreader broadcasted the seed over the standing corn, which was approximately 2 feet tall at the time. The cover crop seed was broadcasted with a fertilizer (46% urea) carrier at a rate of 100 lbs/acre. Since the cover crop seed is very light, a carrier is needed to obtain an even seed broadcast over the field. These first three plot treatments were chosen because they are methods that could be utilized by Midwest farmers in the early summer, before the corn becomes too tall to drive over.

The first treated plot was cultivated after the cover crop seed was broadcasted (ISTC). The second plot was broadcasted with seed and no cultivation was done before or after (ISNT). The third plot was cultivated prior to the interseeding (ISCP). The last treated plot was planted on August 12th, 2014, using a helicopter to broadcast the seed mix over the corn field (ASNT). This treatment was chosen because it represents an interseeding method that can be used after the corn is too tall to drive over. Due to limited seed availability, the ASNT cover crop mix consisted of 20 lbs/acre tillage radish and 136 lbs/acre winter cereal rye. The higher seed application rates used for the aerial seeding are recommended because the mature corn canopy can catch the seed, allowing less to reach the soil. No seed carrier was used for ASNT because the helicopter was at a height that allowed for a fairly even seed broadcast.

The cover crop stand density was evaluated in the four treatments on October 16th, 2014. In each treatment, a 1 ft^2 quadrat plot was placed between the corn rows and the counts of all established plants were recorded by species. A total of 12 plots were measured for each treatment: 6 were taken in separate corn rows 100ft from the field's edge and 6 more were taken in the same corn rows at 200 ft from the field's edge.

Soil cores were collected on November 2nd, 2014. In both the 4 treatments and the control plot, soil cores were taken from 3 random locations. Two cores were taken at each location: one with an exact volume for calculating percent moisture, bulk density, and organic matter; and the second was used for calculating nitrate and ammonium concentrations.

The corn was harvested on November 4th, 2014. Three combine passes were taken in each of the June interseeded plots and each pass was weighed. One pass was taken on the aerial seeding and weighed and one pass was taken on the control and weighed. Yields were calculated from dividing the weight of the corn by the acreage covered in each pass.

Collected data was analyzed using ANOVA, contingency tables, and correlation tests in R Commander (R version 3.0.2, 2013). ANOVA was used to compare the means of the corn yields and soil properties. Contingency tables were used to compare the cover crop stand counts. Correlation tests were used to determine if competition was occurring within each treatment by comparing the counts of the different cover crop species. Costs of each method of interseeding were broken down into seed and application costs for simple comparison.

Results

Cover Crop Stand Density

Cover crop stand densities were quite similar between the three June interseedings. ISNT had the highest combined average of established plants per ft^2 for all three species, but the densities were not significantly different across the 3 treatments (p-value: 0.13, Table 1). Between all four interseeding methods, rye density was not significantly different (p-value: 0.46, Figure 1). However, ASNT had a significantly higher radish density than the June interseedings (p-value: <0.0001, Figure 1). To account for the higher radish seed application rate (4.5 seeds/ ft^2 compared to 3.6 seeds/$ft^{2)}$ in the ASNT treatment, one radish was subtracted from each count for ASNT, and the analysis was re-run. After adjustment, the ASNT still had a significantly higher radish count, with an average of 3.3 radish/ft^2 compared to a June interseeding average of 0.7 radish/ ft^2 (p-value: <0.0001, Figure 2).

Correlation tests for the June interseedings showed a positive significant correlation between clover and radish (p-value: 0.028, r = 0.37, Figure 3) as well as rye and clover (p-value: 0.008, r = 0.43, Figure 3).

Soil Properties

Soil moisture and organic matter were very close across all four treatments and the control, and consequently no significant differences were observed (p-value: 0.22, Figure 4). Bulk density showed more variation between the different groups, with ASNT having a higher mean than all other plots, yet there were no significant differences between them (p-value: 0.89, Figure 4). Nitrate and ammonium concentrations showed the greatest variations across the different groups, with ISCP having the highest concentrations for both. However, no significant differences were exhibited between the 5 plots for nitrate or ammonium concentrations (p-value: 0.11, 0.25, respectively, Figure 4).

