2019 Annual and Perennial Forage System Impact on Soil Health and Corn Silage Yield

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Producing high quality forage crops is exceedingly challenging in Vermont as climate change progresses with more precipitation, faster rates of precipitation, and higher annual temperatures (Faulkner, 2014). Organic farmers in the NE need reliable strategies for increasing quality forage production and decreasing risks associated with extreme weather events and pest outbreaks. Organic farmers who rely on pasture-based forage systems have reported challenges with meeting the dry matter and nutrient requirements of livestock due to short-term droughts and prolonged periods of soil wetness. Increasing forage crop diversity and integrating annual forage crops into perennial-based systems can help to increase forage reserves and protect against weather related crop stress, pest outbreaks, and feed price volatility. Although annual crops can have many benefits it is possible these systems can increase weed pressure and decrease soil health. The objectives of this trial were to compare soil quality, weed pressure, and yields of corn silage following annual or perennial based forage systems.

MATERIALS AND METHODS

In 2016, a forage systems trial of annual and perennial forages was initiated at Borderview Research Farm in Alburgh, VT on a Benson (loamy-skeletal, mixed, active, mesic Lithic Eutrudept) rocky silt loam, over shaly limestone, 0 to 3 percent slopes, and USDA plant hardiness zone 4b. Both systems contained forage treatments at four levels of diversity. The Very Low treatments had one species, the Low treatments had four varieties of one species, the High treatments had one variety of four species, and the Very High treatments had four varieties of four species. The experimental design was a spatially balanced, randomized complete block split-plot design where cropping systems were blocked and the diversity level of the cropping system was randomized within the blocks. Plots were 20 x 35 ft and each had four replicates. Between blocks, there was 10 ft buffer around each side planted with meadow fescue. The annual forage system rotated between cool and warm season forage varieties (Table 1 and Table 2). The perennial forage systems consisted of perennial forage varieties (Table 3).

Soil samples were collected on 5-Nov 18 and were submitted to the Cornell Soil Health Laboratory for the Comprehensive Assessment of Soil Health analysis. Five soil samples within each plot were collected six inches in depth with a 3-inch diameter auger, thoroughly mixed, put in a labeled gallon bag, and mailed. Percent aggregate stability was measured by Cornell Sprinkle Infiltrometer and indicates ability of soil to resist erosion. Percent organic matter was measured by loss on ignition when soils are dried at 105°C to remove water then ashed for two hours at 500°C. Soil respiration (CO_2 mg/soil g) is measured by amount of CO_2 released over a four-day incubation period and is used to quantify metabolic activity of the soil microbial community. The Soil Health Score is a weighted calculation of different soil quality parameters.

On 5-Nov 18 soil samples were collected for enzyme analysis. Results from enzyme assays are indicative of specific microbial processes. Three soil cores were taken per plot to a depth of 8 inches, passed through a 2 mm sieve, and placed in a whirl-pak for transport to University of Vermont's Soil Ecology & Biological Indicators Laboratory. Methods for microbial enzyme activity analysis were followed using procedures outlined in Saiya-Cork et al. (2002) and Neher et al. (2019). Substrates were chosen to target cellulose, peroxidase activity, chitin, amino acid leucine, and phosphatase activity. Cellulose is an indicator of easily decomposable organic matter and provides carbon to microbes. Peroxidase is released during degradation of lignin, a more complex form of organic matter, and provides carbon to microbes. Degradation of chitin provides carbon and nitrogen. Degradation of leucine provides nitrogen. Phosphatase activity indicates that microbes are producing phosphatase to access phosphate that is bound in organic molecules. If simpler forms of these molecules are available from other sources, then microbes will not spend energy to produce specific enzymes targeted to degrade more complex sources into forms that make absorption possible. In other words, enzyme production increases in response to limitation of these molecules.

