Northern New York Agricultural Development Program
2021-2022 Project Report

Is Soil Compaction a Big Driver of Yield?

Project Leader:

- Kitty O'Neil, Ph.D., Regional Field Crops and Soils Specialist, Cornell University Cooperative Extension, North Country Regional Ag Team, 2043B State Highway 68, Canton, NY 13617; 315-854-1218, kitty.oneil@cornell.edu

Collaborators:

- Cornell University Department of Animal Science: Quirine Ketterings, Ph.D., Professor, Director, Nutrient Management Spear Program; Manuel Marcaida III, Crop Yield Data Analyst; Jonathan Berlingeri, Research Assistant II
- Michael Hunter, Regional Field Crops and Soils Specialist, Cornell University Cooperative Extension, North Country Regional Ag Team

Cooperating Producers:

- Jon Greenwood, Greenwood Dairy, Canton, NY
- Jon Rulfs, Adirondack Farms, Peru, NY

Background:

Soil health is a concern for Northern New York's farmers as it determines crop yield, farming economics, and ecological functions. Healthier soils generally support higher crop yield, resist erosion, and cycle nutrients better as well. One of the main contributors for a decline in soil health over time is compaction. Soils become compacted by tillage and multiple passes by heavy field equipment, including manure spreaders and forage trucks, each year. Another factor contributing to soil compaction on dairy farm fields across New York State is the necessity to occasionally harvest forages in wet soil conditions.

In a 2019 Northern New York Agricultural Development Program (NNYADP)-funded study of nine conventionally-tilled dairy farm fields in Northern NY, serious soil compaction at the surface and at depth was revealed in all fields, 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 this wide variation in compaction severity is directly proportional to, or a driver of, crop yield performance within a field.

The Nutrient Management Spear Program (NMSP) at Cornell University has developed a protocol for analyzing multiple years of corn grain or silage yield to generate "yield stability maps" for farmers. 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 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.

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 could result from soil compaction in headland areas.

This NNYADP project in 2021 generated preliminary 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 4 dairy farm fields on 2 NNY farms.

Methods:

Yield stability maps were generated by the NMSP lab for 2 fields on each of 2 NNY dairy farms using corn silage yield monitor data over multiple years and whole farm corn silage yield averages and variability. All fields sampled in this study were in corn in 2021. Fields are described in Table 1. This project focused on comparing soil compaction severity in yield stability zones Q1, Q3 and Q4.

Five plot areas were selected within each of the 3 yield stability zones. Plot locations were selected where the surrounding 3,000 square yards were within the same yield zone. Each plot center was located using a handheld GPS unit (GPSMap 64st, Garmin International, Inc., Olathe, KS USA). At each plot, 24 soil penetrations were conducted within a 39.4 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.

Data from 360 penetrations were collected on each of 4 cornfields in October and November 2021. An 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. Stones were encountered on a high percentage of penetrations in most plots. When a penetration obviously intersected a stone, data was discarded, and the penetration was repeated within a distance of 1-2 ft. Penetration to 12.6" was sometimes not possible, due to high soil resistance. Maximum resistance measured was about 1,130 PSI across all 4 fields. Composite soil samples were simultaneously collected from each field to record soil moisture. Saturated or nearly saturated soils are unsuitable for such measurements so time was allowed for adequate drainage and drying following frequent rains during October and November 2021.

JMP statistical software (JMP Pro 16.2.0, SAS Institute) was used to calculate and compare soil penetration resistance across 3 yield stability zones. Each individual penetration yielded a resistance curve with 32 data points. Figure 1 depicts one individual penetration resistance curve.

Table 1. Descriptions of 4 commercial farm fields used for collection of soil penetration resistance measurements in fall of 2021; Soil Compaction Project, NNYADP, 2021.

