Eastern Soybean Board Project Final Report

Developing Soybean Production Practices that Maximize Yield and Enhance Environmental Stewardship in Northern Climates

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Due to extended periods of low milk prices and high input costs, farmers in the Northeast are looking for ways to increase on-farm feed production and diversity their operations to increase profitability. Soybeans could be grown for human consumption, animal feed, and biodiesel in Vermont. However, due to the relatively short growing season soybeans have not been a crop of major focus for yield or quality research. The purpose of our trials is to evaluate soybean yield and quality under conventional and organic growing conditions, when planting dates are varied, and under various tillage regimes following fall planted cover crops. Understanding how crops are impacted by varying planting dates can help producers make important management decisions. With a growing concern of agriculturally related water quality implications in Vermont waterways, farmers are now required in some instances to cover crop their annually cropped fields. However, with this increase in cover cropping there is a need to investigate potential impacts on following cash crops and best practices for establishing cover crops into and following soybeans. Similarly, with the concerted effort to reduce nutrient loading in waterways due to soil erosion, farmers are becoming more interested in adoption reduced and no-till practices. Understanding how to best combine these two practices into soybean cropping systems specifically for the Northeast is critical to the success of soybean crops in Vermont.

This year we initiated several soybean trials at Borderview Research Farm in Alburgh, VT. These trials include a conventional variety trial, a planting date trial, and a cover crop trial in which soybeans follow fall planted cover crops under varying tillage regimes. This report will summarize our research and outreach activities around these trials in 2019.

Weather data was recorded throughout the season with a Davis Instrument Vantage PRO2 weather station, equipped with a WeatherLink data logger at Borderview Research Farm in Alburgh, VT (Table 1). Overall, the season began cooler and wetter than normal but became hot and dry in the middle of the summer. The month of July brought above normal temperatures and little rainfall. The longest period without rainfall in July lasted 12 days. This dry period, which occurred around the time of pod formation, may have negatively impacted soybean plant growth and productivity. However, these warm conditions did provide the accumulation of Growing Degree Days (GDDs) that greatly benefited the crop. A total of 2211 GDDs accumulated between Jun and Sep, 197 GDDs above normal.

Table 1. Weather data for Alburgh, VT, 2019.

Alburgh, VT	June	July	August	September	October
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.

Objective 1 is to identify soybean varieties that produce maximum yields in the far north.

<u>MATERIALS AND METHODS</u>

The conventional variety trial included 25 varieties from four different seed companies spanning maturity groups 0.90 to 2.4. The trial was planted on 31-May 2018 into a Benson rocky silt loam at a rate of 185,000 seeds ac^{-1} treated with soybean inoculant and with 5 gal ac^{-1} 9-18-9 liquid starter fertilizer.

Throughout the season the trial was inspected for insect and disease issues however due to extremely hot and dry conditions very little disease and insect pressure was seen until late August. Tissue samples were collected from potentially diseased plants and taken to the UVM Plant Diagnostic Clinic for identification. Two diseases were found in the trial, soybean downy mildew caused by *Peronospora manshurica* (Figure 1) and soybean bacterial blight caused by *Pseudomonas syringae* pv. *glycinea* (Figure 2). To capture varietal differences in infection, the trial was scouted on 8-23-19. Each plot was rated on a 0-5 scale where 0 indicated no visible infection and each subsequent rating corresponded to increments of 20% of leave surface infection (Figure 3). During this scouting we also noted leaf damage caused by Japanese beetles using the same scale.

On 24-Oct, the soybeans were harvested using an Almaco SPC50 small plot combine. Seed was cleaned with a small Clipper M2B cleaner (A.T. Ferrell, Bluffton, IN). They were then weighed for plot yield and tested for harvest moisture and test weight using a DICKEY-John Mini-GAC Plus moisture and test weight meter. Soybean oil was extruded from the seeds with an AgOil M70 oil press on 14-Nov and the amount of oil captured was measured to determine oil content and oil yield.

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 varieties were treated as fixed. Hybrid mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant ($p<0.10$).

Figure 1. Soybean leaf infected with downy mildew

Figure 2. Soybean leaf infected with bacterial blight

Figure 3. Soybean disease/insect damage rating scale (left to right 1, 2, 3, 4 ratings)

Results

Despite cool early conditions and dry weather through much of the summer, the soybeans performed very well resulting in yields ranging 47.4 to 71.1 bu ac^{-1} (Table 2). The top yielding variety was S11XT78 which produced 4264 lbs ac^{-1}. This variety was also the top performer in 2018 yielding 4764 lb ac^{-1}. This variety performed statistically similarly to fourteen other varieties (Figure 4).

Varieties also differed in moisture content at harvest with the lowest moisture of 18.7% being observed in variety S13XT89. This was statistically similar to thirteen other varieties, and all varieties required additional drying to reach proper storage moistures. Test weights were slightly below the target of 60.0 lbs bu^{-1} with test weights averaging 57.2 lbs bu^{-1}. The lack of moisture during pod formation and seed fill may have contributed to these low test weights.

Soybean oil content and yield were also determined. Oil content ranged from 6.47% to 9.36% with the highest content being observed in variety SG 1543XT. This was statistically similar to nine other varieties. These differences in seed yield and oil content led to a significant range of oil yields from 211 lbs ac^{-1} or 27.6 gal ac^{-1}, to 339 lbs ac^{-1} or 44.4 gal ac^{-1}. The highest oil yield was obtained from variety MY160RX which was statistically similar to fourteen other varieties.

Table 2. Harvest characteristics of soybean varieties – Alburgh, VT, 2019.

Company	Variety	Maturity group	Population	Harvest moisture	Test weight	Yield @ 13% moisture		Oil content	Oil yield	
			plants ac^{-1}	%	lbs bu^{-1}	lbs ac^{-1}	bu ac^{-1}	%	lbs ac^{-1}	gal ac^{-1}
Mycogen	5N206R2	2.0	148104	21.3	56.8	3707*	61.8*	7.80	292*	38.2*
Mycogen	5N245R2	2.4	164076*	26.4	57.4	3840*	64.0*	8.07	311*	40.8*
Mycogen	MY1602RX	1.6	121968	21.8	56.8	3980*	66.3*	8.54*	**339**	**44.4**
Syngenta	S09-D4X	0.9	165528*	21.8	58.3	2989	49.8	8.22*	246	32.2
Dyna-Gro	S09XT50	0.9	168432*	20.1*	56.9	2842	47.4	7.38	211	27.6
Syngenta	S10-H7X	1.0	181500*	19.1*	57.3	3719*	62.0*	9.10*	339*	44.3*
Dyna-Gro	S11EN40	1.1	143748	19.9*	57.0	3235	53.9	8.51*	272	35.6
Dyna-Gro	S11XT78	1.1	126324	19.6*	56.7	**4264**	**71.1**	7.99	327*	42.8*
Dyna-Gro	S13XT89	1.3	139392	**18.7**	56.8	3151	52.5	8.67*	273	35.8
Syngenta	S14-B2X	1.4	**196020**	20.0*	57.1	3446	57.4	8.36*	290*	37.9*
Dyna-Gro	S14EN90	1.4	155364	19.9*	57.1	3856*	64.3*	7.85	304*	39.8*
Syngenta	S14-U9X	1.4	177144*	18.9*	57.4	3826*	63.8*	7.29	280*	36.7*

