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 continued economic and climatic pressures, farmers in the Northeast are looking for ways to increase on-farm feed production and diversity their operations to increase resilience and profitability. Soybeans could be grown for human consumption, animal feed, and biodiesel in the Northeast. However, farmers face challenges due to the relatively short growing season and limited research-based information available in our area. The purpose of our trials is to evaluate soybean yield and quality when planting dates are varied, and under various tillage regimes following fall planted cover crops. Understanding how crops are impacted by varying planting dates and tillage strategies can help producers make important management decisions that lead to better crop success. With a growing concern of agriculturally related water quality implications in 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 soybeans in the region.

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 were 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). The season began with cooler than normal temperatures, but temperatures quickly increased and remained above normal for much of the season. Rainfall was below normal for much of the season with the region being designated as D0 or abnormally dry (Drought.gov) throughout the season. Much of the rain that fell throughout the season came in short duration storms. For example, in August there were 6 rain events that accumulated at least 0.1”. Of these, 2 events totaled 1.53” and 2.98”, contributing 67% of the month’s entire accumulation. Furthermore, temperatures remained above normal for much of the mid-summer. In July, of 75% of the month saw temperatures climb above 80˚F with some days reaching above 90˚F. These temperatures contributed to above normal Growing Degree Day (GDD) accumulations of 2611, 134 above the 30-year normal.

Table 1. Weather data for Alburgh, VT, 2020.

Alburgh, VT	May	June	July	August	September	October
Average temperature (°F)	56.1	66.9	74.8	68.8	59.2	48.3
Departure from normal	-0.44	1.08	4.17	0.01	-1.33	0.19
Precipitation (inches)	2.35	1.86	3.94	6.77	2.75	3.56
Departure from normal	-1.04	-1.77	-0.28	2.86	-0.91	0.00

Growing Degree Days (base 50°F)	298	516	751	584	336	126
Departure from normal	6	35	121	2	-24	-6

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 variety trial included twenty varieties, sourced from four seed companies, spanning maturity ratings 0.7 to 2.1. The trial was planted on 21-May 2020 into a Covington silty clay loam at a rate of 185,000 seeds ac^{-1} treated with soybean inoculant and receiving 5 gal ac^{-1} 9-18-9 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 September. On 17-Sep plots were assessed for severity of infection with downy mildew (*Peronospora manshurica),* brown spot (*Septoria glycines),* frogeye leafspot (*Cerospora sojina*)*,* white mold (*Sclerotinia sclerotiorum),* and damage from chewing insects, primarily Japanese beetles. These were the only pests and diseases observed in the trial. Assessments were made by inspecting each plot and assigning a rating (0-5) where 0 equated to damage/infection not present and 5 equated to infection or damage present on 100% of leaf area. White mold incidence was measured by counting individual affected plants in each plot as the infection primarily was isolated to stems. The percent of each plot experiencing lodging was estimated visually. 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 and test weight meter. Soybean oil was extruded on 14-and 16-Dec using an AgOil M70 oil press and the amount of oil captured and measured to determine oil content and oil yield.

<u>RESULTS</u>

Warm and dry conditions allowed for all soybeans to reach maturity; however moderate drought conditions resulted in some production issues (Table 2). Wildlife pressure was substantial in the trial leading to the loss of several plots and in one case the inability to evaluate the yield performance of a variety entry. Drought conditions appeared to force lots of wildlife into agricultural fields. Harvest moistures ranged from 13.0 to 14.4% indicating that little additional drying was needed for most of the soybeans to reach an adequate moisture level for storage. Test weights ranged from 54.8 to 58.7 lbs bu^{-1}. All soybean varieties produced test weights below the industry standard of 60 lbs bu^{-1}. This was likely influenced by the drought conditions that persisted through the season, especially during critical developmental stages including pod formation and seed fill. Yields ranged from 2765 to 4893 lbs ac^{-1} or 46.1 to 81.6 bu ac^{-1} and averaged 3920 lbs ac^{-1} or 65.3 bu ac^{-1}. Overall the soybeans performed better than in 2019 when the average moisture at harvest was 20.8% and the yield 3640 lbs ac^{-1} or 60.7 bu ac^{-1}. The highest yielding variety in 2020, Dyna-Gro variety S18XT38, performed statistically similarly to 13 other varieties across maturity groups 0.9 to 2.0. These data suggest that soybeans from maturity groups 0-2 can produce high yields in northern climates. However, it is important to note some large differences between varieties even within similar relative maturities. These data highlight the importance of utilizing local variety evaluation information in variety selection. Comparisons between all varieties can be seen in Figure 1 where varieties that share a letter yielded statistically similarly. Soybean oil content also differed significantly by variety ranging from 4.65% to 12.4%. Oil yields ranged dramatically from 187 to 582 lbs ac^{-1} which equates to approximately 24.4 to 76.2 gal ac^{-1}.

Table 2. Harvest characteristics of soybean varieties – Alburgh, VT, 2020.

Company	Variety	Maturity group	Harvest moisture	Test weight	Yield @ 13% moisture		Oil content	Oil yield	
			%	lbs bu^{-1}	lbs ac^{-1}	bu ac^{-1}	%	lbs ac^{-1}	gal ac^{-1}
Pioneer	P07A18X	0.7	13.6*ŧ	56.7	3192	53.2	9.78*	316	41.4
Pioneer	P09A62X	0.9	**13.0**	57.5	4095*	68.2*	6.40	263	34.5
Seedway, LLC	SG 0975	0.9	13.2*	56.7	3949*	65.8*	9.89*	385	50.5
Dyna-Gro	S10XT71	1.0	13.1*	56.2	3826*	63.8*	7.40	287	37.6
Dyna-Gro	S11EN40	1.1	13.5*	57.6*	4433*	73.9*	6.56	290	37.9
Seedway, LLC	SG 1194XT	1.1	13.3*	56.5	4064*	67.7*	10.8*	455*	59.6*
Local Seed Company	LSX1411E3	1.4	14.1	56.2	4222*	70.4*	10.2*	431*	56.4*
Dyna-Gro	S14EN90	1.4	13.6*	56.6	3606	60.1	7.55	278	36.4
Seedway, LLC	SG 1543XT	1.5	13.2*	56.7	3890*	64.8*	5.20	201	26.4
Pioneer	P16A84X	1.6	13.9	55.3	N/Aŧ	N/A	N/A	N/A	N/A
Dyna-Gro	S17EN80	1.7	13.5*	**58.7**	4634*	77.2*	**12.4**	**582**	**76.2**
Seedway, LLC	SG 1776	1.7	13.4*	55.5	3964*	66.1*	9.09*	357	46.8
Local Seed Company	LS1887X	1.8	13.6*	55.5	4222*	70.4*	7.22	316	41.4
Pioneer	P18A98X	1.8	14.4	54.8	3235	53.9	5.07	165	21.6
Dyna-Gro	S18XT38	1.8	13.5*	56.6	**4893**	**81.6**	4.65	227	29.8
Seedway, LLC	SG 1863XT	1.8	13.4*	56.5	3806*	63.4*	5.73	218	28.5
Pioneer	P19A14X	1.9	14.0	55.8	2765	46.1	7.64	213	27.9
Local Seed Company	ZS1999GL	1.9	13.7	55.0	3956*	65.9*	4.66	187	24.4
Seedway, LLC	SG 2055XT	2.0	13.1*	56.9	4427*	73.8*	8.71*	387	50.6
Pioneer	P21A28X	2.1	13.9	55.7	3303	55.0	8.80*	302	39.6
LSD (p = 0.10)			0.689	1.07	p <.001	p <.001	3.72	170	22.3
Trial Mean			13.8	56.2	3920	65.3	7.78	308	40.4

ŧ*Varieties that performed statistically similarly to the top performing variety, identified in **bold,** are indicated with an asterisk.
ŧN/A- yield data are unavailable for this variety due significant wildlife damage.