In 2019, the annual and perennial forage systems were harvested in late-May and early-Jun, respectively. Subsequently, the field was moldboard plowed to a depth of 8" and disked. Afterward, organic corn variety Viking 0.45-88P (88 RM) was planted on the 7-Jun then cultipacked. In 2019, the annual and perennial systems were harvested, the soil was moldboard plowed, and subsequently corn was planted. Forage diversity treatments were divided into subplots of ambient weed pressure and weed-free. These plots are referred to as weed present or weed absent throughout the document. The weed-free subplots were weeded with hoes once week from 19-Jun to canopy closure. To assess impact of weed presence on corn yield, corn and weed biomass was harvested on 3-Oct from two 0.50 m^2 quadrats in each subplot at a height of 5 cm with clippers. To assess silage quality, four rows of corn were harvested for silage on 10-Oct with a John Deere 2-row chopper, weighed in a wagon fitted with scales, and subsampled for quality analysis. Corn populations were determined by counting number of corn plants in 17.5 feet section in the middle two rows of each plot. See Table 4 for a summary of agronomic and trial information.

Table 1. Annual system cool season treatments and seeding rates.

Annual system cool season treatments				
Very Low **211.8 lbs ac^{-1}**	**Low** **211.8 lbs ac^{-1}**	**High** **154.1 lbs ac^{-1}**	**Very High** **154.1 lbs ac^{-1}**	
Triticale (100%) *Trical 815*	Triticale (25% each) *Trical 85* *Fridge* *NE426GT* *Hy octane*	Triticale (34%) *Trical 85* Cereal rye (34%) *Wheeler* Red clover (3%) *Mammoth* Winter pea (29%) *Austrian*	Triticale (34%) *Trical 85* *Fridge* *NE426GT* *Hy octane* Cereal rye (34%) *Wheeler* *Guardian* *Aroostook* *Spooner*	Red clover (3%) *Mammoth* *Freedom* *Starfire* *Duration* Winter pea (29%) *Austrian* *Frostmaster* *Whistler* *Windham*

Table 2. Annual system warm season treatments and seeding rates.

Annual system warm season treatments				
Very Low **52.9 lbs ac^{-1}**	**Low** **51.1 lbs ac^{-1}**	**High** **44.7 lbs ac^{-1}**	**Very High** **47.6 lbs ac^{-1}**	
Sudangrass (100%) *Hayking*	Sudangrass *Hayking* (25.9%) *Piper* (18.7%) *SSG886* (30.9%) *Promax* (24.5%)	Sudangrass (29.6%) *Hayking* Pearl millet (21.0%) *Wonderleaf* Sorghum sudangrass (32.9%) *Greengrazer* Ryegrass (16.5%) *Enhancer*	Sudangrass *Hayking* (6.9%) *Piper* (5.0%) *SSG886* (8.3%) *Promax* (6.6%) Pearl millet *Wonderleaf* (5.0%) *FSG315* (5.0%) *Exceed* (6.1%) *Trileaf* (5.2%)	Sorghum sudangrass *Greengrazer* (7.7%) *400 x 38* (9.2%) *AS6401* (9.5%) *Sweet 6* (10.2%) Ryegrass *Enhancer* (3.9%) *Tetraprime* (4.4%) *Marshall* (2.7%) *Kodiak* (4.3%)

Table 3. Perennial system treatments and seeding rates.

Perennial System Treatments				
Very Low **23.5 lbs ac^{-1}**	**Low** **23.5 lbs ac^{-1}**	**High** **17.4 lbs ac^{-1}**	**Very High** **17.4 lbs ac^{-1}**	
Alfalfa (100%) *Viking 370HD*	Alfalfa (25% each) *Viking 370HD* *FSG 420LH* *KF Secure BR* *Roadrunner*	Alfalfa (34%) *Viking 370HD* Orchardgrass (34%) *Extend* Timothy (25%) *Climax* White Clover (7%) *Alice*	Alfalfa (34%/each) *Viking 370HD* *FSG 420LH* *KF Secure* *Roadrunner* Orchardgrass (34%/each) *Extend* *Benchmark Plus* *Niva* *Intensiv*	Timothy (25%/each) *Climax* *Summit* *Glacier* *Promesse* White Clover (7%/each) *Alice* *Liflex* *Ladino* *KopuII*

Table 4. Agronomic and trial information, 2019.