Dyna-Gro	S17EN80	1.7	168432*	21.0*	**58.5**	4075*	67.9*	7.78	317*	41.6*
Syngenta	S18-H3X	1.8	166980*	21.4	56.9	3115	51.9	8.23*	253	33.1
Dyna-Gro	S18XT38	1.8	169884*	22.3	57.0	3691*	61.5*	8.58*	314*	41.1*
Syngenta	S20-J5X	2.0	143748	21.6	57.2	3785*	63.1*	8.07	301*	39.5*
Syngenta	S21-W8X	2.1	161172	19.8*	57.3	4193*	69.9*	6.47	271	35.4
Seedway, LLC	SG 1194XT	1.1	187308*	21.2	57.7	3315	55.3	7.02	232	30.4
Seedway, LLC	SG 1455E3	1.4	164076*	21.0*	57.4	4251*	70.9*	7.86	334*	43.8*
Seedway, LLC	SG 1543XT	1.5	175692*	19.0*	57.6	3523	58.7	**9.36**	333*	43.6*
Seedway, LLC	SG 1776	1.7	135036	21.7	57.6	3867*	64.4*	8.74*	335*	43.9*
Seedway, LLC	SG1780E3	1.7	188760*	19.9*	57.4	3649*	60.8*	7.79	285*	37.3*
Seedway, LLC	SG 1863XT	1.8	139392	19.2*	57.3	3729*	62.2*	7.85	292*	38.2*
Seedway, LLC	SG 2017E3	2.0	130680	22.7	56.6	3382	56.4	7.85	265	34.7
Seedway, LLC	SG 2055XT	2.0	182952*	20.6*	57.2	3580	59.7	6.77	243	31.8
LSD (*p* = 0.10)			33954	2.49	NS†	661	11.0	1.21	62.4	8.17
Trial Mean			160069	20.8	57.2	3640	60.7	8.01	290	38.0

The top performing variety is indicated in **bold**.
*Varieties that were not significantly different from the top performing variety are indicated with an asterisk.
‡NS; not significant at the p=0.10 level.

Despite dry conditions through the later part of the season, variable incidence of disease was observed throughout the trial (Table 3). Infections with downy mildew and bacterial blight were observed as well as defoliation due to Japanese beetles. Interestingly, varieties differed significantly in terms of downy mildew and Japanese beetle damage. Six varieties including S09-D4X, S17EN90, SG 1455E3, SG 1780E3, S18-H3X, and SG 2055XT, experienced no downy mildew infection. The overall average infection rating for downy mildew in the trial was 0.605 indicating that infection, although present on almost all the varieties in the trial, did not affect more than 20% of the leaf area. Furthermore, the highest level of infection was 2.25 observed in variety MY1602RX. This was significantly higher than any other variety in the trial. Despite this infection and very low plant populations, MY1602RX produced high seed and oil yields. Bacterial blight was observed in a few varieties but at very low levels. Varieties also differed significantly in Japanese beetle defoliation. Variety S14-U9X had the lowest rating of 0.75 which was statistically similar to twelve other varieties. The highest level of infection was 1.50 observed on four varieties.

Table 3. Disease and insect pressure of soybean varieties – Alburgh, VT, 2019.

Company	Variety	Maturity group	Downy mildew	Bacterial blight	Japanese beetle
			0-5 scale†		
Mycogen	5N206R2	2.0	0.75	0.000	1.50
Mycogen	5N245R2	2.4	1.25	0.000	1.00*
Mycogen	MY1602RX	1.6	2.25	0.000	1.25
Syngenta	S09-D4X	0.9	0.00*	0.250	1.50
Dyna-Gro	S09XT50	0.9	1.00	0.000	1.25
Syngenta	S10-H7X	1.0	0.25*	0.000	1.50
Dyna-Gro	S11EN40	1.1	0.75	0.000	1.25
Dyna-Gro	S11XT78	1.1	1.50	0.000	1.00*
Dyna-Gro	S13XT89	1.3	0.25*	0.000	1.25
Syngenta	S14-B2X	1.4	1.25	0.000	1.00*

Dyna-Gro	S14EN90	1.4	0.13*	0.000	1.13
Syngenta	S14-U9X	1.4	0.75	0.250	**0.75**
Dyna-Gro	S17EN80	1.7	0.00*	0.000	1.00*
Syngenta	S18-H3X	1.8	0.25*	0.000	1.00*
Dyna-Gro	S18XT38	1.8	0.00*	0.000	1.00*
Syngenta	S20-J5X	2.0	0.75	0.000	1.00*
Syngenta	S21-W8X	2.1	0.50*	0.000	1.00*
Seedway, LLC	SG 1194XT	1.1	0.75	0.250	1.00*
Seedway, LLC	SG 1455E3	1.4	0.00*	0.000	1.00*
Seedway, LLC	SG 1543XT	1.5	1.00	0.000	1.25
Seedway, LLC	SG 1776	1.7	0.75	0.000	1.25
Seedway, LLC	SG1780E3	1.7	0.00*	0.000	1.25
Seedway, LLC	SG 1863XT	1.8	0.50*	0.000	1.00*
Seedway, LLC	SG 2017E3	2.0	0.50*	0.000	1.50
Seedway, LLC	SG 2055XT	2.0	**0.00**	**0.000**	1.00*
LSD (p = 0.10)			0.671	NS	0.363
Trial Mean			0.605	0.030	1.145

†0 to 5 rating, where 0 equated to damage/infection not present and 5 equated to infection or damage present on 100% of leaf area.
The top performing variety is indicated in **bold**.
*Varieties that were not significantly different from the top performing variety are indicated with an asterisk.
‡NS; not significant at the p=0.10 level.

These differences in yield potential and pest resistance highlight the need for such work to help farmer's select regionally appropriate soybean varieties that will support high yields and quality.