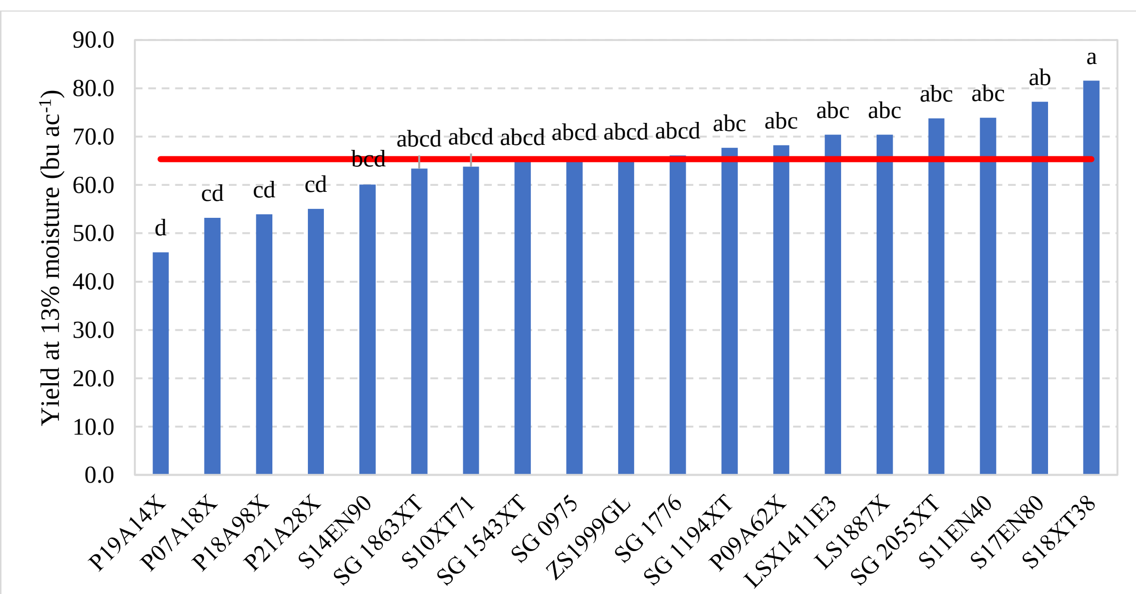

Figure 1. Seed yield at 13% moisture for 19 soybean varieties. The red line indicates the average yield.
**Varieties that share a letter performed statistically similarly to one another at the p=0.10 level.*

Soybeans experienced little arthropod and disease pressure throughout the season (Table 3). Plots were assessed later in the season once more regular rainfall was accumulating. However, the only disease that appeared to differ in severity by variety was downy mildew. Severity of downy mildew infection ranged from 0-2.75 on a scale from 0-5. The variety with the most severe downy mildew was the longest season variety which may have contributed to the plants being leafier and more susceptible to foliar infection later in the season when leaf moisture was present. Minimal lodging was also observed in the trial and did not differ significantly by variety. Looking at stand quality overall you can also see some differences; SG 1194XT experienced lodging and at least moderate levels of infection of all the observed diseases while S18XT38 observed no lodging and only minimal infection of some of the disease. These apparent differences in disease susceptibility are important to consider when selecting a variety as performance may be more severely impacted in wetter years with more disease pressure.

Table 3. Disease and stand characteristics of soybean varieties – Alburgh, VT, 2020.

Company	Variety	Maturity group	Lodging	Downy mildew	Frogeye leaf spot	Septoria brown spot	Sclerotinia white mold
			%	0-5 scale†			Plants plot^{-1}
Pioneer	P07A18X	0.7	0.00	2.00	0.25	1.00	0.00
Pioneer	P09A62X	0.9	0.00	1.00	0.00	1.00	0.00
Seedway, LLC	SG 0975	0.9	25.0	1.00	0.00	1.00	0.00
Dyna-Gro	S10XT71	1.0	0.00	1.25	0.00	1.00	5.00
Dyna-Gro	S11EN40	1.1	0.00	1.25	0.00	1.00	0.75
Seedway, LLC	SG 1194XT	1.1	25.0	1.25	0.75	1.25	1.50
Local Seed Company	LSX1411E3	1.4	50.0	1.50	0.25	1.00	0.00
Dyna-Gro	S14EN90	1.4	0.00	1.50	0.25	1.00	0.25
Seedway, LLC	SG 1543XT	1.5	0.00	1.25	0.00	1.00	0.00
Pioneer	P16A84X	1.6	0.50	1.25	0.25	1.00	0.00
Dyna-Gro	S17EN80	1.7	50.0	1.25	0.00	1.00	2.50
Seedway, LLC	SG 1776	1.7	25.0	0.25*ŧ	0.00	1.00	0.25
Local Seed Company	LS1887X	1.8	0.00	0.25*	0.00	1.00	1.50
Pioneer	P18A98X	1.8	0.00	0.50*	0.25	1.00	0.75
Dyna-Gro	S18XT38	1.8	0.00	0.00	0.25	1.00	1.00
Seedway, LLC	SG 1863XT	1.8	25.0	0.50*	0.00	1.00	0.25
Pioneer	P19A14X	1.9	0.00	2.25	0.25	1.00	0.25
Local Seed Company	ZS1999GL	1.9	25.0	1.25	0.50	1.00	0.75
Seedway, LLC	SG 2055XT	2.0	0.00	2.25	0.00	1.00	0.00
Pioneer	P21A28X	2.1	0.00	2.75	0.00	1.00	0.00
LSD (p = 0.10)			NS¥	0.840	NS	NS	NS
Trial Mean			0.152	1.15	0.174	1.01	0.891

†0 to 5 scale; rating of 0 = no infection or damage and rating of 5 = 100% infection or damage.
ŧ*Varieties that were not significantly different from the top performing variety are indicated with an asterisk.
¥ NS; no significant difference amongst treatments at the p=0.10 level.

Overall, soybean varieties performed very well averaging over 65 bu ac^{-1} despite very droughty conditions through much of the season. Under these conditions, all soybean varieties, ranging in relative maturity from 0.7 to 2.1, reached maturity and dried down to under 15% moisture. This is significantly lower than in 2019, which also saw drought conditions, in which the soybeans only reached an average of 20.8% moisture.

Although little pest and disease pressure was observed, some differences were still observed and highlight the importance of local variety evaluation in soybean variety selection. Overall, these data suggest that soybeans in maturity groups 0, 1, and 2 can produce high yields under conventional management in far northern climates. It is important to remember that these data only represent one year at one location and therefore should not solely be used to make management decisions. Data gathered from the last 4 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 2).