Field	Soil Type(s)	Acres	Cobbles, Rock Fragments[1]	Overall Slope	Elevation Change	Moisture content at sampling, w/w
B	Appleton Loam, Bombay Loam, Roundabout Silt Loam, Northway Loamy Fine Sand, Pipestone Fine Sand, Covert Loamy Sand	24	0-10%	East-facing	110’	21%
F	Hogansburg Loam, Malone Loam, Stockholm Loamy Fine Sand, Hailesboro Silt Loam, Swanton Fine Sandy Loam, Muskellunge Silty Clay Loam, Elmwood Fine Sandy Loam, Adjidaumo Silty Clay	72	0-13%	Southeast-facing	30’	18%
M	Tonawanda Silt Loam, Amenia Fine Sandy Loam, Bombay Gravelly Loam	71	0-5%	Northeast-facing	80’	20%
P	Grenville Loam, Malone Loam, Hogansburg Loam, Swanton Fine Sandy Loam	45	0-13%	North-facing	15’	19%

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

Resistance is typically low near the surface and often increases to a local maximum at a depth of 5” to 9” and then increases again to an overall maximum near a depth of 10-12.6”. Individual penetration resistance curves varied greatly in this study, however.

To analyze and compare data between yield zones, resistance data from individual penetrations was summed over meaningful ranges to permit integrated, simple ANOVA variance calculations. Total resistance over depth ranges of 0-4”, 4-9” and 9-12.6” was calculated to represent surface, middle ‘plow pan’ and below ‘plow pan’ subsets for ANOVA analysis. When complete penetration to a 12.6” depth was impossible, a pressure of 1150 PSI (slightly higher than the highest resistance pressures of 1130 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 measurement, penetration beyond 11.5” was not possible, and 1150 PSI was artificially used for the last 4 measurement intervals for that penetration.

Results:

Soil penetration resistance results are summarized in Figures 2 and 3. Figure 2a depicts average total resistance encountered, summed across 32 depth intervals from 0” to 12.6” for each yield stability zone within each farm field in this study. Figure 2b shows the average maximum penetration resistance encountered from 0” to 12.6” for each yield stability zone within each field. Average total and maximum resistance yield zone means with different letters, within a field, are

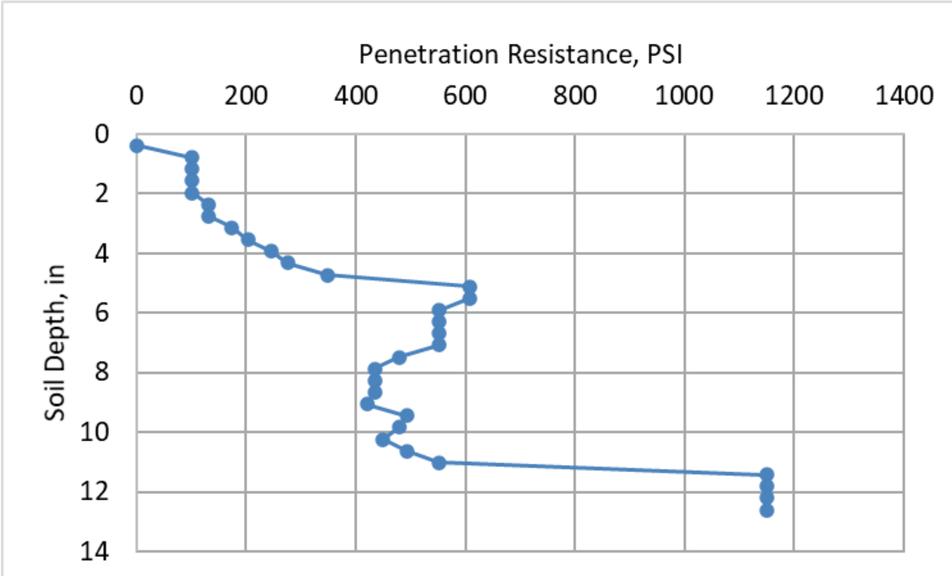

Figure 1. Example of soil penetration resistance pressure data, in PSI, collected from one individual 12.6" soil penetration in this study; Soil Compaction Project, NNYADP, 2021. Penetration resistance pressure was recorded at 0.39" (1.0 cm) intervals to a depth of 12.6" (32 resistance pressure measurements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

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, in all 4 fields in this study, penetration resistance measured in yield stability zone Q1, representing field areas with consistently-higher-than-farm-average corn silage yields, was significantly lower than yield stability zone Q4, which represents field areas with consistently-lower-than-farm-average corn silage yields. Q1 zone averaged about 21% lower total penetration resistance than Q4 over the 12.6" range. In these 4 fields, total penetration resistance measured in yield stability zone Q3 was somewhat intermediate compared to Q1 and Q4. In 2 fields, Q3 total resistance was statistically similar to Q1 and in 2 fields it was similar to Q4. On average, Q3 resistance was about 13% lower than for Q4, across all 4 fields.

