Tillage and AMF Inoculant Impacts on Organic Vegetable Production in the Upper Great Plains

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I. Project Abstract

In the Northern Great Plains, adoption of roller-crimping for weed suppression in no-till organic cropping systems remains a challenge due to limited growing season and delayed soil warming, which limit production of sufficient cover crop biomass to suppress weeds. A solution may be to grow weed-suppressive biomass out of phase spatially and temporally with the main crop, an approach called 'deep mulching.' Field experiments were conducted at two sites in North Dakota to investigate effects of no-till deep mulch compared to tillage on soil quality indices, weed densities, and weed seedbank densities. We hypothesized that employing no-till deep mulch and arbuscular mycorrhizal fungi (AMF) inoculant would be associated with reductions in realized weed and weed seedbank densities, time required for hand weeding, as well as with improvements in soil quality and vegetable yield. No-till deep mulch treatments were associated with reductions in weed seedbank density and realized weed density compared to tilled treatments, reductions in weeding time, improvements in soil quality indices (e.g., aggregate stability and soil respiration), increased soil N and P, and greater AMF biomass. No-till deep mulch treatments were consistently associated with greater vegetable crop yield compared to tillage. AMF inoculant did not affect realized weed or seedbank density, soil quality, or vegetable yield. Our findings suggest no-till deep mulch (especially using alfalfa hay as a mulch) may be a viable option for small scale organic vegetable producers in the Northern Great Plains to improve or maintain soil quality, increase crop yield, as well as reduce weed densities, weed seedbank densities, and time required for weeding. Additional economic research is needed to determine costs associated with sowing, harvesting, baling, and applying alfalfa mulch compared to tilling.

II. Introduction

Two overall objectives were addressed by this research project:

1. Investigate the utility of a 'deep mulch' system for weed suppression in various organically produced vegetable crops.

2. Evaluate the efficacy of a commercially available AMF (arbuscular mycorrhizal fungi) inoculant for enhancing crop yield and nutrient uptake.

Investigation of the 'deep mulch' weed management system was motivated by previous studies conducted in the northern Great Plains indicating that other methods of achieving organic no-till do not work well in the cold climate of this region. In particular, implementing no-till via roller-crimped cover crops is seldom possible because the growing season is too short to allow production of most crops once the cover crops are terminated at anthesis. Another solution would be to produce weed suppressive plant residue spatially and temporally dislocated from cash crop production. One version of such an approach is practiced by a North Dakota organic vegetable producer, with whom we consulted to develop this project. The idea is simple: vegetable beds are mulched with a thick layer of alfalfa hay, which suppresses weed emergence and decomposes over time to add nutrients and organic matter into

the soil. The ND producer claims that they have never applied any inputs other than the alfalfa hay during the twenty years they have employed this system. We wanted to scientifically document the impacts of the no-till deep mulch system on both weed suppression and various indicators of soil health.

Investigation of AMF inoculants was motivated by previous research indicating possible crop benefits associated with AMF inoculation. Also, many companies have been touting the benefits of AMF inoculant products. However, as the benefits of AMF depend on many factors, including soil attributes and crop species, we were interested in testing an inoculant in conjunction within our comparison of the deep mulch system with a conventionally tilled system in soils characteristic of the northern Great Plains.

Within a four crop (snap pea, onion (Allium cepa), beet (Beta vulgaris), and winter squash) (Cucurbita moshata) crop sequence, our objectives were to measure and assess the effects of no-till deep mulch, conventional tillage, and AMF inoculant on 1) weed seed bank density and species diversity; 2) realized weed density and diversity; 3) crop leaf nutritional status, crop leaf chlorophyll, crop leaf stomatal conductance, and crop yield; 4) soil quality indices including PLFA (general microbial community composition), soil respiration, aggregate stability, active carbon, soil macro- and micro- nutrients, and soil organic matter; and 5) crop root colonization by AMF and non-AMF fungi (likely plant pathogens).

We hypothesized that: 1) No-till deep mulch would be associated with greater crop yield, reduced weed pressure, reduced weeding time, and greater AMF abundance within crop roots compared to a tilled system; 2) No-till deep mulch be associated with positive changes in soil quality indices compared to a tilled system; and 3) AMF inoculant would be associated with greater AMF abundance in crop roots, and enhanced crop yield compared to no inoculant.

