What's Cropping Up?

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Biological Control of Corn Rootworm with Persistent Entomopathogenic Nematodes: An opportunity to try them on your farm

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Corn rootworm (CRW) is the number one pest of corn in both NY and the U.S. Recent NY field data are showing that the biocontrol nematodes being released against alfalfa snout beetle are also having an impact on CRW after the field is rotated from alfalfa into corn. Research in NNY for the past 18 years has shown that a single field application of persistent biocontrol nematodes inoculates the field for multiple years and across rotations. In 75 fields following a typical alfalfa-corn rotation, not only did the biocontrol nematodes persist for multiple years at sufficient populations to suppress soil insects, but biocontrol nematode populations were higher after 4-years of corn than in the alfalfa before being rotated to corn. These results suggested the biocontrol nematodes were attacking CRW during the corn years of the rotation.

In test plots on the Cornell Musgrave farm, biocontrol nematodes applied in 2014 in continuous corn production prevented CRW larval feeding damage in 2016 at the same level as the best BT-CRW traited corn (Fig 1 & 2). Even though the CRW populations were sub-economic in 2017 and 2018, the biocontrol nematodes continued to persist at levels where they can react to an economic population of CRW larvae. We are anticipating an economic population of CRW larvae in the research plots in 2019. Similar results

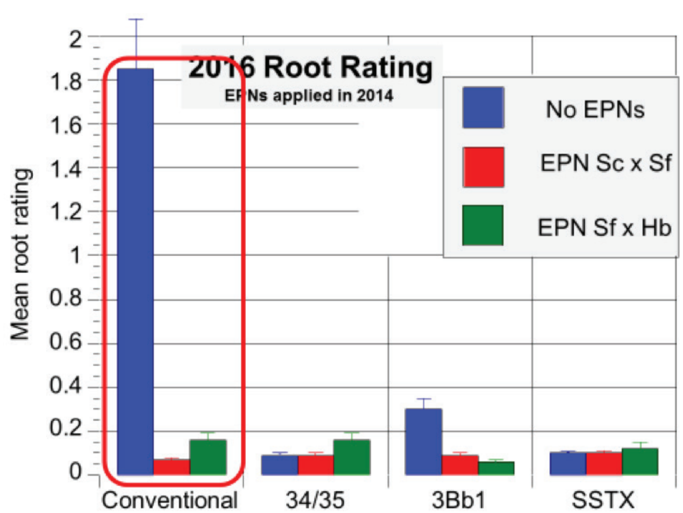

Fig 1. In conventional corn (column 1), the untreated check had economic root damage from CRW larval feeding with >1.8 root nodes destroyed. Convention corn + biocontrol nematodes had less than 0.2 nodes destroyed from CRW feeding. Biocontrol nematodes were applied in June 2014 and economic levels of CRW were in 2016, two years after biocontrol nematode application.

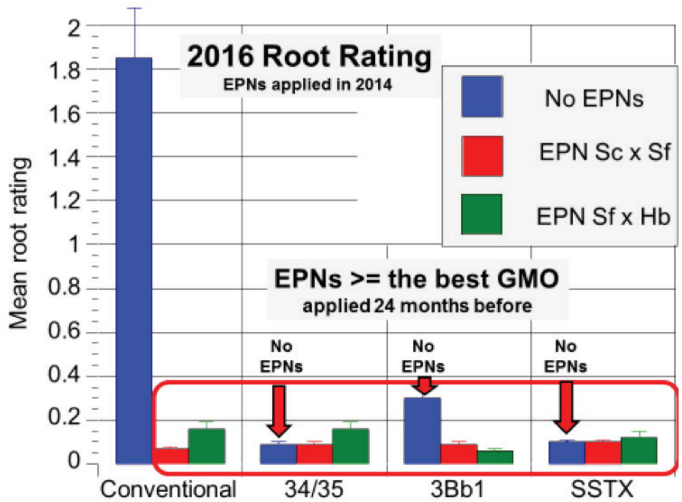

Fig 2. Biocontrol nematodes on conventional corn reduced the root injury to the levels of the best Bt-CRW traited corn. Biocontrol nematodes were applied in June 2014 and economic levels of CRW were in 2016, two years after biocontrol nematode application.

were recorded in a cooperative study with Texas A&M in Dalhart, Texas under extremely heavy CRW pressure. Cornell joint research projects against CRW continues in 2019 in NY, Texas, and Michigan with new cooperative research plots planned in Pennsylvania, Vermont and SW Kansas. Research on impact of these biocontrol nematodes on wireworms in the Hudson Valley has shown reduction in the soil populations of these soil insects along with reduced root injury in areas where these biocontrol nematodes have been established.

The Shields' lab at Cornell has just been awarded a NE SARE grant to work with NY corn producers interested in inoculating a corn field with native biocontrol nematodes to replace other CRW management practices such as Bt-CRW corn varieties. Full establishment of the biological control nematodes requires a full year and will be fully effective in year 2. Farmers interested in apply biocontrol nematodes to corn for corn rootworm control have the opportunity to participate in a NE SARE grant for the next 3-years. This grant is focused on the biological control of corn rootworm with persistent biocontrol nematodes. Participants will receive a reduced biocontrol nematode price for their first field entered into the program. Biocontrol nematodes are applied through conventional spray equipment in 50 gallons of water per acre. In order to use the spray equipment, 1) all screens and filters need to be removed; 2) sprayer needs to be cleaned similar to changing of herbicides and 3) Nozzles need to be replaced to fertilizer stream nozzles similar to TeeJet 0015. The cost of the biocontrol nematodes for fields participating in the NE SARE program will be $50/ac which is a 50% reduction in the price of the biocontrol nematodes. The application window for biocontrol nematodes on corn is between pre-planting and growth stage V4. If farmers are interested in participating in the application of biocontrol nematodes on their fields for CRW control, they need to contact the Shields' Lab no later than **45** days prior to a planned application.