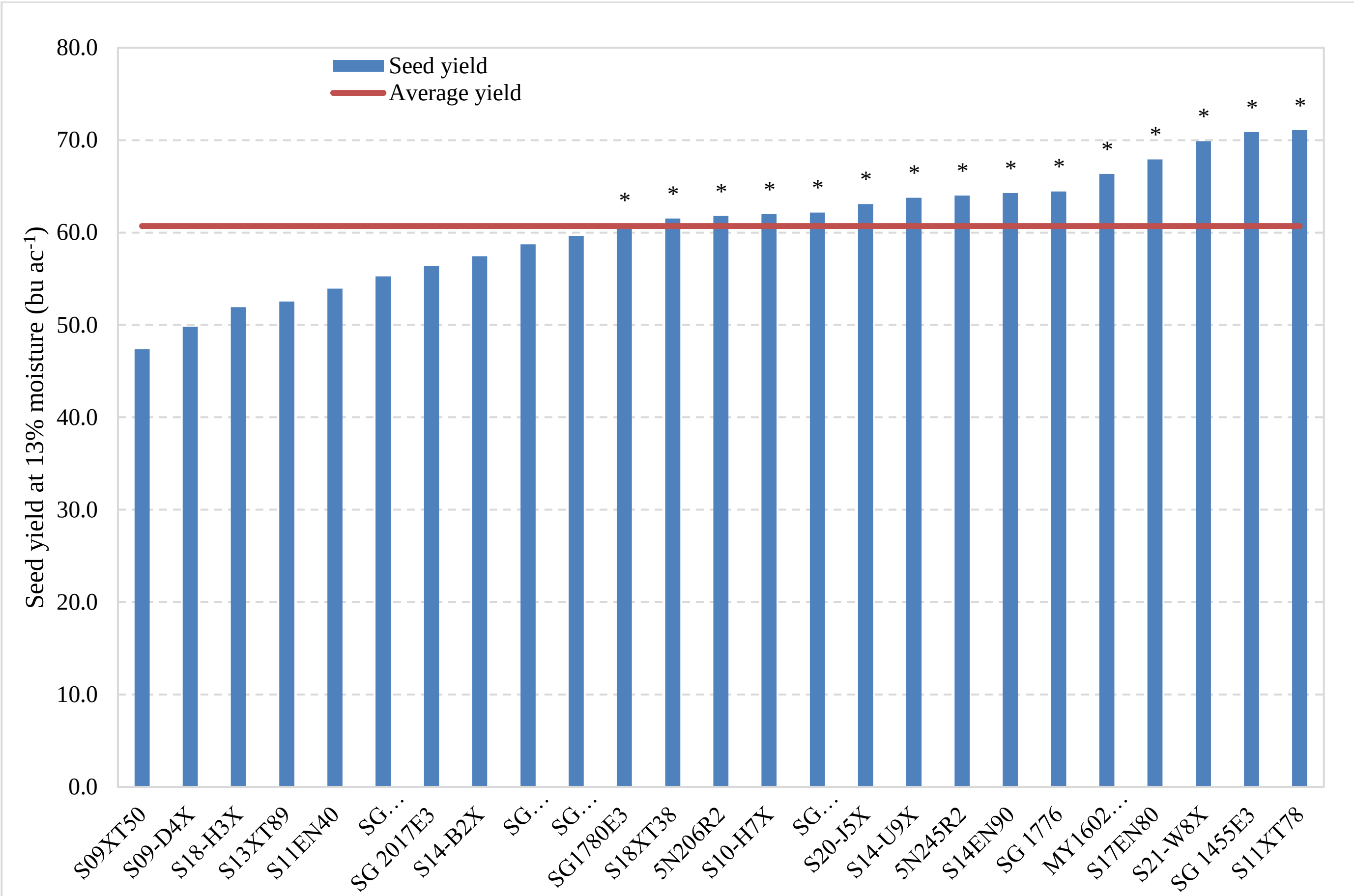

Figure 4. Seed yield at 13% moisture for 25 conventional soybean varieties. The red line indicates the average yield.*Varieties that did not perform significantly lower than the top performing variety are indicated with an asterisk.*

Data gathered from the last 3 years indicates that high soybean yields can be obtained from a wide range of maturity ratings in far northern regions. However, based on the data highest yields have been obtained from varieties that fall within the 1.0 and 2.0 maturity group (Figure 5).

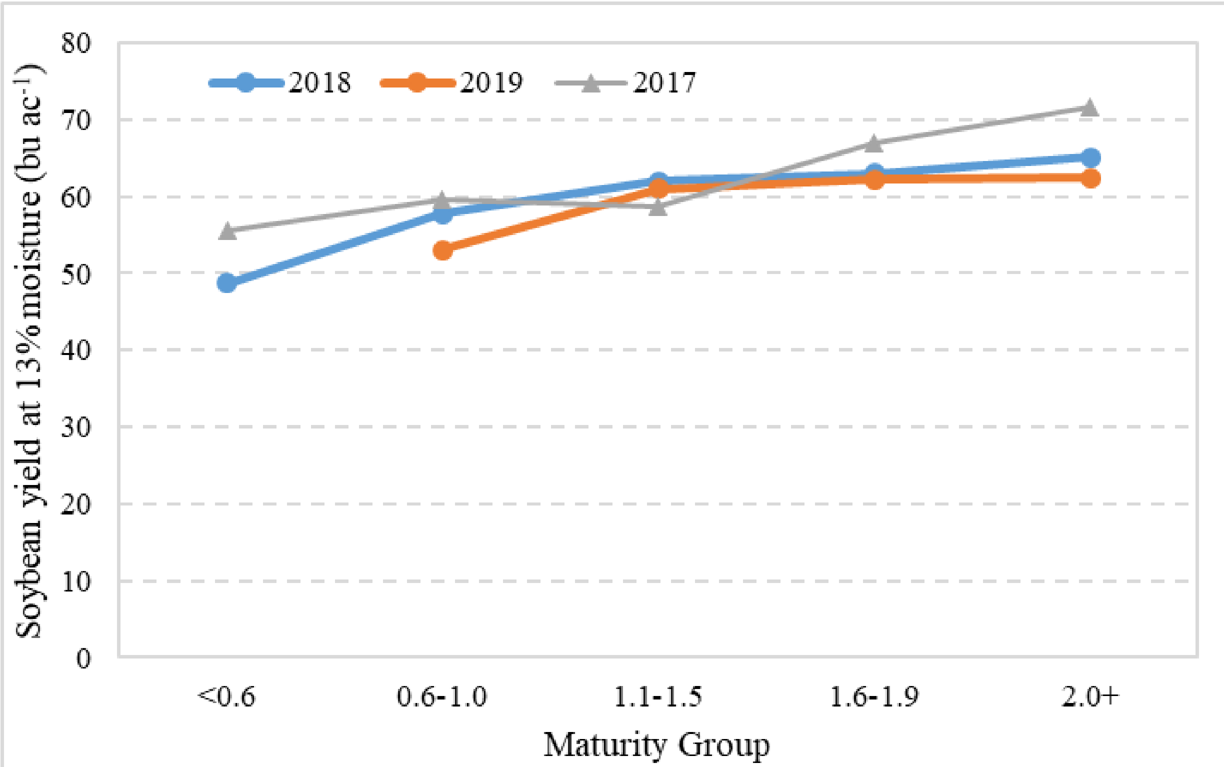

Figure 5. Soybean yield across maturity grouping from 2017 to 2019.

Objective 2 is to determine the impact of planting date on soybean yield and quality.

MATERIALS AND METHODS

One of the goals of this planting date study was to determine how late soybeans can be planted in Vermont while still reaching maturity and producing adequate yields. In addition, we wanted to determine how soybeans respond to shifting planting dates in terms of other characteristics such as pest and disease pressure. In a previous planting date study involving sunflowers, we have found that shifting planting dates can be a tool for farmers to avoid certain insect or bird pest pressures. To investigate these interactions, the planting date trial contained two varieties, one early and one mid-group 1 maturity. Plots were planted on 17-May, 23-May, 31-May, 7-Jun, 13-Jun with a 4-row cone planter with John Deere row units fitted with Almaco seed distribution units (Nevada, IA). Starter fertilizer (9-18-9) was applied at a rate of 5 gal ac^{-1}. Plots were 20' long and consisted of two rows spaced at 30 inches. The seeding rate was 185,000 seeds ac^{1}. Plots were monitored for pest and disease pressure throughout the season.

On 27-Aug plots were assessed for severity of infection with downy mildew (Peronospora manshurica), bacterial blight (Pseudomonas syringae pv. glycinea), and damage from Japanese beetles. These were the only pests and diseases observed in the trial. Assessments were made by inspecting each plot and assigning a rating from 0 to 5, where 0 equated to damage/infection not present and 5 equated to infection or damage present on 100% of leaf area.

On 15-Oct, the soybeans were harvested using an Almaco SPC50 small plot combine. Seed was cleaned with a small Clipper M2B cleaner (A.T. Ferrell, Bluffton, IN). They were then weighed for plot yield, tested for harvest moisture and test weight using a DICKEY-John Mini-GAC Plus moisture and test weight meter. Soybean oil was extruded from the seeds with an AgOil M70 oil press on 14-Nov, and the amount of oil captured was measured to determine oil content and oil yield.

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 planting date and variety were treated as fixed. Hybrid mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant ($p<0.10$).

RESULTS

Impact of Variety x Planting Date Interactions

There was a significant variety x planting date interaction for test weight indicating that the maturities responded differently in terms of test weight when planted on different dates. Generally, as planting dates become later, farmers must modify varieties to fit the length of the growing season. Hence, with later planting dates generally shorter season varieties begin to outperform longer season types. This trend was not observed this year as the 1.7 maturity group variety produced soybeans with higher test weight than the 0.9 maturity group variety at most planting dates including the later ones (Figure 6). The highest test weight was obtained by planting the late maturing variety on the third date and the early maturing variety on the fourth planting. A similar trend was observed in our 2018 trial.

