BIOAg Project Report

Report Type
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Title
Tracking the Tango between Tillage, Soil Health, and Weeds

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Abstract
Tillage is a crucial stage in annual agricultural systems that terminates overwintering vegetation, incorporates plant residues, and prepares the soil for crops. Tillage activities may degrade soil health and impact indicators such as soil microbial biomass, organic matter, and aggregate stability. Weed populations are also influenced by tillage as seed and vegetative parts are horizontally and vertically re-distributed within the soil. Tillage implements differ in their impact on soil health indicators and weed seed distribution within the soil profile based on their method of tillage and depth of influence. Much of the tillage research to date has focused on effects from the conversion of intensive to conservation or no-till practices. This project is evaluating the impact that tillage has on soil health and weeds and will attempt to evaluate the relationship between the two. Study treatments in Trial 1 included: i) continued no-till (Continual No-Till; NT) and ii) one-time spring tillage (Till + No-Till; OT) in a field planted to orchardgrass. Study treatments in Trial 2 included: i) a chisel plow, disc, and rototiller (Rototiller) and ii) a chisel plow, disc, and power harrow (Power Harrow) in a field planted with kale in Year 1 and squash in Year 2. The experiment was a randomized complete block design with four replications with two repetitions (year). Soil physical property measurements included bulk density, soil penetration resistance, and saturated hydraulic conductivity, each measured 1 month after spring tillage in Trial 1 and 1 month after fall tillage in Trial 2. Samples for soil biological analyses were collected at key timepoints around tillage events and microbial biomass and community composition were evaluated using phospholipid fatty acid (PLFA) analysis. Weed populations were quantified from seedbank samples, in-season weed counts, and weed seed production from two key weeds. Overall, in Trial 1, a one-time tillage event in an otherwise no-till field increased the BD at 0-2” depth and reduced the 8-10” BD, field saturated hydraulic conductivity, and gravimetric water content in the short-term (2021), but only the effects on surface BD and penetration resistance persisted after one year (2022). In Trial 2, the treatments did not influence

BD in 2021, but Power Harrow plots had higher field saturated hydraulic conductivity than Rototiller plots. In 2022, Power Harrow plots had lower BD than the Rototiller plots averaged across depth, and there were no treatment effects on field saturated hydraulic conductivity. Weed populations were significantly higher on several assessment dates after a single tillage event. In the second trial we have not found a difference between the two tillage implements.

Project Description

Tillage is essential for termination of overwintering foliage (e.g., cover crops, weeds) and seedbed preparation, but can degrade biological and physical soil health (Congreves et al. 2015, Nunes et al. 2020, Stirling et al. 2012). Weed seedbanks are dynamic and many driving factors, such as tillage, influence them through their impact on seed germination and survival (Liebman et al. 1996). Ball and Miller (1990) and Buhler et al. (1997) found that tillage is the primary driver of vertical weed seed movement in fine-textured soils. Tillage implements differ in their impact on soil health indicators (Leghari et al. 2016, Morris et al. 2010) and weed seed distribution within the soil profile (Swanton et al. 2000). Moldboard plowing resulted in more uniform weed seed distribution than chisel plowing (Ball 1992, Clements et al. 1996) or reduced tillage (RT) (Pareja et al. 1985) in finer textured soils. Tillage research has focused on the conversion of intensive to conservation tillage or no-till practices, as described in an analysis of 302 studies by Nunes et al. (2020), while fewer studies have evaluated the impacts of reintroducing tillage to soil that has not been tilled for 10+ years. Continuous no-till (NT) and RT are recognized to have positive impacts on soil health and benefit farmers by allowing them to cultivate their fields with reduced energy, labor and machinery input requirements (Triplett Jr and Dick 2008). Conversion from plowing to less intensive tillage has been shown to increase soil microbial biomass, soil organic carbon, and microbial respiration in topsoil across soil types and systems, and conversion to NT increases an even larger suite of positive soil biological indicators in both the topsoil and subsoil (Nunes et al. 2020; Krauss et al. 2020). However, NT systems can lead to increased reliance on herbicides, limit cultivation equipment options, build up weed seed on the soil surface, and lead to greater and more diverse populations of perennial weeds (Buhler et al. 1994). One-time tillage or strategic tillage can address some of these issues by burying weed seeds below emergence depths and can act as a promising management operation for herbicide-resistant weeds. That said, the re-introduction of tillage also accompanies a potential risk of bringing buried weed seeds to the surface that could germinate once the optimal conditions for their growth are met. Furthermore, tillage intensity and the degree of vertical mixing will likely directly affect weed seed distribution, survival, germination, and may indirectly influence these properties through effects on soil hydro-physical and biological properties. Blanco-Canqui and Wortmann (2020) reported variable effects of one-time tillage on soil bulk density, neutral to negative impacts on water stable aggregates, and mixed effects on water infiltration. Thus, the effects of re-introduction of tillage on soil physical and biological properties and weed populations in a field without recent tillage are not clearly understood and limited work on this aspect has been done in western Washington. This proposal addresses questions that are particularly relevant to the complex perennial-annual rotations in western Washington including: (i) Does a one-time tillage event neutralize the benefits provided by the long-term absence of tillage in terms of soil hydro-physical properties and the soil microbial community?, (ii) How does tillage re-introduction influence weed demographics?, and (iii) How does tillage intensity after re-introduction influence soil hydro-physical and biological properties, and weed emergence and survival at different depths in the soil profile? This project aimed to measure the impacts that the re-introduction of tillage after 10+ years has on weed populations and soil health and investigate the relationships between the two.

Outputs

Work completed:

- Assessment of bulk density, penetration resistance, gravimetric water content and field saturated hydraulic conductivity from Trial 1 and 2 has been completed
- Soil sampling for soil biological analyses occurred in both trials at multiple timepoints in fall and spring, and samples were analyzed for microbial biomass and community composition
- Soil fertility samples collected in spring, post-tillage and prior to planting
- Spring and fall weed seedbank sampling occurred at various depths for both trials 2021-2022
- In-season weed density assessments for both trials 2021-2022
- Acquired seed samples from *C. album* and *C. bursa-pastoris* in both trials to estimate seed production 2021-2022
- Meetings with partners at Cloud Mountain Farm Center and Viva Farms
- Posted about the overall project via several blog posts (https://soilhealth.wsu.edu/2022/09/06/monitoring-the-mambo-between-soil-biology-and-tillage/, https://soilhealth.wsu.edu/2022/07/14/watching-the-waltz-weed-seeds-and-tillage/, https://soilhealth.wsu.edu/2021/07/21/tillage-soil-health-and-weeds-wsu-organic-transitions-project/)

Work in progress(to be completed outside of grant period):

- Samples collected for wet aggregate stability from Trial 1 and 2 are being analyzed
- Data analysis on PLFA microbial community composition data in conjunction with other soil properties
- Sampling from both trials and analysis will be repeated in 2023 for the same hydro-physical and biological properties
- Greenhouse grow-out (2022) and elutriation (2021-2022) of weed seedbank samples are currently underway, 2021 greenhouse grow-out has been analyzed
- Weed seed production of *C. album* and *C. bursa-pastoris* estimates from both trials are underway

Methods and Results

Methods

This experiment is underway at the WSU Mount Vernon NWREC in a field planted to alfalfa in 2011 and maintained since with mowing and baling. Two parallel experiments (Trial 1 and 2) began in spring 2021 in half of this field (Repetition 1); each was set up in a randomized complete block design with four treatment replicates. Identical trials were initiated in 2022 in the other half of the field (Repetition 2). Each replication was 10 ft by 180 ft and is divided into three sub-sections for sampling.

Trial 1 consisted of: a) continued no-till planted to orchardgrass (Continual No-Till; NT) and b) one-time spring tillage in 2021 planted to orchardgrass (Till + No-Till; OT). Tillage in OT consisted of three passes with a rototiller followed with one pass of a chisel plow. Orchardgrass was seeded (17 lbs./A) using a Land Pride (Salinas, KS) no-till planter from a local dairy on 4/30/21 in Repetition 1 and a Land Pride high residue drill on 5/18/22 in Repetition 2. Because of spotty establishment, it was decided to overseed all plots once again on 6/9/21 in Repetition 1 and 6/30/22 in Repetition 2. Once seeded, all plots were fertilized using a certified organic blend (4-4-2 Perfect Blend Organic) delivered at 200 lbs./A. The orchardgrass was maintained through periodic mowing/haying by a local farmer. Because plots were too weedy for our farmer collaborator to make hay, we mimicked haying operations by mowing all plots on 6/30/21 with a field rotary mower that left all plant biomass in the field. Two additional (7/29/21 and 8/22/21) mowing/bailing activities occurred afterward by our farmer collaborator. Biomass samples of the orchardgrass were only obtained prior to the first (false haying) and second mowing by cutting all plant material at the soil surface, recording fresh weights, placing samples into a drying oven (99F), and then re-weighing. In 2022, grassland plots planted in 2021 were hayed on 5/29/22, 8/4/22, and 9/1/22 with newly planted 2022 plots occurring only on the last two aforementioned dates. The planting of 2022 plots occurred on 5/18/22 and was then overseeded on 6/30/22. Irrigation needs were determined using WSU AgWeatherNet Irrigation Scheduler and the orchardgrass was irrigated using line pipe irrigation and run times were recorded.

