Northern New York Agricultural Development Program
2023 Project Final Report

Is Soil Compaction a Big Driver of Yield? Continued in 2023

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Background:

Soil health is a concern for Northern New York’s farmers as it helps determine crop yield, farming economics, and ecological functions. Healthier soils generally support higher crop yield, resist erosion, and cycle nutrients more efficiently. One of the major contributors to suboptimal soil health found on many NYS farms today is soil compaction. Soils become compacted by heavy field equipment, such as manure tanks and forage trucks, traveling several times per year over soils with weakened structure due to many decades of tillage. Another factor contributing to soil compaction on dairy farm fields across New York State is the necessity to occasionally plant or harvest forages in wet soil conditions.

Soil compaction is a form of soil degradation and is difficult for farms to detect and evaluate, mainly because it is difficult to observe from above the soil surface. A 2019 Northern New York Agricultural Development Program (NNYADP)-funded study of 9 conventionally-tilled dairy farm fields in Northern NY revealed serious soil compaction at the surface and at depth in all fields measured, with considerable within-field variation. While it is generally understood that severely compacted soils limit plant root development and reduce soil function, especially in a wet season, it is not known whether variation in compaction severity is directly proportional to, or a driver of, crop yield performance within a field.

A 2020 NNYADP study investigated this relationship between soil compaction severity and corn yield performance in 4 fields on 2 NNY dairy farms. The new data revealed a significant relationship between yield stability zone and soil compaction severity within conventionally-managed corn fields. Compaction from 0" to 12.6" depths, measured with a standard penetrometer, was serious across all yield zones in all fields, but was more severe in the consistently lower-yielding Q4 zone than in the highest yielding Q1 zone. It is likely that the causes of yield reduction for Q3 and Q4 zones, in comparison to Q1 zones, may be numerous and variable across fields or years, but one potential cause may be increased soil compaction as revealed in this study.

In a related study, also using yield monitor data, the NMSP investigated how much corn yield may be lost on headland areas across 2,648 fields on 63 farms. Using georeferenced corn yield data collected with on-harvester yield monitors, they discovered 90% of fields had significantly lower yields on headlands, and that loss averaged about 15%. Soil compaction was not measured in this study, but, because headlands typically receive above-average field traffic, it is possible that some of this yield loss may have resulted from more severe soil compaction in headland areas.

This NNYADP soil compaction and yield research project in 2023 generated additional data to examine whether corn yield over time is related to severity of soil compaction, within a field. The study used yield stability maps based on multiple years of corn silage yield for 2 fields on 2 NNY dairy farms.

Methods:

This project is based on the Cornell Nutrient Management Spear Program's (NMSP) protocol for analyzing multiple years of corn grain or silage yield to generate "yield stability maps" for individual farm fields. This analysis uses a minimum of 3 years of yield data, collected with on-harvester yield monitors, and a data-cleaning and smoothing strategy to map corn yield and yield stability over years into as many as 4 stability zones for each field. Zone Q1 areas are those that yield above the farm average consistently over multiple seasons. Field areas in zone Q4 yield below the farm average consistently across years. Field areas mapped as zones Q2 and Q3 are those which are less consistent year to year but yield above and below average, respectively. Because yield monitor data within each field is compared to the whole farm average, all 4 yield stability zones are not always found in every field. Some fields may contain areas of all 4 zones, but others may have only 2 or 3 yield stability areas.

Yield stability maps were generated by the NMSP lab for several fields on 3 NNY dairy farms using corn silage or corn grain yield monitor data over 3+ years to calculate whole farm corn yield averages and within-field high resolution variability. Two fields used for this project in 2023 are described in Table 1.

Prior to sampling, 5 plot areas were selected within each yield stability zone in each field. Plot locations were selected where the surrounding 3,000 square yards were also within the same yield zone. At data collection, each plot center was located using a handheld GPS unit (GPSMap 64st, Garmin International, Inc., Olathe, KS USA). At each plot, 20 soil penetrations were conducted within a 27 ft radius using a digital penetrometer that stored soil resistance pressure data on board (Penetrologger with GPS, Eijkelkamp Soil and Water, Giesbeek, Netherlands, hardware v. 6.00, software v. 6.03). Soil penetration resistance pressure was measured and recorded at 0.39" (1.0 cm) intervals to a depth of 12.6" (32 resistance pressure measurements per penetration). This digital penetrometer was equipped with a standard 0.44" diameter (1 cm^2) 60° cone appropriate for penetration-resistant mineral soils.

