BIOAg Project Report

Report Type

Progress

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. The experiment was a randomized complete block design with four replications. 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 results are forthcoming. Weed populations were quantified from seedbank samples, in-season weed counts, and weed seed production from two key weeds. Overall, the results from Trial 1 showed that a one-time tillage event in an otherwise no-till field did not affect bulk density or the soil's penetration resistance but reduced the field saturated hydraulic conductivity by 87% and gravimetric water content by 12%. Weed populations were significantly higher on most assessment dates in the OT treatment in Trial 1. In trail 2, for most of the assessment dates there was no significant difference between the Power Harrow and Rototiller treatment.

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 has been completed
- Soil sampling for physical and hydraulic properties from Trial-2 has been completed
- Soil sampling for soil biological analyses occurred in both trials at multiple timepoints in fall and spring
- 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
- In-season weed density assessments for both trials
- Acquired seed samples from *C. album* and *C. bursa-pastoris* in both trials to estimate seed production
- Planning meetings with partners at Cloud Mountain Farm Center and Viva Farms
- Posted about the overall project on the project blog

Work in progress:

- Samples collected for wet aggregate stability from Trial 1 will be analyzed
- Measurement and analysis of soil physical and hydraulic properties from Trial 2
- Phospholipid fatty acid analysis of soil samples to assess microbial biomass and community composition
- Sampling from both the trials will be repeated in 2022 for the same hydro-physical and biological properties
- Greenhouse grow out and elutriation of weed seedbank samples are currently underway
- Weed seed production of *C. album* and *C. bursa-pastoris* estimates from both trials are underway
- Electronic outreach outputs highlighting the project on such topics as weed population dynamics and role of biology in soil health

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; each is set up in a randomized complete block design with four treatment replicates. Each replication was 10 ft by 200 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. Because of spotty establishment, it was decided to overseed all plots once again on 6/9/21. 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 (three in 2021). Because plots were too weedy for our farmer collaborator to make hay, we mimicked haying operations by mowing all plots on 6/30/21with a field rotary mower that left all plant biomass in the field. Two additional 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, samples then placed into a drying oven

(99F), then re-weighed. Irrigation need was determined using WSU AgWeatherNet Irrigation Scheduler and the orchardgrass was irrigated using line pipe irrigation and run times 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 (6/2/21). After tillage, kale was transplanted (6/3/21) into plots using a mechanical transplanter and maintained following local commercial practices. All weeds were suppressed using mechanical cultivation to a depth of 1.5" (6/23, 7/1, 7/9) and shallow hand weeding (7/21-7/22). Irrigation need was determined using WSU AgWeatherNet Irrigation Scheduler and the kale was irrigated using drip irrigation and run times recorded. Kale was harvested when commercially mature (59 DATP) by cutting all aboveground plant biomass in a 10' 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. 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 Trial 1 on June 1st, 2021, one month after the lone tillage event in spring. In Trial 2, sampling was conducted on October 19th, 2021, one month after fall tillage. 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 on 22 April (pre-tillage), 26 May (1-month post-tillage), 21 June (2 months post-tillage), and 18 October. In Trial 2, samples were collected on 22 April (pre-tillage), 21 June (1-month post-tillage in spring), and 18 October (1-month post-tillage in fall). At all samples, 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 analysis, a soil health metric that gives microbial biomass and community composition of broad microbial groups. Data is forthcoming. Soil samples for chemical properties were also collected 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, prior to any tillage implementation, seedbank samples were acquired by using a tractor attached probe (Giddings Machine Co.). The probe was inserted to 24+”, cores were then placed onto a wooden tabletop, and sectioned at 3” increments down to 12” then 6” increments down to 24”. These samples were taken in the spring prior to any tillage activity and again in the fall after the cover crop was established. Weed seedbank samples were separated into three 2.2 lb. 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 0.55 lbs. soilless growing media, placed into plastic lined flats, 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 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 (9.84”^{2}) quadrates randomly throughout each plot. In trial 2, weeds were assessed at two-week intervals from transplanting through the end of October. Counts were not performed between 7/20/21 – 10/4/21 due to harvest activities and post-harvest tillage. Weeds were counted by species (> cotyledon stage) and 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 placing the individual plants through metal sieves.