III. Project Materials and Methods

From 2015-2017, field experiments were conducted to assess weed management, crop nutrition and yield, soil quality impacts of tillage (no-till deep mulch vs. tilled with no mulch), and AMF inoculant efficacy. These experiments were conducted on certified organic land at two sites (Absaraka and Dickinson ND) with differing soil types and climates.

Experiments at each site consisted of 64 7.44-m^2 plots, with 1.2 m alleys, repeated during 2015, 2016, and 2017. Each plot contained a factorial combination of crop × AMF inoculation (4 crops (sequence phase) × 2 levels of AMF), assigned randomly. Plots were not re-randomized each year so that we could assess the cumulative impact of tilling vs mulching over a three-year period. In May 2015, the site at Absaraka received composted poultry manure at a rate of 67 kg N ha^{-1} (Rosen and Eliason, 2005). At Dickinson, composted beef cattle manure was applied at a rate of 39 kg N ha^{-1} during 2013.

At Absaraka, alfalfa hay mulch was locally-sourced, grown without synthetic pesticides, and free from germinable weed seed. Hay bales at both sites were approximately 0.28 m^3 and slabs from the bale were placed to cover the entire plot surface, except where crop rows were located (Figure 1). Slabs were moved aside during planting and moved back post crop emergence. Each plot received approximately 28 slabs of hay and each slab weighed an average of 650 g. At Dickinson, hay mulch was locally sourced, grown without synthetic pesticides, and consisted of crested wheatgrass (*Agropyron cristatum* L.). Hay mulch was left in place for the duration of the study and was replenished in the spring and fall as needed to maintain even mulch thickness. At each site, the 32 no-till plots received approximately 18 kg of mulch each, at a depth of 12 cm, for an approximate total of 24,000 kg ha^{-1}. During each spring, mulch was shifted aside to allow for soil warming and replaced after crop emergence.

Crops were grown in a sequence designed to optimize crop N requirements: (1) snap pea ('Sugar Ann'), (2) onion ('Dakota Tears'), (3) table beet ('Sweet Dakota Bliss'), and (4) butternut squash (Cucurbita moschata 'Burpee's Butternut') (Table 4.). To separate year effects from crop effects, each phase of the crop sequence was present during each year. Crop rows used for data collection were located in the center of the plot. Drip irrigation was used at Absaraka only during 2017 (the only year it was needed), whereas Dickinson was irrigated throughout the study. Weeds were removed as they were quantified, so treatment effects on crop yield were due to factors not directly related to weed presence as modified by mulch or lack thereof (because we know weeds cause yield loss).

Commercially available organically certified AMF inoculant, which contained four AMF species (*Glomus intraradices*, *G. mosseae*, *G. aggregatum*, and *G. etunicatum*; Mycogrow for Vegetables, Fungi Perfecti LLC. P.O. Box 7634. Olympia, WA), was applied directly to each crop after transplanting or sowing during each year of the study at the recommended rate of 3.8 g m^{-2}.

Measurements included weed density, weed seedbank density, time required for weeding, soil respiration, soil wet aggregate stability, soil nutrients (N, P, K), extent of crop root colonization by AMF, microbial biomass, crop leaf tissue nutrient content (N, P, K), and crop yield. ANOVA statistical tests were used to determine the effects of tillage, AMF, and crop on these response variables.

IV. Results

Deep mulched no-till treatments were associated with reductions in weed densities each growing season, at both of the research sites (Figures 2 and 3). Squash crops were consistently associated with reductions in weed densities for both tilled and deep mulched plots at Absaraka and Dickinson during 2016 and 2017, demonstrating that squash is highly competitive against weeds (data not shown). Weed seedbanks were reduced within both no-till deep mulch and tilled plots at Absaraka, likely due to frequent weeding events throughout each season. No-till deep mulch resulted in more pronounced reductions in weed seedbank densities at Absaraka compared to tillage (Figure 4). At Dickinson, seedbank densities did not change over time in no-till deep mulched plots, but seedbank density increased over time for tilled plots (Figure 5). Producers may be able to save time/money by focusing on weed seedbank management, as fewer weeds seeds in the seedbank results in reduced labor needed for removing weeds.