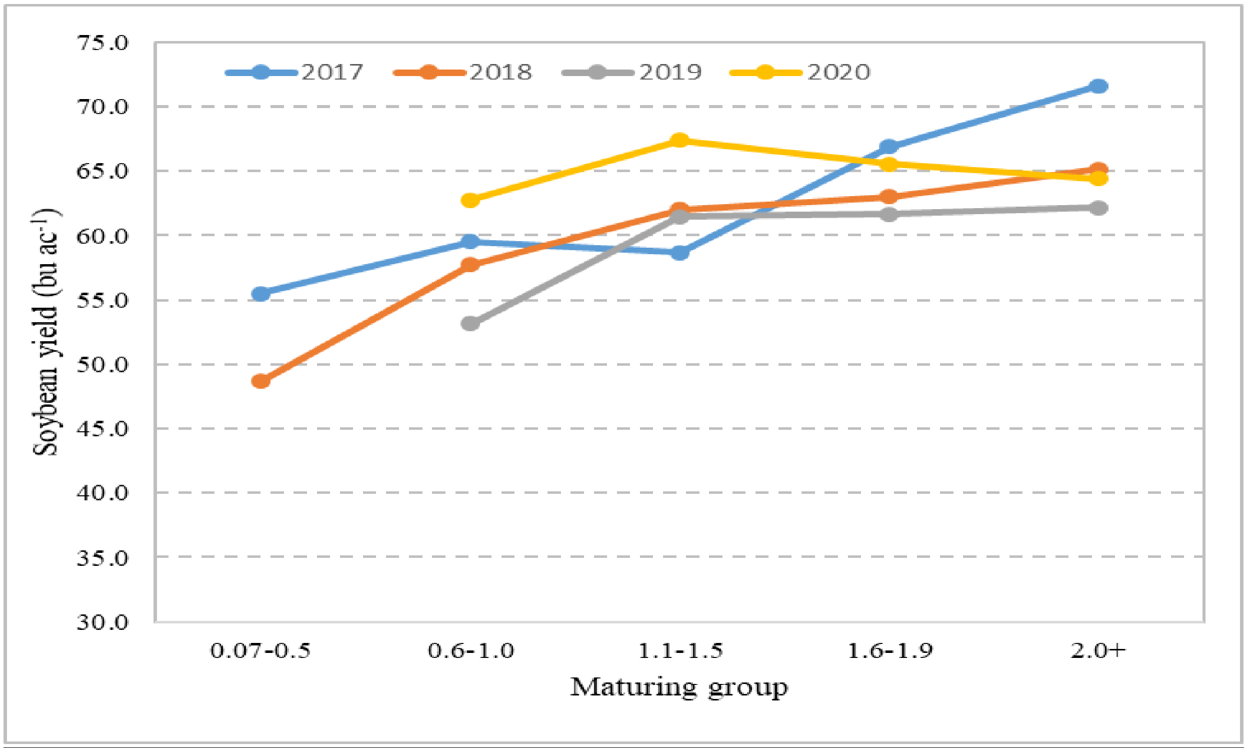

Figure 2. Soybean yield across maturity grouping from 2017 to 2020.

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 approximately weekly from 14-May through 2-Jul 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 9-Jun, early planting dates were scouted for slug damage, however no damage was observed. Plots were assessed on 6-

Aug and 15-Sep for growth stage, lodging, and pest/disease incidence. No major pest or diseases were observed so a formal scouting was not conducted. On 14-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.

<u>RESULTS</u>

Impact of Relative Maturity x Planting Date Interactions

There was a significant relative maturity x planting date interaction for yield, harvest moisture, and test weight indicating that the maturities responded differently in terms of these variables when planted on different dates. Generally, as planting dates become later, farmers must modify varieties, selecting relative maturities to fit the remaining length of the growing season. Hence, with later planting dates generally shorter season varieties begin to outperform longer season types. Although this trend was not observed in our 2018 and 2019 trials, in 2020 we saw soybeans in the early (0.9) maturity group produce higher test weight soybeans across all but the latest planting dates where they were more similar to the test weights of the late (1.7) maturity group (Figure 3). The highest test weight was obtained by planting the early maturing variety on the third planting date and the late maturing variety on the second planting date. The drop in test weight observed in both varieties planted after the fifth planting date is likely due to the relation of drought conditions to soybean growth stages associated with higher water demand including seed fill. Earlier planted soybeans reached these critical stages prior to the most severe conditions avoiding some of the damage to soybean test weights. Overall, however, all test weights were below the industry standard of 60 lbs bu^{-1} demonstrating the impact the dry conditions had on soybeans regardless of planting date. This was further exacerbated by early frost which also likely contributed to reduced test weights in later planted soybeans that were in earlier growth stages at the time.

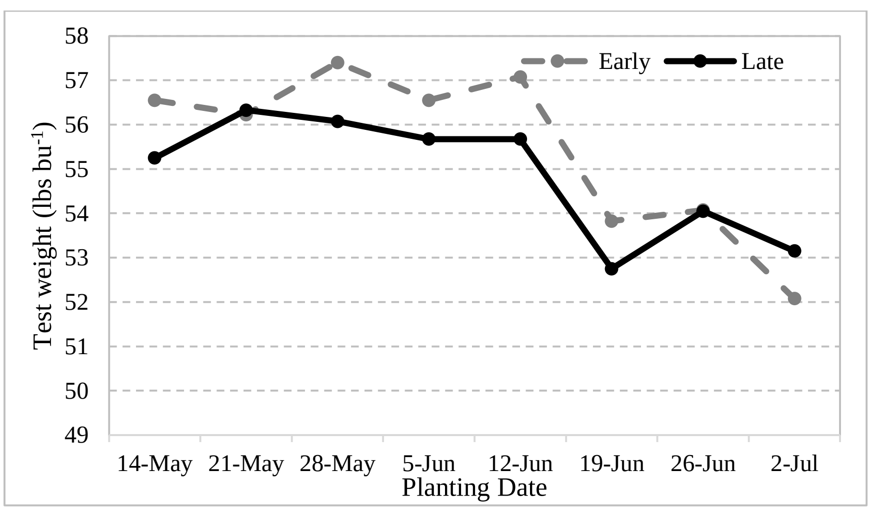

Figure 3. Soybean relative maturity x planting date interaction for test weight, 2020.

The significant interaction between relative maturity and planting date for harvest moisture indicates that soybeans of different maturity groups produced different responses in terms of harvest moisture to altering planting dates (Figure 4). Soybean harvest moisture is related to the plant's ability to reach physiological maturity thus reducing seed moisture content at the time of harvest. Therefore, we'd expect shorter season varieties to begin to outperform longer season varieties as planting dates are delayed. However, this is not the trend we observed in 2020. As planting dates were delayed, both the early and late maturity group varieties experienced a decline in harvest moisture until the 6th planting date, after which time the harvest moistures greatly increased.

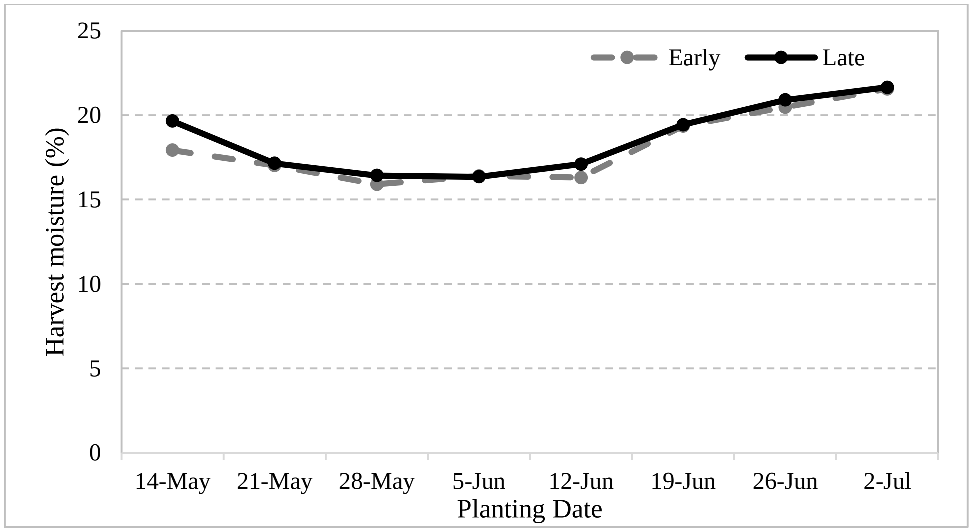

Figure 4. Soybean relative maturity x planting date interaction for harvest moisture, 2020.

The significant interaction between relative maturity and planting date for yield indicates that soybeans of different maturity groups have different yield responses to delaying planting dates (Figure 5). We would expect shorter season varieties to begin to out yield longer season varieties as planting dates are delayed. However, that is not what we observed in this trial. Although we did see the later maturing variety out yielding the early maturing variety in early planting dates, both varieties experienced significant yield declines as planting dates were delayed beyond mid-June and the early maturing variety did not outperform the late maturing variety at these dates. This indicates that, even for shorter season varieties, delaying planting until late June or later will have a significant impact on soybean yields. This was likely impacted by the early frost that negatively affected both maturities despite adequate GDDs. The extremely low yields experienced in the first two planting dates was likely due to an error in herbicide application that contributed to damage to early planted treatments, not a factor or the planting date itself.