For more information please contact your area CCE specialist:

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Western Bean Cutworm and Mycotoxins in Corn Silage

Joe Lawrence, Gary Bergstrom, Jaime Cummings, Elson Shields, Ken Wise, Mike Hunter

Mold and mycotoxin development in corn ears and stalks, and the resulting corn silage continues to be a major concern for dairy producers. Mycotoxins can result in a range of problems for livestock throughout the year as they are ingested with the feed. The presence of mold does not always have a strong correlation to mycotoxin development but it does present the chance for incidence to occur.

A number of factors influence the prevalence of molds from year to year. Conducive weather conditions for mold and mycotoxin development are outside the control of management options. But hybrid characteristics and physical damage to the ears can be managed through the selection of hybrids and pest resistance traits in the hybrids.

Western Bean Cutworm (WBC) is a pest of corn (as well as dry beans) and its territory has been expanding eastward over the last 10 to 15 years with pockets of high populations now found in New York and Ontario, Canada. The moth emerges near the time of corn tasseling and lays its eggs near the ear leaf of a pollinating corn plant. When the larvae hatch they enter the corn ear, often opening a wound in the husk, and feeding on kernels. Unlike other earworms, which are cannibalistic, you can find multiple WBC larvae feeding on one ear, increasing the chances for significant ear damage.

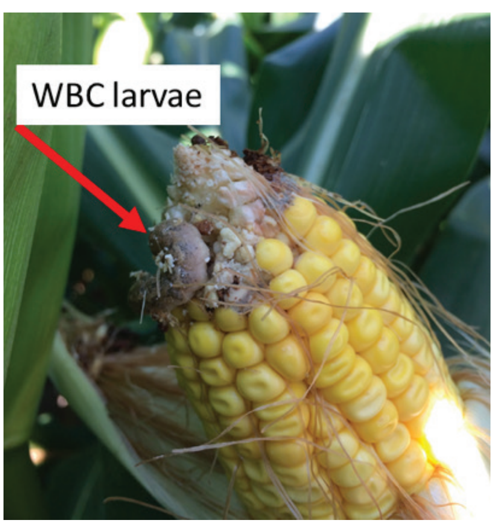

Fig 1. WBC larvae beginning to feed on tip of corn ear prior to silage harvest. Photo by Joe Lawrence

Where WBC populations are high, the corresponding ear damage from WBC feeding can leave wounded corn ears more susceptible to pathogen development, but a clear relationship between ear damage and mycotoxin development has not been documented. A number of mold species may develop on corn ears though relatively few of these produce mycotoxins. Principal concern in New York is with the mycotoxins deoxynivalenol (DON or vomitoxin) and zearalenone (ZON), both produced by the fungus *Fusarium graminearum*. Infection by this fungus also occurs in roots and stalks and leads to Gibberella stalk rot and the accumulation of DON and ZON in stalk tissues. Much of the toxin loading in 2018 corn silage in New York was contributed by contaminated stalks as well as ear tissues.

While WBC damage to corn ears can be significant and may have detrimental effects on corn grain yield and quality, the economic impact on corn silage is less understood. For corn silage growers, understanding whether or not this pest significantly impacts the yield or quality of the forage is critical to their decision making for managing this pest.

Since the Cry1F protein, which has most commonly been utilized for protection against numerous corn insect pests, has been found to be ineffective against WBC, producers are left with limited management options. Currently, the Vip3A trait in select corn hybrids in combination with a scout and spray program is the best option for WBC management in areas where the pest is prevalent.

With the increased population of WBC in NY, the Commercial Corn Silage Hybrid Evaluation program conducted by Cornell University in collaboration with the University of Vermont and the Northeast dairy industry offers a good opportunity to evaluate numerous hybrids for ear damage from WBC and mycotoxins. This was done in 2017 and 2018 with financial support from both the New York Corn Growers Association and the Northern New York Agricultural Development Program.

Each hybrid is planted (in triplicate) at two locations in NY and one location in Vermont (VT), with the locations

Table 1: NY & VT Corn Silage Hybrid Trial Locations		
Relative Maturity	Location	
80-95 Day	Willsboro, NY	Northern NY
	Albion, NY	Western NY
	Alburgh, VT	Northwest VT
96-110 Day	Madrid, NY	Northern NY
	Aurora, NY	Central NY
	Alburgh, VT	Northwest VT

each hybrid is planted at based on hybrid relative maturity (Table 1).

Mycotoxin screening was limited to the NY locations based on funding available. In 2017, composite whole plant silage samples (3 replicates combined) were taken for each hybrid at two locations; Madrid in Northern NY and Aurora in Central NY. In 2018, a slightly different strategy was used with individual replicate samples taken on a subset of hybrids at each location.

Both seasons, each plot was scouted prior to harvest to assess WBC feeding damage to the ears. At harvest a whole plant silage sample was collected and submitted to the Dairy One forage laboratory for a mycotoxin screening package which included aflatoxins B1, B2, G1, G2, vomitoxin, 3-acetyl DON, 15-acetyl DON, zearalenone, and T2 toxin.

Through the New York State Integrated Pest Management (NYS IPM) WBC Pheromone Trapping Network, WBC populations were monitored at each location. Though it should be noted that as the traps only attract male moths, they help in understanding geographic differences in WBC population but may not be representative of the population of egg laying females.

