Vermont Grass Biomass Energy

UNIVERSITY OF VERMONT EXTENSION

CULTIVATING HEALTHY COMMUNITIES

Research Report

Evaluation of a Seed Vigor Test and Seed Dormancy on Germination and Emergence of Switchgrass for Biomass Production

Support for this project was provided by the U.S. Department of Energy. Thanks for the generous support from the office of U.S. Senator Patrick Leahy and the Vermont Sustainable Jobs Fund for ongoing renewable energy research and education.

The UNIVERSITY of VERMONT

Plant and Soil Science

Evaluation of a Seed Vigor Test and Seed Dormancy on Germination and Emergence of Switchgrass for Biomass Production

Prepared by Sid Bosworth, Extension Agronomist

Switchgrass (*Panicum virgatum*) is considered one of the most viable perennial grass species for utilization as a biomass crop in the U.S. It grows on a wide range of soils, tolerates low fertile sites and with can be very high yielding. One of the major challenges of switchgrass is its slowness to establish. This can be a serious challenge for switchgrass since an important aspect for the success of introducing a new and unfamiliar grass to farmers is the ease to which the crop establishes. Unlike many crops that have been domesticated for thousands of years, switchgrass has had less than one hundred years of agronomic study. Most all of the cultivars on the market are ecotypes selected from native populations. Therefore, any seed a farmer purchases still has much of the seed characteristics of wild germplasm including a tendency to have a high level of innate dormancy, slow germination and slow seedling growth.

In this project, two studies were conducted to evaluate the affects of differences in cultivars and seed dormancy on the establishment of switchgrass and test a "vigor test" method of evaluating seed quality in order to adjust for seeding rate.

Study 1: Vigor Test and Seeding Rate

The objective of this study initiated in 2009 was to evaluate a switchgrass "vigor" test developed at the University of Massachusetts. The idea is to have a test that does not required special equipment or specially trained personnel (Figure 1). It only requires an eight inch plant pot (perforated on the bottom for drainage), sand, daily watering and a warm environment (normal room temperature). The test not only evaluates the proportion of seed that germinates but also tests the vigor of the seedlings. The results of the test would be used to adjust the seeding rate for each particular lot of switchgrass seed.

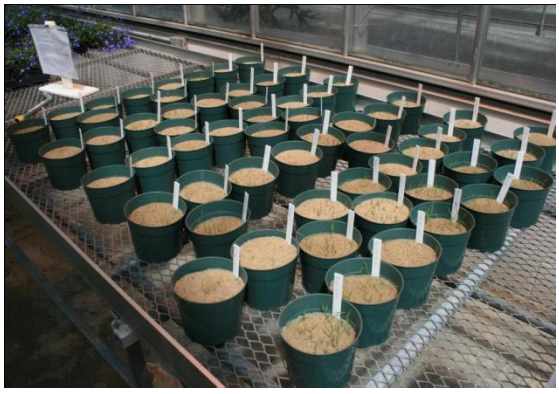

Figure 1. Vigor test of several warm season grasses to determine emergence rate, UVM Greenhouse.

Grass Seedling Vigor Test - For our study, the seedling vigor test was conducted at the UVM greenhouse in a room set at about 70F. Fifty seed from four sets of switchgrass seed (Table 1) were planted per 8 inch greenhouse pots in medium course sand (playground sand). Three of the cultivars had been stratified just prior to the study and, therefore, had a low amount of dormant seed. There were six replications of pots for each cultivar/seed treatment. The seed were placed at a 2 inch (5 cm) depth from the surface, watered daily, and monitored for emergence weekly for three to four weeks. Seedlings that emerged were counted and a percentage emergence was determined for each pot.

Table 1. Description of seed sources for Study 1.

Seed Source	Year of Purchase	Type	Seed Tag Information				Description
			Germination	Dormancy	Purity	PLS[1]	
			%	%	%	%	
Cave In Rock[2]	2007	Upland	20	80	95.0	19	Stored in freezer > 1 year
Cave In Rock	2009	Upland	86	5.8	95.6	82	Previously stratified
Shawnee	2009	Upland	75	1.0	99.9	74	Previously stratified
Kanlow	2009	Lowland	67	1.8	93.4	62	Previously stratified

[1] Pure Live Seed = % Germination X % Purity

[2] The seed tag information for this seed was no longer valid since dormancy had likely decreased

Field Seeding Rate Trials - To evaluate the results of the vigor test, the same four sets of seed were planted in June of 2009 in a replicated field trial at two locations, the UVM Horticultural Farm in South Burlington and Meach Cove Farm in Shelburne, VT. The Hort Farm site was a Deerfield fine sandy loam soil, moderately well drained and the Meach Cove site was a Scantic silt loam, somewhat poorly drained. Treatments included four seeding rates of 8, 12, 16 and 20 lbs per acre. These seeding rates were the actual rates by weight of the seed and did not account for percent pure live seed (PLS) based on germination and dormancy testing.