Location	Borderview Research Farm-Alburgh, VT
Soil type	Benson silt loam
Previous crop	Annual or perennial forage
Plot size (ft.)	20 x 35
Replications	4
Management treatments	Different levels of forage diversity and weed pressure
Annual harvest date	28-May
Perennial harvest date	6-Jun
Corn variety	Organic Viking 0.45-88P
Seeding rate (seeds ac^{-1})	36,000
Planting equipment	John Deere 1750 corn planter
Plow and disk date	5-Jun
Row width (in.)	30
Corn planting date	7-Jun
Corn weeding start date	19-Jun
Corn harvest date	3-Oct to assess effect of weed pressure on corn yield
Corn harvest date	10-Oct to assess effect of forage diversity treatment on corn quality

Dry matter yields were calculated and yields were adjusted to 35% dry matter. Silage quality was analyzed using the FOSS NIRS (near infrared reflectance spectroscopy) DS2500 Feed and Forage analyzer. Dried and coarsely-ground plot samples were brought to the UVM's Cereal Grain Testing Laboratory where they were reground using a cyclone sample mill (1mm screen) from the UDY Corporation. The samples were then analyzed using the FOSS NIRS DS2500 for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), 30-hour digestible NDF (NDFD), total digestible nutrients (TDN), and Net Energy-Lactation (NE_L).

The bulky characteristics of forage come from fiber. High fiber is negatively associated with forage feeding values since the less digestible portions of plants are contained in the fiber fraction. The detergent fiber analysis system separates forages into two parts: cell contents, which include sugars, starches, proteins, non-protein nitrogen, fats and other highly digestible compounds; and the less digestible components found in the fiber fraction. The total fiber content of forage is contained in the neutral detergent fiber (NDF). Chemically, this fraction includes cellulose, hemicellulose, and lignin. Because of these chemical components and their association with the bulkiness of feeds, NDF is closely related to feed intake and rumen fill in cows. Recently, forage testing laboratories have begun to evaluate forages for NDF digestibility (NDFD). Evaluation of forages and other feedstuffs for NDFD is being conducted to aid prediction of feed energy content and animal performance. Research has demonstrated that lactating dairy cows will eat more dry matter and produce more milk when fed forages with optimum NDFD. Forages with increased NDFD will result in higher energy values and, perhaps more importantly, increased forage intakes. Forage NDFD can range from 20-80% NDF.

Milk per acre and milk per ton of harvested feed are two measurements used to combine yield with quality and arrive at a benchmark number indicating how much revenue in milk can be produced from an acre or a ton of corn silage. This calculation relies heavily on the NE_L calculation and can be used to make generalizations about data, but other considerations should be analyzed when including milk per ton or milk per acre in the decision making process.

Yield data and stand characteristics were analyzed using mixed model analysis using the mixed procedure of SAS (SAS Institute, 1999). Replications within trials were treated as random effects, and cropping system and/or treatments within cropping systems were treated as fixed. Treatment mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant ($p<0.10$).

Variations in yield and quality can occur because of variations in genetics, soil, weather, and other growing conditions. Statistical analysis makes it possible to determine whether a difference among treatments is real or whether it might have occurred due to other variations in the field. All data was analyzed using a mixed model analysis where replicates were considered random effects. At the bottom of each table, a LSD value is presented for each variable (e.g. yield). Least Significant Differences (LSDs) at the 10% level (0.10) of probability are shown. Where the difference between two treatments within a column is equal to or greater than the LSD value at the bottom of the column, you can be sure in 9 out of 10 chances that there is a real difference between the two values. In the example, treatment A is significantly different from treatment C, but not from treatment B. The difference between A and B is equal to 400, which is less than the LSD value of 500. This means that these treatments did not differ in yield. The difference between A and C is equal to 650, which is greater than the LSD value of 500. This means that the yields of these treatments were significantly different from one another.