The results of the WBC and mycotoxin screening project revealed large differences in the pheromone trap counts and the number of plots damaged by WBC (Tables 2a and 2b). There was also wide variation in the prevalence of samples testing positive for mycotoxins, particularly in 2018. However, there was a lack of correlation between WBC damage and incidence of mycotoxins in both years (Table 2a and 2b).

Additionally, despite the damage to corn kernels inflicted by WBC, in plots with up to 60% of ears showing some level of WBC damage, the WBC feeding did not correlate to any negative impact on silage yield or forage starch content in this study.

The most prevalent species of mycotoxin-producing mold found in the screening was *Fusarium graminearum*. This fungal pathogen can also infect corn ears through the silk channels at the time of pollination during favorable weather conditions and result in contamination of the grain and silage with the mycotoxins DON, 3-ADON, 15-ADON, or zearalenone. A review of the weather data from both years (despite very different overall weather patterns) showed wet conditions at silking conducive to this type of infection. As expected for New York, no aflatoxins were detected.

While there aren't many in-field management options to reduce the chances of mycotoxin development (note that controlling plant diseases and mycotoxins are not the same thing), harvesting corn silage at the proper whole plant dry matter is helpful. Based on numerous field observations, and notable at the 2018 Aurora location in this study, a whole plant dry matter in the high 30's or above appears to

Table 2a: 2017 Hybrid Screening for Western Bean Cutworm and Mycotoxins			
		Aurora	**Madrid**
WBC Trap Counts (seasonal total)		211	356
# Hybrids Screened		49	49
# Hybrids with WBC Damage		14 (28.6%)	32 (65.3%)
Hybrids Positive For Mycotoxins	Total Hybrids	17 (34.6%)	19 (38.8%)
	NO WBC Damage	13	6
	WBC Damage Present	4	13

Table 2b: 2018 Hybrid Screening for Western Bean Cutworm and Mycotoxins		Aurora	Madrid	Albion	Willsboro
WBC Trap Counts (seasonal total)		84	385	220	135
# Plots Screened		63	63	33	33
# Plots with WBC Damage		15 (24%)	13 (21%)	4 (12%)	8 (24%)
Plots Positive For Mycotoxins	Total Plots	57 (90%)	7 (11%)	15 (45%)	6 (18%)
	NO WBC Damage	46	5	14	4
	WBC Damage Present	11	2	1	2

increase the risk of mycotoxin development.

While there are numerous ways in which molds can establish themselves in forages, this study reflects a common challenge researchers face while attempting to document the conditions where mycotoxin development is likely. These results, over two growing seasons, provide no evidence that WBC damage is an added risk factor for corn silage growers who are worried about deoxynivalenol and zearalenone in their silage. In areas of the country where other toxins are more prevalent the impact of WBC and other insect pest may differ. It is important to note that these results do not reflect what may occur in corn harvested for grain because the time between silage harvest and grain harvest offers additional opportunities for infection and growth.

Growers should continue to scout for this pest and weigh the cost of control with the potential for damage. However, it does not appear that controlling WBC should be viewed as a significant management consideration for reducing the risk of mycotoxin development in corn for silage.

2018 Corn Silage Hybrid Evaluation Results

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The New York & Vermont Corn Silage Hybrid Evaluation Program continues to provide side by side evaluation of corn hybrids grown under a range of growing conditions representative of those experienced in the Northeast. In 2018 the program evaluated 77 hybrids from 17 different seed brands. Each hybrid was planted in replicated plots at 3 locations based on relative maturity (**RM**; Table 1).

Table 1. Trial locations by maturity group for the NY & VT Corn Silage Hybrid Evaluation Program

Maturity Group	Location
80 – 95 day RM 20 entries	Willsboro, NY Albion, NY Alburgh, VT
96 – 110 day RM 57 entries	Madrid, NY Aurora, NY Alburgh, VT

The growing season was defined by below average precipitation and above average heat, measured as growing degree days (**GDD**) across trial locations (Figure 1). A defining difference between trial locations was the timing and amount of rainfall from late July to early September. While all locations realized some level of improvement in growing conditions with more frequent rainfall in late July and August, its timing and impact on the crop varied. In general, rain arrived at all locations in time to facilitate normal pollination of the crop but ear development varied by location.

The above average GDD accumulation throughout the season and particularly as the crop neared maturity resulted in fast dry down of the crop to target whole plant moisture content for silage harvest. A noticeable characteristic at harvest in many corn fields, including trial fields, was a healthy green plant with a dry ear.

While nutrient inputs at all locations met or exceeded crop needs, a lack of soil moisture may have compromised nutrient uptake at varying stages of crop development. Recognizing these real world influences and how a hybrid might perform under varying stressors is important to understand when evaluating this data.

The influence of growing conditions lead to location variability in hybrid performance in 2018 but overall better performance when compared to growing conditions experienced in 2017 (Figure 2).

The full report provides detailed data on individual hybrids entered into the program for 2018. The most significant parameters in the report vary by individual farm and that farms resources but some of the key data includes, yield, whole plant dry matter, starch content, measurements of fiber digestibility including neutral detergent fiber (**NDF**) digestibility at 30 hours (**NDFD30**) and undigested NDF at 240 hours (**uNDF240**), and predicted milk yields modeled in the Cornell Net Carbohydrate and Protein Synthesis (**CNCPS**) model. The CNCPS model predicts the expected milk yield of