All plots were planted by with a Carter small plot cone seeder (**Figure 2**). The UVM and Meach Cove sites were planted in 2009 on June 2 and June 17, respectively. At each location, treatments were planted in 10' by 23' plots, replicated four times and arranged in a randomized block design. At all three sites, germination and seedling growth was very good for most species, producing vigorous stands for most treatments. High quality seed, planting at the right soil temperature, relatively low weed pressures due to past cropping history, and timely rain in July and August, were all major factors in stand success. All the sites were hand weeded at least once within the first few weeks after emergence.

Fig 2. Carter cone planter.

Prior to planting, a composite soil sample was collected across the whole study area at each location. At the UVM Farm, the soils were adequate for P but low to moderate for K; whereas, at the Shelburne site, P was low to moderate but K was adequate. However, since the objective of this project was to evaluate these grasses under "marginal" conditions, no additional fertilizer was applied that year since these grasses have been shown to grow in low fertile soils.

Biomass yield and stand populations were made in mid-October of 2009 and 2010. All plots were harvested using a Carter self propelled research harvester which flail chops and collects a 3 foot wide swath. Subsamples were collected, weighed fresh, then dried and reweighed to determine dry matter content. Statistical analysis included an analysis of variance (ANOVA) to compare treatment means of each parameter using a Least Significant Difference (LSD) test ($P<0.05$).

Results - The number of seedlings that emerged appeared to level off at about three weeks of time which was then used to determine percent emergence. There was a lot of variability across replications (**Figure 3**). Shawnee, which had the highest germination and lowest dormancy, had the least variation. Based on these results, it would be recommended that at least four pots should be used with 50 seed each if the vigor test is to be useful as a routine method.

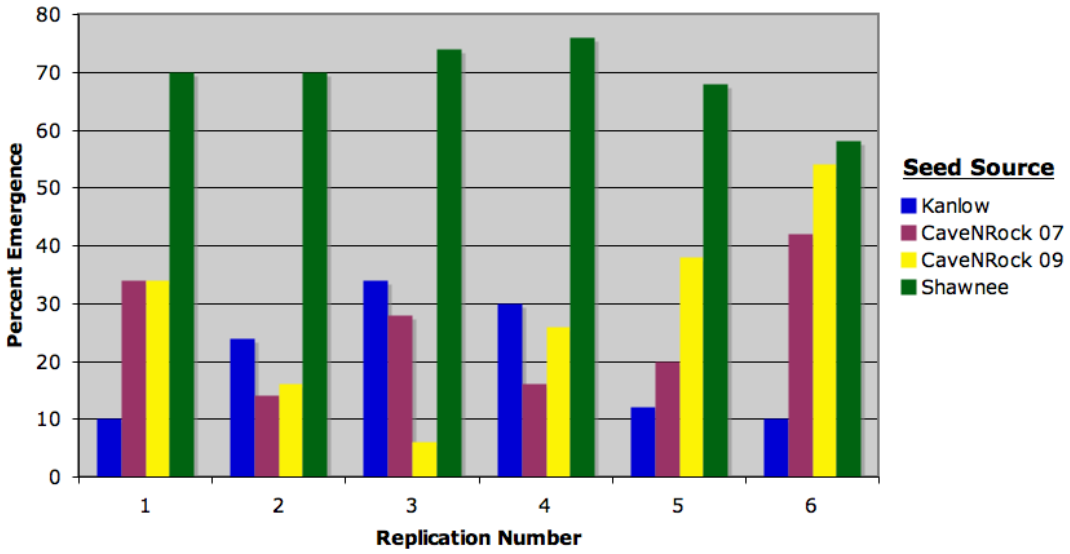

Figure 3. Percent emergence of switchgrass cultivars seeded in sand medium at a 5 cm depth in the UVM greenhouse as part of a switchgrass vigor test.