Soil moisture in the surface 8" was simultaneously measured at each sampling location using a time domain reflectometry meter (FieldScout TDR 350, Spectrum Technologies, Inc., fitted with two 8" rods). Six soil moisture readings (% volumetric by weight) were recorded at each plot location. Soils can be too dry or too wet for meaningful penetrometer resistance data collection. Northern NY was extremely wet in fall of 2023 when these data collections were planned. According to the Northeast Regional Climate Center's Applied Climate Information System TD-3200 Daily Weather dataset, Field F2 received 4.46" of rain in the 30 days prior to data collection, including 1.92" in the preceding 14 days. The F2 field saw no precipitation for the 5 days immediately prior to sampling, so had some chance to drain. Field A received 8.85" of rain in the 30 days prior to data collection, including 4.3" in the preceding 14 days and 0.54" in the 5 days immediately prior to sampling. Weather forecasts at the time of sampling indicated that soils would soon become frozen and penetration resistance data collection would not be useful. Field A data is not shown in this report as the data accuracy was influenced by excessive soil moisture. Field F2 was also wet, but not to the degree that data accuracy was considered compromised. Field F2 soil types were also able to drain slightly better in the days prior to sampling. See Table 1.

Data from 300 penetrations were collected on each of the 2 fields in November 2023. A single individual penetration was complete when a depth of at least 12.6" was reached or when soil became impenetrable by the penetrologger tool without encountering a stone. When a penetration occasionally encountered a stone, that data was discarded, and the penetration was repeated within 6-12" from the initial penetration. Penetration to 12.6" was sometimes impossible, due to high soil resistance. The maximum soil resistance measured was approximately 1,100 PSI in this study.

JMP statistical software (JMP Pro 16.2.0, SAS Institute) was used to calculate and compare soil penetration resistance results across yield stability zones. Each individual penetration yielded a resistance curve with 32 data points. Figure 1 depicts one individual penetration resistance curve.

Penetration resistance is typically minimal in the first few inches near the surface and often increases to a local maximum at a depth of 5" to 9" and then typically remains steady or increases slightly to an overall maximum resistance near the 12.6" depth reached in this study. Individual penetration resistance curves vary greatly, however.

Table 1. Descriptions of 2 commercial farm fields used for collection of soil penetration resistance measurements in Fall of 2023; Soil Compaction Project, NNYADP, 2023.

Field	Soil Type(s)	Acres	Cobbles, Rock Fragments[1]	Overall Slope / Elevation Change	2023 Crop	Moisture content at sampling, w/v, %
F2	Adjidaumo silty clay, Flackville loamy fine sand, Grenville loam, Hogansburg loam, Hogansburg-Grenville, Malone loam	120	0-3%	ENE-facing / 25’	Soybeans	30.8% (18.2-46.5%)
A	Adjidaumo silty clay, Grenville loam, Hailesboro silt loam, Hogansburg loam, Muskellunge silty clay	127	0-2%	East-facing / 25’	Soybeans	38.5% (25.5-47.6%)

[1] presence of rock fragments and cobbles in the surface 12”, exclusive of gravel, from USDA official soil descriptions

To analyze and compare data between yield zones, resistance data from individual penetrations was summed over meaningful depth ranges to permit integrated, simple variance calculations. Total resistance over depth ranges of 0-12.6”, 0-4”, 4-9” and 9-12.6” was calculated to represent surface, middle ‘plow pan’ and below ‘plow pan’ subsets for analysis.

When complete penetration to a 12.6” depth was not possible, a pressure of 1200 PSI (slightly higher than the highest resistance pressures of 1100 PSI measurable in this study) was artificially entered for those unpenetrated depths, to permit subsequent calculations and meaningful comparisons of summed pressures.

Maximum resistance observed within each depth range was also compared across yield zones within each field. The resistance pressure curve example in Figure 1 shows that, for this individual, single measurement, penetration beyond 11.5” was not possible, and 1200 PSI was artificially used for the last 4 measurement intervals for that penetration.