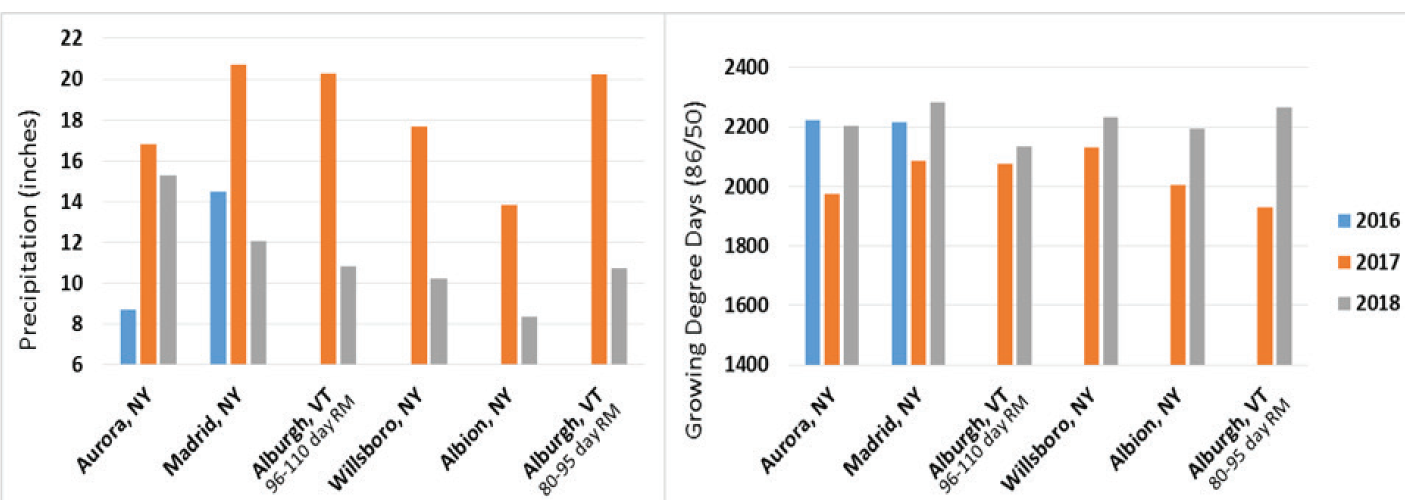

Fig 1. Rainfall and growing degree day accumulation by location and season for the NY & VT Corn Silage Hybrid Evaluation Program

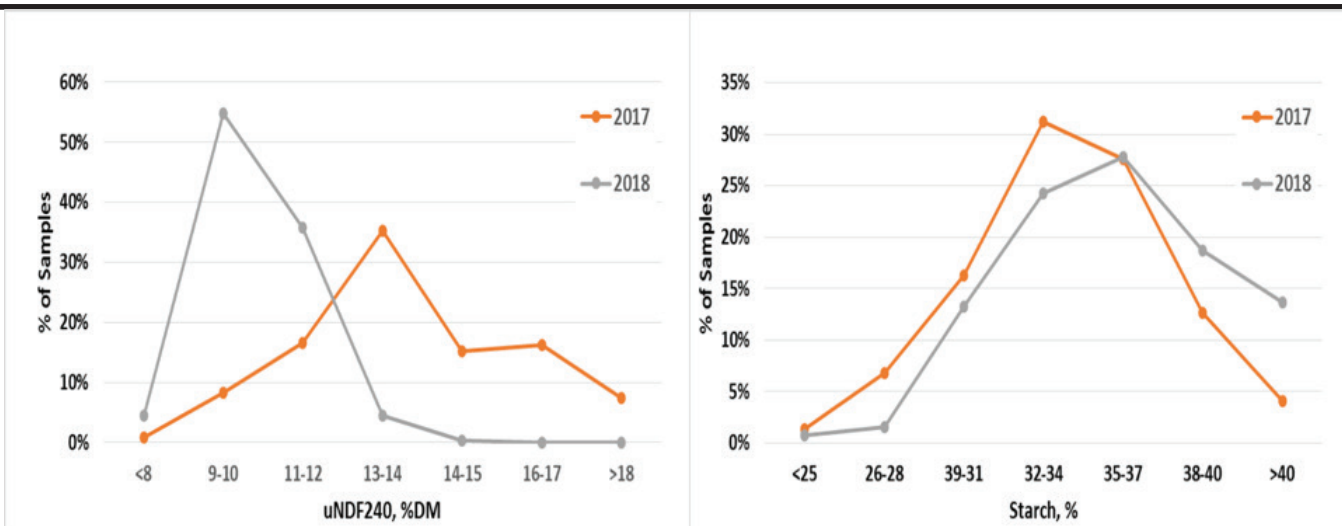

Fig 2. Percentage of samples across all locations over a range of uNDF240 and starch levels by year for the NY & VT Corn Silage Hybrid Evaluation Program

different hybrids based on their inclusion into a high corn silage total mixed ration representative of the diets fed on many NY and Northeast dairy farms.

It is important to evaluate this data in the context of your farm when selecting hybrids. The top performing hybrid at any one location or in any one category may not be a good fit for your feeding program. Factors that influence this vary by farm but include land base, soil resources, forage inventory, quality of available hay crops, access and cost of supplemental ingredients, and expectations of cow performance.

The trial results and location averages serve as a means to calibrate hybrid performance to a particular growing season and these averages can be used in conjunction with a company's data on hybrids in their lineup, including hybrids not entered into these trials, to understand how a hybrid performed relative to what is realistic for that growing season. For example, in Figure 2 we see that over 50% of samples taken in 2018 had an uNDF240 value between 9 and 10 so this can be used to evaluate how close and far away from these values other hybrids performed in 2018. However, due to the challenging growing conditions experienced in 2017 and the impact of growing conditions on fiber digestibility we see that the highest percentage of samples in 2017 had a uNDF240 value of 13-14 while a very small percentage (less than 10%) of 2017 samples were as digestible as the majority of 2018 samples. Therefore it would not be fair to hold hybrid fiber digestibility or other performance indicators from 2017 to the same standards as 2018.