Trial 2 consisted of spring tillage with a) a chisel plow, disc, and rototiller (Rototiller) and b) a chisel plow, disc, and power harrow (Power Harrow). Prior to tillage, all plots were fertilized using a custom blend certified organic mix (feather meal [11-0-0], bone meal [4-13-0], intrepid trio [0-0-22], sop [0-0-50]) delivered at 1338 lbs./A. Then one of the two (described above) different tillage implements were used. Tillage occurred in 2021 plots (Repetition 1) on 6/2/21 and then on 5/29/22 and 2022 plots (both Repetition 1 and 2) were tilled 6/15/22. Kale was transplanted into plots in Year 1 and winter squash was transplanted into plots in Year 2. Kale was transplanted (6/3/21 and 6/23/22) into plots using a mechanical transplanter and maintained following local commercial practices. Squash was transplanted by hand on 6/16/22. All weeds were suppressed using mechanical cultivation to a depth of 1.5" (6/23/21, 7/1/21, 7/9/21 & 7/21/22, 8/9/22, 8/24/22) and shallow hand weeding (7/21/21-7/22/21 & 8/10/22). Irrigation needs were determined using WSU AgWeatherNet Irrigation Scheduler and the kale and squash were irrigated using drip irrigation and run times recorded. Kale was harvested when commercially mature (59 DATP 2021 & 62 DATP 2022) by cutting all aboveground plant biomass in a 3 m row length with three subsamples per plot, total weight quantified, marketable leaves separated and weighed, and all biomass dried in an oven separately and then re-weighed. Squash was harvested by picking all squash in a 3 m row length with three subsamples per plot, squash was then separated into marketable and unmarketable, counted, and then weighed. After harvest, plots were tilled with the respective tillage treatments again and then planted to an overwintering cover crop blend of oats (61 lbs./A) and fava beans (86 lbs./A).

Measurement of Soil Hydro-Physical Properties

Sampling for soil hydro-physical properties was conducted in the Repetition 1 of Trial 1 on June 1st, 2021 (Year 1), one month after the lone tillage event in spring, and on June 8th, 2022 (Year 2). In the Repetition 1 of Trial 2, sampling was conducted on October 19th, 2021 (Year 1), one month after fall tillage and on November 14th, 2022 (Year 2). Intact soil cores (2" high and 3" internal diameter) were collected from 0-2 and 8–10" depths from three locations per plot for measurement of oven-dry bulk density, and bulk soil samples were taken at 0–6 and 6–12" depths from two locations per plot for soil aggregate analysis. To examine the soil compaction status, soil penetration resistance was recorded at three locations per plot using a dynamic cone penetrometer (DCP) up to 16" depth, which measures the penetration of cone into the soil after each hammer drop (to drive the cone into the soil) in terms of DCP index (inches per blow). Also, a digital electronic soil penetrometer (Field Scout™ SC 900; Spectrum Technologies Inc., Aurora, Illinois) was used to record the soil strength in terms of cone index, which is defined as the force required per unit cone base area to press the cone through the soil layers, up to 18" depth. Soil moisture samples were taken from 0-6", 6-12" and 12-18" at three locations per plot then composited within each depth. Lastly, field saturated hydraulic conductivity (Kfs) was measured with a SATURO dual head infiltrometer (METER Group, Inc.) from two locations per plot.

Soil Biological and Chemical Properties

In Trial 1, sampling for soil biological properties were conducted in spring pre-tillage (4/22/21 and 4/28/22) and 2 months post-tillage (6/21/21 and 6/15/22). In Trial 2, samples were collected in spring pre-tillage (4/22/21, 6/3/22 [repetition 1], and 6/16/22 [repetition 2]), and 1-month post-tillage (6/21/21, 7/5/22 [repetition 1], and 7/15/22 [repetition 2]). Samples were also collected post-till in fall and were archived at -80 C for potential future analysis. At all sampling times, soil cores (1" diameter) were collected from 3 locations across the plot and divided into depths of 0-6" and 6-12". Cores from each location were kept separate to assess within-plot spatial variability as well as between plots. Samples were homogenized and frozen at -80 C, except a for a subsample which was used to measure gravimetric water content. Select samples were sent to Ward Labs for phospholipid fatty acid (PLFA) analysis, a soil health metric that gives microbial biomass and community composition of broad microbial groups. Frozen samples were sent in 2021 and fresh samples were sent in 2022 after additional research on the benefits of PLFA analysis on fresh soil. In 2021, soil samples for chemical properties were also collected pre-planting from 0-6" and 6-12" from each trial on 26 May in both trials, and analyzed for major macronutrients, soil organic matter, and pH.

Weed Population Monitoring

In both trials and for both years, prior to any tillage implementation, seedbank samples were collected by using a tractor mounted probe (Giddings Machine Co.). The probe was inserted to 61 cm, cores were then placed onto a wooden tabletop, and sectioned at 7.62 cm increments down to 30 cm then 15 cm increments down to 61 cm. Seedbank samples were collected in the spring before any tillage activity and again in the fall after the cover crop was established for all trials and both years. Weed seedbank samples were separated into three 1 kg subsamples. One sample was assigned to be used in a greenhouse grow out, the second for elutriation, and the final for archiving. Greenhouse grow out samples were mixed with 250 g soilless growing media, placed into lined flats with landscape fabric, and weeds counted by species as they emerge. Elutriation samples will be processed using a soil elutriator that extracts the seeds from the soil, seed will be identified and counted by species, and then placed through a series of germination and viability assessments to determine if they are viable. Each section was placed in a bucket and subsamples (15 per plot) combined by plot. In trial 1, weeds were assessed beginning on 7/6/21 and roughly every two weeks thereafter by placing 10 (25 cm^2) quadrats randomly throughout each plot. In trial 2, weeds populations were assessed at two-week intervals from transplanting through the end of October. Density assessments were not performed between harvest activities and post-harvest tillage. Weeds density was assessed by species (> cotyledon stage) and weed biomass samples (1/4 m^2) were collected prior to all harvest. Weed seed production was estimated for two key indicator species, common lambsquarters (*C. album*) and shepherd's purse (*C. bursa-pastoris*), throughout the course of the growing season. If either of these two weeds were nearing seed production during counts, 10 plant samples per plot were acquired, placed into plastic sealed containers, and dried in a drying cabinet. Once dry, seeds were extracted manually by sieving individual plants. Hundred-seed weights were determined and used to calculate total seed production per species.

Results

Crops

Overwintering cover crop was similar across treatments in Trial 2 in 2022 (Fig. 1). Associated weed dry biomass (not shown) were also similar across treatments. In trial 1, treatments were similar for orchardgrass dry biomass for both the sampling dates in both of the years despite significantly higher weed biomass on specific sampling dates (Table 1). The timing of orchardgrass biomass samples was driven by the need to hay the plots and it should be noted because of a miscommunication with our farmer collaborator we were unable to take samples prior to the third mowing of the plots in August 2021.