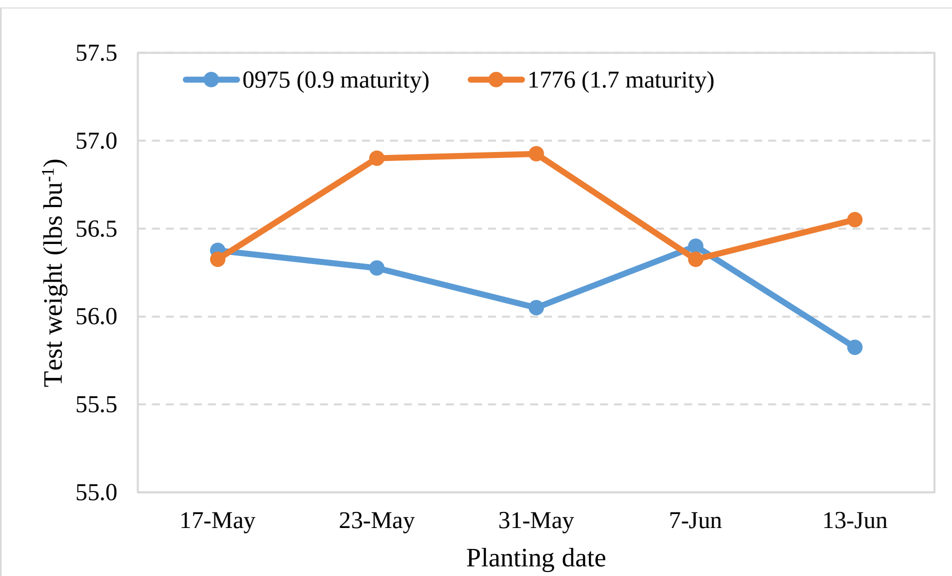

Figure 6. Soybean variety x planting date interaction for test weight, 2019.

Impact of Variety

The two soybean maturities performed significantly different in terms of yield, test weight, and oil yield, but were statistically similar in all other harvest characteristics (Table 6). Moisture at harvest averaged 15.2% and did not differ statistically, indicating that both the longer and shorter season varieties reached similar maturity by the time of harvest. Both required some drying prior to storage. Similarly, populations were low for both varieties likely due to variable weather conditions following planting. Test weights varied slightly between varieties with the later maturing variety producing seed with a test weight of 56.6 lbs bu^{-1}, 0.4 lbs bu^{-1} higher than the early maturing variety. However, both were below the target of 60 lbs bu^{-1} likely due to low rainfall throughout the growing season leading to reduced seed fill. Yields also varied statistically between the two varieties. The late maturing variety, 1776, yielded 3915 lbs ac^{-1} or 65.3 bu ac^{-1}. Overall, this was 757 lbs ac^{-1} more than the early maturing variety. Because the varieties had similar oil contents, oil yield was significantly higher in the later maturing variety, which produced 34.6 gal ac^{-1}, 5.5 gal ac^{-1} more than the early maturing variety.

Table 6. Harvest characteristics of soybeans by variety, 2019.

Variety	Maturity group	Population	Harvest moisture	Test weight	Yield @ 13% moisture		Oil content	Oil yield	
		plants ac^{-1}	%	lbs bu^{-1}	lbs ac^{-1}	bu ac^{-1}	%	lbs ac^{-1}	gal ac^{-1}
SG0975	0.9	119645	**15.2**	56.2	3158	52.6	**6.98**	194	29.1
SG1776	1.7	**132132**	15.3	**56.6**	**3915**	**65.3**	6.74	**230**	**34.6**
LSD (*p* = 0.10)		NS†	NS	0.231	466	221	3.68	28.4	4.28
Trial Mean		125888	15.2	56.4	3291	3567	59.0	212	31.9

The top performing variety is indicated in **bold**.
†NS; Not statistically significant.

Varieties also differed in defoliation due to Japanese beetles (Table 7). Overall the damage due to Japanese beetles was low, averaging <40% of the leaf area. The early maturing soybean variety had a statistically higher rating than the later maturing variety. This may be due to the stage of maturity and therefore the attractiveness to the beetles at the time the Japanese beetle population expanded. Yields were higher in the later maturing variety; however, it is not clear that the Japanese beetle defoliation impacted these yields.

Table 7. Disease and insect pressure of soybeans by variety, 2019.

Variety	Maturity group	Downy mildew	Bacterial blight	Japanese beetles
		0-5 rating scale†		
SG0975	0.9	1.00	**0.000**	1.90
SG1776	1.7	**0.90**	0.000	**1.35**
LSD (*p* = 0.10)		NS‡	NS	0.179
Trial Mean		0.95	0.000	1.63

†0 to 5 rating, where 0 equated to damage/infection not present and 5 equated to infection or damage present on 100% of leaf area.
The top performing variety is indicated in **bold**.
‡NS- Not statistically significant.

Impact of Planting Date

Harvest moistures ranged from 14.7% to 15.6%. Statistically, there was no difference in soybean moisture contents at harvest between the five planting dates. Test weights ranged from 56.2 to 56.6 lbs bu^{-1}. There was no significant difference in test weight between planting dates, and all produced soybeans with test weights below the industry standard of 60 lbs bu^{-1}. Planting date significantly impacted soybean yield (Table 8). Soybean yields ranged from 3249 to 3993 lbs ac^{-1} or 54.2 to 66.5 bu ac^{-1}. The seed yield was significantly higher for the planting dates of 31-May and 7-Jun, and the yields were almost 10 lb bu^{-1} more than any of the other three planting dates (Figure 7). The five planting dates performed statistically similar in oil content and oil yield.

Table 8. Harvest characteristics of soybeans by planting date, 2019.

Planting date	Population	Harvest moisture	Test weight	Yield @ 13% moisture		Oil content	Oil yield	
	plants ac^{-1}	%	lbs bu^{-1}	lbs ac^{-1}	bu ac^{-1}	%	lbs ac^{-1}	gal ac^{-1}
17-May	126324	**14.7**	56.4	3249	54.2	6.86	195	29.3
23-May	**133584**	15.3	**56.6**	3391	56.5	**7.59**	226	34.0
31-May	129228	15.4	56.5	**3993**	**66.5**	6.80	**234**	**35.3**
7-Jun	121968	15.6	56.4	3793*	63.2*	6.69	224	33.7
13-Jun	118338	15.4	56.2	3259	54.3	6.37	180	27.1
LSD (p = 0.10)	NS†	NS	NS	349	5.82	NS	NS	NS
Trial Mean	125888	15.2	56.4	3567	59.0	6.86	212	31.9

The top performing planting date is indicated in **bold**.
Within a column, planting dates with the asterisk (*) did not differ significantly from the top performer.
†NS- Not statistically significant.