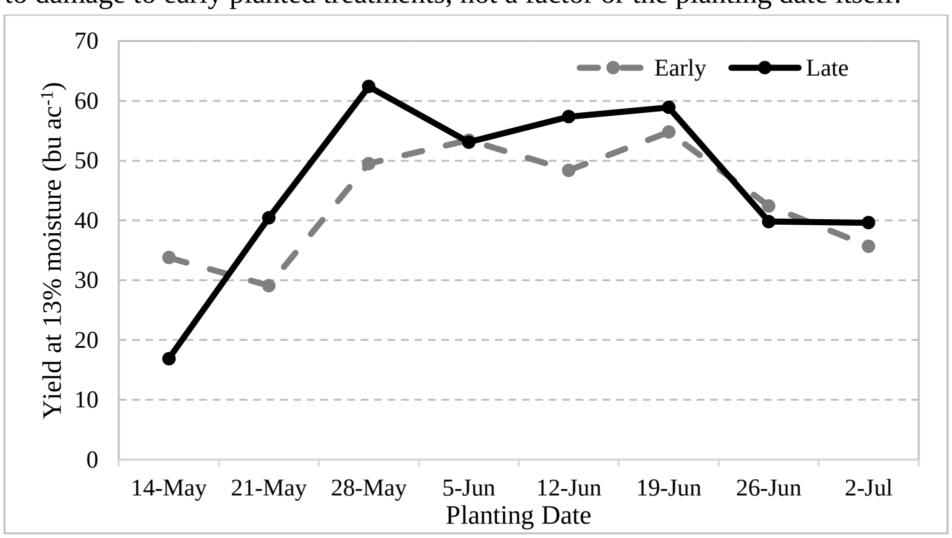

Figure 5. Soybean relative maturity x planting date interaction for yield, 2020.

Impact of Variety

The two soybean maturities performed significantly different in terms of harvest moisture and test weight but were statistically similar in all other harvest characteristics (Table 4). Moisture at harvest was 0.5% lower in the short season variety, however, both varieties were above a safe storage moisture and required additional drying prior to storage. Similar moisture content between maturity groups suggests that both the longer and shorter season varieties reached similar maturity by the time of harvest. Test weights varied slightly between varieties with the earlier maturing variety producing seed with a test weight of 0.6 lbs bu^{-1} higher than the later maturing variety. However, both were below the target of 60 lbs bu^{-1} likely due to low rainfall throughout the growing season and also an early frost leading to reduced seed fill. Yields averaged 2683 lbs ac^{-1} or 44.7 bu ac^{-1} and did not differ statistically between the two varieties. Oil content and oil yield also did not differ between varieties. Oil content averaged 10.8% while oil yield averaged 288 lbs ac^{-1} or 37.7 gal ac^{-1}.

Table 4. Harvest characteristics of soybeans by variety, 2020.

Variety	Maturity group	Harvest moisture	Test weight	Yield @ 13% moisture		Oil content	Oil yield	
		%	lbs bu^{-1}	lbs ac^{-1}	bu ac^{-1}	%	lbs ac^{-1}	gal ac^{-1}
SG0975	0.9	18.1	55.5	2603	43.4	11.3	295	38.6
SG1776	1.7	18.6	54.9	2763	46.1	10.3	281	36.8
LSD (p = 0.10)†		0.302	0.404	NSŧ	NS	NS	NS	NS
Trial Mean		18.3	55.2	2683	44.7	10.8	288	37.7

†LSD: least significant difference at the p=0.10 level.
ŧ NS; no significant difference amongst treatments at the p=0.10 level.

Impact of Planting Date

Soybean planting dates performed statistically differently in all harvest characteristics except for oil content (Table 5). Harvest moistures ranged from 16.2% to 21.6% with lower moistures being produced when planting dates ranged between 21-May through 12-Jun. Test weights ranged from 52.6 to 56.7 lbs bu^{-1}. Higher test weights were produced when soybeans were planted between 21-May through 12-Jun, however, all planting dates produced soybeans with test weights below the industry standard of 60 lbs bu^{-1}. Planting date also significantly impacted soybean yield (Figure 6).

Table 5. Harvest characteristics of soybeans by planting date, 2020.

Planting date	Harvest moisture	Test weight	Yield @ 13% moisture		Oil content	Oil yield	
	%	lbs bu^{-1}	lbs ac^{-1}	bu ac^{-1}	%	lbs ac^{-1}	gal ac^{-1}
14-May	18.8	55.9	1519	25.3	**13.8**	216	28.3
21-May	17.1	56.3*	2086	34.8	10.8	221	28.9
28-May	**16.2†**	**56.7**	3357*	56.0*	10.3	361*	47.3*
5-Jun	16.4*ŧ	56.1*	3195*	53.3*	11.3	360*	47.2*
12-Jun	16.7*	56.4*	3172*	52.9*	10.9	344*	45.0*
19-Jun	19.4	53.3	**3411**	**56.9**	10.9	**365**	**47.8**
26-Jun	20.7	54.1	2467	41.1	9.80	241*	31.6*
2-Jul	21.6	52.6	2259	37.6	8.73	196	25.6
LSD (p = 0.10)	0.604	0.808	480	8.00	NS ¥	126	16.5
Trial mean	18.3	55.2	2683	44.7	10.8	288	37.7

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

Soybean yields ranged from 1519 to 3411 lbs ac^{-1} or 25.3 to 56.9 bu ac^{-1} with the highest yields being obtained when planting between 28-May and 19-Jun. However, the first two planting date yields were likely negatively impacted by an erroneous herbicide application. These data suggest that delaying planting to late June and beyond negatively impacts soybean yields in this region. However, some of the later dates may not support such high yields in years where weather conditions are less conducive to soybean productivity.

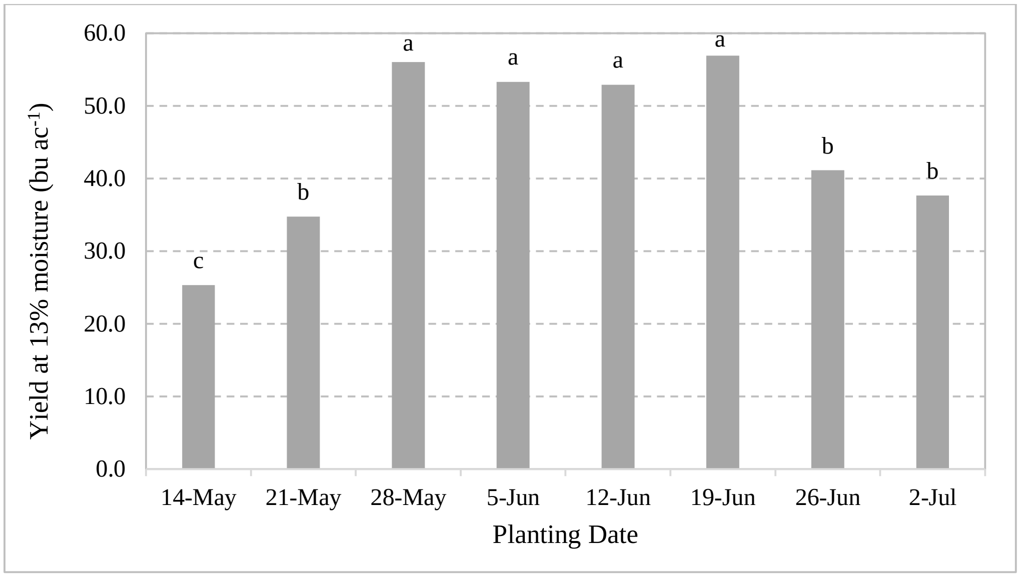

Figure 6. Soybean yield across eight planting dates, 2020.
Treatments that share a letter were statistically similar at the p=0.10 level.

In 2020, soybean yields were significantly impacted by planting date with the highest yields observed when soybeans were planted between late-May and mid-June. These data suggest that delaying planting of soybeans beyond this is likely to result in depressed yields. After evaluating planting date of soybeans in the northern regions from 2017 to 2020, it can be summarized that planting late-May into early-June generally always resulted in the highest yields. Planting earlier or later in all years provided additional risks. Only in 2018, did planting before late-May result in significantly higher yields compared to other dates.