The average of the six pots was used to determine the percent emergence of each cultivar seed source. By determining the density of the seed, a calculation was made of the expected plant populations at four seeding rates when using the vigor test or using information from the seed tag (**Table 2**). Using the vigor test to determine plant populations, 'Kanlow' and 'Shawnee' were expected to produce more tillers compared to the two sources of 'Cave-In-Rock'. Although the percent emergence of 'Kanlow' was the lowest of the seed sources, it had smaller seed (**Figure 4**) and, therefore, more seed per pound.

Table 2. Expected plant populations based on either the vigor test or seed tag information

		Expected Plant Populations Based on Two Seed Tests									
		Vigor Test					Pure Live Seed from Seed Tag				
			Seeding Rate (lbs/acre)					Seeding Rate (lbs/acre)			
Seed Source	Seed Density[1]	Emer-gence	8	12	16	20	PLS[2]	8	12	16	20
	seeds/lb	%	*plants per square foot*				%	*plants per square foot*			
Cave-n-rock 2007	230,108	26	11	16	22	27	na[3]	na	na	na	na
Cave-n-rock 2009	256,108	29	14	20	27	34	82	39	58	77	97
Kanlow	565,797	20	21	31	42	52	62	65	97	129	161
Shawnee	244,612	69	31	47	62	78	74	33	50	67	84

[1]Determined by weighing 300 seed of each seed source

[2]Pure live seed was calculated from the original seed tag for each source of seed. PLS = %Germination x % Purity

[3]CIR 2007 had been stored for over a year and its original seed tag information was be no longer valid.

Figure 4. Seed size of 'Kanlow' compared to 'Shawnee' switchgrass.

Plant population counts measured one month after seeding at the UVM Hort farm and in October after harvests at both locations (**Table 3**) did indicated that 'Kanlow' and 'Shawnee' cultivars produced more tillers per area than either 'Cave In Rock' seed source, as predicted by both the vigor test and the PLS test (**Table 2**). The relationship between expected populations (Table 2) and measured populations (Table 3) was reasonably good. Seedling counts made one month after establishment more approximated the PLS method of estimating expected populations (Table 2). Generally, the Hort Farm site, which had better soil conditions, produced more plants per area than the Meach Cove site.

It is interesting to note that the 'Cave In Rock' seed from 2007 had originally been about 80% dormant (from seed tag information) and when seeded in that year, establishment at two sites were very slow and ended up unsuccessful at one of those sites due to heavy weed pressures. But with long term storage (in a freezer), we found the seed germinated as quickly as the same cultivar from the 2009 seed source which had only 5.8% dormancy since it had been stratified by the seed company. We know that the mechanism of dormancy used by switchgrass is one that declines with time; however, seed viability also decreases with time. By storing the seed in the freezer, we were able to reduce dormancy but maintain seed viability.

Table 3. Average seedling and tiller populations of switchgrass measured in 2009.

	UVM Hort Farm 7/2				UVM Hort Farm 11/9				Meach Cove 11/18			
Seed	Seeding Rate (lbs/acre)				Seeding Rate (lbs/acre)				Seeding Rate (lbs/acre)			
Source	8	12	16	20	8	12	16	20	8	12	16	20
	Seedlings per square foot				*Tillers per square foot*				*tillers per square foot*			
CIR 2007	65 b[1]	64 b	94 b	142 a	42 bc	34 bc	46 ab	49 a	29 a	28 a	33 a	32 a
CIR 2009	46 b	65 b	78 ab	112 a	29 c	32 bc	36 bc	49 ab	27 a	33 a	33 a	28 a
Kanlow	62 b	78 b	144 a	153 a	33 c	45 bc	58 ab	58 ab	29 c	35 bc	43 ab	50 a
Shawnee	71 bc	66 c	108 ab	134 a	35 c	48 bc	59 ab	65 a	31 b	41 a	38 a	40 a
Average	60 c	68 c	106 b	135 a	35 b	40 ab	50 a	55 a	29 c	34 bc	36 ab	37 a

[1]Any means within rows (seeding rates) and within location/dates with the same letter are not significantly different (P<0.05)