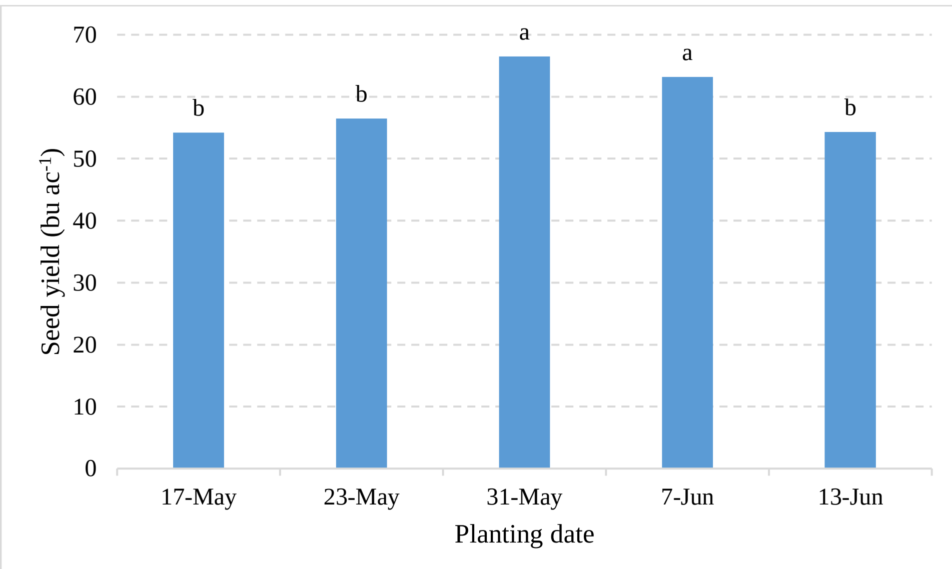

Figure 7. Soybean yield across five planting dates, 2019. Treatments that share a letter were statistically similar.

Planting dates differed significantly in downy mildew severity, but not in Japanese beetle defoliation (Table 9). The severity of downy mildew, on a 0-5 scale, ranged from 0.375 in the first planting date to 1.25 in the fourth planting date. The later planting dates at the end of May to mid-June had higher downy mildew severity than the earlier planting dates.

Table 9. Disease and insect pressure of soybeans by planting date, 2019.

Planting date	Downy mildew	Japanese beetles
	0-5 scale†	
17-May	**0.375**	1.63
23-May	0.875	1.50
31-May	1.13	1.75
7-Jun	1.25	1.75
13-Jun	1.13	**1.50**
LSD (p = 0.10)	0.264	NS‡
Trial Mean	0.95	1.63

†0 to 5 rating, where 0 equated to damage/infection not present and 5 equated to infection or damage present on 100% of leaf area. The top performing variety is indicated in **bold**.
‡NS;Not statistically significant.

Soybean yields were significantly impacted by planting date with the highest yields observed when soybeans were planted at the end of May and first week of June (Figure 7). Cool temperatures and wet conditions experienced in early May likely impacted soybean yields from these planting dates. There was no significant difference in oil content or oil yield between planting dates. Soybean yield was also significantly impacted by maturity group, with the later maturing variety having higher test weight, yield and oil yield. However, the early maturing variety produced soybeans with a significantly higher oil content.

Soybean planting dates have been evaluated since 2017 in Vermont. Interestingly in 2017 & 2019, soybeans planted in May yielded lower than those planted in June (Figure 8). In 2018, soybeans planted in the last two weeks of May had the highest yields. Overall, these data indicate that a soybean maturity range from 0.9 to 1.7 can mature in Vermont even when planted into mid-June. Early season planting should only occur if weather and soil conditions are advantageous for soybean germination and growth. Further research over additional years and environments will help develop optimum planting date ranges for Vermont.

Image 1. Earlier planted soybeans (left) exhibiting more advanced maturity.

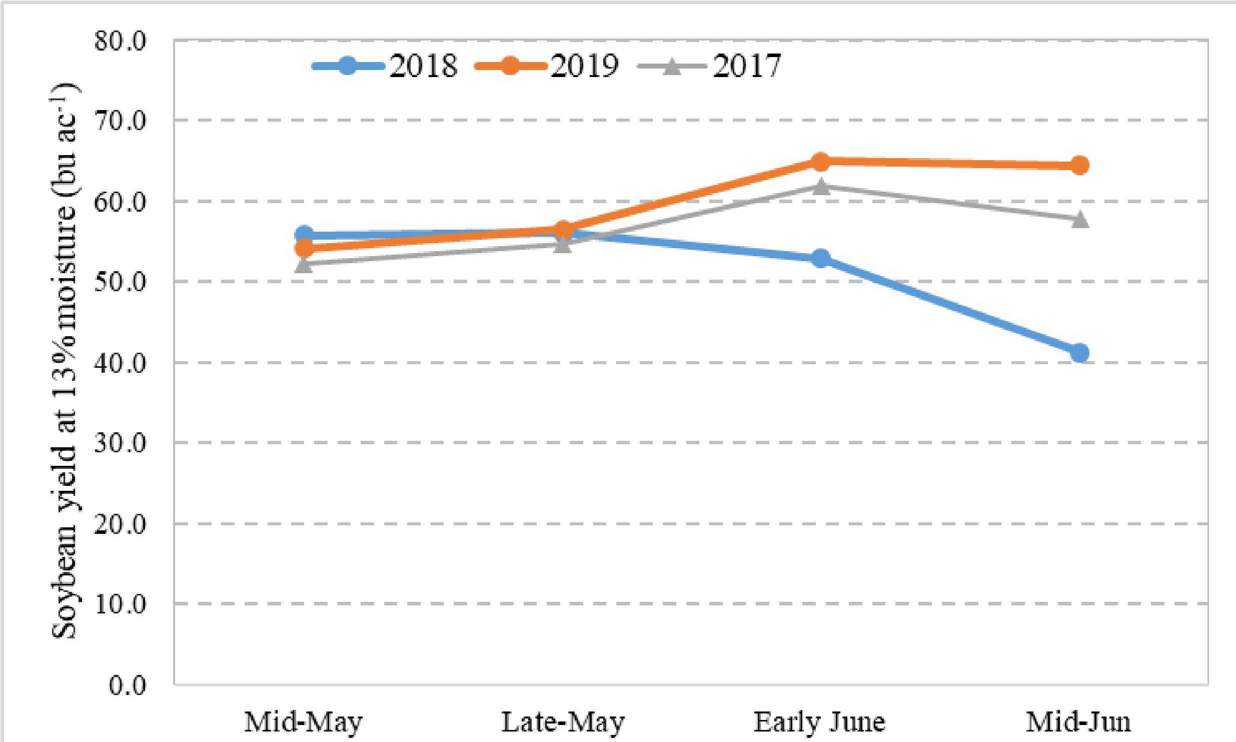

Figure 8. Soybean yield across five planting dates, 2019.

Objective 3 is to develop cover cropping strategies for soybean production systems that maximize yield, protect soil health, and minimize pest and disease pressure.

Impact of Cover Crops on Subsequent Soybean Yields

MATERIALS AND METHODS

In the fall of 2018, 10 cover crop treatments, summarized in Table 10 below, were planted at Borderview Research Farm in Alburgh, VT on 24-Aug 2018. Treatments consisted of mixtures that would both be over-wintered and some that would be winter-killed, and a control in which no cover crop was planted. Biomass was collected on 22-Oct 2018 from a 0.25m2 area in each plot. Samples were weighed prior to and after drying to determine dry matter content and calculate yield. Cover crop biomass was measured again in the spring on 6-May 2019 prior to soybean planting using this same method. All cover crop treatments were terminated in the spring, just prior to soybean planting using a moldboard plow and disc harrow.

Table 10. Fall cover crop mixtures planted in Alburgh, VT, 2018.