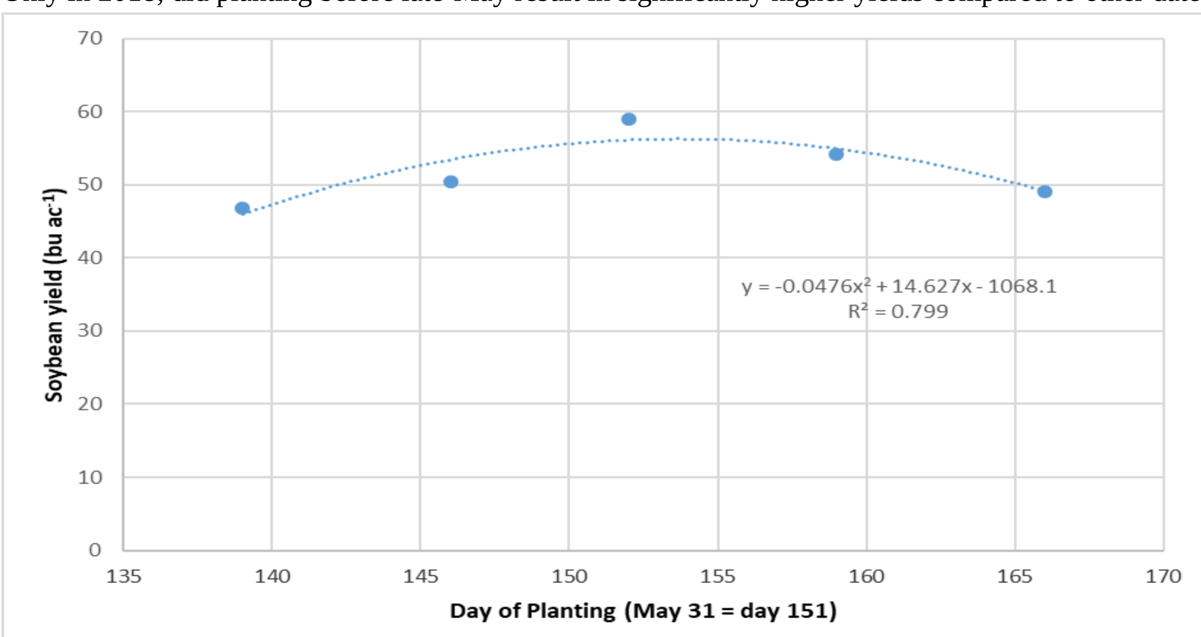

Figure 7. Soybean yield across years (2017-2020) by planting date.

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

The goals of this trial were: 1) to investigate the impact of various cover crop species and mixtures on subsequent soybean yield and quality, as well as nutrient and soil health dynamics, and 2) investigate the impact of termination methods on soybean yields and quality. For simplicity, methods and results will be presented for these objectives separately.

Impact of Cover Crops on Subsequent Soybean Yields

MATERIALS AND METHODS

The treatments were 10 cover crop monocultures or mixtures planted on 20-Aug 2019. Treatments consisted of cover crops that would over winter and others that would be terminated by winter conditions. Cover crop treatments and seeding rates are listed in Table 6. Fall biomass samples were collected on 29-Oct 2019 from a $0.25m^2$ area in each plot. Samples were weighed prior to and after drying to determine dry matter yield. On 28-Apr 2020, cover crop height and ground cover were measured in all plots. Ground cover was assessed using the beaded string method allowing for distinction between living and dead cover (Sloneker and Moldenhauer, 1977). Soil health samples were also collected from all plots and air-dried and prior to being sent to the Cornell Soil Health Laboratory (Ithaca, NY) for analysis. On 5-May cover crop biomass was measured for plots containing living cover crop biomass using the same sampling protocol as in the fall. All cover crop treatments were terminated on the 14-May using a moldboard plow and disc harrow.

On 12-Jun 2020, the soybeans were planted into the terminated cover crop treatments using a John Deere 1750 MaxEmerge 4-row corn planter at 185,000 seeds ac^{-1} treated with soybean inoculant and 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 following planting 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.

Table 6. Cover crop treatments, 2020.

Species	**Variety**	**Over-winters?**	**Seeding rate** lbs. ac^{-1}
Annual ryegrass	Centurion	No	25
Radish	Daikon		3
Oats	Everleaf 125	No	75
Radish	Daikon		3
Oats	Everleaf 125	No	75
Crimson clover	Diogene		10
Oats	Everleaf 125	No	125
Annual ryegrass	Centurion	No	30
Crimson clover	Diogene	No	15

Radish	Daikon	No	6
Triticale	Trical815	Yes	100
Winter rye	VNS	Yes	100
No cover		No	N/A

RESULTS

In the fall, cover crop treatments differed significantly in dry matter yield (Table 7). Fall dry matter yield ranged from 0.31 tons ac^{-1} (Control) to1.80 tons ac^{-1} (Oats), and the trial average was 1.26 tons ac^{-1}. The highest yielding treatment, oats, was statistically similar to three other treatments (Oat/radish, Annual ryegrass/radish, and Oat/crimson clover). All cover crop treatments had fall yields that were significantly greater than the control. In the spring, the winter rye had the highest biomass, 2.07 tons ac^{-1}, which was statistically greater than all other treatments. The triticale produced the second highest spring biomass, 1.73 tons ac^{-1}. Typically, in the region, annual ryegrass is winter-killed, but mild winter conditions allowed for the cover crop to survive into the spring. The annual ryegrass and the annual ryegrass/radish treatments produced 1.00 tons ac^{-1} and 0.66 tons ac^{-1} respectively. All other treatments were winter-killed and did not produce any spring biomass. The cover crop treatment had no statistically significant impact on soybean yield or test weight in 2020. Soybean yield ranged from 3334 lbs. ac^{-1} (Oat/crimson clover) to 3696 lbs.ac^{-1} (Winter rye), and the trial average was 3486 lbs. ac^{-1}. The average test weight was 56.6 lbs. bu^{-1}.

Table 7. Cover crop and soybean harvest characteristics, 2019-2020.

Cover crop treatment	**Over-winters**	**Dry matter yield**		**Soybean harvest 2020**	
		Fall 2019	Spring 2020	Yield at 13% moisture	Test weight
		tons ac^{-1}		lbs. ac^{-1}	lbs. bu^{-1}
Annual ryegrass, radish	No†	1.57^{ab‡}	0.66^{d}	3422	56.7
Oats, radish	No	1.71^{ab}	0.00^{e}	3445	56.6
Oats, crimson clover	No	1.56^{ab}	0.00^{e}	3334	56.6
Oats	No	**1.80^{a}**	0.00^{e}	3482	56.8
Annual ryegrass	No†	1.44^{bc}	1.00^{c}	3353	56.3
Crimson clover	No	1.26^{c}	0.00^{e}	3613	56.5
Radish	No	1.23^{cd}	0.00^{e}	3451	**57.0**
Triticale	Yes	0.77^{e}	1.73^{b}	3499	56.4
Winter rye	Yes	0.94^{de}	**2.07^{a}**	**3696**	56.6
No cover	No	0.31^{f}	0.00^{e}	3569	56.8
LSD (p = 0.10)		0.303	0.26	NS¥	NS
Trial mean		1.26	0.55	3486	56.6

†Generally, annual ryegrass does not over winter in our region, however, more mild than usual conditions through the winter allowed the treatments containing annual ryegrass to survive into the spring of 2020.
‡Within a column, treatments marked with the same letter were statistically similar. Top performers are in **bold.**
¥NS; No significant difference between treatments at the p=0.10 level.

Soils were analyzed for soil nitrate-N (NO_3) concentration starting from mid-May through the end of June (Table 8, Figure 8). Overall, soil nitrate-N (NO_3) was highest in plots that had the radish cover crop treatment. The radish treatment had significantly greater soil NO_3-N than all other treatments on three of the soil sample dates (12-May, 19-May, and 15-Jun).

Table 8. Soil nitrate-N (NO_3) concentration (ppm) by cover crop treatment, Alburgh, VT, 2020.