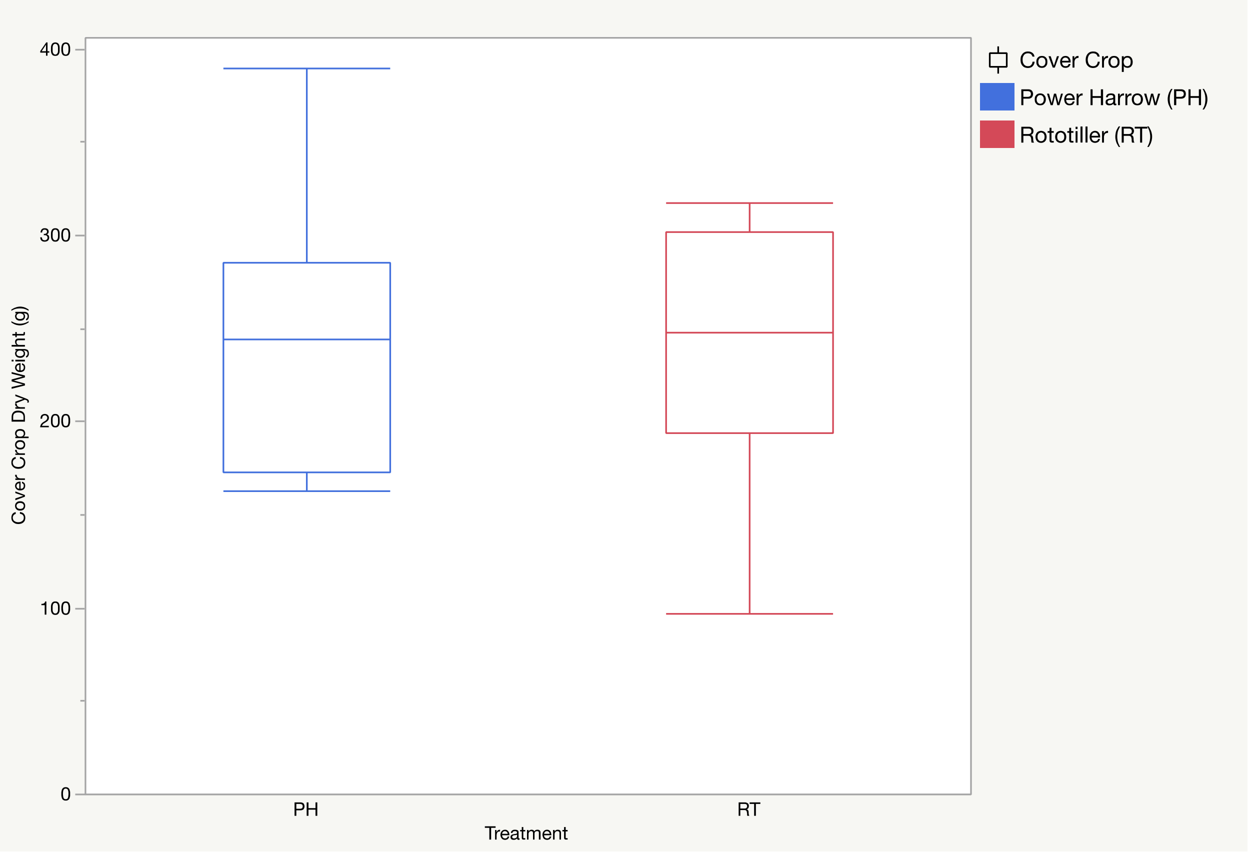


Fig. 1. Overwintering cover crop biomass and associated weed biomass Trial 2, 2022.

Table 1. Dry weights (grams per ¼ m^2) values for orchardgrass and weeds prior to mowing/haying activities in Trial 1, 2021-2022.

		Date	**6/29/21**		**7/30/21**		**5/25/22**		**7/27/22**		**8/31/22**	
Planted	**Planting Date**	**Treatment**	**OG[1]**	**Weeds**	**OG**	**Weeds**	**OG**	**Weeds**	**OG**	**Weeds**	**OG**	**Weeds**
2021	**4/30/21**	**One Till**	7.05	36.65	74.29	65.16	102.78	11.14	56.15	22.26	41.59	5.11
2021	**4/30/21**	**No Till**	9.40	8.22	100.25	48.76	134.76	14.41	56.22	20.07	37.68	2.39
		p-value	0.256	<.0001	0.195	0.175	0.090	0.596	0.221	0.765	0.784	0.005
2022	**5/18/22**	**One Till**	-	-	-	-	-	-	52.03	40.13	28.32	5.67
2022	**5/18/22**	**No Till**	-	-	-	-	-	-	45.27	18.98	27.46	7.72
		p-value							0.4857	0.0015	0.1721	0.2392

[1] *Orchardgrass*

In trial 2, there were significant differences in dry weights (per plant) between treatments for both marketable and unmarketable kale leaves with higher values for both categories in the rototiller treatment in 2021, but in 2022 higher yields were present in the power harrow treatment (Table 2 and 3). Squash yields or the number of fruits were similar between the treatments (Table 4).

Table 2. Dry weights per plant of marketable and unmarketable kale leaves in Trial 2 from 3.1 meters of row, 2021.

	Marketable Dry Weight Per Plant	**Unmarketable Dry Weight Per Plant**
Treatment	**grams**	
Rototiller	53.41 ± 2.86[1]	54.13 ± 2.76
Power Harrow	41.62 ± 2.48	41.89 ± 2.64
p-value	0.0052	0.0041

[1] *Standard error of the mean*

Table 3. Dry weights per plant of marketable and unmarketable kale leaves in Trial 2 from 3.1 meters of row, 2022.

	Marketable Dry Weight Per Plant	**Unmarketable Dry Weight Per Plant**
Treatment	**grams**	
Rototiller	54.69 ± 5.37[1]	72.72 ± 5.06
Power Harrow	72.75 ± 3.87	77.69 ± 4.99
p-value	0.0122	0.4918

[1] *Standard error of the mean*

Table 4. The number of marketable/unmarketable fruits per plant and average fresh weight of marketable/unmarketable squash in Trial 2 from 3.1 meters of row, 2022.

	Squash Number Marketable Fruit Per Plant	**Squash Number Unmarketable Fruit Per Plant**	**Fresh Weight per Fruit Marketable**	**Fresh Weight per Fruit Unmarketable**
Treatment			**grams**	
Rototiller	3.74 ± 0.31[1]	0.37 ± 0.10	467.53 ± 10.77	359.11 ± 67.89
Power Harrow	3.20 ± 0.37	0.38 ± 0.10	466.34 ± 9.28	301.90 ± 63.82
p-value	0.2701	0.9429	0.9344	0.5491

[1] *Standard error of the mean*

Soil Health

The data for soil hydro-physical properties presented in this report are from Repetition 1 of Trials 1 and 2. The laboratory analyses and data analysis for aggregate stability for both trials are ongoing. Preliminary results from Trial 1 showed an interaction between the tillage treatments (NT and OT) and depth for the bulk density (BD) in both years ($p<0.01$; Fig. 2). In 2021, OT had higher BD than the NT at 0-2" ($p=0.02$) and this trend reversed at 8-10" depth ($p=0.06$; Fig. 2i). In 2022, similar results were observed at 0-2", but the difference in BD at 8-10" depth disappeared (Fig. 2ii). Under both NT and OT, the BD increased with depth in both years. For cone index, an interaction between the tillage treatments and depth was observed in both years ($p<0.01$; Fig. 3). In 2021, the cone index was higher under NT than under OT at 4-5" and 8-9" depths ($p<0.05$); however, this trend reversed numerically below 12" depth (Fig. 3i). In 2022, cone index showed a similar trend, and NT had a higher cone index than OT ($p<0.05$) from 4-10" depth (Fig. 3ii). Gravimetric water content was higher in NT compared to OT at all the three depths (0-6", 6-12" and 12-18") ($p<0.05$) and was higher at 12-18" than at 0-6" and 6-12" under both the treatments in 2021 ($p<0.05$; Fig. 4i). However, by 2022, the difference in water content between the treatments had disappeared though it followed a similar trend with depth as in 2021 (Fig. 4ii). Field saturated hydraulic conductivity was higher under NT (26.2 cm/hr) than under OT (3.4 cm/hr) in 2021 ($p=0.01$; Fig. 5i), but that difference between the treatments similarly disappeared ($p=0.34$) by 2022 (Fig. 5ii).

Preliminary results from Trial 2 showed that in 2021, the BD did not differ between PH and RT ($p=0.65$) when averaged across depth, however, it was higher in 8-10" depth compared to the 0-2" when averaged across the treatments ($p<0.0001$; Fig. 6i). In 2022, RT had higher BD than PH when averaged across the depths ($p=0.0161$), and increased with depth under both PH and RT (Fig. 6ii). It should be reiterated that unlike in Trial 1, in which treatments were only applied in 2021 to Repetition 1, treatments were applied to Repetition 1 in Trial 2 in both 2021 and 2022. In 2021, the cone index under PH and RT generally had an increasing trend with depth until 13" after which it decreased with depth (Fig. 7i). In 2022, an interaction between the treatments and depths was observed ($p=0.0003$; Fig. 7ii), and cone index under PH was higher than under RT at 6" depth ($p=0.03$) but lower than under RT at 9" depth ($p=0.02$). Gravimetric water content did not differ between PH and RT in both the years, though a depth effect was observed where the water content was lower at 6-12" than at 0-6" and 12-18" (Fig. 8). Field saturated hydraulic conductivity was higher under PH (35.8 cm/hr) than under RT (14.0 cm/hr) in 2021 ($p=0.0013$; Fig. 9i), whereas it did not differ between the treatments ($p=0.52$) in 2022 (Fig. 9ii), possibly due to the much greater variability observed in the PH plots in 2022.

Overall, in Trial 1, a one-time tillage event in an otherwise no-till field increased the BD at 0-2" depth and reduced the 8-10" BD, field saturated hydraulic conductivity, and gravimetric water content in the short-term (2021), but only the effects on surface BD and penetration resistance persisted after one year (2022). In Trial 2, the treatments did not influence BD in 2021, but Power Harrow plots had higher field saturated hydraulic conductivity than Rototiller plots. In 2022, Power Harrow plots had lower BD than the Rototiller plots averaged across depth, and there were no treatment effects on field saturated hydraulic conductivity. No treatment effect on gravimetric water content was observed in either year of this trial.