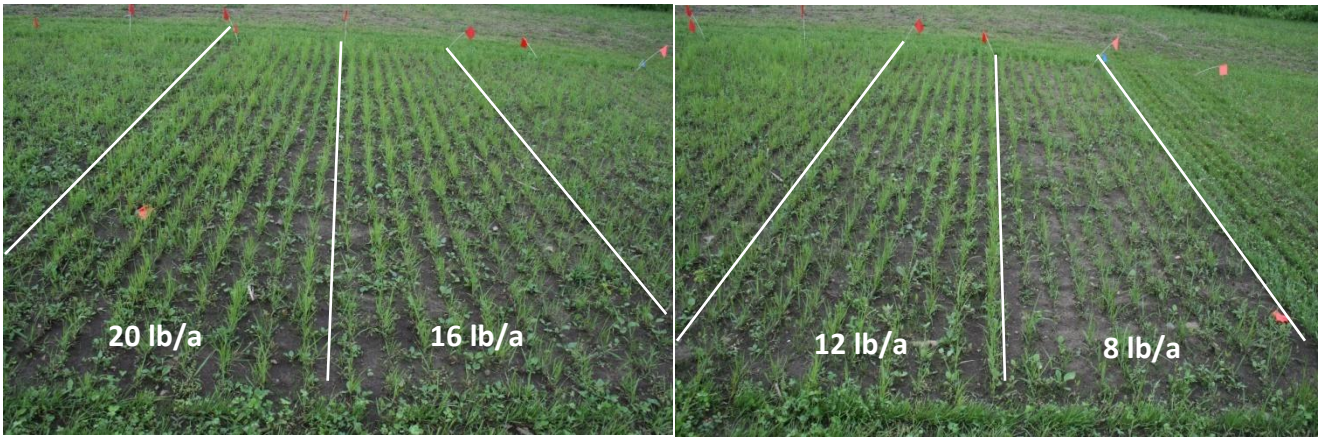

Figure 5. Switchgrass seedlings of four seeding rates on July 22, 2009 (planted on June 2) from the 2007 source of 'Cave-In-Rock' seed.

In the seeding year, only the lowest seeding rate (8 lbs per acre), which was targeted to be less than normally recommended, showed a lower significant biomass yield averaged across all cultivar seed sources (**Table 4**). However, its yield was not dramatically lower than the higher rates, probably due to higher tiller weights since the plants had more space to grow. But even at this low seeding rate, stands were at populations considered adequate (according to recommendations for the Northeast). This may have been due to good seedbed preparation and weed control as well as the use of a seed drill that placed the seed at a optimum depth with good surface compaction (use of press wheels) following seeding.

Biomass yield was higher at the Meach Cove farm than at the UVM Horticulture farm in the seeding year (**Table 4, Figure 3**). Rainfall was less than normal in July and August in 2009 (**Table 7**) and we did observe more deficit water stress at the UVM Hort. Farm site which has well drained soils.

Table 4. Average biomass yields, tiller populations and tiller weights of four switchgrass cultivars harvested in autumn of 2010 from plots seeded in 2009.

Seeding Rate		UVM Hort. Farm			Meach Cove		
Actual	PLS[1]	D.M Yield	Tiller Pop.	Tiller Wt	D.M Yield	Tiller Pop.	Tiller Wt
lb/a	*lb/a*	*(t/a)*	*(no./ft²)*	*(gm/100)*	*(t/a)*	*(no./ft²)*	*(gm/100)*
8	6	0.81 b	35 b	51 a	1.36 b	29 b	105 a
12	9	0.91 ab	40 b	50 a	1.43 ab	34 a	92 ab
16	12	0.98 a	50 a	42 ab	1.47 a	36 a	87 b
20	15	0.98 a	55 a	37 b	1.49 a	37 a	86 b

[1] Seeding rate when adjusted for pure live seed based on seed tag information
[2] Any means in a column with the same letter are not significantly different (P< 0.05)

When separated by seed source, 'Kanlow' and 'Shawnee' yields increased with increasing seeding rates (**Figure 6**); however, 'Cave In Rock' was not responsive to seeding rate except for the 2007 seed at

Meach Cove farm. Yield did not always correlate with plant populations (**Table 3**) since plants would compensate in weight at lower populations.