Corn Yield

The ISTC interseeding method had the highest average yield at 232.9 bushels/acre. The control had the lowest yield with 227.5 bu/acre. ASNT yielded 229.5 bu/acre. Together, all the cover crop treatments averaged 230.9 bu/acre. There were no significant differences between the mean yields of the three June interseedings (p-value: 0.341, Figure 5). Similarly, upon comparison of the mean yields between all 4 treatments and the control, no significant differences were found (p-value: 0.498, Figure 5).

Cost Analysis

For the three June interseedings, the seed application fee was \$7.31/acre, and the seed cost was \$31.82/acre, so the total cost was \$31.82/acre. The aerial seeding application fee was \$20/acre and the seed cost was \$45.45/acre, so the total cost was \$65.45/acre.

Discussion

Cover Crop Stand Density

Our results revealed that cover crop establishment may be achieved successfully in the Midwest by interseeding between late June and mid-August. All four interseeding methods resulted in sufficient stand densities for the purpose of cover cropping. However, ASNT did have a significantly higher mean radish density. This significant difference in radish density is likely a consequence of increased shade from the corn canopy during the early growth of the radishes in the June interseedings. A study examining radish dependency on light determined that growth rates and mean mass decreased with decreasing light (Schmitt et al. 1986). The radishes planted in the June interseeding were likely trying to grow in mid-July, when the corn canopy was at its fullest. The increased shade was likely what caused the observed decrease in radish density. By late-August, when the aerial seeding was beginning to grow, the corn's leaves were beginning to die and drop, allowing more light penetration for increased radish growth.

It is also possible that the lower stand densities in the June interseedings were due to increased competition from the additional clover species. However, the correlations suggested that this was not the case, since the more clover there was in a given plot, the more radish and rye there also were. This correlation follows the trend we saw with the increased yields for the June interseedings. If competition was occurring between the cover crop species, it could be assumed that they were also competing with the corn, and thus we would have expected to see decreases in corn yields as a result.

In conclusion, all four interseeding methods established respectable stands of cover crops and none of them caused increased nutrient competition between the plant species. Aerial seeding appears to be the best method for radish establishment.

<u>Soil Properties</u>

Soil properties didn't significantly differ between the interseeding methods. The importance of this finding is that even with the addition of fertilizer in the June interseedings, the available ammonium and nitrate concentrations weren't significantly different from the plots that didn't receive additional fertilizer. This means that the cover crops may be uptaking any excess N that wasn't used by the corn. This possibility is supported by the findings of Tonitto et al (2006), in which they found that nitrate leaching was reduced by 40% in legume-based systems relative to conventional fertilizer-based systems. Our findings support this study, as well as the findings of Blesh and Drinkwater (2013), in which they determined that using cover crops significantly reduces surplus N in the soil, thus reducing N leaching. If this weren't the case, concentrations of ammonium and nitrates would have likely been significantly higher in the June interseedings. It is possible that the corn could have uptaken the excess N, but then we would have most likely seen significant increases in corn yield as a result, but that was not the case.

Corn Yield

Across all the treatments, corn yields were not significantly different, indicating that the cover crops didn't interfere with corn growth. The interesting component here is that the control plot actually had a lower yield than all of the cover crop treatments. It is possible that the added fertilizer in the June interseedings allowed for the higher mean yield. However, the aerial treatment received no fertilizer and it still had a higher yield than the control. Ideally, more yields would have been determined for all of the plots, especially for the control and aerial plots, in which only one yield measurement was taken. This would have allowed for a sounder analysis of yields and so collecting more in-depth yield data is a recommendation for future studies. Abdin et al (1998) conducted a several year experiment with cover crops and they found that interseeding cover crops 20 days after corn emergence did not affect corn yields. In conclusion, summer interseeding of cover crops did not create any yield drag, and so the worry of potential yield losses from planting cover crops should be alleviated for concerned farmers.

Cost Analysis

Aerial seeding cost more than the tall-wheeled tractor spreader seeding because it is much more expensive to operate a helicopter than it is to operate a tractor. Also, due to the interference of the mature corn canopy, seed application rates are increased for aerial seeding and so the cost of seed also rises. In terms of cost efficiency, these two realities put the June interseedings at an advantage over the aerial seeding.