Maximum soil penetration resistance pressure results from 0" to 12.6" are depicted in Figure 2b. Average maximum resistance encountered for all fields and yield stability zones ranged from 403 PSI to 822 PSI across these 4 fields. It should be noted that, using the method of penetrometer measurement implemented in this study, a soil resistance of 300 PSI is considered to be the maximum soil resistance that plant roots may 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 all 4 fields in this study, maximum resistance pressures measured in yield stability zone Q1, representing field areas with consistently-higher-than-farm-average corn silage

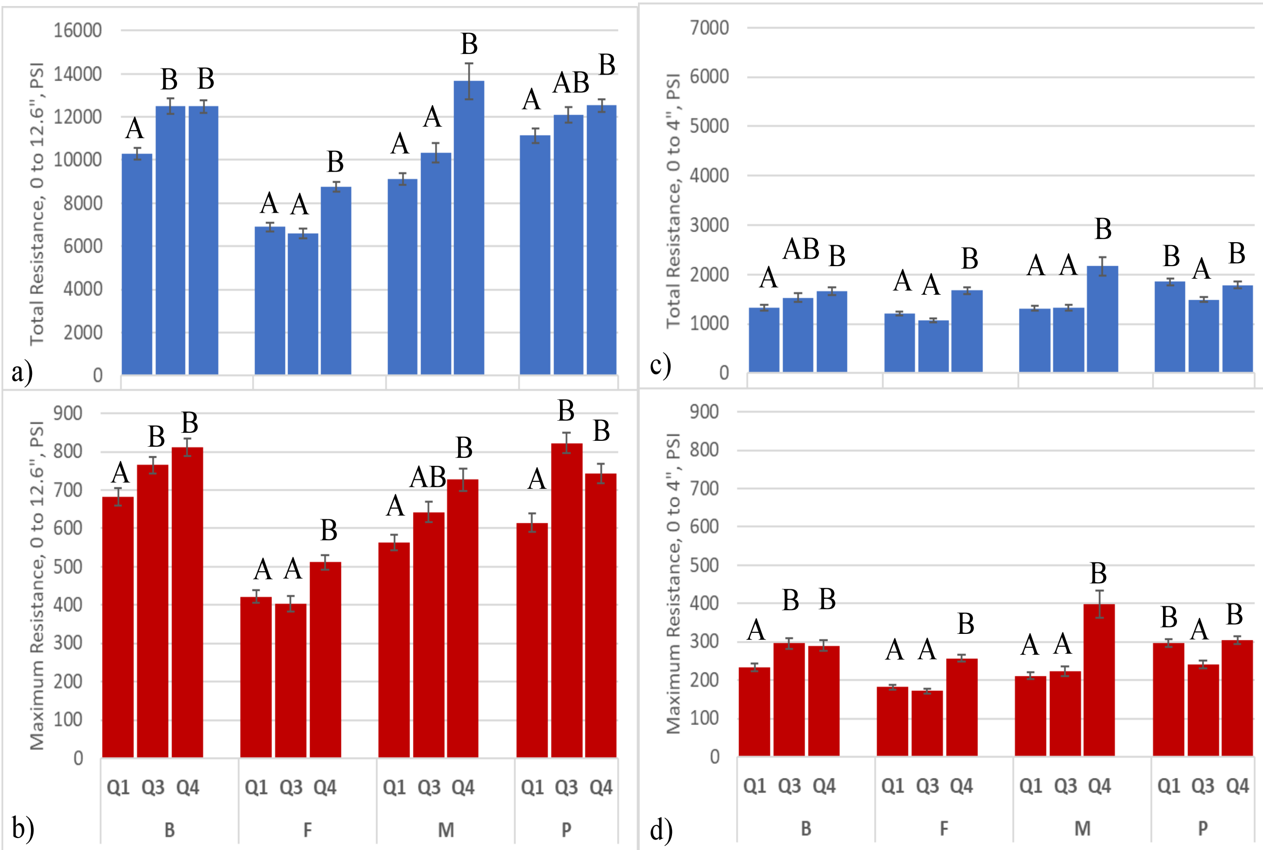

Figure 2. a) Total resistance encountered (PSI) from 0" to 12.6" depth by yield zone (Q1, Q3 and Q4) within each of 4 commercial farm fields (B, F, M and P). b) Maximum resistance encountered (PSI) from 0" to 12.6" depth by yield zone within each field. c) Total resistance encountered (PSI) from 0" to 4" depth by yield zone within field. d) Maximum resistance encountered (PSI) from 0" to 4" depth by yield zone within field. Error bars represent standard error of each mean. A, B, C Key: significant differences among yield zones within a field grouping (P <0.05, significance levels are listed in tables) are indicated with different letters. Soil Compaction Project, NNYADP, 2021.