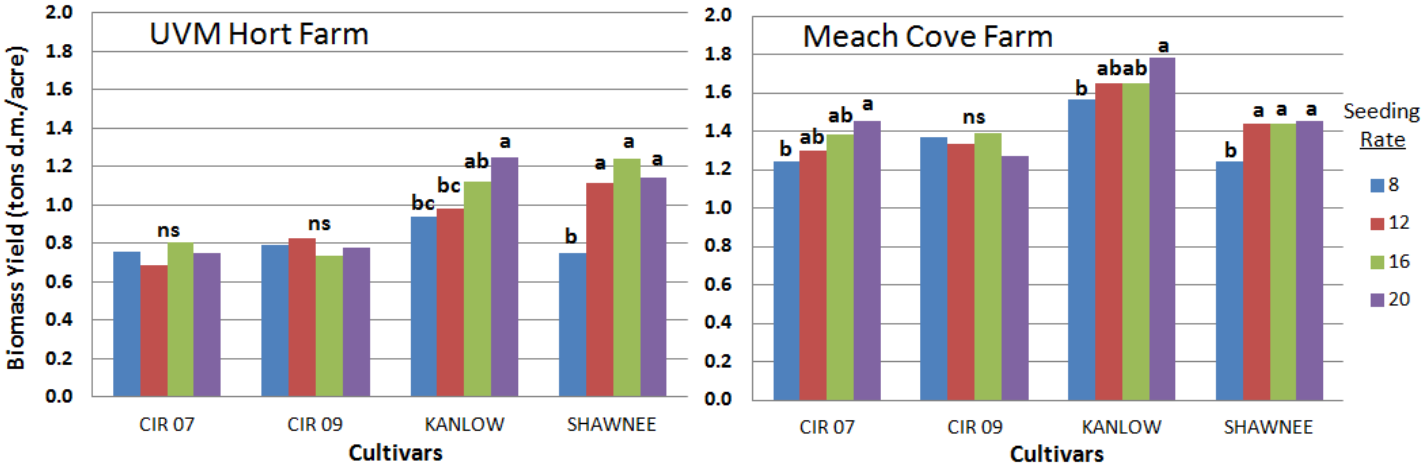

Figure 6. Average biomass yield of switchgrass cultivars in the seeding year, 2009. For each cultivar, columns with the same letters were not significantly different (P<0.05)

In 2010, biomass yield and stand density was determined to see if there was any carryover affects of seeding rate (**Table 5**). At the South UVM location, there was still a difference in stand density due to seeding rate; however, the lower seeding rate stands compensated with higher tiller weights and, therefore, there was no significant (P<0.05) difference in biomass yield. At the Shelburne (Meach Cove) site, there was a statistical difference in yield with the 20 lb. seeding rate resulting in a slightly higher biomass yield. However, there was no difference in tiller populations nor tiller weight and the actually yield differences were less than a third of a ton.

Overall, we can conclude that the 8 to 10 lb per acre recommended seeding rate for switchgrass was adequate for a good stand and optimum yield. The Vigor Test did may be a good tool for adjusting seeing rates but more work would need to be done to fine tune its prediction ability.

Table 5. Average biomass yields, tiller population and tiller weight of four switchgrass cultivars harvested in autumn of 2010 from plots seeded at four different seeding rates in 2010.

Seeding Rate		UVM Hort. Farm						Meach Cove					
Actual	PLS[1]	D.M Yield		Tiller Pop.		Tiller Wt		D.M Yield		Tiller Pop.		Tiller Wt	
lb/a	*lb/a*	*(t/a)*		*(no./ft^2)*		*(gm/100)*		*(t/a)*		*(no./ft^2)*		*(gm/100)*	
8	6	3.12	a[2]	39	b	172	a	2.03	c	33	a	136	ab
12	9	3.11	a	39	b	177	a	2.15	bc	39	a	120	b
16	12	3.04	a	44	ab	153	a	2.18	ab	35	a	140	ab
20	15	3.32	a	46	a	158	a	2.30	a	35	a	149	a

[1] Seeding rate when adjusted for pure live seed based on seed tag information

[2] Any means in a column with the same letter are not significantly different (P< 0.05)

Study 2: Switchgrass Emergence and Seed Dormancy

Many native warm season grasses such as switchgrass have a mechanism of seed dormancy which, under natural conditions, prevents the plant from germinating at vulnerable time periods such as in autumn when the seedling would be too young to persist that first winter. This phenomenon also means that farmers will often purchase switchgrass seed that is high in dormancy, as indicated on the seed tag. Although the dormant seed will eventually germinate over time, this may cause an initial stand with poor cover and, therefore, less ability to compete with weeds. Adjusting a seeding rate based only on percent germination could require such high seeding rates that the cost for establishment would become too prohibitive. However, according to experienced switchgrass producers even high dormant seed will eventually germinate in the seeding year and provide an adequate stand. To test this observation, a study was initiated in 2010 to assess how dormancy of switchgrass seed affects stand density during the establishment year and subsequent production years.