When comparing the June interseedings, the uncultivated treatment (ISNT) is the most cost efficient because it saves a trip through the field, thus reducing gas usage, machinery wear, and soil compaction.

Suggestion for Farmers

The advantage of aerial seeding is that the seed can be applied after the corn is too tall to drive over, whereas with the earlier interseeding, it has to be done by late June/early July. Also, if radishes are desired, aerial also has an advantage because of the potential for increased light reaching the ground. However, there are many alternative species (buckwheat, turnips, or rapeseed, to name a few) that could fulfill the role of radishes, and so further research could examine their potential success as a cover crop.

The big advantage of June interseeding is that it is considerably cheaper than aerial seeding. The other big advantage is that since many farmers apply a fertilizer application after corn emergence, this could be done in sync with cover crop interseeding, as was done in this study. This would significantly reduce nutrient leaching while still fertilizing the corn. From these conclusions, our suggestion for Midwest conventional farmers would be to utilize whatever interseeding method best fits their operation. However, in terms of cost efficiency, our recommendation for cover crop interseeding would be the June interseeding with no cultivation (ISNT), as this treatment had the highest combination of mean species densities, it had comparable soil properties, and it saved a trip through the field.

Conclusion

Increasing fertilizer, fuel, equipment, and environmental costs are causing many farmers to consider employing farm-generated renewable resources, including the use of cover crops (Scholberg et al. 2010). Although cover crops were an integral part in early farming history, their use decreased significantly due to the production of synthetic fertilizers during the agricultural revolution. As a result, most of today's farmers are part of a generation that has little experience with them. In the Midwest, much of the perceived complexity and skepticism of cover-crop-based systems comes from this lack of knowledge and past experience with cover crops.

From the results of this study, it is evident that cover crops can be incorporated into conventional systems without having to sacrifice yields. Early summer seed broadcasting appears to be a cost efficient interseeding method that does not create any yield drag but does allow for optimal cover crop benefits.   Although nitrogen fixation may be of highest priority right now, the implementation of cover crops has been shown to have many more beneficial effects than just fixing N. Some of these additional effects include reduced soil erosion, increased soil organic matter, improved water infiltration, uptake of excessive nutrients, higher levels of biodiversity, weed and pest-insect suppression, reduced soil compaction, and increased soil productivity (Lu et al. 2000). Cover crops appear to be an incredible multi-purpose practice that may allow farmers to reduce, or better yet to end, synthetic fertilizer use, nutrient leaching, and soil erosion without decreasing crop yields. As is evident from this study, incorporating cover crops is not that difficult, and Midwest farmers need to be encouraged to try it for themselves, as most local co-ops have tall-wheeled tractor spreaders and cover crop seed. Cover cropping could be a key step in the transition to sustainable agriculture.

Acknowledgments

Thank you to Gene Kuntz for allowing me to help with this project, Jim Pufferest for use of his farm, Kathy Shea for her guidance and instruction, Kate Seybold for assisting with soil analysis, Spencer Malick for helping collect soil cores, and St. Olaf College for providing me with the equipment and opportunity to conduct this study.

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Table 1. Contingency table cover crop species total counts and percents of total for June interseedings that took place at the farm in Faribault, MN. Interseeded with no cultivation (ISNT) had highest total percent for all species counts combined, but the three treatments weren't significantly different (p-value: 0.13).

	Rye	Clover	Radish	% of Tota
ISTC	186	50	6	31.6
ISNT	206	65	9	36.6
ISCP	162	72	10	31.9