Cover crop treatment	**Over-winters**	**Soil NO_3 (ppm)**				
		12-May	19-May	2-Jun	15-Jun	29-Jun
Annual ryegrass, radish	No[†]	7.15[b‡]	7.49[c]	12.6[ab]	22.8[b]	20.3[b]
Oats, radish	No	7.77[b]	10.1[b]	12.4[ab]	22.1[bc]	20.7[ab]
Oats, crimson clover	No	6.26[b]	6.96[cd]	10.8[bc]	16.2[de]	17.0[bc]
Oats	No	7.64[b]	7.65[c]	10.6[bc]	18.0[cd]	16.1[bc]
Annual ryegrass	No[†]	3.63[c]	5.20[de]	9.00[c]	14.9[de]	13.4[c]
Crimson clover	No	2.99[c]	5.78[cde]	10.9[bc]	19.1[bcd]	16.1[bc]
Radish	No	**9.90[a]**	**12.5[a]**	**15.5[a]**	**31.8[a]**	**26.8[a]**
Triticale	Yes	2.64[c]	4.60[e]	8.72[c]	12.8[e]	14.8[bc]
Winter rye	Yes	2.54[c]	4.74[e]	10.3[bc]	11.9[e]	15.3[bc]
No cover	No	2.53[c]	5.07[de]	9.63[bc]	14.7[de]	18.4[bc]
LSD (p = 0.10)	N/A	2.03	1.96	3.26	4.44	6.23
Trial mean		5.31	7.01	11.1	18.4	17.9

†Generally, annual ryegrass does not over winter in our region, however, more mild than usual conditions through the winter allowed the treatments containing annual ryegrass to survive into the spring of 2020.
‡Within a column, treatments marked with the same letter were statistically similar. Top performers are in **bold.**
N/A – No statistical analysis run on this parameter.

On 2-Jun and 29-Jun, the radish treatment was statistically similar to the cover crop mixtures that contained radish (oat/radish and annual ryegrass/radish). Overall, the annual ryegrass/radish and oats/radish treatments both had relatively high soil NO_3-N concentrations, and had the second and third highest soil NO_3 concentrations on 2, 15, and 29-Jun. The two overwintering cover crop treatments, triticale and winter rye, had some of the lowest soil NO_3-N concentrations. On all five dates, both triticale and winter rye treatments had soil NO_3-N concentrations that were not significantly different than the control. Plots that had the annual ryegrass treatment had soil NO_3-N concentrations similar to the two overwintering species.

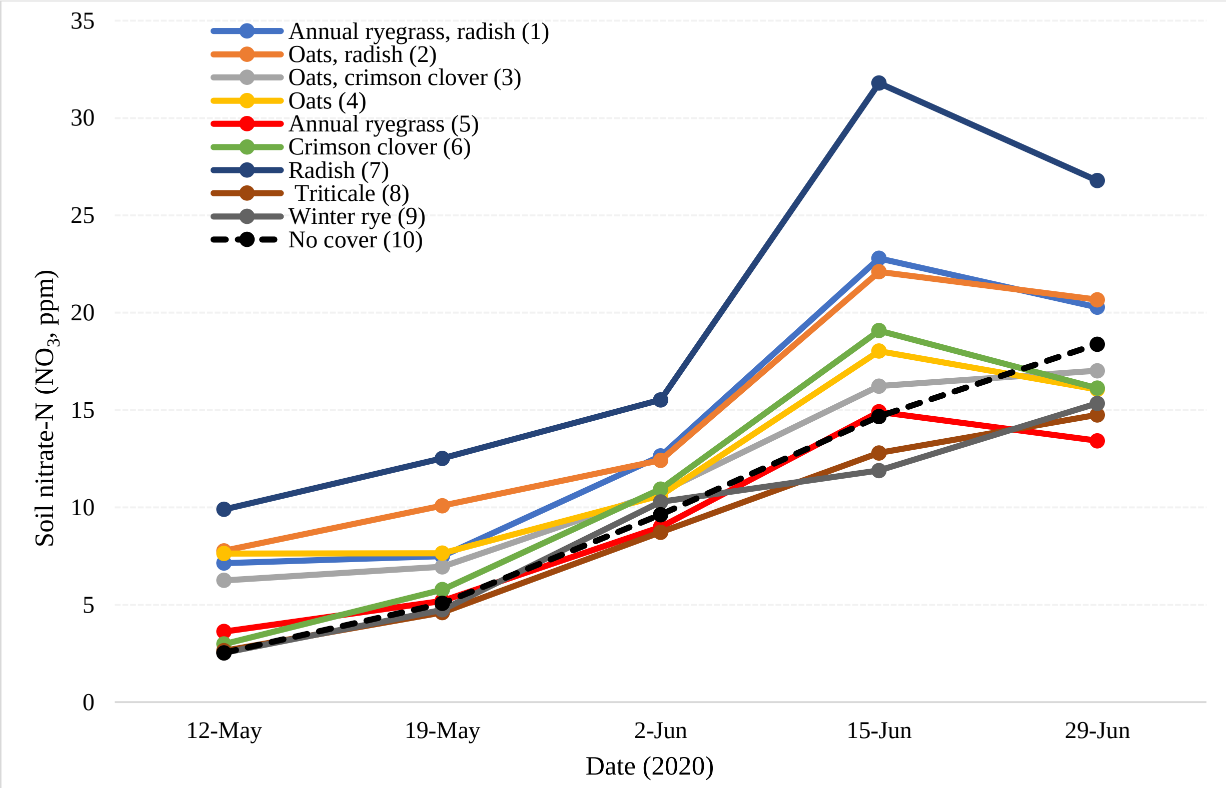

Figure 8. Soil nitrate-N (NO_3) concentration (ppm) by cover crop treatment, Alburgh, VT, 2020.

Table 9 below displays the impact of cover crop type (overwinter vs. winterkill) on soybean yield over the past four years. 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. In 2019 the trend was similar to that of 2018. This year, the results were similar to the previous two years, although the difference in soybean yield was only 0.2 bu. ac^{-1} less in plots that had an overwintering cover crop. This yield difference was less than in the past three years. In 2020, the overwintering cover crops were incorporated into the soil approximately one month prior to planting the soybeans. This time between cover crop termination and planting of the cash crop may limited the impact on the cash crop.

Table 9. Soybean yield by cover crop type, Alburgh, VT.

Overwinter	**Soybean yield** (bu. ac^{-1})			
	2017	2018	2019	2020
Yes	60.4	61.1	72.3	65.9
No	**67.9**	**63.9**	**79.0**	**66.1**
p value	0.007	NS†	NS	NS
Trial mean	64.2	62.6	76.3	66.0

The top performers are in **bold.**
†NS; No significant difference between treatments.

Cover Crop Termination Methods for Soybean Cropping Systems

MATERIALS AND METHODS

Treatments included three tillage termination methods and two over wintering cover crops (Tables 10 and 11). On 28-Apr 2020, cover crop height and ground cover were measured in each plot. The beaded string method (Sloneker and Moldenhauer, 1977) was employed so that cover could be attributed to living and/or dead plant biomass. On 5-May and 19-May cover crop biomass was measured prior to termination in the plow and herbicide terminated treatments respectively. 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. To understand the nutrient release rates of the different cover crop treatments and how this is impacted by termination method, soil nitrate and moisture content were assessed in each plot prior to termination and biweekly following termination and planting. On 22-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. An herbicide application error caused the replanting of the soybeans in the tillage terminated plots on 12-Jun 2020. 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.

Table 10. Cover crop termination treatments, 2020.

Treatment	Cover crop termination details
Tillage (9-May)	Tilled under with moldboard plow and disc harrow prior to soybean planting
Pre-spray (9-May)	Sprayed with Roundup PowerMAX® at 1qt ac^{-1} prior to soybean planting
Post-spray (23-May)	After soybeans were planted, cover crop was sprayed with Roundup PowerMAX® at 1qt ac^{-1}

Table 11. Overwintering cover crop mixtures grown prior to soybean crop, Alburgh, VT, 2020.

Treatment	Species	Variety	Seeding rate lbs ac^{-1}
Tr	Triticale	Trical815	100
WR	Winter rye	VNS	100

RESULTS

Prior to cover crop termination and subsequent soybean planting, the spring soil coverage and cover crop dry matter yield were measured (Table 12, Figure 9). There was no significant difference in spring soil coverage between the termination methods. The soil coverage provided by living biomass, dead biomass, and total combined were 88.6%, 4.82%, and 93.4% respectively. Cover crop biomass was significantly different between treatments, prior to termination. The tillage treatment had the most spring cover crop dry matter, 2.24 tons ac^{-1}, and was statistically similar to the post-spray treatment, 2.16 tons ac^{-1}. Soybean yield was statistically different between the termination methods. The pre-spray treatment had the highest subsequent soybean yield with 4287 lbs. ac^{-1} or 71.5 bu. ac^{-1}; the tillage treatment (3952 lbs. ac^{-1} or 65.9 bu. ac^{-1}) was statistically similar to the pre-spray treatment. There was no significant difference in soybean test weight between the cover crop termination methods. The trial average was 56.5 lbs. bu^{-1}.