It is also important to recognize the companies that make these trials possible through their entry of hybrids. The following companies participated in the 2018 trials. Albert Lea – Viking, Augusta Seed, Channel, CROPLAN, Dairyland, Dekalb, Doebler's, Dyna-Gro, Growmark FS, Hubner, Local Seed Company, Masters Choice, Mycogen, Pioneer, Seedway, Syngenta – NK, Wolf River Valley

The full report of 2018 can be found at the Cornell Soil and Crop Sciences website.
https://scs.cals.cornell.edu/extension-outreach/field-crop-production/variety-trials/#corn-silage

Additional trial information can be found in the following article and webinar.

Article: 2018 Corn Silage Overview
https://prodairy.cals.cornell.edu/production-management/resources/
Webinar: 2018 Corn Silage Hybrid Test Results, New York and Vermont Corn Silage Hybrid Tests – 2018
https://prodairy.cals.cornell.edu/webinars/

Warm-Season Grass Binary Mixtures for Biomass in the Northeast

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Over five million acres of marginal agricultural land in the Northeast USA are no longer in use and have great opportunities for grass biomass production, although environmental or other supplemental compensation may be required for profitable production on low-yielding marginal land. Warm season grasses are considered a viable herbaceous second generation biofuel feedstock but are better suited to marginally productive cropland Future selection through breeding should have a significant focus on low-input types of environments.

Additional environmental benefits may accrue when mixtures are used instead of monocultures. Studies have suggested that polycultures sequester more carbon in the soil profile and have less N leaching compared to monocultures. Profitability in biomass production, however, is most strongly influenced by yield, and we focused on yield potential in this study.

Experimental layout

A long-term plot study was sown in 2010 in Ithaca (central NY, Williamson fine sandy loam soil) and Chazy (northern NY, Roundabout silt loam soil), and was completed in 2018. A goal was to determine if binary mixtures of warm-season grasses would result in increased yield over pure stands.

Three replicates of 12 treatments compared pure species with binary mixtures (Fig. 1). Binary mixtures had one species seeded in one direction, and the second species seeded perpendicular to the first. Pure species also were seeded twice, with one half the total seed sown perpendicular to the other half. Pure switchgrass and Atlantic coastal panic grass plots were seeded at 10 lbs pure live seed (PLS)/acre. Pure big bluestem plots were seeded at 12 lbs PLS/acre. Mixtures contained half the seeding rate of pure species plots for each species in a binary mixture. All entries were commercially available varieties, with the exception of RC Big Rock switchgrass, which was an experimental selection from Cave-In-Rock (REAP-Canada, Ste-Anne-de-Bellevue, QC). Insufficient seed was available of Timber switchgrass to seed at both sites.

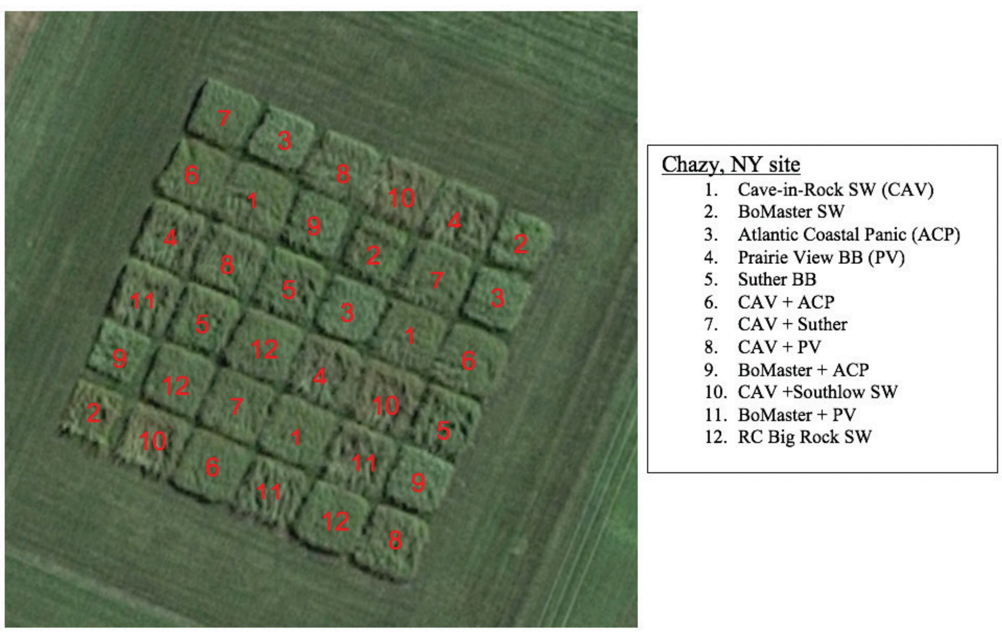

Fig. 1. Plot layout at the two NY sites.

Plots (15' x 15') were fertilized with 50 lbs N fertilizer/acre at spring green up each year. Roundup was sprayed in the spring prior to warm season grass green up to control weeds after 2013. A few weeds were resistant to Roundup and remained, such as milkweed. Plots were well established by the 2013 growing season. Plots were harvested for yield determination each year in early October generally after first frost at a 4" stubble height using a flail harvester, harvesting 78 sq. ft. of plot area (3' x 13' twice per plot). Samples were collected for dry matter (DM) determination.