Data for these 8 parameters across 3 yield zones in field F2 were not normally distributed and variances were often not equal across yield stability zones, so non-parametric methods of analysis were used. Yield stability zone effects and means were analyzed using the Wilcoxon test and a threshold $P \leq 0.05$.

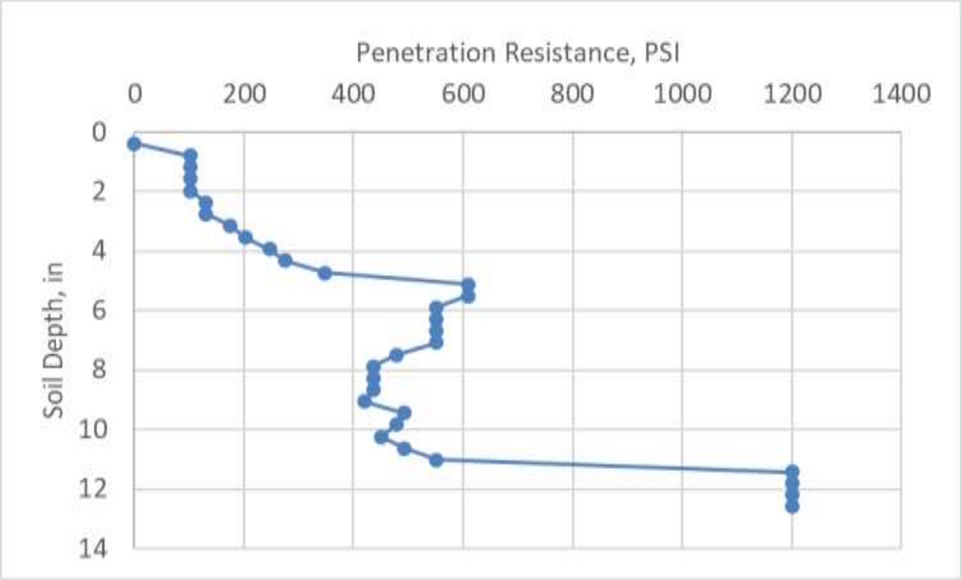

Figure 1. Example of soil penetration resistance pressure data, in PSI, collected from one individual 12.6" soil penetration; Soil Compaction Project, NNYADP, 2021 report. Penetration resistance pressure was recorded at 0.39" (1.0 cm) intervals to a depth of 12.6" (32 resistance pressure measurements per individual penetration).

Results:

Soil penetration resistance results for field F2 are summarized in Figures 2 and 3. Figure 2a depicts average total resistance encountered, summed across all 100 penetrations and 32 depth intervals from 0" to 12.6" for each of the 3 yield stability zones present in field F2. Figure 2b shows the average maximum penetration resistance encountered across those 100 penetrations and 32 depth increments from 0" to 12.6" for each yield stability zone within field F2. Average total and maximum resistance yield zone means with different letters, within a field, are significantly different ($P < 0.05$). Yield zones with a significantly greater total resistance are more compacted than those with lower total maximum resistance means.

Figure 2a shows that total penetration resistance over the entire depth range measured in yield stability zone Q1, representing field areas with consistently-higher-than-farm-average corn silage yields, was slightly lower than yield stability zones Q3 and Q4, which represents field areas with lower-than-farm-average corn silage yields. This small 5% difference was not significant for field F2. In the 4 fields sampled and summarized in the 2020 study, Q1 total resistance was significantly lower than Q4 in all 4 fields sampled. Q3 in those fields, was typically intermediate to Q1 and Q4 total resistance over the 12.6" sampling depth.