Treatment	Species	Variety	Over-winters?	Seeding rate lbs ac-1
AR/CC/TR	Annual ryegrass	Centurion	No	15
	Crimson clover	Dixie		8
	Radish	Eco-till		2
O/CC/TR	Oats	Shelby	No	70
	Crimson clover	Dixie		15
	Radish	Eco-till		3
WR/RC/TR	Winter rye	unknown	Yes	50
	Red clover	Medium		12

	Radish	Eco-till		3
WR/HV	Winter rye	unknown	Yes	50
	Hairy vetch	unknown		20
WR	Winter rye	unknown	Yes	75
AR	Annual ryegrass	Centurion	No	25
TR	Radish	Eco-till	No	6
CC	Crimson clover	Dixie	No	15
RC	Red clover	Medium	Yes	15
NC	No cover		No	N/A

On 23-May, the soybeans were planted into the terminated cover crop treatments using a 4-row cone planter with John Deere row units fitted with Almaco seed distribution units (Nevada, IA) at 185,000 seeds ac^{-1} with 5 gal ac^{-1} starter fertilizer (9-18-9). The variety SG0975 (maturity group 0.9, Genuity® RoundUp Ready 2 Yield) soybean was obtained from Seedway, LLC (Hall, NY) for the trial. Soybeans were sprayed with Roundup PowerMAX® herbicide on 27-May to control weeds. On 15-Oct, the soybeans were harvested using an Almaco SPC50 small plot combine. Seed was cleaned with a small Clipper M2B cleaner (A.T. Ferrell, Bluffton, IN). They were then weighed for plot yield and tested for harvest moisture and test weight using a DICKEY-John Mini-GAC Plus moisture/test weight meter.

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 cover crops were treated as fixed. Hybrid mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant ($p<0.10$).

RESULTS

Fall and spring cover crop biomass and soybean yield and test weights are summarized in Table 11. The top yielding cover crop treatment in the fall was WR/RC/TR which produced 2430 lbs ac^{-1} (Table 11). This treatment performed statistically similar to O/CC/TR, and TR. As many of the treatments consisted of species that do not overwinter, only three mixtures had a measurable spring biomass. The WR treatment had the highest spring dry matter yield with 1595 lbs ac^{-1} and WR/HV was statistically similar with 1536 lbs ac^{1}.

Soybean yield and test weight were not significantly impacted by the preceding cover crop treatments. Yields averaged 4580 lbs ac^{-1} or 76.3 bu ac^{-1} and test weight averaged 56.4 lbs bu^{-1}. The test weights were consistent with the averages observed in our other soybean trials in 2019 while the average soybean yield in this trial was higher than in other soybean trials from this season.

Table 11. Cover crop and soybean harvest characteristics.

Mix	Overwinters?	Fall 2018	Spring 2019	Soybean harvest 2019	
		Dry matter yield		Yield at 13% moisture	Test weight
		lbs ac^{-1}		lbs ac^{-1}	lbs bu^{-1}
AR/CC/TR	No	1318	0	5350	56.1
O/CC/TR	No	2039*	0	4192	55.7
WR/RC/TR	Yes	**2430**	771	4650	55.9
WR/HV	Yes	1390	1536*	4182	57.0
WR	Yes	1315	**1595**	4422	56.0

AR	No	626	0	4307	56.7
TR	No	2296*	0	4506	56.6
CC	No	655	0	4451	56.7
RC	Yes	545	0	4098	56.5
NC	No	617	0	5640	56.9
LSD (p = 0.10)		826	243	NS†	NS
Trial mean		1323	1390	4580	56.4

*Varieties that did not perform significantly lower than the top performing variety in **bold** are indicated with an asterisk.
†NS; no significant difference at the p=0.10 level.

In 2017, we saw a significant decrease in soybean yields when following an overwintering cover crop. In 2018, while there was a decrease in soybean yields following an overwintering cover crop, it was not significantly different than the yield of soybeans planted following a winter-killed cover crop. This year, the trend was similar to that of the previous year (Table 12).

Table 12. Impacts of overwintering cover crop on soybean yields, 2017-2019.

Overwinter	**Soybean yield** (bu ac^{-1})		
	2017	2018	2019
Yes	60.4	61.1	72.3
No	67.9	63.9	79.0
p value	0.007	NS†	NS
Trial mean	64.2	62.6	76.3

†NS; no significant difference at the p=0.10 level.

Soils were analyzed for nitrate (NO_3) content four times between the planting and harvesting of soybeans in 2019 (Figure 9). Cover crops were terminated in late May, and soybeans were planted on 23-May. At this time, there were no significant differences in soil nitrate levels between overwinter and winterkilled plots. By early June, soil nitrate levels in the overwinter plots start to exceed that of the winterkill plots. This trend holds through the middle of July. This suggests that the nitrogen in the living cover crop material that was incorporated into the soil prior to planting soybeans was mineralized in mid-July. The extra nitrogen released from the overwintered cover crops did not appear to impact soybean yield. It is important to recognize that starter fertilizer was applied at planting to all soybean plots. A greater impact may have been seen, had starter not been used. We plan to continue to investigate nitrogen cycling in these cover crop treatments and its potential impacts on subsequent soybean productivity.

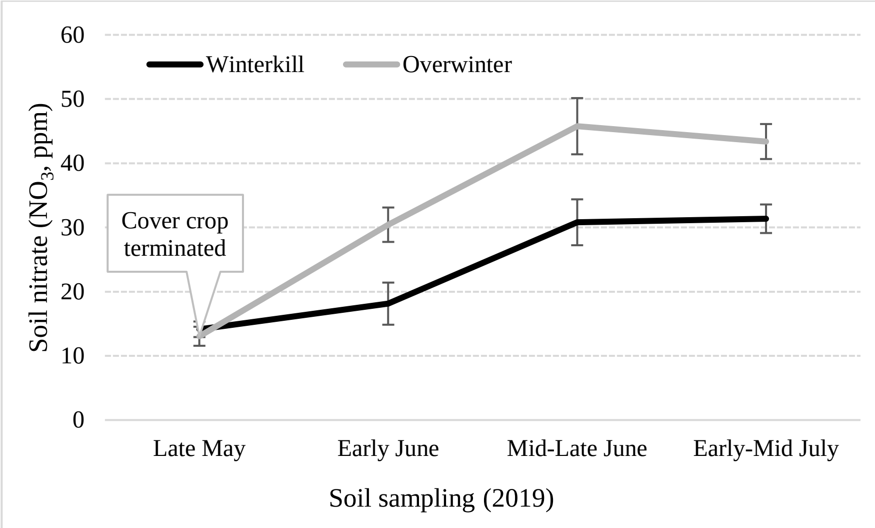

Figure 9. Soil NO_3 content by cover crop treatment type, 2019.

Cover Crop Termination Methods for Soybean Cropping Systems

The trial was conducted at Borderview Research Farm, Alburgh, VT in 2018-2019. The experimental design was a complete randomized block design with split plots and four replications. The main plot was spring termination method including tillage, herbicide termination before planting, and herbicide termination after planting (Table 13). Subplots were 3 cover crop treatments including winter rye, winter rye & vetch, winter rye, red clover, radish (Table 14).

Table 13. Cover crop termination method details.

Treatment	Cover crop termination details
Tillage (10-May)	Tilled under with moldboard plow and disc harrow prior to soybean planting
Pre-spray (8-May)	Sprayed with Roundup PowerMAX® at 1qt ac^{-1} prior to soybean planting
Post-spray (27-May)	After soybeans were planted, cover crop was sprayed with Roundup PowerMAX® at 1qt ac^{-1}

Table 14. Overwintering cover crop mixtures grown prior to soybean crop, Alburgh, VT, 2019.

Treatment	Species	Variety	Seeding rate lbs ac^{-1}
WRRR	Winter rye	VNS	50
	Red clover	Medium	12
	Radish	Eco-till	3
WRV	Winter rye	VNS	50
	Hairy vetch	VNS	20
WR	Winter rye	VNS	75

On 1-May, cover crop biomass and percentage of soil covered were measured prior to termination. A $0.25m^2$ area in each plot was harvested and samples were weighed prior to and after drying to determine dry matter content and calculate yield. The beaded string method (Sloneker and Moldenhauer, 1977) was used to calculate percent of soil covered by plant biomass.

On 23-May, the soybeans were planted into each of the termination treatments using a 4-row cone planter with John Deere row units fitted with Almaco seed distribution units (Nevada, IA) at 185,000 seeds ac^{-1} with 5 gal ac^{-1} starter fertilizer (9-18-9). The variety SG0975 (maturity group 0.9) soybean was obtained from Seedway, LLC (Hall, NY) for the trial.