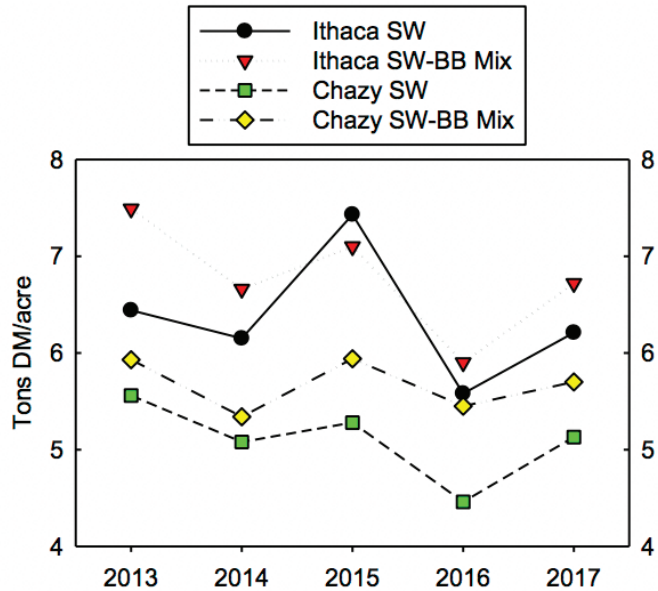

Fig. 2. Average yields of pure switchgrasses (SW) vs. SW mixtures with big bluestem (BB).

Yield

The more southern, generally wetter, Ithaca site averaged 22% greater yield across all years and species combinations. Ithaca long-term average precipitation is 4.5" per year more than Chazy (Plattsburgh, NY weather station), and Ithaca averaged 5.5" more per year during the experiment. Although Chazy is considerably farther north than Ithaca, long-term average heat units are very similar. Over the 2013-2017 period from May 1 to Oct. 1, both sites averaged 4916 GDD per growing season (base 32F). Warm season grass mixtures behaved differently on different sites. At Chazy, big bluestem (BB) tended to compete very well in mixtures with switchgrass (SW), while at the Ithaca site switchgrass tended to be the major component.

Big bluestem was the slowest species to become fully established, but Prairie View BB pure stands were the highest yielding at the Chazy site, averaged over five years. RC Big Rock switchgrass selection had the greatest yield in Ithaca for pure SW stands, averaging 6.6 tons DM/acre over 5 years. Cave-in-Rock SW (CAV) and the CAV-Prairie View BB mixture both yielded 13% less at Chazy than Ithaca, but pure Prairie View stands produced similar yields at both sites. Upland switchgrass mixed with Prairie View BB tended to produce the best overall results and was the most compatible mixture (Fig. 2). Other mixtures tended to become mostly monocultures over time.

Atlantic coastal panic grass (ACP) was promising the first year, but quickly deteriorated to a weak stand after the first year, and had significant weed invasion in later years, particularly at Chazy. BoMaster switchgrass struggled in pure stands and became a very minor component of mixtures. In later years, big bluestem and switchgrass tended to invade plots with weaker stands, as ripe seed was scattered each year during harvest with a flail harvester.

Mixtures

At both sites, mixtures of Cave-in-Rock SW and ACP quickly became pure switchgrass stands. By the end of the trial, mixtures of Cave-in-Rock and Suther BB were pure switchgrass at Ithaca, and averaged 10% BB at Chazy. BoMaster SW and ACP, as well as mixtures of these two, tended to be weak stands at both sites, with up to 25% weeds observed in the summer of 2018. Prairie View BB and BoMaster SW mixtures were essentially pure big bluestem stands in 2018 at both sites. Suther BB and Cave-in-Rock SW mixtures were pure switchgrass in Ithaca, and averaged 10% big bluestem in Chazy. Prairie View BB and Cave-in-Rock SW mixtures averaged 15% bluestem in Ithaca and 35% bluestem in Chazy, at the end of the trial.

Ground cover

Plots in Ithaca were observed for ground cover in the spring of 2018 (Fig. 3). The three replicates were very consistent in ground cover. Switchgrass provided the most ground cover early in the season, with RC Big Rock SW appearing to have the greatest ground cover. BoMaster was the weakest switchgrass, typically with weed infestations. Approximately 50% of the ground area was bare in BB plots, but open areas were generally free of weeds. Even less surface area was covered by ACP, and open areas tended to be infested with weeds annually. With the exception of ACP at both sites, and BoMaster SW at Chazy, other species and species combinations developed into a closed canopy by mid to late summer, regardless of the ground cover observed in spring.

Fig. 3. Ground cover in spring of 2018 in Ithaca, NY

Summary

The only mixtures with a significant contribution from both species were Prairie View BB and Cave-in-Rock SW mixtures. These mixtures had considerably more switchgrass at the Ithaca site compared to the Chazy site. Our results agree with other studies suggesting that species mixtures will be largely influenced by environmental variation. Results from a single location may not be applicable to other environments. Mixtures can improve yields mainly in the establishing years, with the potential for better yield stability over the life of the stands. Farmers should consider planting adapted cultivar mixtures of big bluestem and upland switchgrass for enhanced yield and yield stability. Improving seedling establishment of big bluestem should be an important breeding priority for more widespread adoption of this crop.

Acknowledgments

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New problem weeds in NY – waterhemp and Palmer amaranth

Weed Management

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Several populations of waterhemp have been found on farms in the central and western parts of our state. These populations have established over the past couple years by plants that have escaped control, likely due to resistance to certain herbicide sites of action. One waterhemp population survived several herbicides and reduced soybean yields by around 50 percent.

Additionally, Palmer amaranth was found growing near one farmer's barn. He believes the seed arrived on some used equipment from the Midwest. The plants were collected and burned, but we'll continue to monitor the site for future emergence.

Both of these weeds are likely resistant to glyphosate and PPO inhibitors, among others. We're hoping to run some spray chamber trials this winter to determine their resistance to certain sites of action.