Variety	**Yield**
A	1600^a
B	1200^a
C	950^b
LSD (0.10)	500

RESULTS

Weather data was recorded with a Davis Instrument Vantage Pro2 weather station, equipped with a WeatherLink data logger at Borderview Research Farm in Alburgh, VT. Table 5 shows the weather data from Jun-Oct 2019 and indicates the growing conditions observed following the planting of corn and the comparison to the 30-year history average. June was cooler, drier, and there were fewer growing degree-days (GDDs) than usual. The month of July brought more GDDs than average, and drier than the 30-year historic average. During the prime growing months (Jun-Aug), there was less rainfall than average. From Jun through Oct 2019, there were an accumulated 2211 GDDs. Although there was an average of 25 more GDDs than average during this time, all months, other than July, had fewer GDDs.

Table 5. Consolidated weather data and GDDs for corn, Alburgh, VT, 2019.

Alburgh, VT	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Average temperature (°F)	64.3	73.5	68.3	60.0	50.4
Departure from normal	-1.46	2.87	-0.51	-0.52	2.32
Precipitation (inches)	3.06	2.34	3.50	3.87	6.32
Departure from normal	-0.57	-1.88	-0.41	0.21	2.76

Growing Degree Days (base 50°F)	446	716	568	335	146
Departure from normal	-36	86	-14	-25	14

Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger.
Historical averages are for 30 years of NOAA data (1981-2010) from Burlington, VT.

Interactions

There were no significant interactions between forage system or diversity treatments for soil health, soil enzyme populations, or corn silage results. There was not a diversity by weed pressure (present or absent) interaction for weed biomass. There was not a forage system or diversity treatment by weed pressure interaction for corn yield. This indicates that these parameters responded similarly regardless of system or treatment.

Main Effect: Forage System

Soil Test Results

On 5-Nov 18, before winter and 2019 field operations, soil health samples were collected on all plots. The soil from the perennial system had 8% higher aggregate stability compared to annual systems (Table 6). This may be the result of fewer tillage events breaking soil aggregates in the perennial system than the annual system. Although there was a difference in percent aggregate stability, there was no impact of forage system on percent organic matter, soil respiration, or the overall Cornell Comprehensive Assessment of Soil Health score. The Overall Quality Score is an average of all soil health indicator ratings it includes the aforementioned quality indicators as well as pH, phosphorus, and potassium levels. It should be considered as a general summary for soil quality. The scores range between 0-100%. Less than 20% is regarded as very low, 20-40% is low, 40-60% is medium, 60-80% is excellent, and greater than 80% is optimal.

These results indicate that the annual forage system resulted in statistically similar soil health to the perennial system. Prior to the start of the experiment, the trial area had been in annual crop production for two years. Hence these results indicate that aggregate stability is the most responsive soil health indicator to the change from an annual to a perennial system. Other changes in soil health may take more than two years to manifest.

Table 6. Soil quality for forage systems, Alburgh, VT, 2018.

Forage system	Aggregate stability %	Organic matter %	Soil respiration CO_2 mg/soil g	Overall Score
Annual	37.9^{b†}	4.80	0.738	82.4
Perennial	45.9^{a}	4.68	0.743	84.2
LSD (0.10) ‡	3.82	NS¥	NS	NS
Trial Mean	41.9	4.74	0.741	83.3

† Within a column, treatments with that same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
¥ NS – No significant difference was determined among the treatments.

Soil Enzyme Results

On 5-Nov-18, soil samples were collected for enzyme analysis on all plots. There were no differences among forage systems for cellulose, peroxidase activity, chitin, or amino acid leucine measured in nanomoles per hour per gram of soil (nmol/h/g) (Table 7). However, there were differences in phosphatase activity among forage systems. Phosphatase activity was statistically higher in the annual system (122 nmol/h/g) than in the perennial system (78.3 nmol/h/g). Despite additions of phosphorus through applications of poultry manure (8-2-2) to the annual forage system, these results indicate that the microbial community in the annual system had fewer simpler forms of phosphorus available than the microbial community in the perennial system. This may be because there was higher competition for simple sources of phosphorus from the annual crop. The annual forage system produced a two-year average of 7,800 lbs acre^{-1} more than then perennial system. It is possible that higher annual system yields resulted in the reduced availability of simpler forms of phosphorus to the microbial community.