On 15-Oct, the soybeans were harvested using an Almaco SPC50 small plot combine. Seed was cleaned with a small Clipper M2B cleaner (A.T. Ferrell, Bluffton, IN). They were then weighed for plot yield and tested for harvest moisture and test weight using a DICKEY-John Mini-GAC Plus moisture/test weight meter.

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 cover crops and termination methods were treated as fixed. Hybrid mean comparisons were made using the Least Significant Difference (LSD) procedure when the F-test was considered significant (p<0.10).

RESULTS

Prior to cover crop termination and subsequent soybean planting, the spring soil coverage and cover crop dry matter yield were measured (Table 15). There was significantly higher spring soil coverage and cover crop yields in the plots that would be tilled prior to soybean planting (Tillage) and the plots that would be sprayed prior to soybean planting (Pre-spray). However, there were no statistical differences in soybean yield, indicating that the cover crop termination method did not significantly impact the yield of the subsequent soybean crop (Table 15). Yields at 13% moisture ranged from 4418 lbs ac-1 (Tillage) to 4673 lbs ac-1 (Pre-spray). There was a significant difference in soybean test weight between the cover crop termination methods. The pre-spray treatment had the highest test weight, 57.7 lbs bu-1, and this was statistically higher than the tillage and the post-spray treatments (56.3 lbs bu-1 and 55.5 lbs bu-1 respectively).

Table 15. Cover crop and soybean harvest characteristics by termination method, 2019.

Termination method	Prior to cover crop termination		Soybean harvest		
	Spring soil coverage	Cover crop DM yield	Yield at 13% moisture		Test weight
	%	lbs ac^{-1}	lbs ac^{-1}	lbs ac^{-1}	lbs bu^{-1}
Tillage	**84.2** **a**†	1571 a	4418	73.6	56.3 b
Pre-spray	82.1 a	**1779** **a**	4673	77.9	**57.7** **a**
Post-spray	61.0 b	1071 b	4634	77.2	55.5 **b**
LSD (*p* = 0.10)	7.49	245	NS‡	NS	1.26
Trial mean	75.8	1473	4575	76.3	56.5

†Within a column, treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold**.
‡NS-No significant difference between treatments.

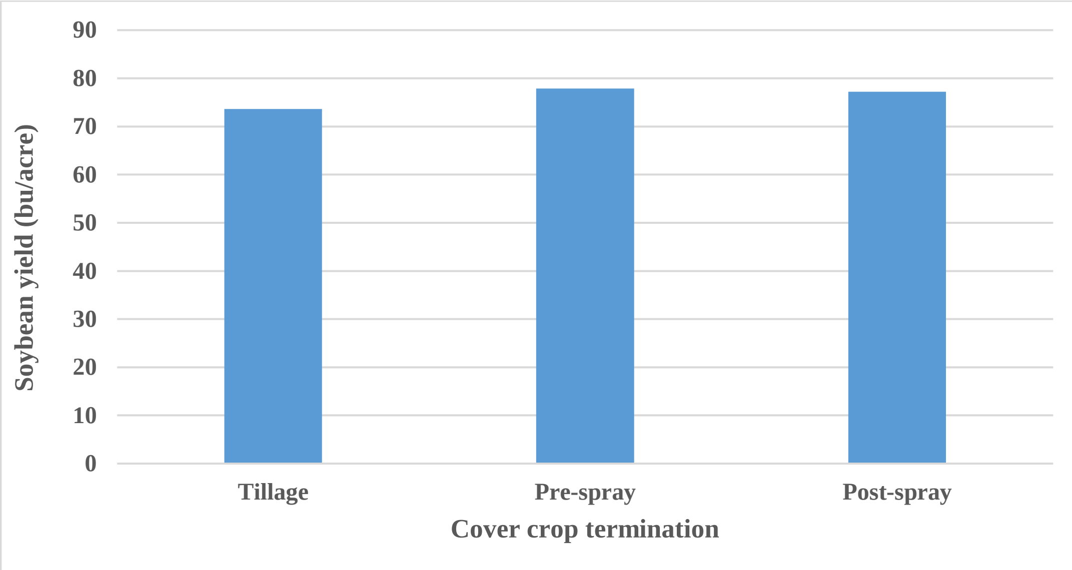

Figure 10. Impact of cover crop termination on subsequent soybean yield, 2019.

Prior to cover crop termination, there was significantly higher spring soil coverage and cover crop yield in WR; WR/HV was statistically similar (Table 16). Soybean yields were impacted by cover crop treatment. The soybean yield was highest in WR/RC/TR with 4816 lbs ac^{-1} and WR/HV was statistically similar (4556 lbs ac^{-1}). Test weight was not significantly different between cover crop treatments.

Table 16. Cover crop and soybean harvest characteristics by cover crop mixture, Alburgh, VT, 2019.

Treatment	Species	Prior to cover crop termination		Soybean harvest 2019		
		Spring soil coverage	Cover crop dry matter yield	Yield at 13% moisture		Test weight
		%	lbs ac^{-1}	lbs ac^{-1}	bu ac^{-1}	lbs bu^{-1}
WR/RC/TR	Winter rye/red clover/radish	71.5 ^{b†}	1183 ^{b}	**4816** ^{a}	**80.3** ^{a}	56.5
WR/HV	Winter rye/ hairy vetch	76.9 ^{ab}	1584 ^{a}	4556 ^{ab}	75.9 ^{ab}	56.5
WR	Winter rye	**79.0** ^{a}	**1653** ^{a}	4353 ^{b}	72.6 ^{b}	56.5
LSD (p = 0.10)		7.49	245.1	451.2	7.52	NS‡
Trial mean		75.8	1473	4575	76.3	56.5

†Within a column, treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold**.
‡NS-No significant difference between treatments.

Interestingly, it was noted that when there was increasing winter rye cover crop biomass the soybean yield declined (Figure 11). Additional research needs to be conducted to understand the relationship between winter rye and impacts on soybean yields.

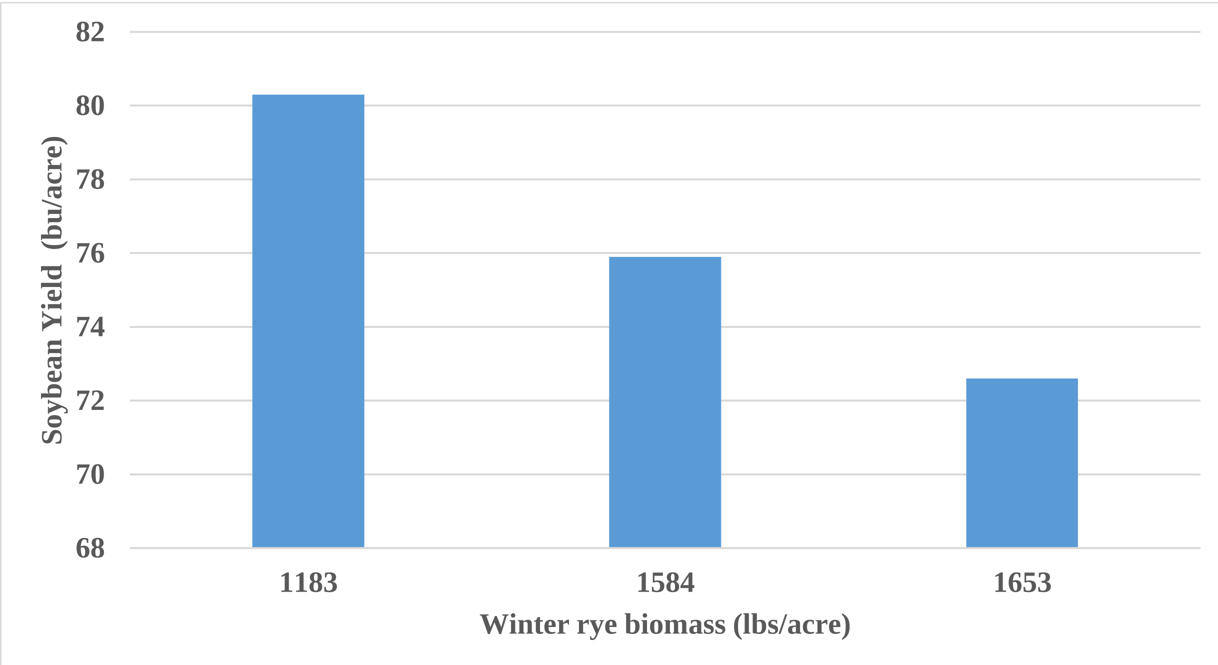

Figure 11. Relationship between winter rye spring biomass and soybean yields, 2019.