Two seed lots of 'Cave-N-Rock' switchgrass varying in germination and dormancy levels, **Low Dormant Seed**, **LSD** (40% germination, 50% dormant) and **High Dormant Seed**, **HSD** (10% germination, 80% dormant) were seeded at four seeding rates (5, 10, 20 and 30 lbs of total seed per acre) in 2010 on June 4 and June 22 at the UVM Hort farm and Meach Cove Farm, respectively. The seed was purchased from Ernst Seed Company, Meadville, PA, in April 2010. Treatments were replicated four times in a strip block design. Field locations, soil types, seeding methods and stand maintenance were similar to that of Study 1. Expected plant populations based on seed tag information is in **Table 6**.

In the seeding year, seedling populations were counted three times from the 5 and 30 lb./a treatments and ended in September once the seedlings began to tiller and it was no longer possible to determine individual plants. Biomass yield and stand populations were made between late October and mid November in 2011 and 2012. Harvest methods were similar to that of Study 1.

Table 6. Expected populations of 'Cave-N-Rock' Switchgrass if planted under ideal conditions at four seeding rates for two seed lots - one with low seed dormancy (Low SD) and one with high seed dormancy (High SD).

	Expected Plant Populations Based on Two Calculations									
	Based only on Germination[1]					Based on Germ. and Dormancy[2]				
Seed Dormancy	Emer-gence	Seeding Rate (lbs/acre)				Emerg ence	Seeding Rate (lbs/acre)			
		5	10	20	30		5	10	20	30
	%	*plants per square foot*				%	*plants per square foot*			
Low	41	12	23	47	70	91	26	52	104	156
High	10	3	6	11	17	90	26	51	103	154

[1]Percent Emergence = % Purity x % Germination

[2]Percent Emergence = % Purity x (% Germination + % Dormancy)

Results

Seeding Year- At both locations, there was a significant difference between seedling populations of the 5 versus 30 lb/acre seeding rate throughout the establishment season (**Figure 7**). There was a significant difference ($P<0.05$) in seedling populations between the low and high dormancy seed types at both locations when averaged across seeding rate and sampling times. There was also a strong dormancy type by seeding rate interaction. In other words, at the Hort Farm, LSD was significantly higher in seedling populations than the HSD at the 30 lb/a rate but not the 5 lb/a rate. However, Meach Cove, it was just the opposite, LSD was significantly higher than HSD only at the 5 lb/a rate. The Hort farm had better seeding conditions and resulted in overall higher seedling populations. When comparing these results to the calculated expected populations from **Table 6**, the actual populations in **Figure 7** seemed to fall in quantity somewhere between the predicted populations that only used % germination to estimate emergence compared to the predictions that used a sum of % germination and % dormancy. This was probably because a portion of the dormant seed were germinating throughout the season. By September, there was no difference in see