Results

Crops

In trial 1, there were no differences between treatments in orchardgrass dry weights for either of the sampling dates despite significantly higher weeds in the earlier samples (Table 1). The timing of these 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. We will continue to take orchardgrass samples in these plots in 2022.

Table 1. Dry weights (lbs./ 9.6”^{2}) values for orchardgrass and weeds prior to mowing/haying activities in Trial 1, 2021.

Date	**6/29/21**		**7/30/21**	
DAP (6/9/21)	**20**		**51**	
Treatment	**Orchardgrass**	**Weeds**	**Orchardgrass**	**Weeds**
One Till	0.02	0.08	0.16	0.14
No Till	0.02	0.02	0.22	0.11
p-value[1]		<.0001		

[1] p-values only shown if <0.05

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 (Table 2).

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

	Marketable Dry Weight Per Plant	**Unmarketable Dry Weight Per Plant**
Treatment	**Lbs.**	**Lbs.**
Rototiller	0.118	0.119
Power Harro	0.092	0.092
p-value[1]	0.0052	0.0041

[1] p-values only shown if <0.05

Soil Health

The data for soil hydro-physical properties presented in this report are from the Trial 1. The laboratory analyses and data analysis for Trial 2 is ongoing due to the fall sampling time point for hydro-physical properties compared to the spring sampling time point for Trial 1. Preliminary results showed that the bulk density between NT and OT was fairly similar at 0-2” ($p=0.05$) and 8-10” depths ($p=0.11$) (Fig. 1). Under both NT and OT, bulk density increased with depth ($p<0.001$ and $p=0.0019$ for NT and OT, respectively). Cone index did not differ between NT and OT at any depth ($p>0.05$); however, it was numerically lower in OT compared the NT from 1-12” depth, and showed a reverse trend thereafter (Fig. 2). Cone index had an increasing trend up to 3” depth and was consistent up to 9” under both NT and OT. Under OT, cone index increased from 9-14” and decreased thereafter and under NT, it remained consistent from 9-18”. Cone index was higher at deeper depths compared to the surface ($p<0.05$) under NT, except at 2” and 10” depths. Similarly, it increased with depth under OT ($p<0.05$), except from 1-12”. Dynamic cone penetrometer index did not differ between NT and OT ($p=0.20$) and between the depths ($p=0.19$; Fig. 3). 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 ($p<0.05$; Fig. 4). Field saturated hydraulic conductivity was higher under NT (26.2 cm/hr) than under OT (3.4 cm/hr) ($p=0.002$; Fig. 5). Overall, a one-time tillage event in an otherwise no-till field did not affect bulk density or the soil’s penetration resistance, but reduced the field saturated hydraulic conductivity and gravimetric water content.