Maximum soil penetration resistance encountered from 0" to 12.6" is depicted in Figure 2b. Average maximum resistance encountered for this entire depth range in the 3 yield stability zones ranged from 485 PSI to 585 PSI. It should be noted that, using the method of penetrometer measurement implemented in this study, a soil resistance of 300 PSI is considered

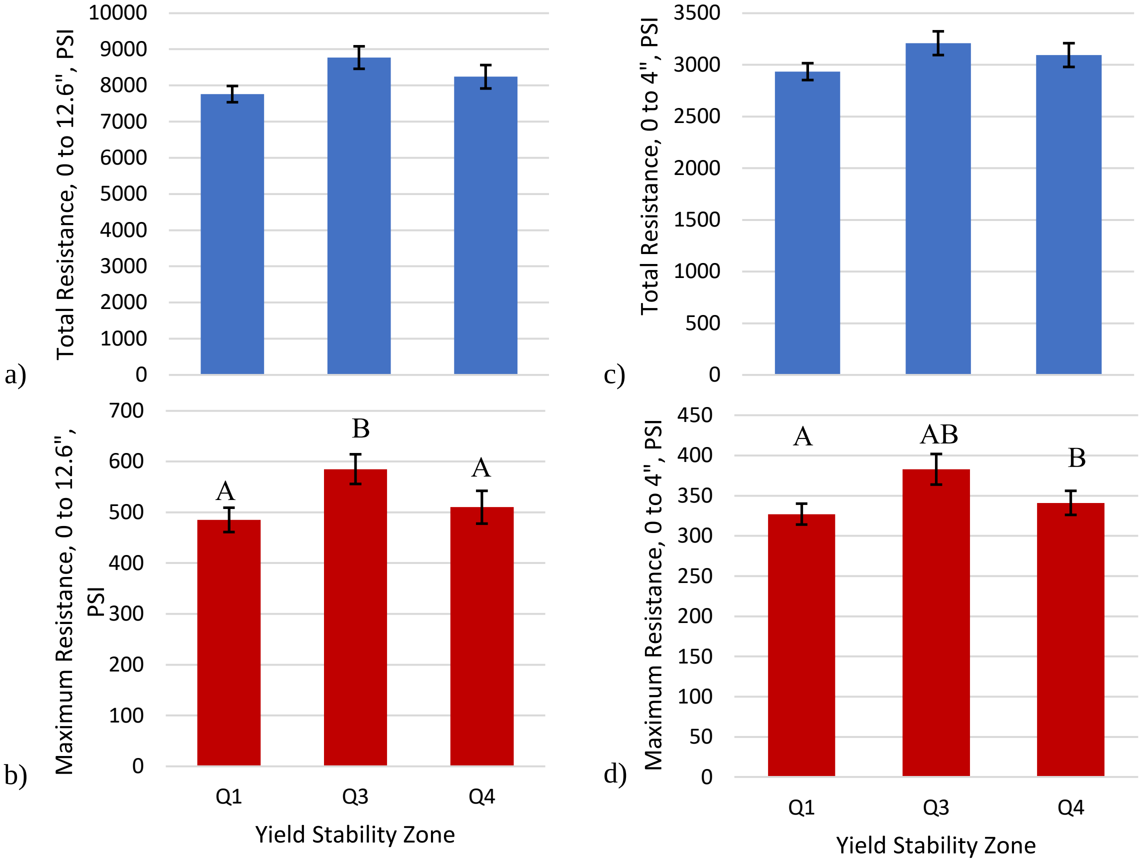

Figure 2. a) Total resistance encountered (PSI) from 0” to 12.6” depth by yield zone (Q1, Q3 and Q4) in field F2. b) Maximum resistance encountered (PSI) from 0” to 12.6” depth by yield zone within field F2. c) Total resistance encountered (PSI) from 0” to 4” depth by yield zone within field F2. d) Maximum resistance encountered (PSI) from 0” to 4” depth by yield zone within field F2. Error bars represent standard error of each mean. Key: $ and % symbols represent significant differences between yield zones within a field parameter ($P < 0.05$, significance levels are listed in tables) are indicated with different letters. Soil Compaction Project, NNYADP, 2023.

to be the maximum soil resistance that plant roots are understood to successfully penetrate. Average maximum penetration resistance, occurring anywhere between 0” and 12.6” depth, for all yield zones in all fields in this study was greater than 300 PSI. Figure 2b shows that, in field F2, maximum resistance pressures measured in yield stability zone Q1, representing field areas with consistently-higher-than-farm-average corn silage yields, and zone Q4, representing consistently-lower-than-farm-average corn silage yields, were significantly lower than those measured in yield stability zone Q3, the zone yielding lower than farm average, but is also inconsistent. In field F, maximum penetration resistance over all depths measured was lower in Q4 than in Q1, unlike previous 2020 results where Q1 were lower than for Q4 in all fields, with Q3 maximum resistances intermediate.