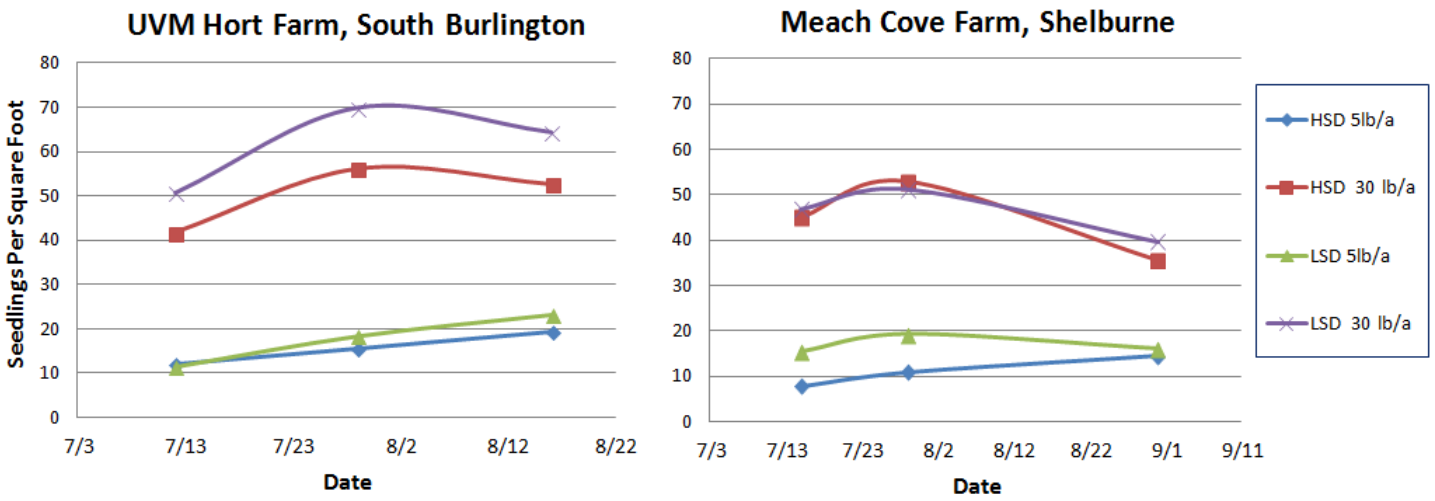

Figure 7. Seedling populations during the establishment year of low (LSD) and high (HSD) seed dormancy groups of 'Cave-N-Rock' switchgrass planted at 5 and 30 lbs. per acre at two sites in Vermont in 2010. At both locations, there was a significant difference in seeding rate when averaged across dates but not between seed dormancy types.

Post Seeding Years - For the next two years (**Table 7**), tiller populations of the two dormancy types were not significantly different at either the Hort farm or Meach Cove, indicating that any of the dormant seed that was going to germinate, most likely did so in the seeding year. The affect of seeding rate on plant population did continue into 2011 at both locations and into 2012 at the Hort farm, with the 30 lb/a rate having significantly more tillers per area than the 5 or 10 lb seeding rate. At the higher seeding rates, plant populations appeared to remain stable across all three years at both locations (ranging from 50 to 55 at the Hort farm and 34 to 38 tillers per ft^2 at Meach Cove). At the 5 lb seeding rate, tiller populations continued to increase each year, indicating that at a lower seeding rate, these plants compensated in growth by increasing their tillering rate until reaching a critical density.

Table 7. Average biomass yields, tiller populations and tiller weights of 'Cave-N-Rock' Switchgrass in 2011 and 2012. The stand was planted in 2010 at four seeding rates from two seed lots - one with low seed dormancy (Low SD) and one with high seed dormancy (High SD).

	UVM Hort Farm, South Burlington[1]					
	2011			2012		
Seeding Rate	Biomass Yield	Tiller Pop.	Tiller Weight	Biomass Yield	Tiller Pop.	Tiller Weight
(lbs / acre)	*tons/acre*	*no./ft²*	*gm / 100*	*tons/acre*	*no./ft²*	*gm / 100*
5	2.4 b[3]	42 c	113	4.5	44 b	221
10	2.7 ab	41 c	143	4.3	46 ab	201
20	3.1 a	48 ab	135	4.6	50 ab	206
30	3.3 a	50 a	137	4.5	55 a	180
Significance[2]	**	*	#	ns	*	ns
Seed Dormancy[4]						
Low SD	3.0	45	140	4.5	47	219
High SD	2.8	46	130	4.4	51	184
Significance	ns	ns	ns	ns	ns	ns

	Meach Cove Farm, Shelburne[1]					
	2011			2012		
Seeding Rate	Biomass Yield	Tiller Pop.	Tiller Weight	Biomass Yield	Tiller Pop.	Tiller Weight
(lbs / acre)	*tons/acre*	*no./ft²*	*gm / 100*	*tons/acre*	*no./ft²*	*gm / 100*
5	1.2 b	21 b	116 a	3.1 b	33	220
10	1.2 ab	26 b	99 ab	3.7 a	36	210
20	1.4 ab	33 a	90 b	3.7 a	39	200
30	1.5 a	34 a	91 b	3.9 a	38	210
Significance[2]	*	***	**	**	ns	ns
Seed Dormancy[4]						
Low SD	1.3	30	100	3.7	37	210
High SD	1.3	27	100	3.5	36	200
Significance	ns	ns	ns	ns	ns	ns

[1]Harvest dates at Hort Farm on 10/25 and 10/24 and Meach Cove on 11/11 and 10/10 for 2011 and 2012, respectively.