Time required for weeding was affected by crop, with squash being associated with less time needed to remove weeds. At both sites, less weeding time was required within no-till deep mulched plots compared to tilled plots (Figures 6 and 7). Although the time required within tilled treatments increased between 2015 and 2016 at Absaraka, this could be due to more seeds within the seedbank germinating from annual tillage disturbance, thus decreasing the seedbank densities over time. Time required for applying mulch was not considered, which may somewhat offset time saved in weeding attributable to mulch. Differences in weeding times between the no-till deep mulch and tilled systems at Dickinson were marginal, likely due to the mulch material selected during 2015, which was evidently contaminated with weed seeds, which highlights the need to carefully select mulches free from weed seed contamination. Costs and time associated with planting, growing, and baling or purchasing mulch were not considered, which also may impact decisions to use deep mulch as a no-till practice. Ideally, a producer would grow the alfalfa on-farm, using the alfalfa phase on a field as a means to improve soil nutrients and to manage creeping perennial weeds, which frequently increase over time in organically managed fields. Using this approach, growing alfalfa would provide additional valuable agroecosystem benefits, although labor and appropriate machinery would be required to grow and harvest the alfalfa.

Soil quality was generally improved by the no-till deep mulch. For example, aggregate stability increased within the no-till deep mulch system over time at Absaraka (Figure 8). However, at Dickinson, both no-till and tillage were associated with increased aggregate stability over time, and during 2017 no differences between tillage treatments were observed for aggregate stability (Figure 9). At both sites, no-till deep mulch was associated with greater soil NO^3-N compared to tillage (Figures 10 and 11), which may offset fertilizer inputs. At Absaraka, soil P increased over time within no-till deep mulch, whereas slight declines were observed within subsequent years for tillage (Figure 12). At Dickinson, soil P levels did not change over time or differ between no-till vs. tillage and were considered high overall (Figure 13). This may have resulted from repeated applications of cow manure for N fertility during years previous to the study.

AMF colonization could have been negatively affected by abundant levels of soil P, and furthermore AMF inoculation may be more efficacious in soils where soil P is scarce and endemic AMF populations have been diminished. Soil respiration was observed to decrease over time within tilled treatments at Absaraka (Figure 14), while at Dickinson, mulched no-till was associated with increased soil respiration (Figure 15). This could be due to precipitation differences between sites, as well as edaphic properties of each soil. AMF colonization of crops were not affected by tillage or by inoculant, but differed between crop species, with less colonization for beets (a non-mycorrhizal species) compared to the other crops. We only quantified % AMF colonization, but did not identify which species were colonizing roots. Linking AMF species identity to specific functions related to AMF species would add more mechanistic insights about the roles that endemic AMF and AMF added via inoculation play in enhancing crop health. Future research should be designed to better quantify land management practice impacts on AMF, using a single crop and including crop-specific AMF species.

Mulched no-till was associated with greater total N, P, and K within crop leaf tissue compared to tillage, often mirroring soil chemical properties which also differed between the no-till and tilled systems, especially at Absaraka. Overall, crops grown under no-till deep mulch yielded greater or similar to crop grown with tillage (data not shown). AMF inoculant had few effects on crop performance or soil quality, and therefore may be a better investment for soils lacking endemic AMF or phosphorous.

Future research should focus on economic analyses to compare both production systems to include time and costs for tilling applications compared to planting, cutting, bailing, and applying alfalfa hay mulch as to provide producers with information for decision making regarding management practices.

V. Dissemination of Results

Greta Gramig spoke about this project at the 2016 NDSU Dickinson Research Extension Center Field Day held on July 13th (~100 participants), the 2016 NDSU Carrington Research Extension Center Field Day held on July 19th (~100 participants), the 2016 NDSU Absaraka Horticultural Research Farm Field Day held August 17th (~60 participants), and the 2017 NDSU NDSU Absaraka Horticultural Research Farm Field Day held August 8th 2017 (~60 participants). At all of these events, Dr. Gramig explained the objectives of the research in great detail. Many participants expressed excitement that NDSU was conducting organic research in vegetable cropping systems. In addition, contact was made with a couple of producers who agreed to meet at their farms with Dr. Gramig and her graduate student so we could talk about how our research results could be applied. This contact eventually led to another funded project through the USDA Specialty Crop Block Grant program.

Results from this research project were also presented at the 2016 MOSES Annual Conference, the 2016 Western Society of Weed Society Annual Conference, and the 2017 American Society of Agronomy Annual Meeting.

Citations:

Beamer KP, Gramig GG, Carr PM. 2017. Weed management and soil quality outcomes of non-chemical weed control tactics. ASA-CSSA-SSSA Annual Meeting. Tampa, FL. 246-4.