There were significant differences in the cellulose to phosphatase activity ratios (CL:PA) among forage systems. The CL:PA was higher in the perennial forage system (1.78) than in the annual system (1.20). This indicates that the microbial community needed to produce more enzymes to access carbon from cellulose than to degrade more complex sources of phosphorus. Stated differently, the perennial system was more limited by sources of carbon than phosphorus.

Table 7. Soil enzyme analysis for forage systems, Alburgh, VT, 2018.

Forage system	Cellulose	Peroxidase activity	Chitin	Amino acid leucine	Phosphatase activity	CL:PA ratio
	------------------------------------	---------nmol/h/g---------			------------------------------------	
Annual	131	3.45	33.4	99.2	122^{a†}	1.78^{a†}
Perennial	126	5.88	27.4	79.6	78.3^{b}	1.20^{b}
LSD (0.10)‡	NS¥	NS	NS	NS	21.2	0.260
Trial Mean	129	4.66	30.4	89.4	100	1.49

† Within a column, treatments with that same letter did not perform significantly different from each other.

‡ LSD – Least Significant Difference at p=0.10.

¥ NS – No significant difference was determined among the treatments.

Corn Silage Results

On 9-Oct 2019, data was collected on corn silage populations. There were no differences in populations among the forage system. However, there were yield differences among forage systems (Table 8). The perennial system averaged three tons more corn silage ac^{-1} than the annual system. As a result of higher yields, the perennial system also produced more than 3,900 milk lbs ac^{-1} more than the annual system. There were no differences in corn silage quality among the forage systems (Table 9).

Table 8. Impact of forage systems on corn silage populations, yield, and percent dry matter, 2019.

Forage system	Harvest population plants ac^{-1}	Dry matter yield tons ac^{-1}	Dry matter %
Annual	32,500	16.8^{b†}	40.7
Perennial	32,562	19.8^{a}	39.7
LSD‡	NS¥	2.02	NS
Trial mean	32,531	18.3	40.2

† Within a column, treatments with that same letter did not perform significantly different from each other.

‡ LSD – Least Significant Difference at p=0.10.

¥ NS – No significant difference was determined among the treatments.

Table 9. Impact of forage system on corn silage quality, 2019.

Forage system	CP % of DM	ADF % of DM	NDF % of DM	TDN % of DM	NE_L Mcal lb^{-1}	Milk	
						lbs ton^{-1}	lbs ac^{-1}
Annual	7.10	21.7	39.3	65.1	1.50	3,382	19,869^b
Perennial	7.26	23.0	40.3	64.7	1.48	3,433	23,788^a
LSD[‡]	NS	NS	NS	NS	NS	NS	2,554
Trial mean	7.18	22.3	39.8	64.9	1.49	3,407	21,829

† Within a column, treatments with that same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
¥ NS – No significant difference was determined among the treatments.

Weed Pressure Results

On 3-Oct, weed biomass was sampled. Weed pressure in the corn was significantly lower when grown following the annual forage system than the perennial forage system (Table 10). On average, there were 221 lbs ac^{-1} more weeds in the perennial forage system than in the annual system. The

Table 10. Impact of forage system on weed pressure, 2019.

Forage system	Weed biomass lbs ac^{-1}
Annual	611
Perennial	832
LSD[‡]	114
Trial mean	721

‡ LSD – Least Significant Difference at p=0.10.

Main Effect: Diversity Treatments

Soil Test Results

There were no soil health differences among forage diversity treatments (Table 11). Different plant species can have different rooting systems with some plants like cool season annual winter grains having shorter, denser fibrous systems and other plants like alfalfa having longer, sparser rooting systems. It was hypothesized that treatments with differences in species rooting systems would have a more positive impact on soil health than mono-species plantings. It can take years for field operation changes to positively impact soil health. These results indicate that over a two-year experimental period, the diversity of species or variety did not significantly impact soil health.