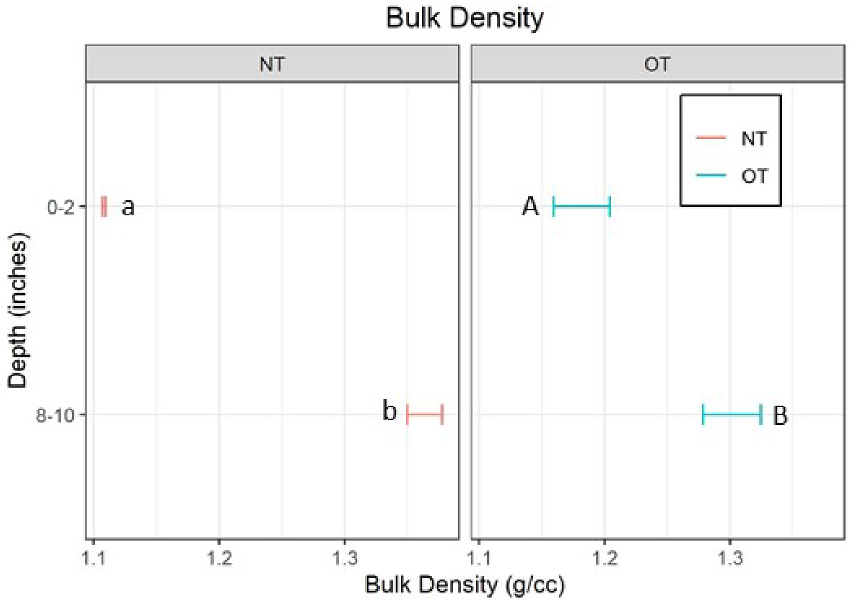

Fig. 1. Bulk density as influenced by no-till (NT) and one-time tillage (OT) treatments. Each point is an average of three samples. Error bars represent standard error. Means within the same panel followed by same letters do not differ at $p < 0.05$ for the soil depth. Bulk density between NT and OT was fairly similar at 0-2” (p=0.05) and 8-10” depths (p=0.11).

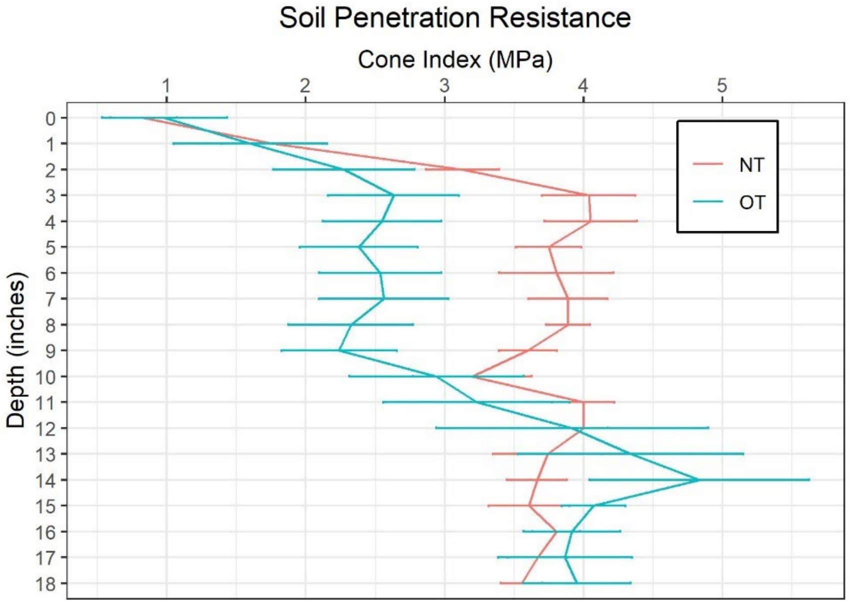

Fig. 2. Cone index as influenced by no-till (NT) and one-time tillage (OT) treatments. Each point is an average of three readings. Error bars represent standard error. Cone index did not differ (p>0.05) between the treatments at each depth.