While other pigweed species have short hairs on their stems, waterhemp and Palmer amaranth have smooth stems. The best way to distinguish waterhemp and Palmer amaranth is to rip off one of the lower leaves. As shown in Figure 1, if the leaf-stem (petiole) is longer than the leaf, it's Palmer amaranth.

Unlike other pigweeds, waterhemp and Palmer amaranth have separate male (pollen producing) and female (seed producing) plants. Herbicide resistance traits can transfer by pollen, which has allowed these weeds to develop resistance faster.

Fig 1. Palmer amaranth leaf and leaf-stem. ID tip: if the leaf-stem is longer than the leaf, as seen here, it is Palmer amaranth, not waterhemp. Photo: W. Curran and D. Lingenfelter, Penn State

To prevent these weeds from taking hold, growers are also recommended to start weed-free with tillage, followed by a 2-pass program of residual and post-emergence herbicides that utilizes several effective sites of action. Foliar applied herbicides should be used when these weeds are less than four inches tall. Since these weeds emerge over a broader timeframe than most weeds, mid-season residual herbicide applications should be considered, along with increased planting density or tighter row spacing to help close the canopy earlier.

If you do find yourself with escapes of these weeds, it makes economic sense to go hand-rogue those weeds out of your fields rather than deal with 200,000 to one million seeds in your soil from each weed. If there are too many to bag up by hand, consider sacrificing that patch of your crop by mowing and tilling the area before the weeds produce seed. Avoid harvesting these areas. Combines are especially good at spreading weed seeds. If you must harvest these areas, know that combines can carry 150 pounds of plant material even you think it's empty, so check out some of the great online videos on how to clean them out after going through weedy fields.

The weakness of waterhemp and Palmer amaranth is the short lifespan of their seeds in the soil. Of those that don't germinate, very few will survive in the soil for more than four years. So, if you can keep it under control for four years, you won't have much of it after that. But as one Pennsylvania grower put it, "the cheapest way to control Palmer amaranth is to never get it in the first place." So, it's important to make sure that your seed, feed, bedding, and equipment are clean from the start.

Resources:

Ohio State University has been dealing with these weeds for a while and has a helpful listing of resources: https://u.osu.edu/osuweeds/super-weeds/palmer-amaranth/.

Soil Health Management

Soil Health Indicators Can Be Correlated to Agronomic Management and Crop Yield

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Take-aways:

- Soil health metrics were sensitive to long-term tillage practices.
- Biological indicators related to labile carbon and nitrogen were best correlated with crop yields.

Soil health has been defined as the "the capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans" (NRCS). The soil health concept recognizes that biological, physical, and chemical constraints must all be addressed for the soil to reach its full potential. Soil health assessment has become a powerful tool to diagnose biological and physical constraints in addition to the more traditionally measured chemical limitations (nutrients and pH).

In 2017, Roper et al. published an article using Cornell University's Comprehensive Analysis of Soil Health (CASH) approach to link soil health indicators to different agronomic management systems in North Carolina. The results from this study allowed us to explore the linkages between soil health and yield, which has remained an important gap in the soil health literature.

Methods

Soil samples were collected from three long-term experiments (20+ years) in the coastal plain, piedmont, and mountain physiographic regions of North Carolina. Samples were sent to Cornell University to be analyzed for the standard CASH package, which includes two physical indicators – wet aggregate stability (AgStab), and available water capacity (AWC); four biological indicators – organic matter (OM), active carbon (ActC), autoclavable citrate extractable protein (Protein), and respiration (Resp); and seven chemical measurements (pH, and extractable P, K, Mg, Fe, Mn, and Zn). The results were made available in a supplemental table in the Roper et al. paper and re-analyzed by us.

Results and Discussion

Sensitivity of Soil Health Measurements

The coastal plain and mountain region experiments involved different tillage practices combined with organic vs. conventional management. When the CASH values were analyzed, we found significant differences in AgStab, ActC, P, and Zn at each site (Table 1), while the mountain site also showed differences in Protein and several other chemical indicators. The effects on chemical indicators were primarily related to the organic vs. conventional treatments as compost applications tended to increase nutrient levels. But the physical (AgStab) and biological indicators (ActC and Protein) were mostly influenced by tillage practices.

The piedmont experiment involved different levels of tillage intensity including moldboard plowing, chisel-till and no-till. Almost all CASH indicators were affected by the treatments at the piedmont site (Table 1). At all three sites, no-till treatments had higher soil physical and biological indicators than conventional tillage (data not shown). These findings are in agreement with many other studies that have demonstrated that CASH indicators are sensitive to management.

Soil Health and Yield

Establishing positive relationships between soil health and crop yield is a difficult task because soil health

Table 1. Statistical significance for treatment effects for Coastal Plain, Piedmont, and Mountain samples. NS: not significant; *: weakly significant at α=0.1; **: modestly significant at α=0.05; ***: highly significant at α=0.01. Surface hardness, subsurface hardness, AWC, and OM were not significant at these sites and are not included in the table.