Table 11. Soil quality for forage treatments systems, Alburgh, VT, 2018.

Forage system	Aggregate stability %		Organic matter %		Soil respiration CO_2 mg/soil g		Overall Score	
	Annual	Perennial	Annual	Perennial	Annual	Perennial	Annual	Perennial
Very Low	36.9	43.1	4.80	4.89	0.749	0.787	83.7	86.2
Low	37.1	46.9	4.47	4.77	0.693	0.723	78.7	86.8
High	36.9	45.7	4.96	4.86	0.754	0.801	81.9	88.0
Very High	40.7	47.8	4.98	4.19	0.757	0.661	85.3	75.8
LSD (0.10)[‡]	NS[¥]	NS	NS	NS	NS	NS	NS	NS
Trial Mean	37.9	45.9	4.80	4.68	0.738	0.743	82.4	84.2

‡ LSD – Least Significant Difference at p=0.10.
¥ NS – No significant difference was determined among the treatments.

Soil Enzyme Results

There were no differences among species diversity treatments for cellulose, peroxidase activity, chitin, amino acid leucine, or phosphatase activity (Table 12). There were significant differences in the cellulose to phosphatase activity ratios (CL:PA) among forage systems and diversity treatments. Across forage systems, the Very High treatments had the statistically lowest CL:PA (1.09) compared to the Very Low (1.73), Low (1.53), and High (1.60) treatments. This indicates that the Very High treatments were less carbon limited than phosphorus limited in comparison to the other species diversity treatments. Considering there were no yield differences across forage systems among diversity treatments in 2019, the difference in CL:PA may be due to the increased species diversity increasing available forms of carbon relative to phosphorus availability compared to other treatments.

Table 12. Soil enzyme analysis for species diversity treatments, Alburgh, VT, 2018.

Forage system	Cellulose	Peroxidase activity	Chitin	Amino acid leucine	Phosphatase activity	CL:PA ratio
	------	------	nmol/h/g	------	------	
Very Low	139	4.64	25.5	111	86.6	1.73[a†]
Low	127	3.01	37.1	78.0	98.4	1.53[a]
High	129	6.84	29.5	95.6	100	1.60[a]
Very High	121	4.16	29.5	72.8	115	1.09[b]
LSD (0.10)[‡]	NS[¥]	NS	NS	NS	NS	0.367
Trial Mean	129	4.66	30.4	89.4	100	1.49

† Within a column, treatments with that same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
¥ NS – No significant difference was determined among the treatments.

Corn Silage Results

Despite the Very High diversity treatment having statistically fewer plants than the other treatments, there were no differences among diversity treatments for yield (Table 13). The higher plant population among treatments did not equate to higher yields. On 10-Oct, corn was harvested to assess effect of forage diversity treatments on corn yield and quality. There were no differences in corn silage quality among diversity treatments (Table 14).

Table 13. Impact of diversity treatment on corn population, yield, and percent dry matter, 2019.

Forage system	Harvest population plants ac^{-1}	Dry matter yield tons ac^{-1}	Dry matter %
Very Low	32,438[ab†]	18.4	40.8
Low	33,500[a]	18.2	40.3
High	32,938[a]	18.8	39.8
Very High	31,250[b]	17.8	39.9
LSD (0.10)[‡]	1,450	NS[¥]	NS
Trial mean	32,531	18.3	40.2

† Within a column, treatments with that same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.
¥ NS – No significant difference was determined among the treatments.

Table 14. Impact of diversity treatments on corn silage quality, 2019.