yields, were significantly lower than those measured in yield stability zones Q4, which represent field areas with consistently-lower-than-farm-average corn silage yields. Results found in Q3 zones were again intermediate. In field F, maximum penetration resistance over all depths measured was similar to Q1, but for the other 3 fields Q3 maximum resistance was similar to Q4 maximums. Overall, Q1 maximum resistance encountered was about 18% lower than for Q4. Q3 maximum resistance averaged about 7% lower than for Q4 across 4 fields in this study.

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 the 4 fields sampled. Surface soils across the 4 fields 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. Tillage can also cause surface soils to be subject to compaction by rainfall, however, causing surface crusting. No crusting was observed in the 4 fields included in this project. The Q1 zones showed lower total resistance and maximum resistance than the Q4 yield stability zones in 3 of the 4 fields sampled. In those 3 fields (B, F and M), Q3 total and maximum resistance was similar to Q1 results, but not uniformly. In field P, Q3 total and maximum resistance pressures were significantly lower than for both Q1 and Q4 zones.

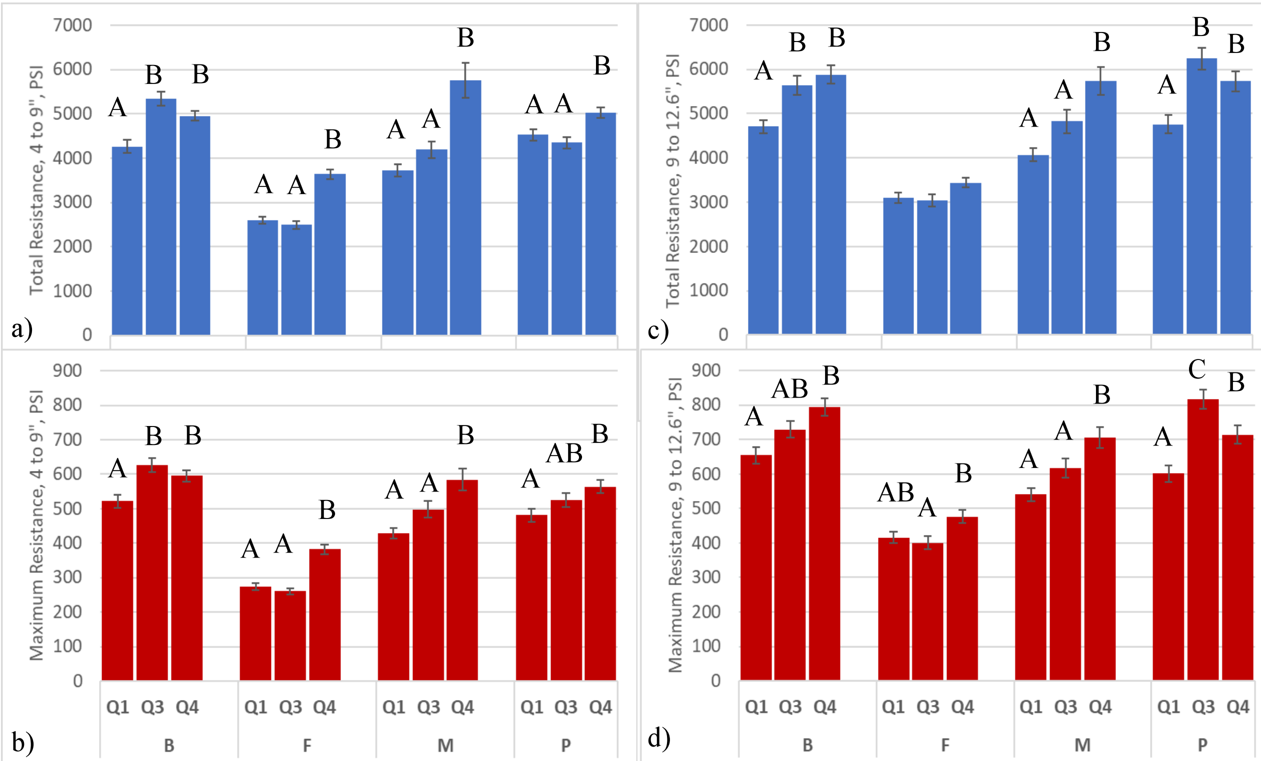

Figure 3. a) Total resistance encountered (PSI) from 4" to 9" depth by yield zone (Q1, Q3 and Q4) within 4 commercial farm fields (B, F, M and P). b) Maximum resistance encountered (PSI) from 4" to 9" depth by yield zone within field. c) Total resistance encountered (PSI) from 9" to 12.6" depth by yield zone within field. d) Maximum resistance encountered (PSI) from 9" to 12.6" depth by yield zone within field. Error bars represent standard error of each mean. A, B, C Key: significant differences among yield zones within a field grouping (P <0.05) are indicated with different letters. Soil Compaction Project, NNYADP, 2021.

Total and maximum penetration resistances measured in the 4-9" and 9-12.6" depths are shown in Figures 3a, 3b, 3c and 3d. Figure 3a depicts total resistance encountered, summed across 12 measurement intervals from 4" to 9", for each yield stability zone within each farm field in this study.

Figure 3b compares the maximum penetration resistance encountered over that same 4-9" depth range for 3 yield stability zones within each field. The 4-9" depth range is expected to include any highly compacted "plow pan" layer in these conventionally-managed fields.

Figure 3a shows again, in all 4 fields in this study, penetration resistance measured in yield stability zone Q1, representing field areas with consistently-higher-than-farm-average corn silage yields, was significantly lower than in yield stability zone Q4, which represents field areas with consistently-lower-than-farm-average corn silage yields. Q1 zone averaged about 22% lower total penetration resistance than Q4 over this "plow pan" range.