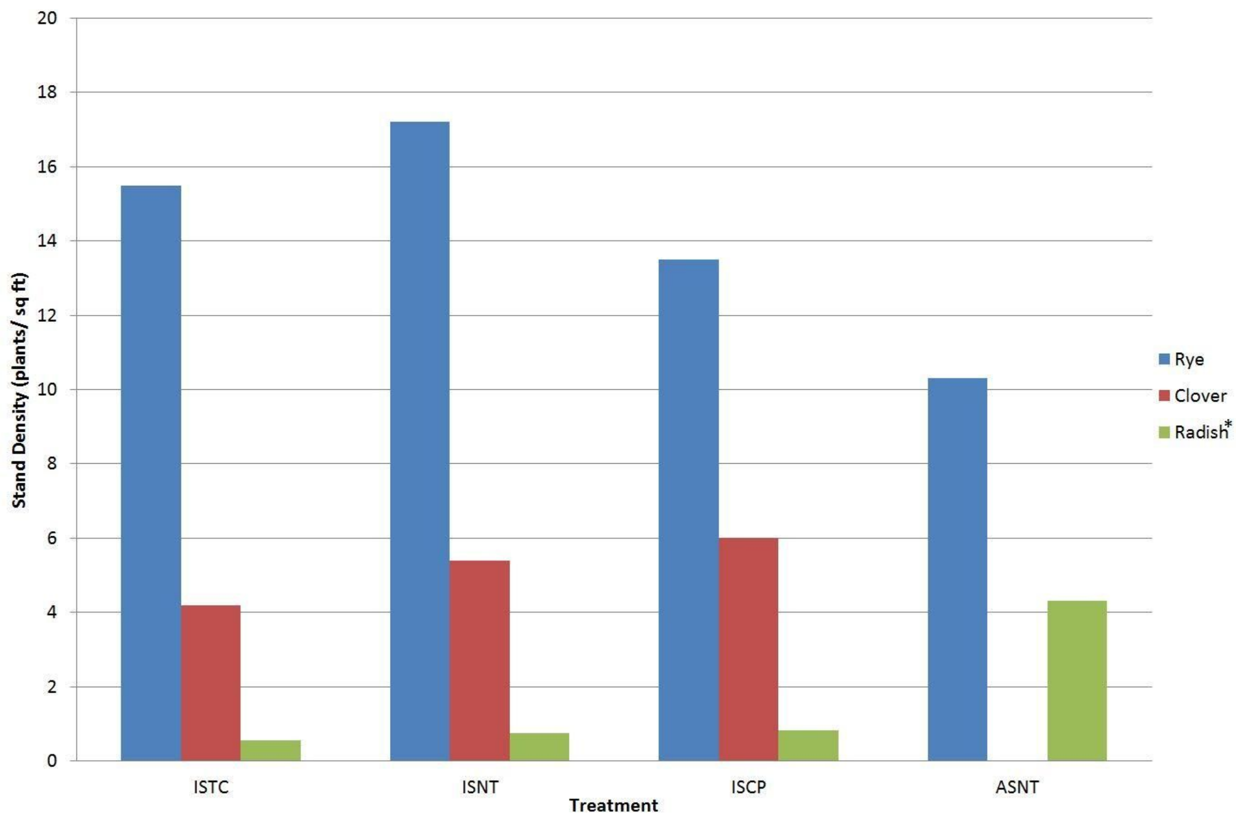

Figure 1. Stand density (established plants/ft^2) results for all four cover crop interseedings into corn. Rye density was not significantly different between the three June interseedings or between all 4 interseedings (p-value: 0.64, 0.46, respectively). Clover density was not significantly different between the three June interseedings (p-value: 0.29). Radish density was not significantly different between the June interseedings (p-value: 0.41), but between all four treatments it was significantly higher in ASNT (p-value: <0.0001).

Figure 2. Mean radish density for the different interseeding methods for actual (left) and adjusted (right) counts. Aerial seeding in August (ASNT) had a significantly higher mean radish density than the June interseedings (p-value:<0.0001). After adjustment for the higher seed application rate, ASNT still had a significantly higher mean radish density (p-value: <0.0001).