Results shown in Figures 2c and 2d depict total resistance and maximum resistance in just the 0” to 4” depth (10 measurement intervals) for 3 yield zones in field F2. Surface soils across all 5 fields measured so far in the 2020 and 2023 projects were less compacted, on average, than deeper layers and some significant differences between yield zones are apparent across fields.

Surface soils are often less compacted than deeper layers on farmed fields, due to regular loosening of soil density with tillage operations. Over time, repeated tillage can also weaken surface soil structure and leave it subject to compaction by rainfall, causing surface crusting of the top inch or two. No significant crusting was observed in the 5 fields included in the 2020 and 2023 projects.

Field F2 showed similar total penetrometer resistance in the surface 4" across 3 yield zones. Maximum resistance in this surface layer showed an opposite trend compared with the 2020 results. In F2, Q4 surface maximum resistance was significantly lower than Q1 maximum.

Total and maximum penetration resistances within the 4-9" and 9-12.6" depths are summarized in Figures 3a, 3b, 3c and 3d.

Generally, soil penetration resistance pressure in the "plow pan" depth and below was greater than for the 4" surface layer in all yield zones in field F2. The 4-9" depth range is expected to include any highly compacted "plow pan" layer in conventionally managed fields while the 9-12.6" depths would be the location of deeper compaction caused by heavy equipment rather than tillage implements.

Figure 3a depicts total resistance encountered, summed across 12 depth intervals between 4" and 9" depth for each yield stability zone within field F2.

Figure 3b compares the maximum penetration resistance encountered over that same 4-9" depth range for each of the 3 yield stability zones in field F2.

Figure 3a and 3c show again no significant differences among the 3 yield stability zones in total penetration resistance encountered over the 4-9" or 9-12.6" depth ranges. Total resistance results for both the 0-12.6" and 0-4" depth ranges show the same pattern, with Q1 averaging lower total and maximum resistance than Q3, with Q4 being intermediate, but in field F2, none of these differences are significant.

Figures 3b and 3d depict maximum penetration resistance encountered within the 4-9" and 9-12.6" depth ranges, respectively. In both depth ranges, yield stability zones Q1 and Q4 averaged significantly lower maximum resistance than Q3. While Q3 and Q4 yield stability zones yield less than the whole farm average corn yield, they differ in their yield consistency. Soil compaction severity in this field appears to potentially be related more strongly to that consistency than the yields achieved.