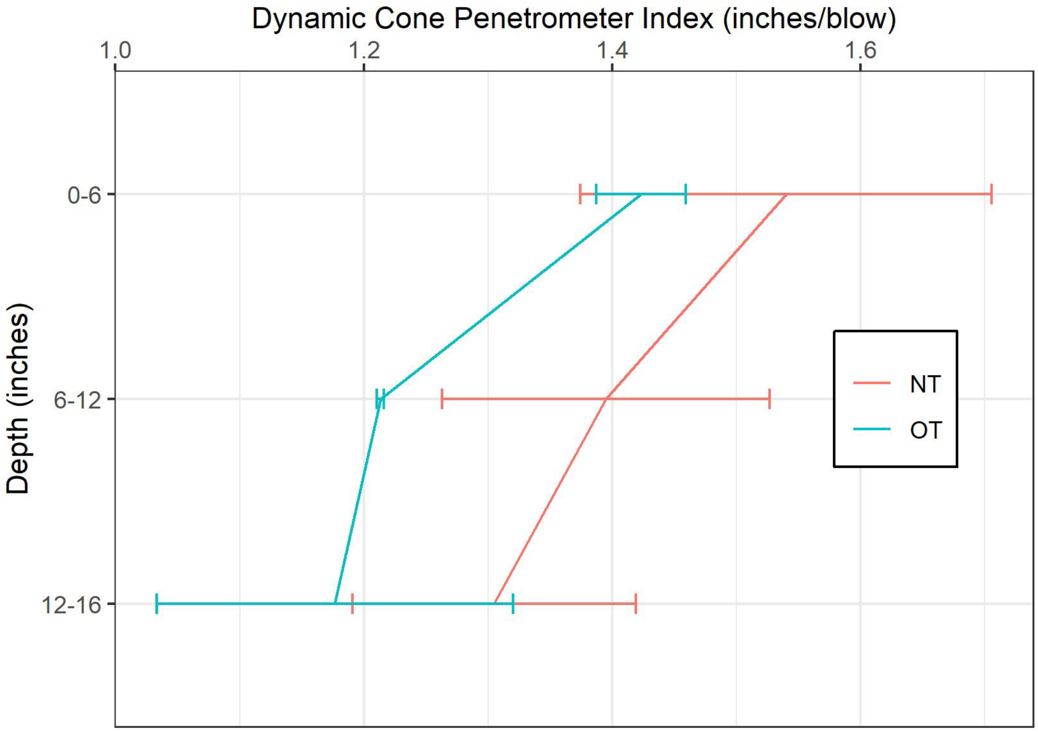

Fig. 3. Dynamic cone penetrometer index as influenced by no-till (NT) and one-time tillage (OT) treatments. Error bars represent standard error. Dynamic cone penetrometer index did not differ between the treatments (p=0.20) and among the depths (p=0.19).

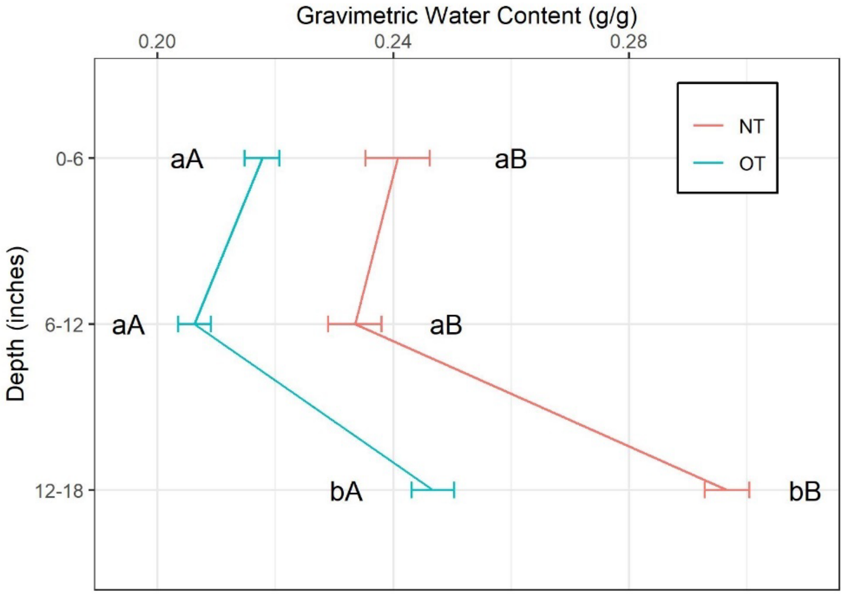

Fig. 4. Gravimetric water content as influenced by no-till (NT) and one-time tillage (OT) treatments. Error bars represent standard error. Means within the same row followed by same upper-case letters do not differ at $p < 0.05$ for the tillage treatments. Means within lines followed by same lower-case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