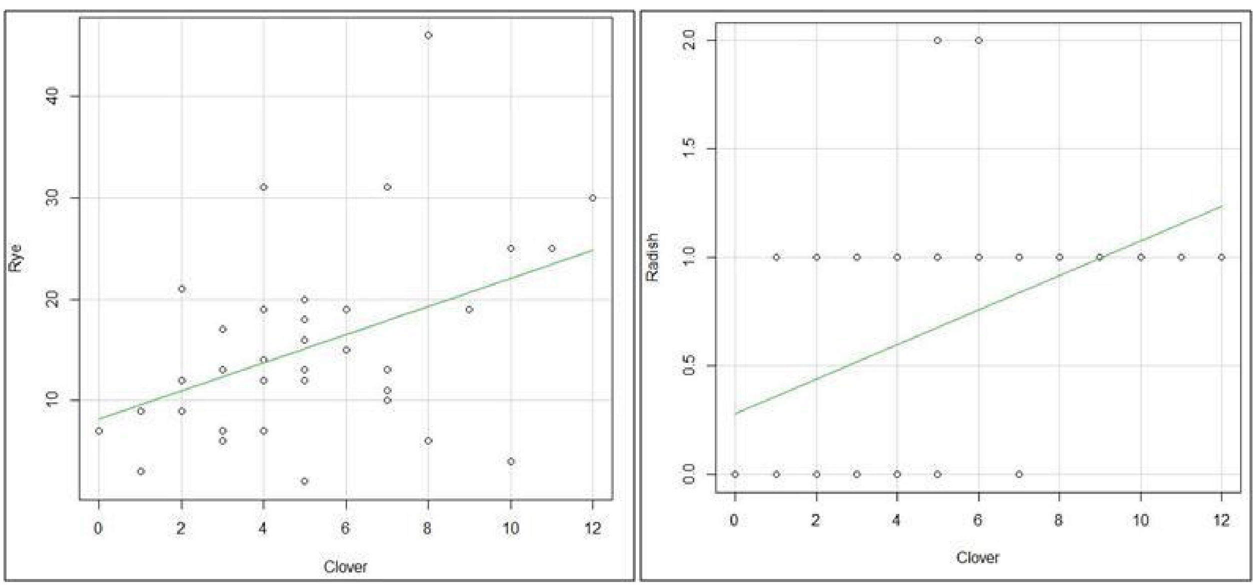

Figure 3. Correlations between clover and rye counts (left) and clover and radish counts (right) for all the 1ft^2 quadrats measured in the June interseeded plots. Clover and rye were positively correlated (p-value: 0.008, r = 0.43), as were clover and radish (p-value: 0.028, r = 0.37), indicating that competition wasn't a significant factor in these treatments.