[2]Significance catagories: n.s. - not significant, # P<0.10 * P<0.05, ** P<0.01, *** P<0.001

[3]Means in the same column with the same letter are not significantly different

[4]From seedtag information: Low SD - Germ. 41% and Dorm. 50%; High SD - Germ. 10% and Dorm. 80%

Post Seeding Year Results (continued) – For the next two years (**Table 7**), biomass yields of the two dormancy types were not significantly different at either the Hort farm or Meach Cove. These results support the idea that dormant seed will germinate over the seeding year and will not affect yield in aftermath years. However, it is critical that seedbed preparation, timing of planting and weed control be optimally managed to assure the switchgrass seedlings have ample opportunity to grow and develop. Also, it is less likely that there will be enough biomass in that seeding year to justify a harvest, whereas, a seeding of very low dormant seed that germinates quickly could have the potential for a harvest (which is what happened in Study 1).

There was a significant difference in biomass yield between the 5 lb seeding rate and the higher seeding rates (Table 7) in 2011 at both locations and in 2012 at Meach Cove as well. Although numerically lower, there was no significant difference between the 10 lb rate and any higher rates for either year or location. This confirms the normal 8 to 10 lb/acre recommendation for switchgrass.

Table 8. Average monthly temperature and precipitation and difference from normal (DFN) from the UVM Horticultural Farm weather station. Weather conditions were similar at both of the South Burlington and Shelburne sites.

	Average Monthly Temperature (F)								Average Monthly Precipitation (inches)							
	2009		2010		2011		2012		2009		2010		2011		2012	
	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN	Ave.	DFN
April	47	2.4	49	4.4	45	0.5	46	1.6	2.1	-0.7	3.3	0.5	6.4	3.6	2.4	-0.4
May	57	0.1	61	4.2	59	2.4	61	5	5.0	1.6	1.6	-1.8	6.2	2.7	3.9	0.4
June	64	-1.4	66	-0.1	67	1.3	67	1.4	4.2	0.5	5.2	1.5	1.9	-1.8	2.8	-0.9
July	68	-2.7	74	3.5	75	4.5	72	1.8	3.9	-0.3	1.6	-2.6	2.5	-1.7	3.5	-0.6
August	71	1.9	70	1.5	72	3.1	72	2.9	2.3	-1.7	2.2	-1.7	5.7	1.8	0.0	-3.9
September	60	-0.5	63	2.7	65	4.5	62	1.4	3.3	-0.4	3.7	0.1	3.9	0.3	5.1	1.5
October	47	-1.7	49	0.7	51	2.4	53	4.7	2.7	-0.9	3.9	0.3	1.9	-1.7	5.0	1.4

Figure 7. Seed dormancy study at Meach Cove in 2012. The high seed dormancy plots had just been harvested leaving the outside edges of each plot.

Summary of Switchgrass Establishment Trials – Based on the results of the studies in this project as well as observations during the establishment of the other warm season grass cultivar evaluation studies, the following assessments can be made:

- A seeding rate of 8 to 10 pounds per acre of switchgrass (accounting for both % germination and % dormant seed found on the seed tag) seems adequate to achieve a productive stand
- Seed should not be planted until the soil is warm enough to promote quick germination. This is usually within the first two weeks of June in Vermont.
- It is best to plant in a field with low weed pressures, particularly summer annual grasses like crabgrass or foxtails.
- To manage weeds, a stale seedbed approach can work affectively if weather allows. The field should be prepared one month to six weeks before planting and allowed to have a couple of weed flushes before planting. Emerging weed seedlings can be killed with blind cultivation using a flex tine weeder (it is most effective when used after the weed seed has germinated but before the seedlings have actually emerged). Set the tines for shallow tillage to avoid bringing up more weed seed form lower soil depths. The flush of weeds can also be killed with a herbicide like glyphosate before the warm season grass is planted. In this situation, the weeds should be allowed to emerge and grow some before spraying in order to get adequate foliage coverage.
- For fields with a history of heavy weed pressures, it may be best to rotate the field for a year or more with an annual forage crop such as sudangrass, millet or sorghum-sudangrass that affectively suppresses weed emergence and growth. This can help reduce the weed seed bank before establishing the warm season grass.

A special thanks to Tim Kelly, Susan Monahan, Evan Reiss, Devon Snyder and Conner Burke for their assistance with preparation, maintenance and harvesting of plots. A special thanks to Chris Davis and his crew of Meach Cove Farm Trust for their collaboration and assistance.

For More Information on Grass Biomass, go to: http://pss.uvm.edu/vtcrops/?Page=energycrops.html

- March 2013