Forage system	CP % of DM	ADF % of DM	NDF % of DM	TDN % of DM	NE_L Mcal lb^{-1}	Milk lbs ton^{-1}	Milk lbs ac^{-1}
Very Low	7.33	23.5	41.5	64.8	1.47	3,369	21,611
Low	7.11	22.4	39.7	64.5	1.48	3,391	21,633
High	7.40	21.7	39.0	64.8	1.49	3,433	22,709
Very High	6.88	21.7	38.9	65.6	1.51	3,436	21,363
LSD‡	NS¥	NS	NS	NS	NS	NS	NS
Trial mean	7.18	22.3	39.8	64.9	1.49	3,407	21,829

‡ LSD – Least Significant Difference at p=0.10.
¥ NS – No significant difference was determined among the treatments.

Weed Pressure Results

There was no impact of diversity treatments on weed biomass (Table 15). This indicates that having more or less diversity across forage systems did not influence weed pressure.

Table 15. Impact of diversity treatment on weed pressure, 2019.

Forage system	Weed biomass lbs ac^{-1}
Very Low	449
Low	421
High	294
Very High	333
LSD‡	NS¥
Trial mean	374

‡ LSD – Least Significant Difference at p=0.10.
¥ NS – No significant difference was determined among the treatments.

Main Effect: Weed Pressure Treatments

On 3-Oct, weed and corn biomass was sampled using methods outlined in the Materials and Methods section. Across forage systems and diversity treatments, the average the ambient weed pressure was 734 lbs ac^{-1} of dry matter biomass. The weed-free plots were not 100% weed free and had an average of 14.1 lbs ac^{-1} dry matter biomass (Table 16). Corn yields were 3.2 tons ac^{-1} higher in the weed-free plots (22.7 tons ac^{-1}) than in the plots with weeds (19.5 tons ac^{-1}) (Table 16). Although corn yields were lower in the treatments with ambient weed pressure and the perennial forage system had higher weed pressure, overall, corn yields were higher in the perennial system than in the annual system.

Table 16. Weed biomass and corn yield grown in weeded and ambient weed pressure conditions, 2019.

Weeds	Weed biomass lbs ac^{-1}	Corn dry matter yield tons ac^{-1}
Present	734^{a}†	19.5^{b}†
Absent	14.1^{b}	22.7^{a}
LSD (0.10)‡	138	1.32
Trial mean	374	21.1

† Within a column, treatments with that same letter did not perform significantly different from each other.
‡ LSD – Least Significant Difference at p=0.10.

CONCLUSION

Planting corn within an annual forage rotation or perennial forage system can increase forage options. Greater diversity within a forage system can increase resilience and mitigate negative impacts from extreme weather, disease and pest pressure when weather conditions are adverse. Species diversity is often cited as having an impact on soil health. For the two years this study took place, species diversity did not impact soil health. However, implementing a perennial system for two years did have a significantly positive impact on percent aggregate stability, but did not differ significantly in overall soil health score from the annual forage system. This is not surprising, as other research has indicated that the soil health benefits of perennial systems can take years to manifest. The legacy effect of years of annual production may also have reduced differences in carbon systems among forage systems. As a result, there were no differences among enzymes produced by microbes to access different sources of carbon. For example, there were no differences in percent organic matter among forage systems or species diversity treatments so it would not be expected that microbes would produce similar levels of enzymes to access carbon. However, results in the microbial community in the annual system indicate phosphorus limitations, but this does not necessarily mean that the crop will be nutrient deficient. A routine soil test is recommended to accurately gauge the nutrient needs of the crop. There may have been more carbon in the Very High treatments because the different species mature and decay at different rates with the potential to offer more consistent or higher rates of available carbon at the time of sampling.

Nonetheless, there was significant positive impact of perennial systems on corn yield. Results indicate that corn following perennial forage can take advantage of some soil health benefits and potentially nitrogen mineralization that allow it to produce significantly higher yields. While different levels of diversity may impact subsequent populations of corn silage, it does not impact corn yield or quality. This indicates that higher species diversity has less impact than the type of forage system on subsequent corn silage yields. There is a clear yield advantage when corn is grown without the presence of weeds. Weeds can compete with corn for resources and decrease yield potential. Further research is needed to determine if cultivating once a strategically optimal time would reduce weed pressure sufficiently.

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