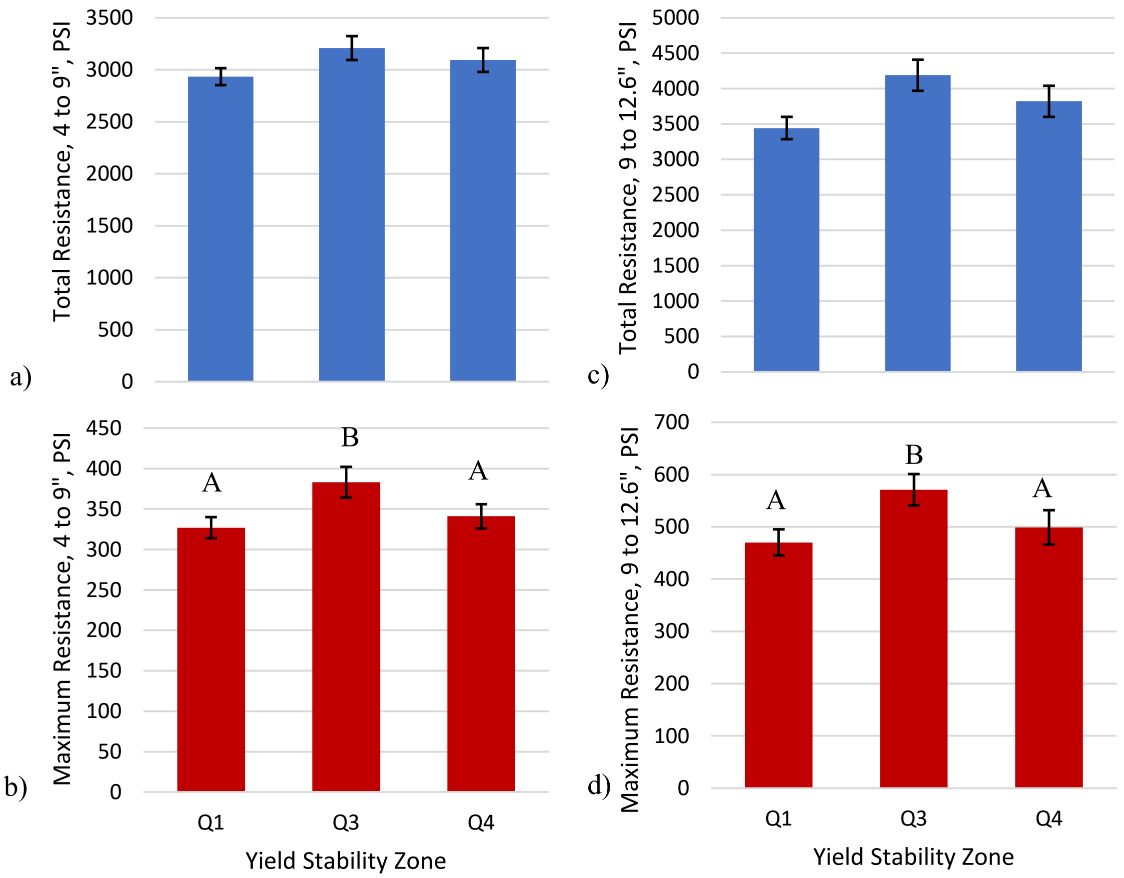

Figure 3. a) Total resistance encountered (PSI) from 4” to 9” depth by yield zone (Q1, Q3 and Q4) within commercial farm field F2. b) Maximum resistance encountered (PSI) from 4” to 9” depth by yield zone within field F2. c) Total resistance encountered (PSI) from 9” to 12.6” depth by yield zone within field F2. d) Maximum resistance encountered (PSI) from 9” to 12.6” depth by yield zone within field F2. Error bars represent standard error of each mean. Key: $ and % symbols represent significant differences between yield zones within a field grouping (P <0.05) are indicated with different letters. Soil Compaction Project, NNYADP, 2023.

The artificial resistance measurement of 1200 PSI entered when further penetration was not possible was used most often for the 9-12.6” depths. Some artificial bias could be introduced with this approach, upward or downward, as a result. Real resistance beyond the impenetrable layer is not known. Q1 total resistance for this 9-12.6” depth appears lower than for Q3 and Q4 however this is not a significant difference. Total summed resistance over this below ‘plow pan’ layer in the Q3 zone was again intermediate compared with Q1 and Q4, and statistically similar to either Q1 or to Q4 in each field. Total resistance was statistically similar across yield zones for field F. Average maximum resistance pressures in this below ‘plow pan’ layer for yield zones with each field are compared in Figure 3d. Again, maximum resistance is significantly lower for Q1 zones than Q4 zones in 3 of the 4 fields with Q3 resistance pressures appearing to be more variable.

Conclusions/Outcomes/Impacts:

Soil compaction, measured in this study as resistance to a standard penetrometer, is considered to be one of the most serious environmental problems caused by conventional agriculture because it limits soil functions and health and also crop productivity.

This study on Northern New York farms has added to a growing dataset examining the relationship between soil compaction severity and historical corn yield. The data in 2023 continues to reveal a relationship demonstrated between soil compaction and yield in commercial farm fields uncovered in our earlier work.

This study shows a significant relationship between yield stability zone and maximum soil resistance encountered at all 3 depths, and across all depths. The data collected in 2023 will be further analyzed, in conjunction with other data from these same fields, to provide more understanding of the relationship between soil compaction, additional soil health parameters, with yield stability across years.