Table 12. Cover crop and soybean harvest characteristics by termination method, Alburgh, VT, 2020.

Termination method	Prior to cover crop termination				Soybean harvest		
	Spring soil coverage			Cover crop dry matter yield	Yield at 13% moisture		Test weight
	Living biomass	Dead biomass	Total				
	%			tons ac^{-1}	lbs ac^{-1}	bu ac^{-1}	lbs bu^{-1}
Tillage	90.7	4.90	**95.6**	**2.24**[a]†	3952[a]	65.9[a]	56.5
Pre-spray	84.1	**8.33**	92.4	1.31[b]	**4287**[a]	**71.5**[a]	**56.6**
Post-spray	**90.9**	1.23	92.2	2.16[a]	2555[b]	42.6[b]	56.4
LSD (p = 0.10)‡	NS§	NS	NS	0.618	687.8	11.5	NS
Trial mean	88.6	4.82	93.4	1.90	3597	60.0	56.5

†Within a column, treatments marked with the same letter were statistically similar (p=0.10).
‡LSD; Least significant difference at the p=0.10.
§NS; No significant difference between treatments.

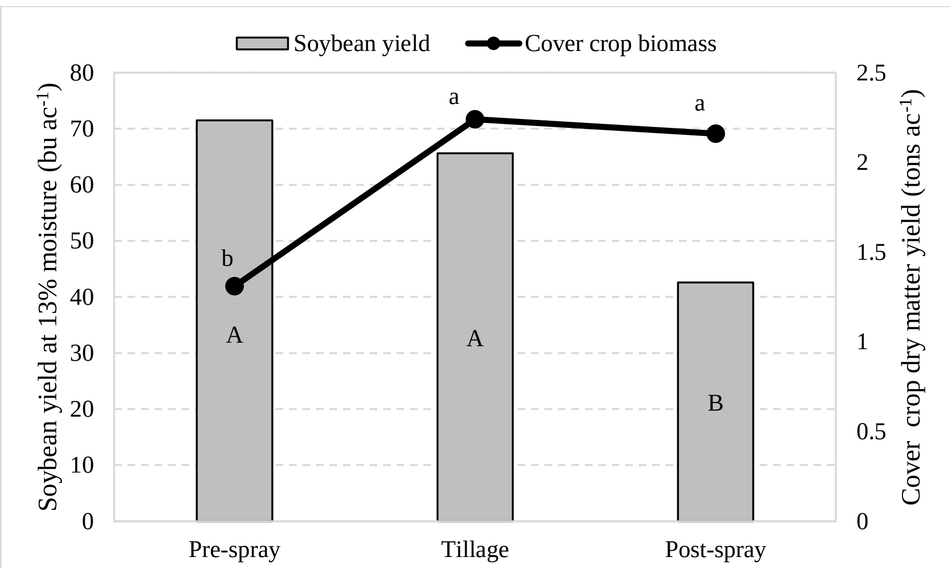

Figure 9. Soybean yield and spring cover crop biomass by termination method, Alburgh, VT, 2020.
Different letters indicate a statistically significant difference between treatments (p=0.10)

Prior to cover crop termination, there was no significant impact of cover crop type on spring soil cover or cover crop dry matter yield (Table 13). The soil coverage contributed by living biomass, dead biomass, and total combined were 85.6%, 4.82%, and 93.4% respectively. The average cover crop dry matter was 1.90 tons ac^{-1}. There was also no significant impact of cover crop treatment on the subsequent soybean harvest. Average soybean yield for this season was 3598 lbs. ac^{-1} or 60.0 bu. ac^{-1} and test weight was 56.5 lbs. bu^{-1}.

Table 13. Cover crop and soybean harvest characteristics by cover crop mixture, Alburgh, VT, 2020.

Treatment	Species	Prior to cover crop termination				Soybean harvest		
		Spring soil coverage			Cover crop dry matter yield	Yield at 13% moisture		Test weight
		Living biomass	Dead biomass	Total				
		%			tons ac^{-1}	lbs. ac^{-1}	bu. ac^{-1}	lbs. bu^{-1}

Tr	Triticale	**90.7**	3.60	**94.3**	1.73	3499	58.3	56.4
WR	Winter rye	86.4	**6.05**	92.5	**2.07**	**3696**	**61.6**	**56.6**
LSD (p = 0.10)‡		NS§	NS	NS	NS	NS	NS	NS
Trial mean		85.6	4.82	93.4	1.90	3598	60.0	56.5

‡LSD; Least significant difference at the p=0.10.
§NS; No significant difference between treatments.

About one week after soybeans were planted, soil moisture and temperature were measured every week for eight weeks. Soil moisture was significantly higher in the tillage treatment than in the pre-spray and post-spray treatment (Table 14). The pre-spray treatment had significantly higher soil moisture than the post-spray treatment on 2-, 9-, and 15-Jun. There were no differences in soil moisture between the pre-and post-spray treatments on the remaining five dates. It is possible that the soil moisture was lower in pre- and post-spray treatments because the overwintering cover crops had more time to grow in the spring, removing some of the soil moisture. In a normal year this may not impact the cash crop, but in a dry year, especially with a season-long drought, there could be negative impacts on soybean yield. The tillage treatment had significantly higher soil temperature on all dates (Table 15); the pre-and post-spray treatments were not statistically different from one another on 13- and 21-Jul. It makes sense that soil temperatures were lower in the pre- and post-spray treatments because the cover crop was sprayed but left unincorporated to act as a mulch, protecting soil microbes and preventing the soil from further drying out.

Table 14. Soil moisture by cover crop termination method, Alburgh, VT, 2020.

Termination method	Soil moisture							
	2-Jun	9-Jun	15-Jun	23-Jun	29-Jun	7-Jul	13-Jul	21-Jul
	%							
Tillage	**20.5[a]**†	**21.7[a]**	**22.4[a]**	**24.8[a]**	**22.2[a]**	**12.5[a]**	**24.6[a]**	**14.6[a]**
Pre-spray	15.7[b]	15.9[b]	16.0[b]	12.7[b]	11.8[b]	7.91[b]	17.6[b]	9.91[b]
Post-spray	11.6[c]	12.6[c]	13.7[c]	12.2[b]	10.9[b]	8.13[b]	16.1[b]	8.81[b]
LSD (p = 0.10)‡	1.06	0.951	1.09	1.57	1.55	1.17	1.56	1.12
Trial mean	15.9	16.7	17.4	16.6	15	9.51	19.5	11.1

†Within a column, treatments marked with the same letter were statistically similar (p=0.10).
‡LSD; Least significant difference at the p=0.10.
§NS; No significant difference between treatments.

Table 15. Soil temperature by cover crop termination method, Alburgh, VT, 2020.

Termination method	Soil temperature							
	2-Jun	9-Jun	15-Jun	23-Jun	29-Jun	7-Jul	13-Jul	21-Jul
	°F							
Tillage	**55.6[a]**†	**65.9[a]**	**61.4[a]**	**77.7[a]**	**72.6[a]**	**75.1[a]**	**75.7[a]**	**74.3[a]**
Pre-spray	55.3[b]	64.3[c]	59.1[c]	75.7[c]	71.4[b]	72.1[b]	74.8[b]	72.7[b]
Post-spray	55.1[c]	64.8[b]	59.8[b]	76.4[b]	70.8[c]	71.4[c]	75.0[b]	72.9[b]
LSD (p = 0.10)‡	0.24	0.175	0.23	0.335	0.264	0.42	0.36	0.33

Trial mean	55.3	65	60.1	76.6	71.6	72.9	75.2	73.3

†Within a column, treatments marked with the same letter were statistically similar (p=0.10).
‡LSD; Least significant difference at the p=0.10.
§NS; No significant difference between treatments.