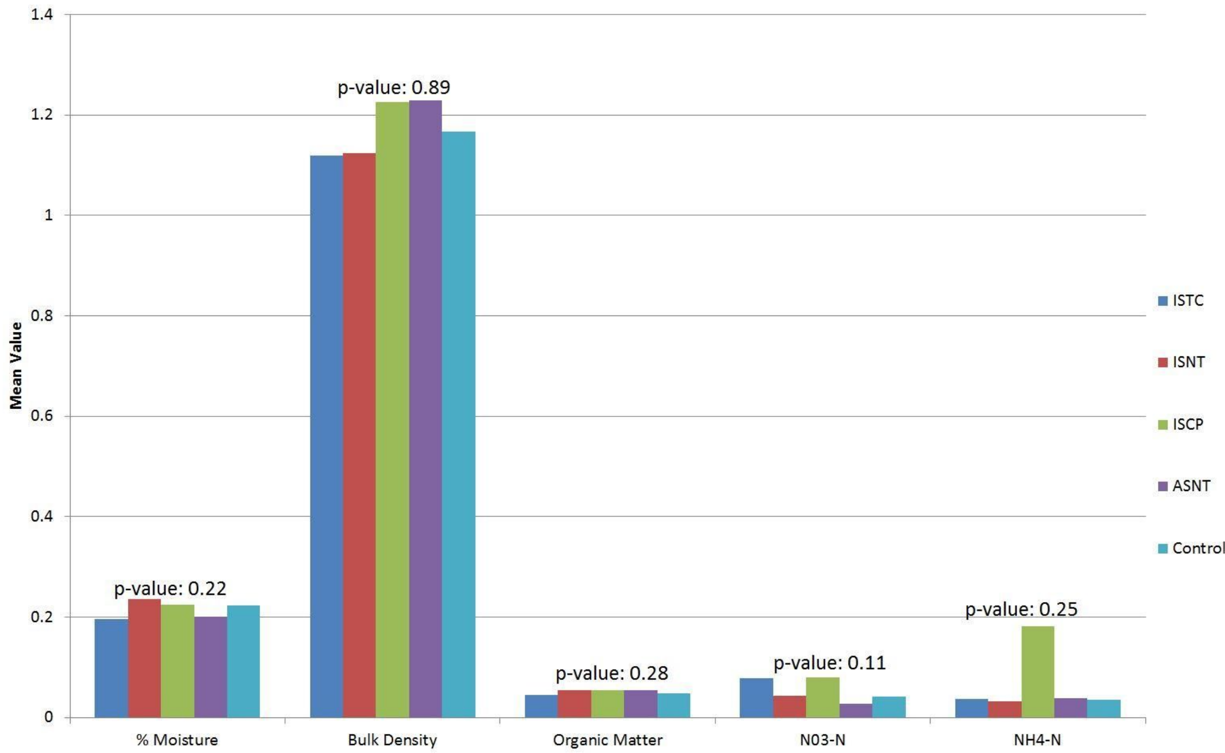

Figure 4. Comparison of means for soil properties measured in each plot. Ammonium and nitrate concentrations exhibited the highest variation between treatments, but no significant differences were observed (p-value: 0.25). The treatment that was cultivated before seeding in June (ISCP) had the highest overall mean soil property values, but no significant differences between plots were found for any of the properties measured.

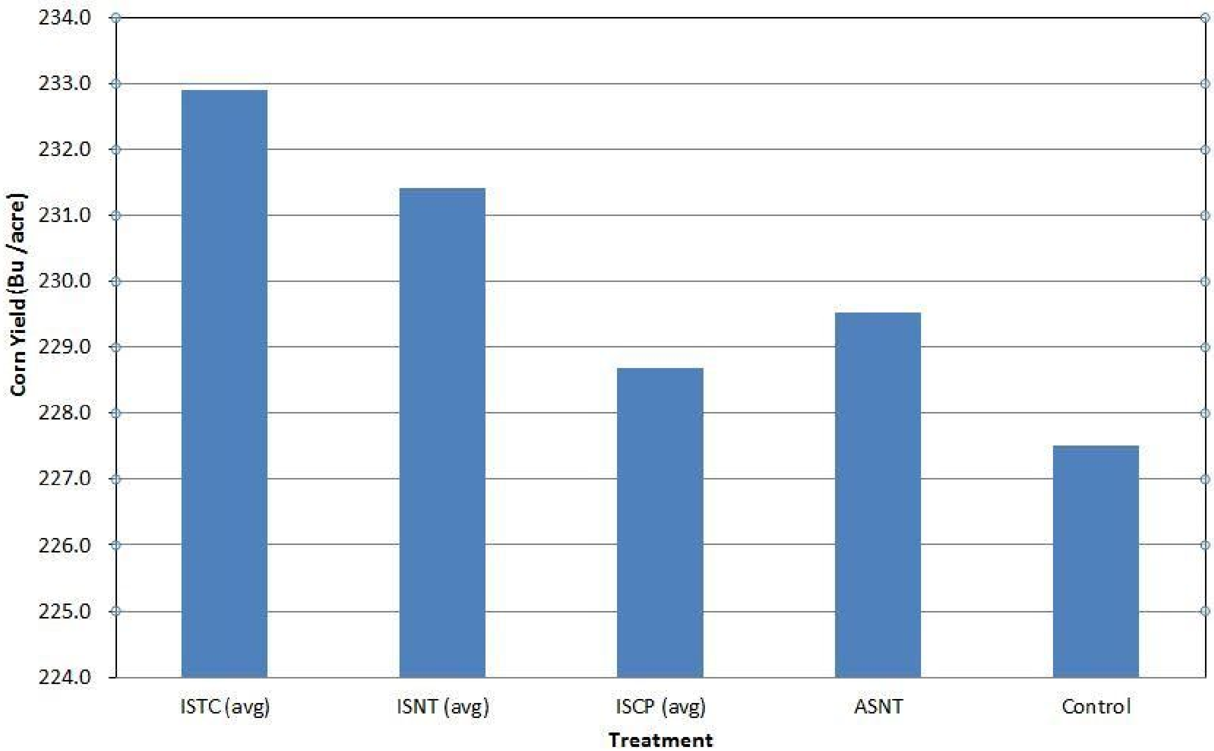

Figure 5. Mean yields for the different interseeding methods and control. ISTC had the highest mean yield, while the control had the lowest yield. Comparison of the June interseedings (ISTC, ISNT, ISCP) revealed no significant differences in mean yield (p-value: 0.341). Likewise, comparison of the mean yields for all the plots showed no significant differences (p-value: 0.498).