Site	AgStab	Protein	Resp	ActC	pH	P	K	Mg	Fe	Mn	Zn
Coastal Plain	**	NS	NS	*	NS	**	NS	NS	NS	NS	**
Mountain	*	***	NS	***	**	***	***	**	NS	NS	***
Piedmont	***	***	***	***	**	*	***	**	*	***	NS

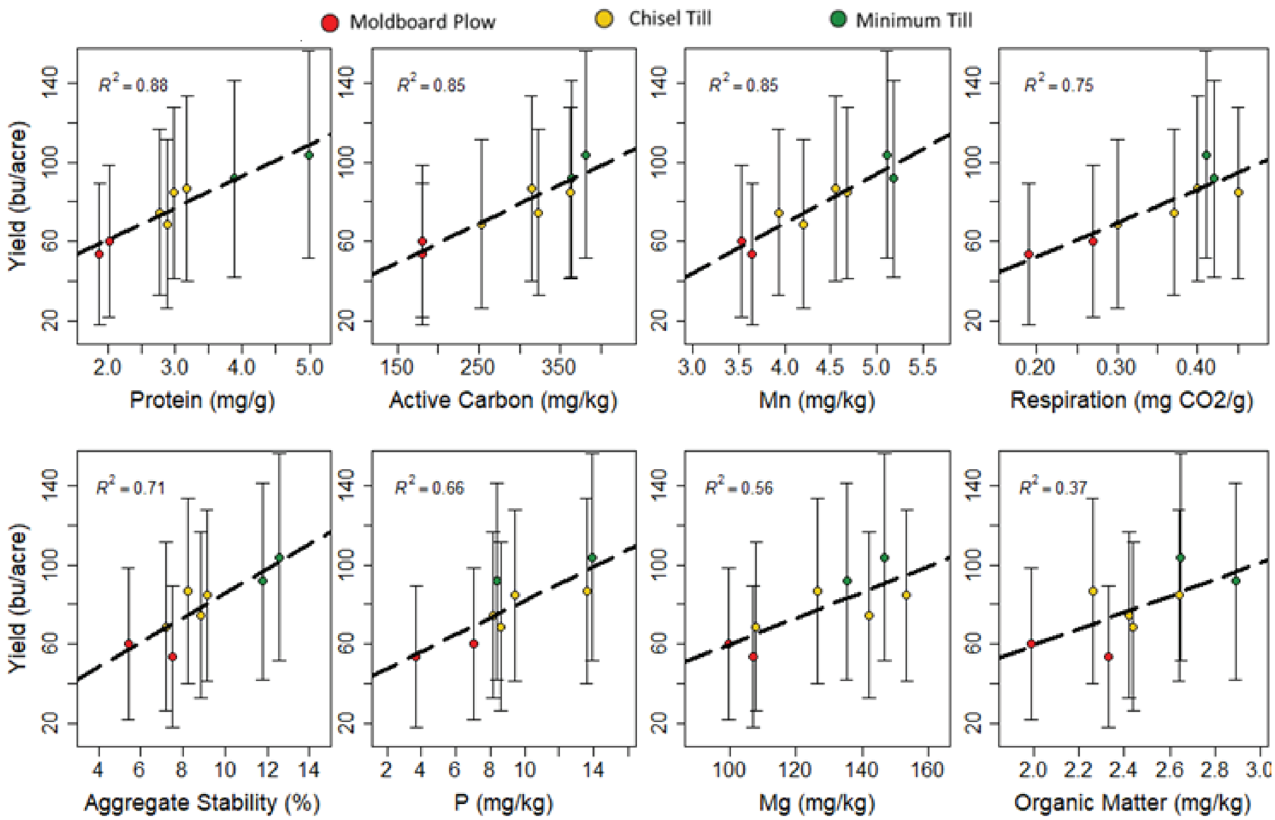

Fig 1. Linear regression of mean corn yield (bu/acre) as a function of different soil health indicators and tillage practices at the Piedmont site. Plots are organized from highest to lowest R^2_{adj} value. Error bars represent standard deviations associated with annual yield variability.

effects are often masked by non-soil factors such as pest and weed pressures, erratic weather, and management effects. However, in the piedmont study, several individual CASH indicator values were positively correlated with mean corn and soybean yield (annual yield variability was not considered here). Specifically, eight CASH indicators (in order of correlation strength: Protein, ActC, Mn, Resp, AgStab, P, Mg, and OM) displayed significant linear relationships to mean corn yields (Figure 1). Each indicator tended to be highest under minimum-till, intermediate under chisel-till, and lowest under moldboard plow.

This implies that reducing tillage positively impacted these SH indicators, which in turn benefitted crop yield. Most notable is the fact that the indicators related to labile carbon and nitrogen (Protein, ActC, Resp, and AgStab) showed the strongest correlations with mean corn yield, while total organic matter content showed weaker relations (Figure 1). This suggests that organic matter *quality* may be more important for improving corn yield than total organic matter *quantity*. When we analyzed the relationship between soil health indicators and mean soybean yield at this site, we found that Protein was a much weaker predictor of soybean yield than it was for corn yield (not shown). This makes sense because a legume crop would be less influenced by nitrogen supply from soil organic nitrogen sources (Protein reflects the largest such pool) than a non-legume crop. Additionally, we found that Mn showed a strong positive relationship to both corn and soybean yield, which could be explained by Mn's important role in organic matter decomposition.

(*Continued on next page*)

Conclusions

Soil health data from three long-term field experiments in North Carolina showed that the CASH indicators were sensitive to agricultural management at each location, which is in line with previous results from our work in New York. Furthermore, soil health indicators were positively correlated with long-term average cash crop yield at the piedmont site, which illustrates the benefit of labile organic matter for crop growth. These results help to demonstrate the linkage between tillage, organic additions, soil health, and crop yield, which had remained an elusive goal.

Acknowledgements

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Calendar of Events

APR 24	2nd Annual Cornell Organic Symposium - Ithaca, NY
JUN 6	Small Grains Management Field Day - Poormon Farms, Seneca Falls, NY
JUL 11	Aurora Farm Field Day - Musgrave Research Farm, Aurora, NY
JUL 25 - 27	Grasstravaganza Grazing and Soil Health Conference - SUNY Cobleskill, Cobleskill, NY

Have an event to share? Submit it to jnt3@cornell.edu!

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