Soils were analyzed for soil nitrate-N (NO_3) concentration starting from 12-May (a week prior to soybean planting) through the end of June (Table 16, Figure 10). There were no statistical differences in soil NO_3-N between the three termination methods on 12-May. From 19-May through 29-Jun, the tillage treatment had the greatest amount of soil nitrate-N and was significantly greater than both the pre- and post-spray treatments on all four dates. The pre-spray treatment had significantly greater soil NO_3 than the post- spray treatment on 19-May and 29-Jun. On 15-Jun, there was spike in soil NO_3-N in the post-spray treatment, making it significantly higher than the pre-spray treatment. Cover crops take up nutrients like nitrogen and store it in plant biomass, as seen with the pre- and post-spray treatments. For comparison, the plow down of cover crops releases that nitrogen by putting the soil in contact with the biomass and allowing for the decomposition of the plant material.

Table 16. Soil nitrate-N (NO_3) by cover crop termination method, Alburgh, VT, 2020.

Termination method	Soil nitrate-N (NO_3, ppm)				
	12-May	19-May	2-Jun	15-Jun	29-Jun
Tillage	5.11	**11.1^{a}**†	**16.5^{a}**	**23.7^{a}**	**27.9^{a}**
Pre-spray	**5.97**	5.82^{b}	9.2^{b}	12.8^{c}	16.1^{b}
Post-spray	4.83	4.13^{c}	7.47^{b}	18.8^{b}	9.66^{c}
LSD (p = 0.10)‡	NS§	1.08	1.78	2.43	3.41
Trial mean	5.31	7.01	11.1	18.4	17.9

†Within a column, treatments marked with the same letter were statistically similar (p=0.10).
‡LSD; Least significant difference at the p=0.10.
§NS; No significant difference between treatments.

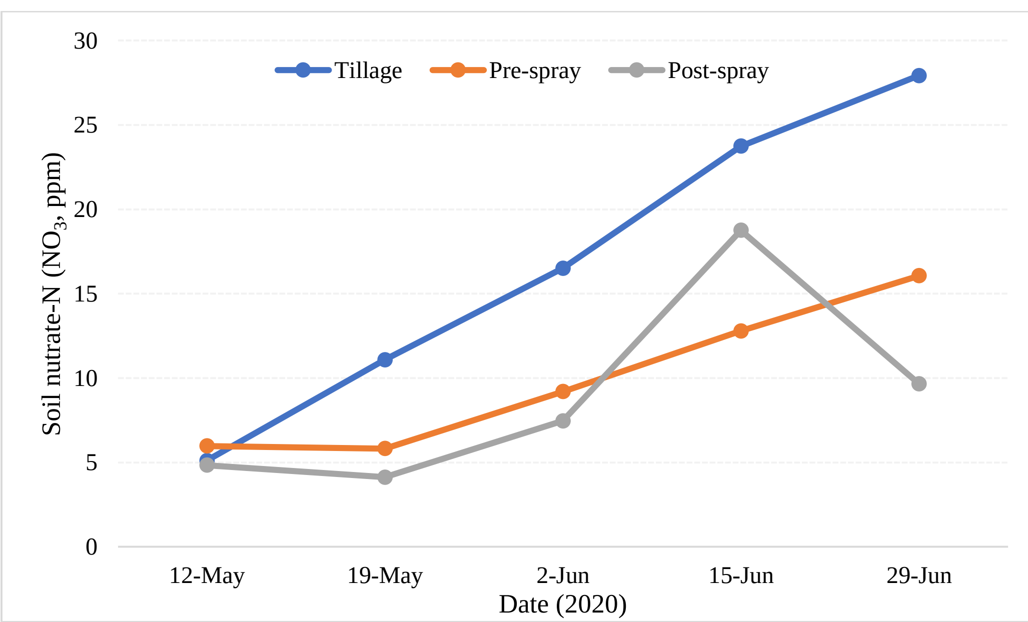

Figure 10. Soil nitrate-N (NO_3) concentration by cover crop termination method, 2020.

In 2020, while the season started out cooler than normal, it quickly became warmer than average for most of the season. Rainfall was below average throughout the growing season, and the precipitation came in short duration storms. The cover crop species did not have an impact on the spring soil coverage or cover crop dry matter yield prior to termination, nor did the cover crop type impact soybean yield or quality. Prior to cover crop termination, there were no significant differences in spring soil coverage amongst the plots that would be tilled, sprayed prior to, or sprayed after soybean planting. However, cover crop dry matter was statistically different. The plots that would be tilled had the greatest dry matter yield prior to termination, and the plots that would be sprayed prior to soybean planting, statistically had the lowest dry matter yield. The pre-spray treatment had the greatest soybean yield, and the post-spray treatment had the lowest. The large cover crop biomass prior to termination may have impacted soybean yields in the post-spray treatment, and inversely the lack of spring biomass in the pre-spray treatment may have allowed for a more successful soybean yield. These differences in cover crop biomass prior to termination may have added to the significant difference in soybean yield, in addition to any effects from the termination methods. Soil moisture and temperature were highest in the tillage treatment, as well as overall soil nitrate-N. The tillage and the pre-spray treatment both had gradual increase in soil nitrate-N from 12-May to 29-Jun, although overall soil nitrate-N levels were much lower in the pre-spray treatment. The post-spray treatment also consistently had lower soil nitrate-N levels until a spike on 15-Jun, but then a drop in soil nitrate-N on 29-Jun. The additional available nitrogen in the tillage treatment did not appear to have an impact on soybean yield since the tillage treatment was statistically similar to the pre-spray treatment in terms of soybean yield. It should be noted that soybeans were replanted later (12-Jun) in the tillage treatment due to herbicide application error.

Overall, soybean yields in this trial were comparable to the yield of soybeans in other trials conducted at Borderview Research Farm in 2020. These data suggest that soybeans can successfully be grown following an overwintering cover crop and but may be negatively impacted by the amount of cover crop biomass prior to spring termination. For comparison, in the 2019 trial, there was no significant difference in soybean yield between termination methods, even though the overall spring cover crop biomass was significantly different. However, soybean yields last year were impacted by the cover crop type. Soybean yields were lowest where there was winter rye likely because the winter rye had the most spring soil coverage and biomass. These data indicate the need for more research on integrating cover crops into a soybean production system in order to make it a viable option for farmers. 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 2021.

OUTREACH

Outreach this last year was different to say the least. Our main mode of outreach during the summer months are typically on-farm workshops and field days which typically attract hundreds of farmers, technical service providers, and other agricultural professionals. We were able to share our research results at our annual No-Till Cover Crop Symposium which attracted 133 attendees, and a Certified Crop Advisor training just before the COVID-19 pandemic hit Vermont. The remainder or our typical in-person events were canceled since March, yet we worked to continue to provide farmers with valuable, research-based, and season relevant information through other modes of communication. This included posting to our blog and social media accounts, creating written resources that can be accessed via our website, webinars and Virtual Friday Field Days. As a result, we were actually able to reach more stakeholders with 316 participants in our webinar series and 217 at our Virtual Field Day Fridays Series. We also posted our research reports to our website where they will remain available.

Blogs:
https://blog.uvm.edu/outcropn/2020/05/27/time-to-plant-soybeans/

https://blog.uvm.edu/outcropn/2020/06/25/watch-out-for-slugs/

https://blog.uvm.edu/outcropn/2020/03/15/dig-into-your-daywith-cover-crops-conservation/

Virtual Events:

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/Virtual%20Field%20Day%20Fridays/opening_slide_-_welcome_FDF.pdf

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

Reports:

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2020%20Research%20Reports/2020_Conventional_Soybean_VT_Report_Final.pdf

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2020%20Research%20Reports/2020_Conventional_Soybean_VT_Summary.pdf

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2020%20Research%20Reports/2020_Organic_Soybean_Variety_Trial_Report.pdf

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2020%20Research%20Reports/2020_Organic_Soybean_VT_Summary_Final.pdf

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2020%20Research%20Reports/2020_Soybean_PD_x_Var_Report.pdf

https://www.uvm.edu/extension/nwcrops/research

https://www.uvm.edu/sites/default/files/Northwest-Crops-and-Soils-Program/2020%20Research%20Reports/2020_Cover_Crop_Termination_Trialdocx.pdf