Recommendations for Addressing Soil Compaction

Soil health management is complex. This compaction research into how the density of soil impacts crop yield gives us a starting point. Compaction impacts soil structure, damaging soil pores and root channels and reducing optimal opportunity for crop growth. For recommendations of steps to begin improving soil health, see “When to Start Restoring Soil Health? Avoid and Repair Soil Compaction,” K. O’Neil, North Country Ag Advisor, January 2020, and Dealing with Rutted Corn Fields in Fall (Appendix/this report).

Next Steps:

An additional outcome of this 2023 data collection has been to highlight the critical need to more discretely identify soil moisture content ranges where penetration resistance data is most reliable. Effort is already underway to add soil moisture limitations to our soil compaction data collection protocols.

Outreach:

The relationship between soil compaction severity and corn yield stability is a topic of great interest among agricultural practitioners. Several presentations have been given, summarizing this study, in conjunction with other related findings in NNY, NYS and beyond. Project results and recommendations for solving soil compaction will continue to be presented and discussed at upcoming producer meetings in 2024 and beyond.

For More Information:

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APPENDIX follows

Field Crops and Soils

Where to Start Restoring Soil Health? Avoid and Repair Soil Compaction

By Kitty O'Neil

North Country dairy, livestock and cash crop farmers are generally aware of the importance of soil health and are very interested in managing fields to improve and recover soil health. It's true though, that soil health is a big, complicated concept, folding together many aspects of soil physical, chemical, and biological properties into a single idea. Additionally, while many aspects of soil health are quick to degrade, they are slow to improve, requiring a few years or even decades. This cumbersome and complicated nature of soil health makes it hard to know where to begin to make progress toward healthier, stronger soils on any given field or farm. Which aspect of soil health is the most critical? Which management changes are the most important? What possible changes will have the biggest bang for the buck? How will I know if I've made an impact? These are all excellent concerns; but I want to suggest a good place to start – with soil compaction.

Soil compaction is a widespread soil structure problem that is a largely 'invisible' limitation to thousands of farm fields across the North Country. Compaction is an increased density of soil, which happens when pore spaces and root channels are destroyed and solid particles are compressed. Compaction is beneficial for road-building, but not for crop growth. Typically, any field that has been managed with tillage and mechanized equipment sometime in the past century probably has at least some soil compaction within the rooting zone, resulting in limited plant development and yield. Tillage destroys and weakens soil structure near the surface and heavier and heavier field traffic has caused subsoil compaction, further below the surface. The combination of tillage and heavy equipment has compounded compaction issues. Planning and managing for reducing and reversing soil compaction is a good place to start improving soil health on your farm. Soil compaction is a widespread problem and we have some specific recommendations for making important changes now.

A small group of NNY farmers and CCE staff attended a Soil Compaction Field Day held in Ontario, Canada, in August 2019. The event was extraordinarily educational. The local Dundas Soil and Crop Improvement Association and the OMAFRA Soil Compaction Team organized several highly impactful field demonstrations to accompany lecture presentations. Many examples of combines, tractors, manure tanks, balers, wagons, and trucks were delivered from nearby farms and were driven across pressure sensors buried at 3 depths beneath the soil surface while the pressure readings were graphically displayed on a giant screen (see picture on next page). Pressures measured at each depth were compared with standard pressures known to cause compaction limitations. The real-time results were mind-blowing. Some of the take-away messages I learned from the speakers and demos were:

1. Check tire pressures frequently, on all equipment. Many of the implements arrived with incorrect and/or uneven pressures which caused important differences in soil pressures.
2. Tire pressures which work well for safe road travel typically do not work well for low-impact field traffic and vice-versa. High pressure road tires can cause serious compaction pressures even from small equipment like sprayers and pickup trucks.
3. Squashed-looking tires aren't necessarily a bad thing, in the field. Lowering tire pressures increases the contact area, spreads out the load and can often keep soil pressures below threshold levels. New flexible tire walls permit this deformation to help with soil damage.
4. Wider tires or tracks don't always reduce soil pressures. Aim for a longer, wider tire contact area. This can be accomplished with bigger, wider tires with lower pressures, but also with increased number of tires and axles.