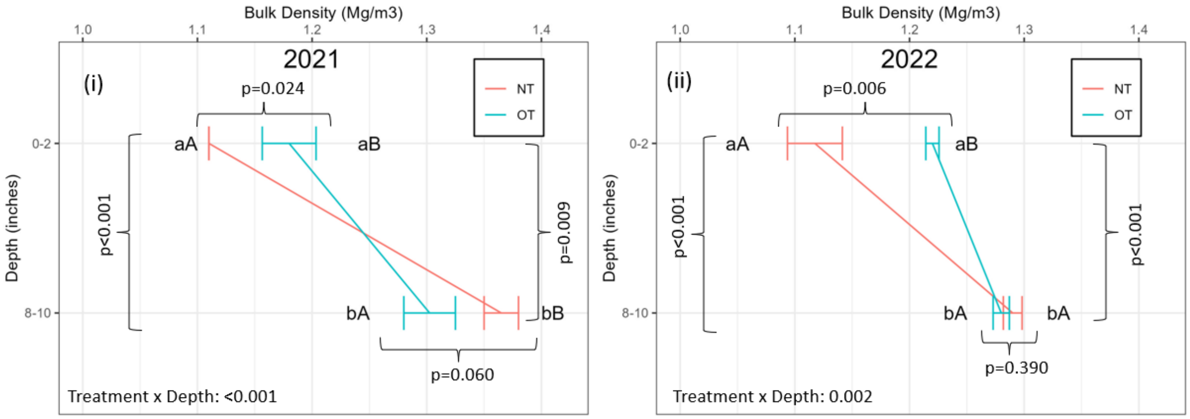


Fig. 2. Bulk density as influenced by no-till (NT) and one-time tillage (OT) treatments in Year 1 (2021) and Year 2 (2022) of Repetition 1 of trial 1. Error bars represent standard error. Means within the vertical direction followed by same lowercase letters do not differ at $p < 0.05$ for the soil depth. Means within the horizontal direction followed by same uppercase letters do not differ at $p < 0.05$ for the treatment.

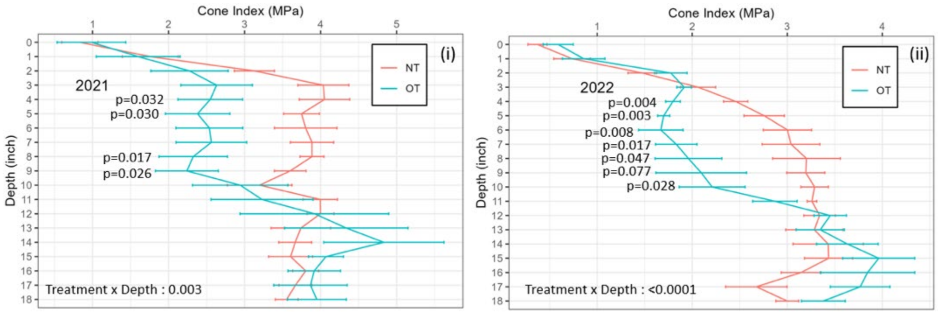


Fig. 3. Cone index as influenced by no-till (NT) and one-time tillage (OT) treatments in repetition 1 in year 1 (2021; i) and 2 (2022; ii) of trial 1. Error bars represent standard error.

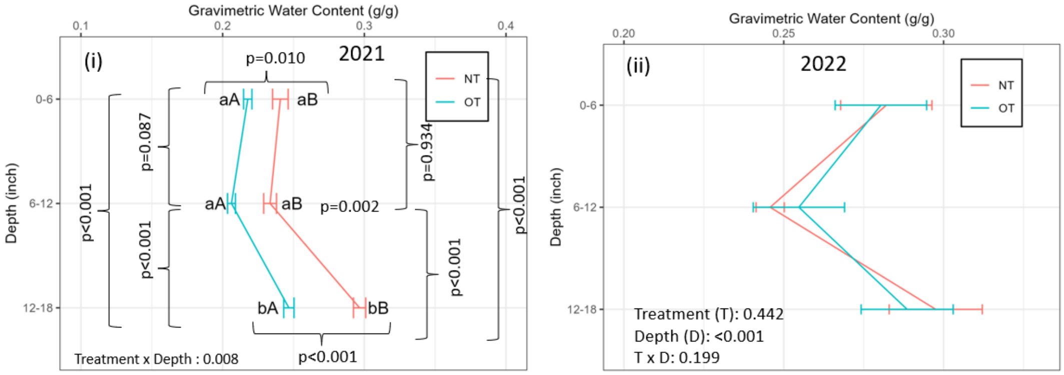


Fig. 4. Gravimetric water content as influenced by no-till (NT) and one-time tillage (OT) treatments in repetition 1 in year 1 (2021; i) and 2 (2022; ii) of trial 1. Error bars represent standard error. Means within the same row followed by same upper-case letters do not differ at $p < 0.05$ for the tillage treatments. Means within lines followed by same lower-case letters do not differ at $p < 0.05$ for the soil depth.

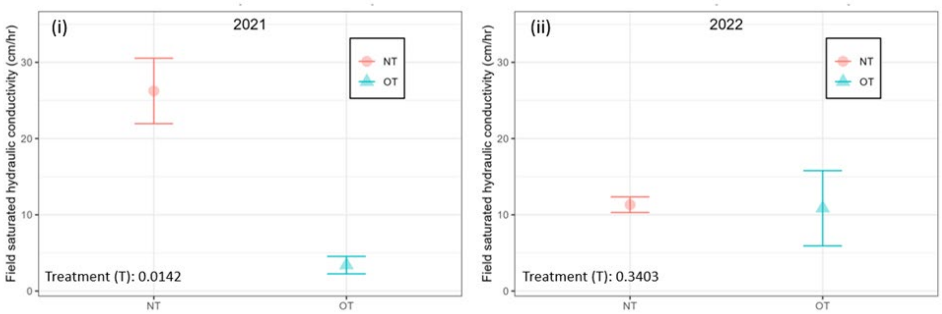


Fig. 5. Field saturated hydraulic conductivity as influenced by no-till (NT) and one-time tillage (OT) treatments in repetition 1 in year 1 (2021; i) and 2 (2022; ii) of trial 1. Error bars represent standard error.

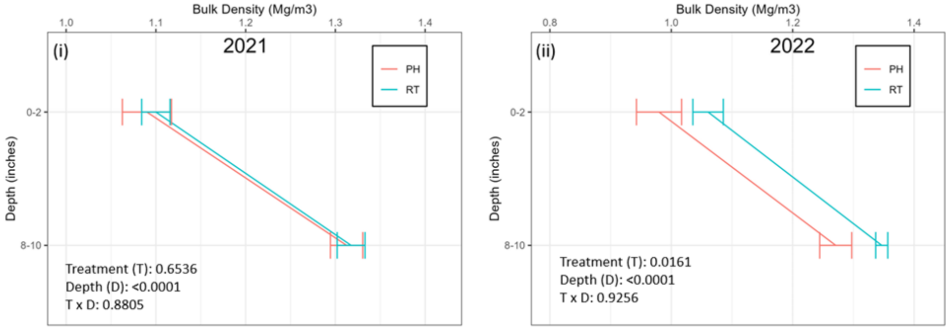


Fig. 6. Bulk density as influenced by power harrow (PH) and rototiller (RT) treatments in repetition 1 in year 1 (2021; i) and 2 (2022; ii) of trial 2. Error bars represent standard error.

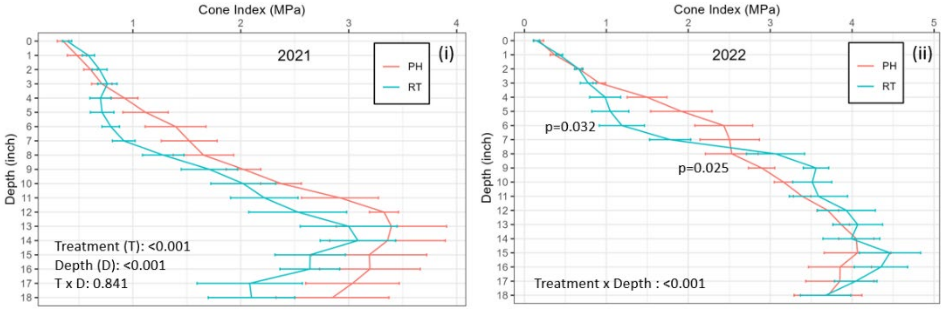


Fig. 7. Cone index as influenced by power harrow (PH) and rototiller (RT) treatments in repetition 1 in year 1 (2021; i) and 2 (2022; ii) of trial 2. Error bars represent standard error.