Gramig GG, Carr PM. 2016. Investigating the potential of hay mulch and AMF inoculant for small-scale organic vegetable crop production. Western Society of Weed Science Annual Meeting. March 7-10, Albuquerque, NM. 69:021.

A peer-reviewed publication to communicate these results is currently in preparation.

VI. Graduate and Undergraduate Training

This Ceres Trust grant provided critical funding to support Kenneth Paul Beamer's M.Sc. program. Mr. Beamer is currently employed as a research associate by the plant breeding company, Calyxt, in Minneapolis, MN. The grant also provided valuable summer research experiences for seven undergraduate students.

VII. Figures

Figure 1. Onions growing in the no-till deep mulch system at Absaraka, ND during summer 2017.

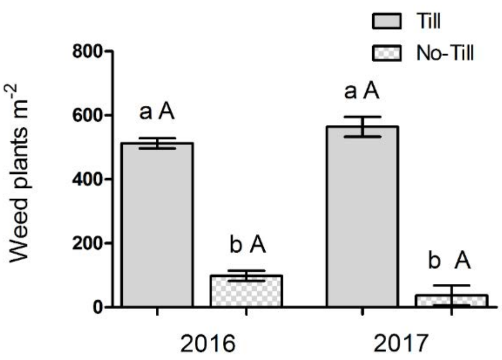

Figure 2. Absaraka mean weed density ± SE for tillage treatments during 2016 and 2017. Bars labeled with different lowercase letters differ between tillage within year ($P \leq 0.05$) according to Tukey's HSD. Bars labeled with different uppercase letters differ between year within tillage ($P \leq 0.05$) according to Tukey's HSD.

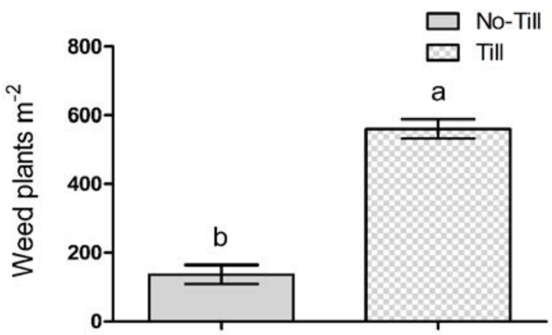

Figure 3. Dickinson mean (±S.E.) total weed density (plants m-2) for tilled and mulched no-till treatments, pooled over year, entry point, and AMF treatments. Tillage effect is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

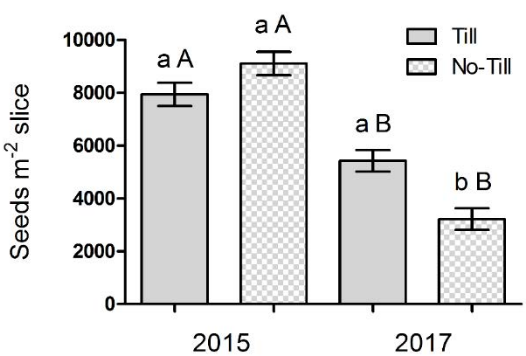

Figure 4. Absaraka mean (±S.E.) total weed seed densities (seeds m-2 slice) for tilled and mulched no-till treatments during 2015 and 2017. Tillage effect within year is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD. The simple effect of year within tillage is shown by bars labeled with different uppercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

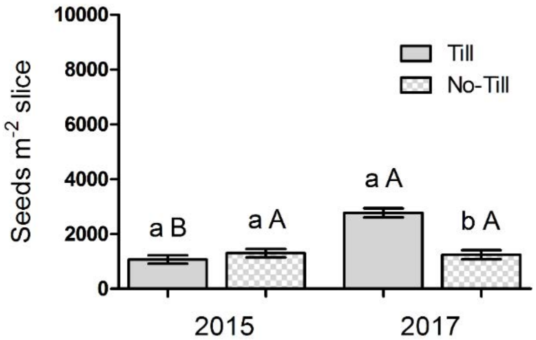

Figure 5. Dickinson mean (±S.E.) Total weed seed density (seeds m-2 slice) for tilled and mulched no-till treatments during 2015 and 2017. Tillage effect within year is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD. The simple effect of year within tillage is shown by bars labeled with different uppercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