To learn more on this important topic, we are welcoming Warren Schneckenberger to Crop Congress on Jan 21 and 22nd to address some of these topics. Warren and his wife operate Cedar Lodge Farms, a cash crop and beef operation near Morrisburg in Eastern Ontario. He was one of the farmers who helped organize and present the Compaction Field Day. Warren won the 2019 Innovative Farmer of the Year award from the Innovative Farmers Association of Ontario, recognizing his commitment to soil-friendly practices, such as

Continued on page 4...

improved rotation, strip tillage, controlled traffic farming, and cover crops. Warren will discuss his approach to managing soil compaction on his farm and will participate in a farmer panel to provide more detailed explanations.

Field equipment has become bigger, faster, more fuel-efficient, and we now have the ability to track and map field operations and yields with GPS. New increased flex and very high flex tire materials and central tire inflation systems, controlled from the cab, may further help limit and control soil compaction from field equipment. With all of this technology, staying off the field with road vehicles and checking tire pressures may be low-cost tools for reducing soil compaction in big ways too.

Below-ground soil pressures being measured under a tractor and baler and displayed in real-time at the Soil Compaction Field Day hosted by the Dundas Soil and Crop Improvement Association and the OMAFRA Soil Compaction Team in August 2019, near Inkerman, ON. Photo credit: K. O'Neil.

Dealing with Rutted Corn Fields in Fall

by Kitty O'Neil, North Country Ag Advisor, November 2019, p. 4

Field traffic during a wet harvest season can cause an irregular soil surface and compaction at multiple depths, from surface inches to subsoil well below tillage depth. Water acts like a lubricant between soil particles and under heavy pressure from field equipment it enables compression of soil solids. Soils at and above field capacity are at greatest risk of compaction. While surface compaction generally is not as long-lasting as sub-soil compaction, it may have more severe consequences in the season or two immediately following the compaction damage.

Surface rutting, even just 2-3" deep, can cause uneven, irregular seed placement in the following spring if it's not corrected. Subsoil compaction below the rut may have long-lasting and severe impacts on subsequent crops, reducing rooting depth and overall plant development. Next year's forage and grain yields can be greatly improved with some remedial action; however, it is critical to wait until soil conditions are right for any field activity, or you can easily worsen the damage.

Often, fall soils remain too wet for corrective operations. Resist the urge to get on fields until conditions are right, even if that means waiting until spring.

Surface rutting and compaction should definitely be smoothed before spring planting if it's as deep as, or deeper than, planting depth. The best approach may be to use a light tillage pass or two with a field cultivator, shallow harrow, disc, or soil finisher a week or few days before planting. If only a portion of the field is rutted, limit this effort to just the affected area to avoid recompacting subsoil across the whole field. Ideally, the goal is to shallowly smooth rutted areas, rather than a full-width tillage of the whole field down to the plow pan. Waiting until warmer weather in the spring should permit drying of surface 2-3" of soil and avoid further compaction which is likely if tillage is attempted this fall.

Using tillage, deep or shallow, to loosen the soil and relieve compaction requires that soil be dry enough for shattering of compacted layers to occur. Check soil moisture before proceeding, not just at the surface, but at deeper layers as well. Deep tillage with a chisel plow or subsoiler, either this fall or next spring, is unlikely to loosen soil effectively if soils remain wet because wet soils do not shatter. This operation could even worsen compaction if conditions are wet at depth.

Remember, too, that depending on air temperatures and snow cover, soil moisture in the surface couple of feet will freeze and thaw, and heave and relax over the winter, and this will help loosen compacted surface soil. Attempting deep tillage, or any tillage, this fall in wet soil conditions may be counter-productive by creating much deeper soil compaction.

While we cannot change what happened this fall, consider some wider options to help avoid soil compaction and improve soil structure going forward. Farms with established no-till fields are generally able to enter fields earlier with minimal to no field rutting, compared to conventionally-tilled neighbor farms. Full-width tillage, over seasons or a single pass, reduces healthy soil structure and increases compaction due to the destruction of soil aggregation. Adopting no-till methods allows soils to rebuild and strengthen structure, which help soils drain and resist compression pressure by field traffic. Farmers can then get onto fields faster after rainy weather and it will cause less compaction. These changes do not happen overnight, however. There's an old Chinese proverb that says: “The best time to plant a tree was 20 years ago. The second best time is now.” This principle is true for eliminating tillage too.