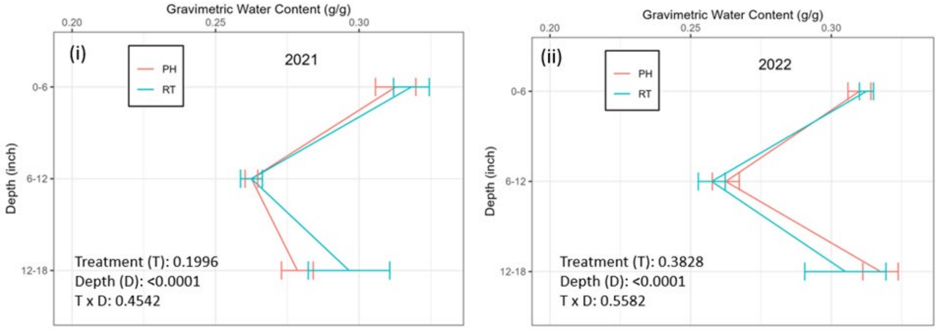


Fig. 8. Gravimetric water content as influenced by power harrow (PH) and rototiller (RT) treatments in repetition 1 in year 1 (2021; i) and 2 (2022; ii) of trial 2. Error bars represent standard error.

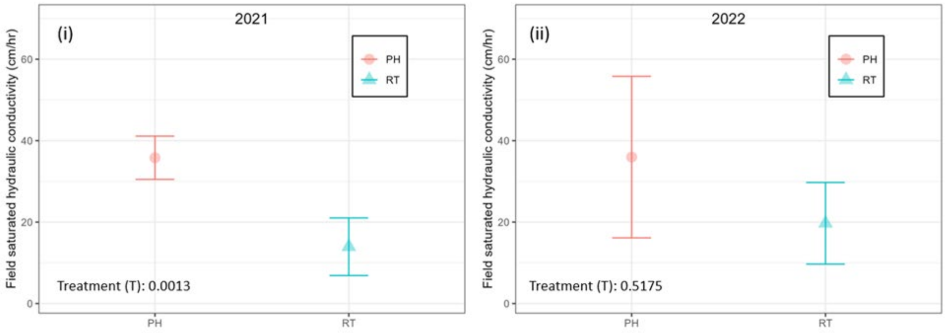


Fig. 9. Field saturated hydraulic conductivity as influenced by power harrow (PH) and rototiller (RT) treatments in repetition 1 in year 1 (2021; i) and 2 (2022; ii) of trial 2. Error bars represent standard error.

Preliminary analysis of microbial biomass data in the first 2-year repetition of the experiment shows higher biomass in the top six inches than 6-12 inches, as expected. General linear mixed models were run on total biomass within trial and for a single depth (1 model for each panel in Fig. 10). There was at least one time point that differed from the original pre-tilled state of the soil (Fig. 10). In Trial 1, there were no differences in microbial biomass between NT and OT among time points. In Trial 2, Rototiller plots have significantly higher biomass than Power Harrow plots post-tillage in 6-12" depth (320 ng/g difference on average, p = 0.03), but not in the top six inches of soil. While consistent across time points this difference is relatively small and may not be biologically meaningful.

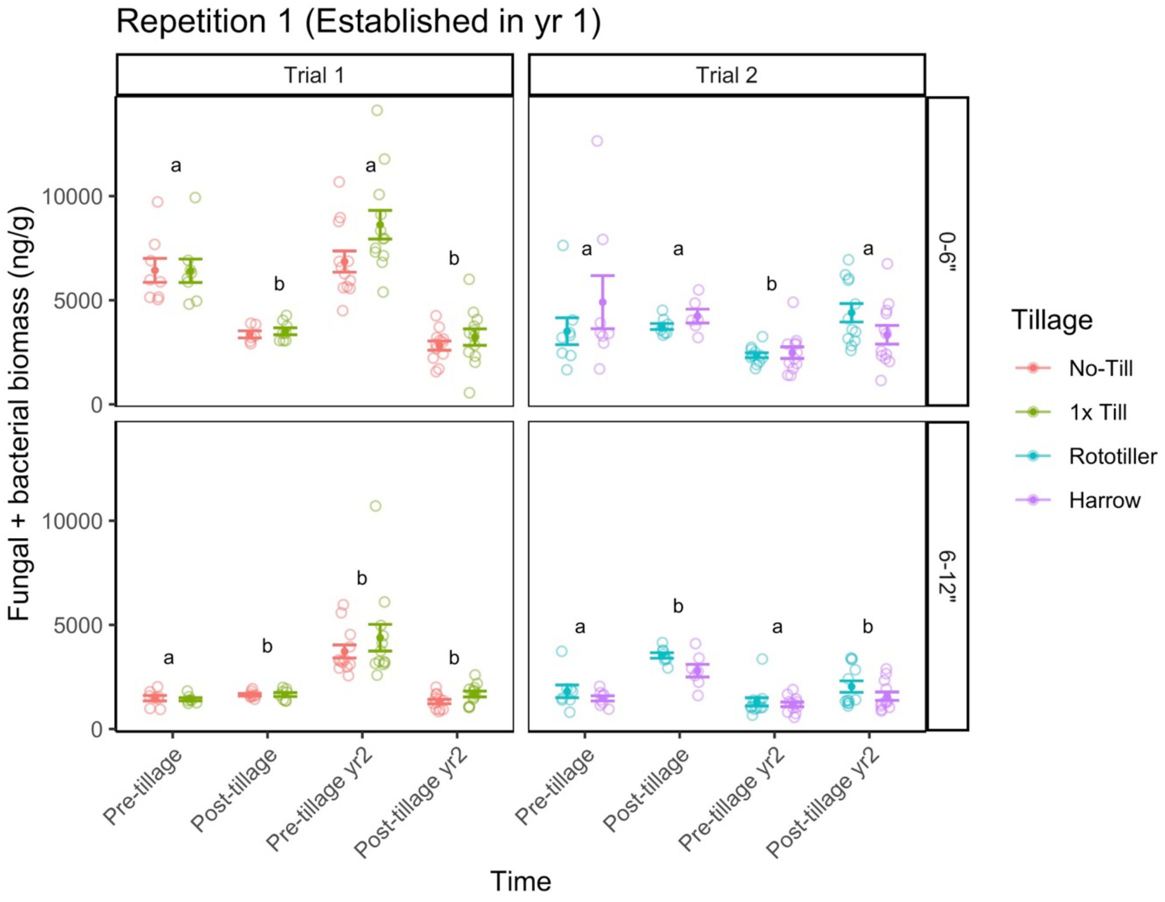


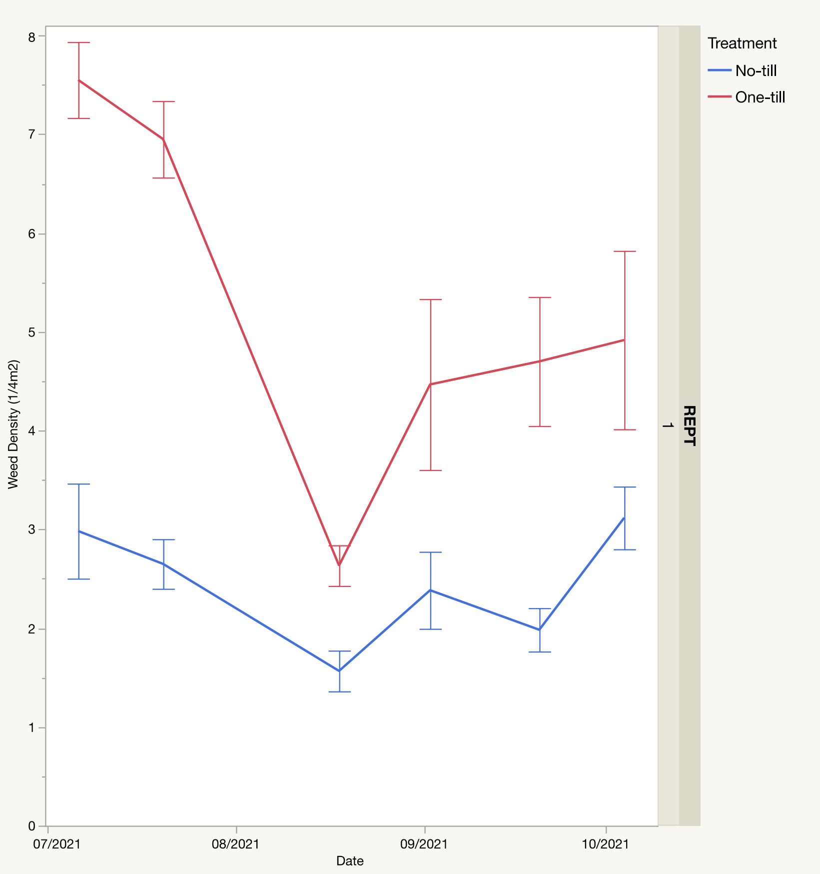
Fig 10. Total microbial biomass (PLFA) data: means and standard error of means with data points representing technical replicates within and among plots. The letters above time points indicate statistically significant groups compared to the pre-tillage sampling time.

Weeds

Weed Density

In trial 1 in 2021 (Fig. 11), weed density was significantly lower in the NT treatment on all assessment dates except for 10/4/21. In the second year of the 2021 planting, the NT treatment weed density continued to be lower during two assessment intervals (5/25/22-6/24/22 & 8/17/22-8/29/22). In Repetition 2, we saw a much different pattern during the first year of this planting.