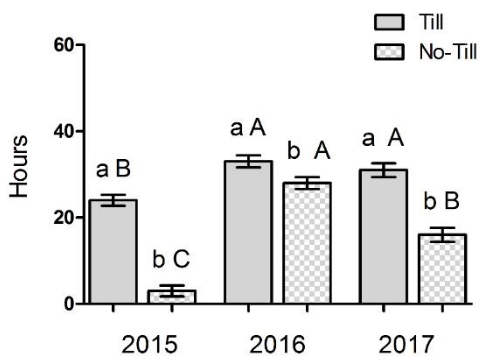

Figure 6. Absaraka mean (±S.E.) weeding time (hours) for tillage treatments between years across AMF treatments. Tillage within year is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD. Year within tillage is shown by bars labeled with different uppercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

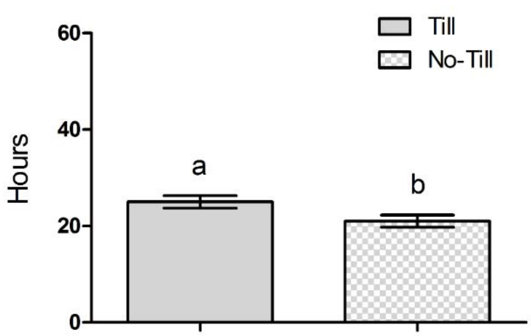

Figure 7. Dickinson mean (±S.E.) weeding time (hours) for tillage treatments across 2015 and 2016, AMF and entry treatments. Entry effect is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

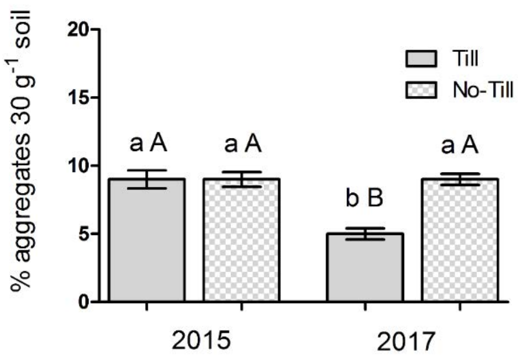

Figure 8. Absaraka mean (±S.E.) % aggregate stability (% 0.25-2.0 mm aggregates 30 g-1 soil) for tillage between years. Tillage effect within year is shown by bars labeled with different lowercase letters differ (P ≤ 0.05) according to Tukey's HSD. The simple effect of year within tillage is shown by bars labeled with different uppercase letters differ (P ≤ 0.05) according to Tukey's HSD.

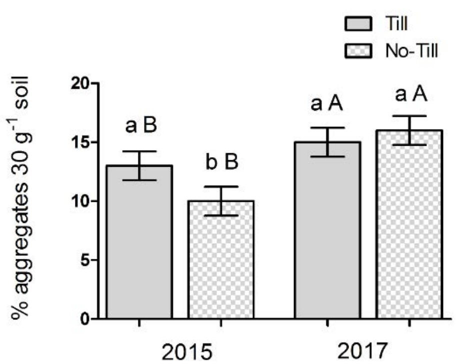

Figure 9. Dickinson mean (±S.E.) % aggregate stability (% 0.25-2.0 mm aggregates 30 g-1 soil) for year x tillage interactions. Tillage effect within year is shown by bars labeled with different lowercase letters differ (P ≤ 0.05) according to Tukey's HSD. The simple effect of year within tillage is shown by bars labeled with different uppercase letters differ (P ≤ 0.05) according to Tukey's HSD.

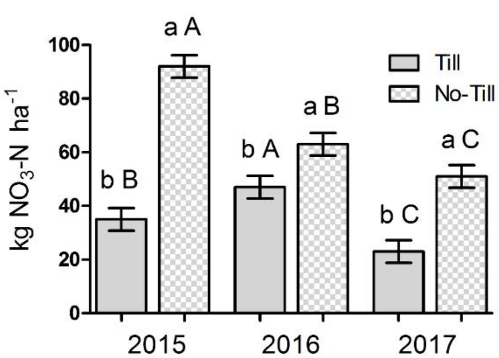

Figure 10. Absaraka mean (±S.E.) NO3-N (kg ha-1) for tilled and mulched no-till treatments during 2015, 2016, and 2017. Tillage effect within year is shown by bars labeled with different lowercase letters differ (P ≤ 0.05) according to Tukey's HSD. The simple effect of year within tillage is shown by bars labeled with different uppercase letters differ (P ≤ 0.05) according to Tukey's HSD.