Soils were analyzed for soil nitrate-N (NO_3) concentration every other week starting from 23-May (time of planting) through mid-July (Table 17, Figure 12). There were significant differences in soil nitrate-N concentrations between the cover crop termination methods. The tillage treatment had statistically higher concentrations of soil nitrate-N throughout the time of soil sampling. By the last week of soil sampling, the pre-spray treatment had a soil nitrate-N concentration that was statistically similar to the tillage treatment. The post-spray treatment consistently had the lowest concentration of soil nitrate-N.

Table 17 .Soil nitrate-N (NO_3) by cover crop termination method, Alburgh, VT, 2019.

Termination method	Soil nitrate-N (NO_3, ppm)			
	Late May	Early June	Mid-Late June	Early-Mid July
Tillage	**13.0** [a†]	**33.6** [a]	**44.2** [a]	**46.4** [a]
Pre-spray	9.57 [b]	17.9 [b]	29.3 [b]	39.7 [a]
Post-spray	3.54 [c]	6.75 [c]	12.0 [c]	16.1 [b]
LSD (*p* = 0.10)	3.18	9.05	10.9	10.9
Trial mean	8.71	19.4	28.5	34.1

†Within a column, treatments marked with the same letter were statistically similar (p=0.10). Top performers are in **bold**.

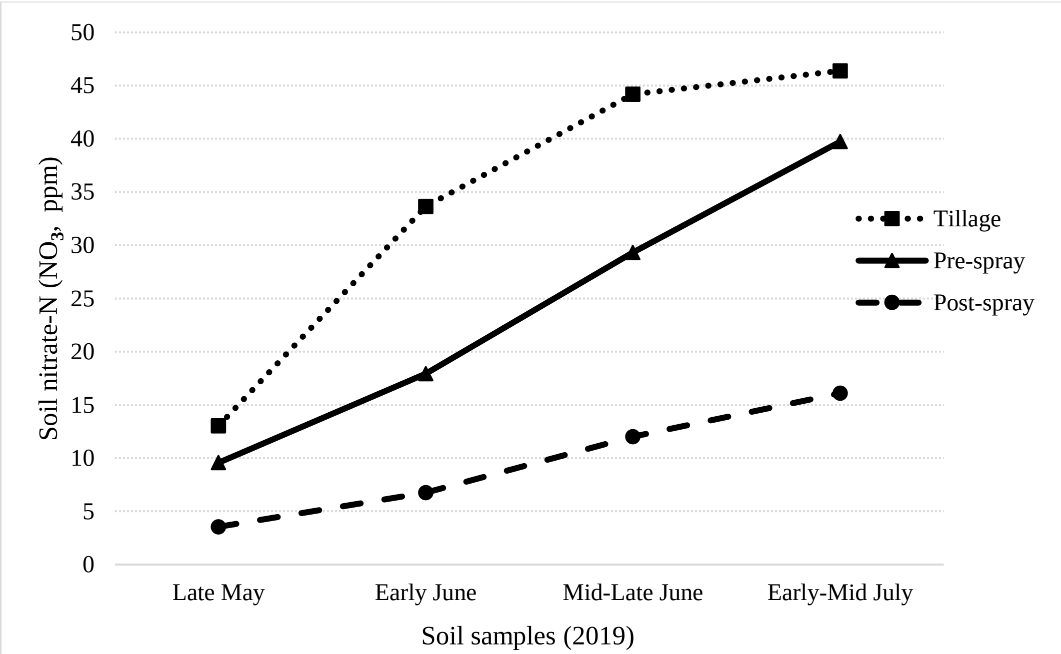

Figure 12. Soil nitrate-N (NO3) concentration by cover crop termination method, 2019.

The concentration of soil nitrate-N starts off low for all treatments at the time of soybean planting in late May and continues to increase through the summer. Concentrations were highest for all treatments by mid-July (Figure 12). The release of nitrogen occurred very gradually in the post-spray treatment, and even by mid-July when soil nitrate-N concentrations peaked for the other two treatments, the concentration was still more than 2.5 times lower in the post-spray treatment. The slower mineralization of cover crop organic matter in herbicide terminated treatments did not impact soybean yields.

In 2019, soybean yields were not significantly impacted by the different cover crop termination methods but there were statistical differences in soybean yield between cover crop treatments. All cover crops treatments were overwintering mixes, but the WR/RC/TR resulted the in highest soybean yields. Interestingly, soil nitrate-N concentrations were not significantly different between the three cover crop treatments, but were significantly impacted by the cover crop termination method. The release of nitrogen from cover crops into the soil was likely due to the timing and method of cover crop termination in the spring. The cover crops that were tilled two weeks prior to soybean planting allowed for a faster release of nitrogen, making it available to the soybeans by mid-July during pod formation. Slower degradation and release of N from herbicide killed cover crops is likely due to the fact that the cover crops are not mixed into the soil and take more time to degrade. The later spray treatment meant that there was even more time for the degradation and release of N. Starter fertilizer was applied at planting to all soybean plots. A greater impact may have been seen had starter fertilizer not been used.

Overall soybean yields in this trial were comparable to the yield of soybeans in other trials conducted at Borderview Research Farm in 2019. These data suggest that soybeans can successfully be grown following an overwintering cover crop and not be negatively impacted by cover crop termination method. It is important to remember that these data represent only one year of research at one location. We will continue to investigate cover cropping practices in soybeans in this region to gain a better understanding of successful cover cropping practices and their impacts on soybean performances. UVM Extension Northwest Crops and Soils Program plans to repeat this trial in 2020.

OUTREACH

Throughout the project period soybean production information was shared with over 370 stakeholders. In February 2019 we held our No-Till Cover Crop Symposium which attracted 135 attendees. At this event, soybean cover cropping research results and experiences were shared with attendees and copies of outreach materials were made available. In July 2019 we hosted our 12th annual Field Day at Borderview Research Farm in which 237 farmers and technical service providers attended. During this event we presented our findings from last year's soybean trials and shared information about our current trials. Time was made available for growers to ask questions and to view the soybean trials in person (Figure 13). Copies of our soybean research reports and summaries from 2019 can be found at the links below.

https://www.uvm.edu/sites/default/files/media/2019_Conventional_Soybean_VT_Report.pdf

https://www.uvm.edu/sites/default/files/media/2019_Soybean_Summary_Tables.pdf

https://www.uvm.edu/sites/default/files/media/2019_Soybean_PD_x_Var_Report_Final.pdf

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2019_Cover_Crop_Termination_Trial.pdf

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2019_Soybean_Cover_Crop_Report.pdf

Figure 13. Visitors investigate the soybean trials during the field day.