The NT initially had a higher weed density on the first assessment date (5/25/22), but weed density changed on 7/5/22 as OT had a higher weed density through the end of July. This pattern once again shifted with the NT having a higher weed density on 9/28/22. The spring weather was notably different between 2021 and 2022 with higher precipitation and cooler soil temperatures in 2022 which may have contributed to the observed change. In Trial 2 (Fig. 12), the weed density pattern was much less clear. Weeds were similar between treatments for all assessment dates except for 7/6/21 and 10/21/21. Cultivation activities occurred on 6/23/21, 7/1/21, and 7/9/21 and should have equally suppressed weeds across treatments. But on 7/6/21 weed populations were significantly higher in the rototiller treatment as compared to the power harrow treatment. While on 10/21/21, there were significantly more weeds in the power harrow treatment and weeds were also taller than in the rototiller treatment. In 2022 for Repetition 2 (kale), the same pattern was not present. On all but one assessment date, no treatment differences were present. 2022 was the first year for squash to enter the rotation and we did not see any difference in weed density between treatments.



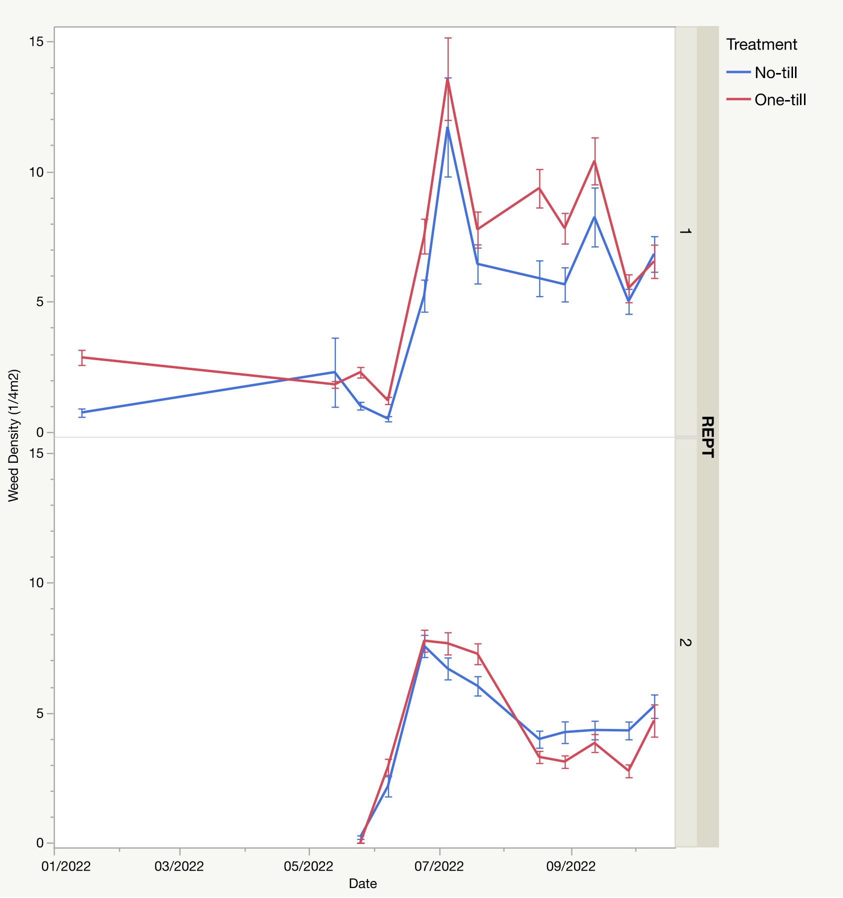
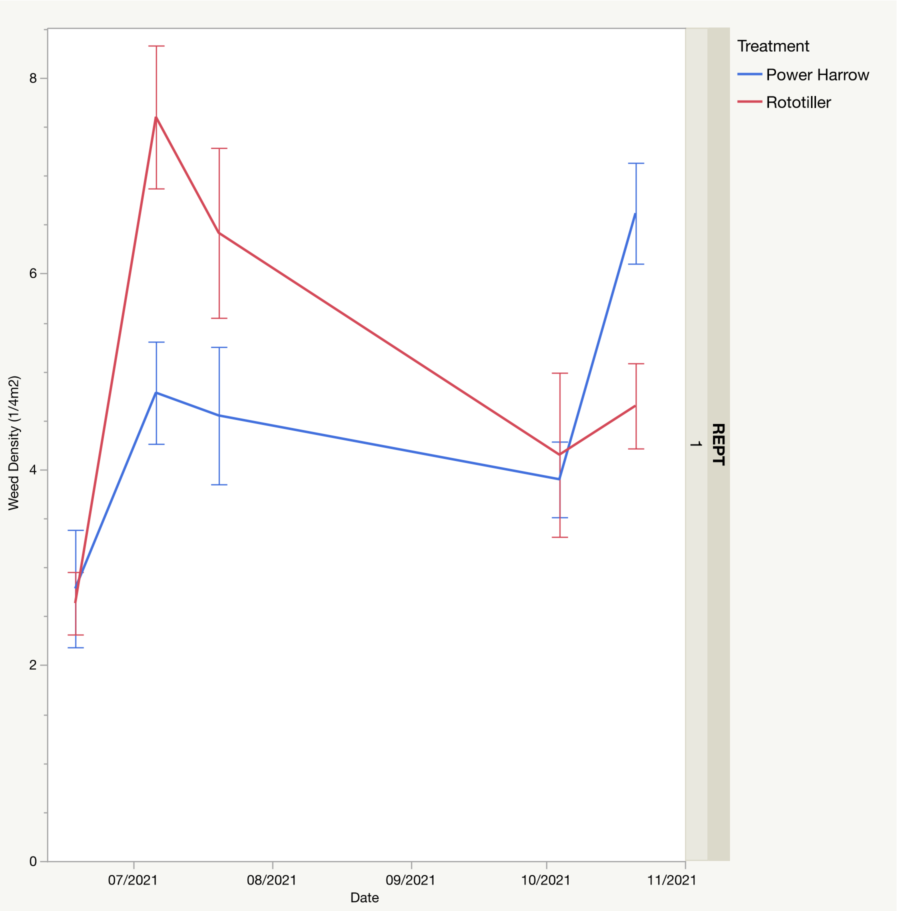


Fig. 11. Weed density in Trial 1 by treatment, year, and repetition, 2021 (top) and 2022 (bottom).


Weed Density (1/4m2)
8
6
4
2
0
07/2021
08/2021
09/2021
10/2021
11/2021
Date
REPT
1
Treatment
Power Harrow
Rototiller