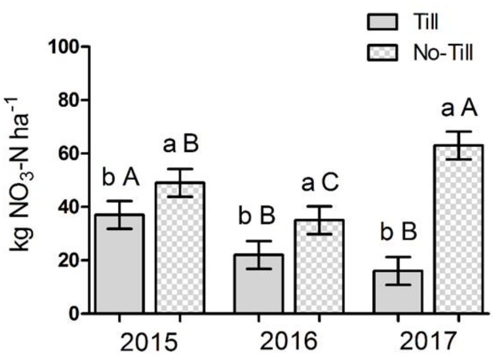

Figure 11. Dickinson mean (±S.E.) NO3-N (kg ha-1) for tilled and mulched no-till treatments during 2015, 2016, and 2017. Tillage effect within year is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD. The simple effect of year within tillage is shown by bars labeled with different uppercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

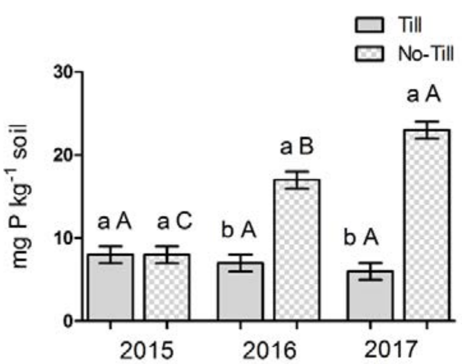

Figure 12. Absaraka mean (±S.E.) phosphorus (mg kg-1) for tilled and mulched no-till treatments during 2015, 2016, and 2017. Tillage effect within year is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD. The simple effect of year within tillage is shown by bars labeled with different uppercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

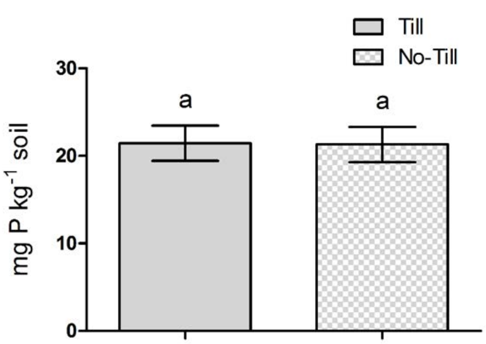

Figure 13. Dickinson mean (±S.E.) phosphorus (mg kg-1) for tilled and mulched no-till treatments across years, entry, and AMF. Tillage effect is shown by bars labeled with different lowercase letters differ ($P \leq 0.05$) according to Tukey's HSD.

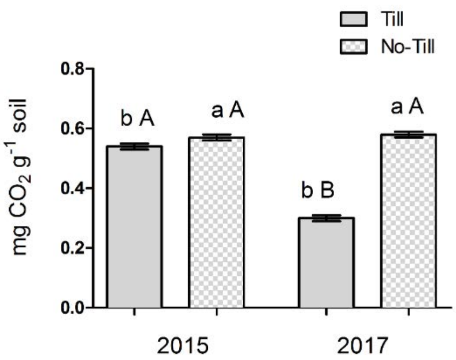

Figure 14. Absaraka mean (±S.E.) soil respiration (mg CO2 g-1 soil) for year by tillage treatment interactions. Bars labeled with different lowercase letters between tillage within year differ (P ≤ 0.05) according to Tukey's HSD. Bars labeled with different uppercase letters between year within tillage differ (P ≤ 0.05) according to Tukey's HSD.

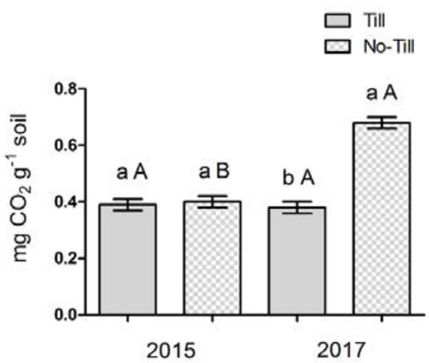

Figure 15. Dickinson mean (±S.E.) soil respiration (mg CO2 g-1 soil) for year by tillage treatment interactions. Bars labeled with different lowercase letters between tillage within year differ (P ≤ 0.05) according to Tukey's HSD. Bars labeled with different uppercase letters between year within tillage differ (P ≤ 0.05) according to Tukey's HSD.