In 3 of the 4 fields, total penetration resistance measured in yield stability zone Q3 was statistically similar to Q1. In field B, Q3 total resistance was statistically similar to Q4. On average, Q3 resistance was about 16% lower than for Q4, across all 4 fields. Figure 3b depicts maximum penetration resistance measured over the 4-9" depth and reveals a similar result. For all 4 fields, Q1 compaction is lower than for Q4 zones with Q3 most statistically similar to Q1 in 3 of 4 fields.

Average soil penetration resistance pressure in the "plow pan" depth was greater than for the 4" surface layer in all yield zones in all fields.

Results shown in Figures 3c and 3d illustrate total resistance and maximum resistance in the deepest layer sampled in this study, the 9-12.6" depth (10 measurement intervals) for 3 yield zones in the 4 fields sampled. Across the 4 fields sampled, on average, this deeper layer was the most resistant to penetration and significant differences between yield zones are apparent, within fields. It is important to note, that if a layer was impenetrable with the penetrometer tool, it was most often within this 9-12.6" layer.

The artificial resistance measurement of 1150 PSI was used for total and maximum resistance calculations most often for the 9-12.6" depths. Some artificial bias is possible, upward or downward as a result, as real resistance beyond the impenetrable layer is not known. Q1 total resistance for this 9-12.6" depth was significantly lower than for Q4 in 3 of the 4 fields studied. 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:

This study on Northern New York farms has revealed a relationship not previously known between soil compaction and yield. 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. Soil compaction is 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. This study discovered a significant relationship between yield stability zone and soil compaction within 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. This data will be further analyzed, in conjunction with other data from these same fields, to provide more understanding of this relationship between soil compaction, and soil health, with yield stability across years.

Outreach:

Now, that this study has revealed a relationship not previously known between compaction and yield, the topic is likely to generate more interest. A factsheet and articles will be written summarizing this study, in conjunction with other related findings in NNY, NYS and beyond. Project results and recommendations for solving soil compaction will be presented and discussed at upcoming producer meetings in 2022 and beyond.

For More Information:

- Kitty O'Neil, Ph.D., Regional Field Crops and Soils Specialist, Cornell University Cooperative Extension, North Country Regional Ag Team, 2043B State Highway 68, Canton, NY 13617; 315-379-9192, kitty.oneil@cornell.edu