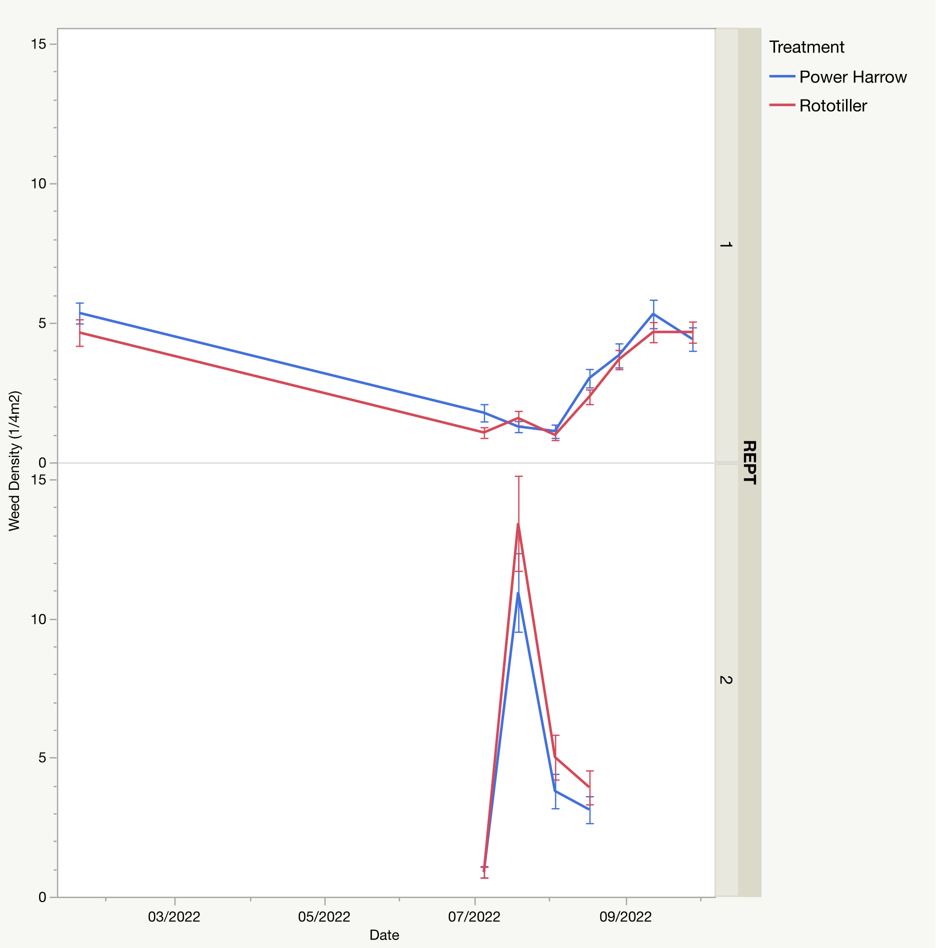
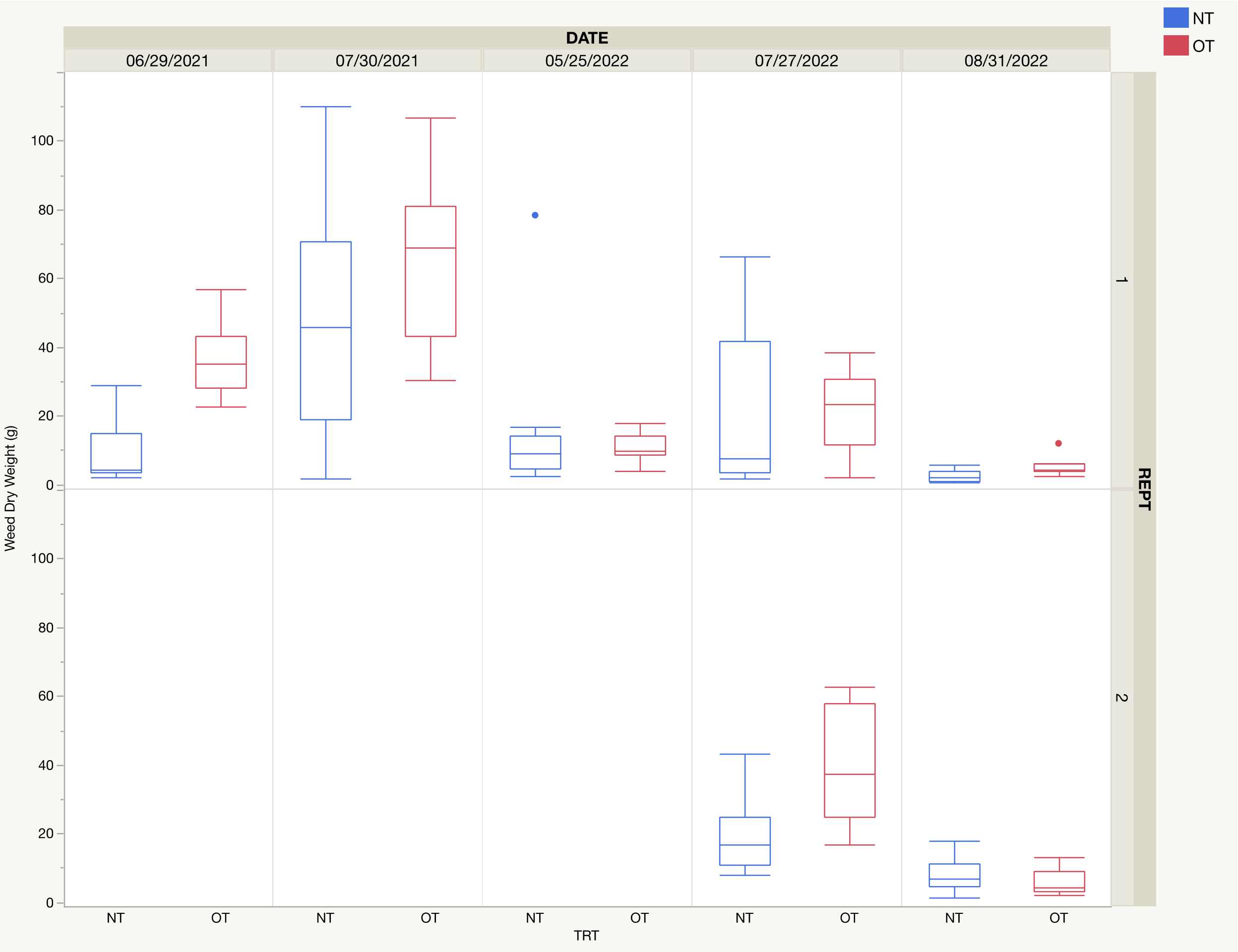


Fig. 12. Weed density Trial 2 by Treatment, Year, and Repetition, 2021 (top) and 2022 (bottom).

Weed Biomass

Weed biomass was assessed at several key points. In Trial 1 (Fig. 13a) for Repetitions 1 & 2, the weed biomass was higher than the one-till treatment on several samplings (likely resulting from the higher weed density those plots). In Trial 2 (Fig. 13b), biomass was similar for either years or repetitions.


NT
OT
DATE
06/29/2021
07/30/2021
05/25/2022
07/27/2022
08/31/2022
REPT
1
2
Weed Dry Weight (g)
0
20
40
60
80
100
TRT
NT
OT

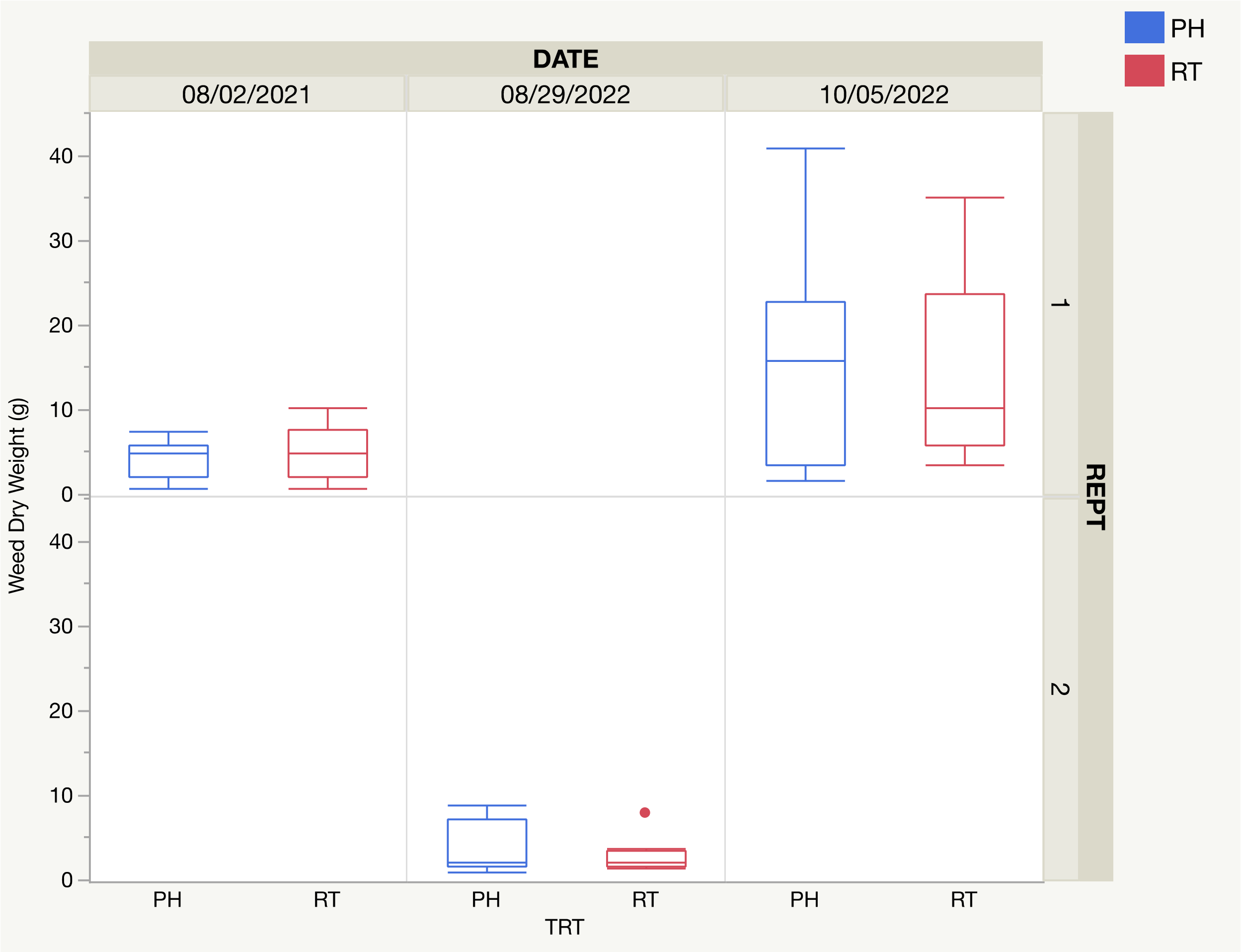


Fig. 13a & b. Weed biomass just prior to haying operations Trial 1(top) and Trial 2(bottom). NT= no-till, OT=one-till, PH=power harrow, RT=rototiller, REPT=repetition. *NOTE: 8/2/21 and 8/29/22 crops were kale, 10/05/22 crop was squash.*

Weed Seedbank

We are still processing the elutriation samples and the 2022 greenhouse grow out is still underway. The spring 2021 trial 1 (Table 5) seedbank data exhibited no treatment differences between treatments at each depth. The fall 2021 trial 1 data shows a significant increase in seed in the shallowest and the deepest assessment zone. This change did not, however, take place in trial 2 where virtually no treatment differences existed. Additional samples were acquired in 2023 with expected results surfacing in 2024.