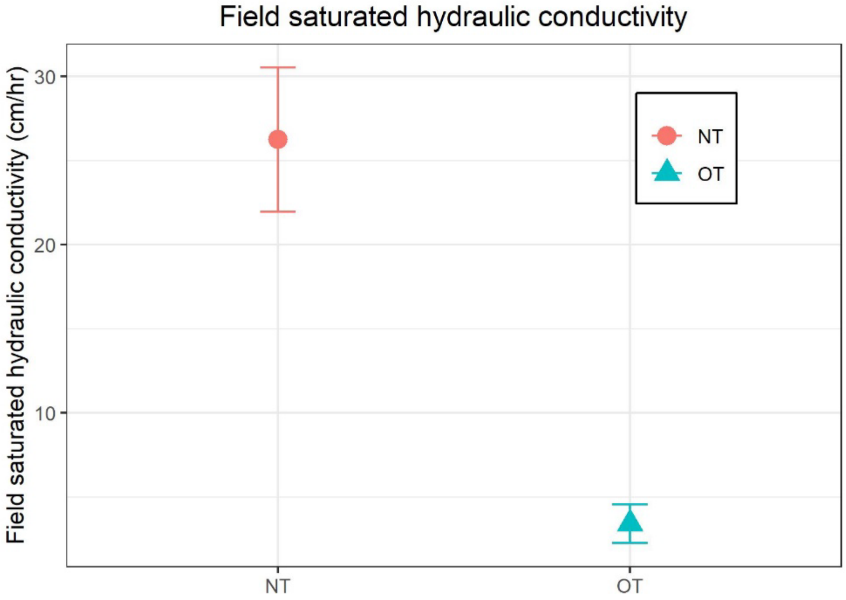

Fig. 5. Field saturated hydraulic conductivity as influenced by no-till (NT) and one-time tillage (OT) treatments. Error bars represent standard error.

Weeds

Weed population results describe herein only include in-season weed density counts as seedbank samples are still being assessed. In trial 1, weeds were significantly higher in the OT treatment for all assessment dates except for 10/4/21 (Table 3). This finding was expected as tillage acts as an environmental cue for many weed species to germinate.

Table 3. Weed densities in Trial 1 planted to orchardgrass, 2021.

Date	**7/6/21**	**7/20/21**	**9/2/21**	**9/20/21**	**10/4/21**
DAP (6/9/21)	**57**	**71**	**137**	**155**	**169**
Treatment	**Average Total Weeds**[1]	**Average Total Weeds**[1]	**Average Total Weeds**[1]	**Average Total Weeds**[1]	**Average Total Weeds**[1]
One Till	40.73	31.13	27.73	21.26	19.87
No Till	12.40	11.13	12.62	8.20	10.00
p-value[2]	<.0001	<.0001	0.0362	<.0001	

[1] Average number of weeds (9.84”^{2}); [2] p-values only shown if <0.05

In Trial 2 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. It will be interesting to see if this results in higher seed production as well as increased weed seed density in current and future seedbank samples.

Table 4. Weed height and densities in Trial 2 planted to kale, 2021.

Date	**6/18/21**	**7/6/21**		**7/20/21**		**10/4/21**		**10/21/21**	
DATP (6/3/21)	**15**	**33**		**47**		**123**		**137**	
Treatment	**Num. Weeds[1]**	**Num. Weeds**	**Weed Height (in)**	**Num. Weeds**	**Weed Height (in)**	**Num. Weeds**	**Weed Height (in)**	**Num. Weeds**	**Weed Height (in)**
Rototiller	2.63	8.17	1.47	6.62	2.38	4.53	1.23	5.4	1.09
Power Harrow	2.78	5.18	1.25	4.67	2.06	4.42	1.24	8.13	1.43
p-value[2]		0.0015						<.0001	0.0062

[1]Average number of weeds (9.84”^{2}); [2]p-values only shown if <0.05

Publications, Handouts, Other Text & Web Products

We have developed a project blog where we have one post thus far that provides an overview of the project (https://soilhealth.wsu.edu/2021/07/21/tillage-soil-health-and-weeds-wsu-organic-transitions-project/). Future posts will focus on weed ecology and management as well as soil health and tillage.

Outreach & Education Activities:

We did not plan any in-person outreach activities during the first year of this project due to COVID-19, but plan to hold a winter meeting with our partners and hope to house an in-person field day in 2022.

Impacts

Short-Term:

In the short-term (1-3 years after project initiation), attendees at field days and presentations will have an increased knowledge of weed identification, weed population dynamics, impacts that various tillage implements have on weed seed distribution in the seed bank, and impacts of these implements on soil health, particularly soil biology and soil hydro-physical properties. These will be measured via self-reported surveys delivered at outreach events. Additionally, we will ask survey respondents whether they have shared any increased knowledge from these events to 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 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, 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 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 by 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 1 until we scope and put together a proposal in 2022.

Graduate students funded

One Ph.D. students

Recommendations for future research

We will have a better idea once we have all of the data from 2021 analyzed and summarized.