Table 5. Weed seedbank density via greenhouse grow out method, by trial and assessment timing ("season"), 2021.

			Mean Number of Weeds per kilogram soil		
Trial	**Depth**	**Season Year**	**No-Till**	**One Till**	**p-value**
1	0-7.62	Spring 2021	2.10	3.25	0.1983
1	7.62-15.24	Spring 2021	1.62	2.25	0.2975
1	15.24-22.86	Spring 2021	1.44	1.62	0.6729
1	22.86-30.48	Spring 2021	1.54	1.17	0.3407
1	30.48-45.72	Spring 2021	0.48	0.79	0.245
1	45.72-60.96	Spring 2021	0.12	0.15	0.6423
1	0-7.62	Fall 2021	2.65	12.31	<.0001
1	7.62-15.24	Fall 2021	1.63	1.69	0.8997
1	15.24-22.86	Fall 2021	1.94	2.71	0.2915
1	22.86-30.48	Fall 2021	1.87	1.77	0.8439
1	30.48-45.72	Fall 2021	0.83	0.98	0.6013
1	45.72-60.96	Fall 2021	0.19	0.56	0.0462
			Power Harrow	**Rototiller**	**p-value**
2	0-7.62	Spring 2021	1.37	1.51	0.6688
2	7.62-15.24	Spring 2021	0.98	1.06	0.7994
2	15.24-22.86	Spring 2021	0.62	0.42	0.3361
2	22.86-30.48	Spring 2021	0.35	0.31	0.8091
2	30.48-45.72	Spring 2021	0.19	0.04	0.0367
2	45.72-60.96	Spring 2021	0.02	0.00	0.3197
2	0-7.62	Fall 2021	1.90	1.48	0.3011
2	7.62-15.24	Fall 2021	0.653	1.115	0.107
2	15.24-22.86	Fall 2021	0.71	0.75	0.8535
2	22.86-30.48	Fall 2021	0.23	0.21	0.8566
2	30.48-45.72	Fall 2021	0.12	0.17	0.5347
2	45.72-60.96	Fall 2021	0.06	0.06	1.00

Discussion

There is still a considerable number of samples to be analyzed and the second repetition of both trials will not be completed until the end of 2023, so any discussion would be premature. Our intention is to outline trends across the various assessments in both trials and to evaluate connections between these assessments. We intend to provide an updated report once this data is properly analyzed.

Publications, Handouts, Other Text & Web Products

We have developed a project blog where we have several posts thus far (https://soilhealth.wsu.edu/shi-featured-articles/).

Outreach & Education Activities:

Based on discussions with our cooperators, we chose to not hold a field day in 2022. We are planning to present final project results at Tilth Alliance Conference in 2023.

Impacts

Short-Term:

In the short term (1-3 years after project initiation), targeted audiences will have increased knowledge of weed identification, weed population dynamics, the impacts that various tillage implements have on weed seed distribution in the seed bank, and the impacts of these implements on soil health, particularly soil biology and soil hydro-physical properties. These will be measured via self-reported surveys. Additionally, we will ask survey respondents whether they have shared any increased knowledge from these events with others in their farming communities.

Intermediate-Term:

Over the intermediate term (3-5 years) we expect several behavioral changes. First, we expect attendees at outreach events to minimize their overall use of tillage/cultivation tools and to more effectively choose appropriate implements and time for these activities to improve weed suppression and reduce deleterious impacts on soil health. We also expect to increase communication and collaboration between the three programs that our partners undertake. An improved social network among new, beginning and minority farmers builds resilience across the food system.

Long-Term:

In the long term (5+ years) we expect several key changes in economic, environmental, and social conditions. As farmers in this region adopt tillage strategies that minimize weed pressure and maintain soil health, the costs of production will eventually decrease. Costs and complexities associated with weed management in diverse production systems are problematic for long-term sustainability. Additionally, land access is one of the keystones for the entrance of new farmers into the food system. This project will assist new landowners to transition untilled land into annual production by better informing them to navigate through this crucial, high-risk stage. The confidence gained from this knowledge can lead to increases in land acquisition. We expect that knowledge increases and behavioral changes resulting from this proposal will address these challenges and improve the social condition of the targeted audience.

Additional funding applied for/secured

As part of WSU’s Soil Health Initiative RFQ, these two trials were included in the Mount Vernon LTARE proposal. We are waiting until we have a clear sense of the dataset from year 2 until we scope and put together a proposal in 2023.

Graduate students funded

One Ph.D. student

Recommendations for future research

We will have a better idea once we have all of the data analyzed and summarized.

Appendix

Fig. 14. Tractor mounted Giddings soil probe

Fig. 15. Trial 2 2022 crops.

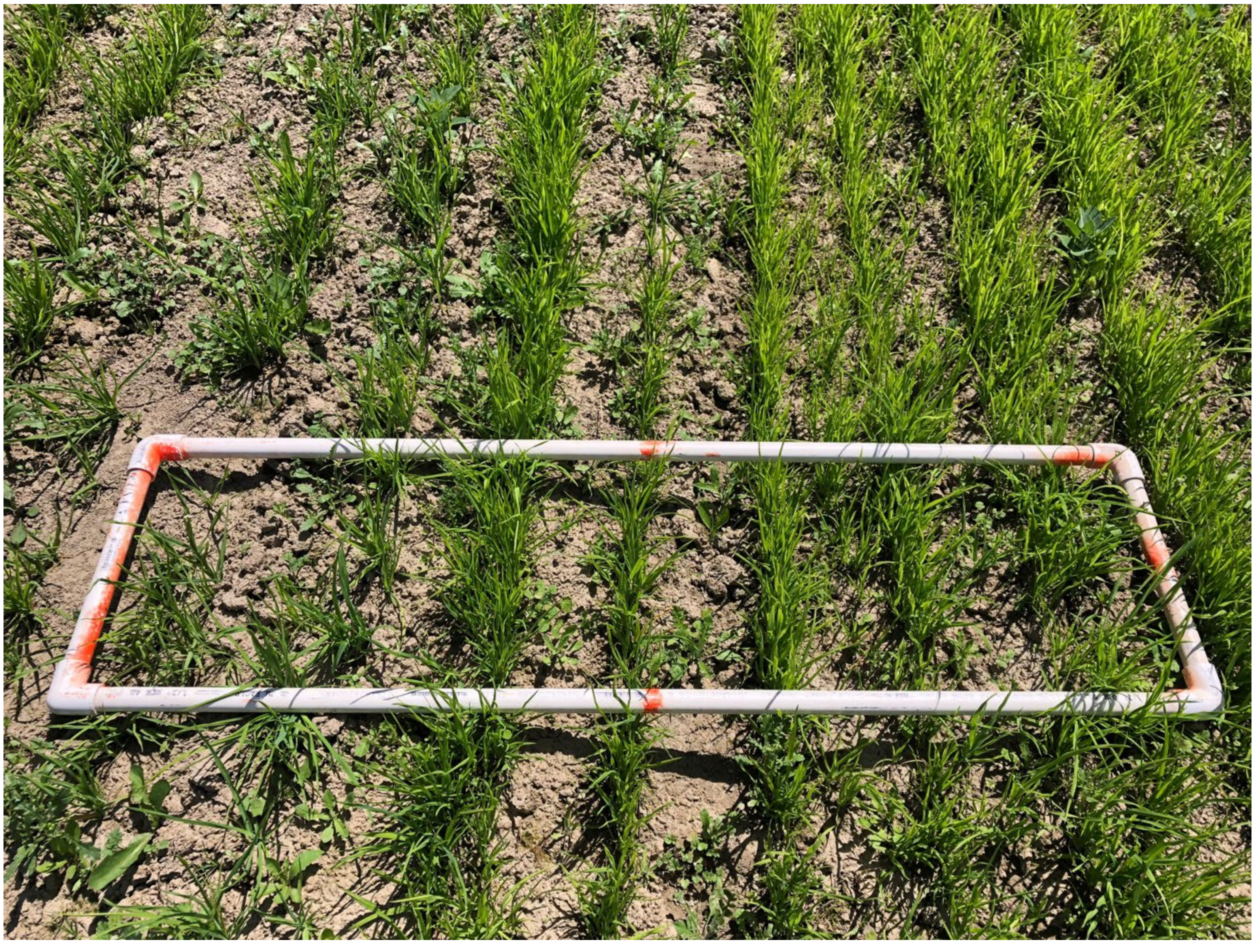


Fig. 16. Weed counts in Trial 1.