United States Department of Agriculture

FINAL STUDY REPORT February 2025
Aberdeen PMC
Aberdeen, Idaho

Evaluation of Cool Season Cover Crop Seeding Rates for Cover and Biomass in Southern Idaho

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ABSTRACT

Idaho producers who plant cover crops need more information on appropriate single-species seeding rates to create economical cover crop mixes that meet their conservation objectives. The purpose of this 2-year study was to compare a range of 4 seeding rates for each of 8 common cover crop species. The effects of cover crop seeding rate on percent canopy cover, aboveground biomass (dry lb/ac) and plant height of beardless winter barley (*Hordeum vulgare* L.) 'P919', oat (*Avena sativa* L.) 'Goliath', facultative triticale (x *Triticosecale*)'Thor', red beardless winter wheat (*Triticum aestivum* L.) 'Gore', oilseed radish (*Raphanus sativus* L.) 'Jackhammer', hybrid turnip (*Brassica rapa* x *B. napus*) 'Vivant', hairy vetch (*Vicia villosa* Roth) 'Villana', and Austrian winter pea (*Pisum sativum* L. ssp. *sativum* var. *arvense*) (VNS, Idaho grown) were investigated at Aberdeen, ID on a Declo loam (2021-22) and a Kimama silt loam (2023-24). Canopy cover was determined monthly using color image analysis, and aboveground biomass was sampled at 2 months after planting (MAP) and prior to termination (either by killing temperatures or by chemical application at 8 MAP). All barley seeding rates reached >90% cover by 2 MAP in both years of the study. Barley pre-termination (PT) biomass ranged from 348 lb/ac at the highest seeding rate in 2022 to 5355 lb/ac at the lowest rate in 2024. Oat canopy cover at 2 MAP in 2021 was 60% at the lowest seeding rate and >80% at the highest rate. All oat seeding rates reached 99% cover by 2 MAP in 2023. Oat PT biomass ranged from 3874 lb/ac at the lowest seeding rate in fall 2021 and 5667 lb/ac at the highest seeding rate in fall 2023. All triticale seeding rates reached or exceeded 74% 2 MAP cover in 2021 and reached 98% 2 MAP cover in 2023. Facultative triticale unexpectedly winterkilled both in 2021 and at the 3 highest seeding rates in 2023. Wheat achieved >90% 2 MAP cover at the 3 highest seeding rates in 2021 and at all seeding rates in 2023. Wheat PT biomass ranged from 1765 lb/ac at the lowest rate in 2022 and >5600 lb/ac at the 3 highest seeding rates in 2023. Radish achieved >90% 2 MAP cover at the 3 highest seeding rates in 2021 and at all seeding rates in 2023. Radish PT biomass ranged from 1287 lb/ac at the lowest seeding rate in fall 2023 to 2927 lb/ac at the second highest rate in fall 2021. All seeding rates of turnip reached >60% 2 MAP cover in 2021 and >90% cover by 3 MAP. All rates reached >90% 2 MAP cover in 2023. Turnip PT biomass ranged from 3790 lb/ac at the lowest rate in fall 2023 to 5102 lb/ac at the highest rate in the same year while 2021 rates were within this range. Hairy vetch grew slowly with the 3 highest rates reaching >50% 3 MAP cover in 2021. In 2023, all seeding rates achieved >80% cover at 3 MAP. Hairy vetch PT biomass ranged from 598 lb/ac at the lowest rate in 2022 to 5371 lb/ac at the highest rate in 2024. Winter pea reached >50% 3 MAP cover at the 3 highest seeding rates in 2021 and >90% cover at the 2 highest seeding rates in 2023. Winter pea unexpectedly winterkilled in 2021-22. In spring 2024, winter pea PT biomass ranged from 1237 lb/ac at the highest seeding rate to 2442 lb/ac at the second lowest rate. For many species, seeding at the highest rate did not provide additional benefit in terms of biomass or canopy cover, while seeding at the lowest rate produced less biomass but similar cover as higher seeding rates. Single species seeding rates that meet producer goals for biomass and cover can be used to create an economical multi-species seed mix.

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INTRODUCTION

NRCS Idaho's Field Office Technical Guide (FOTG) currently does not contain cover crop seeding rates under the CPS-340 Practice Standard. Idaho NRCS Planners use two sources for cover crop seeding rates: 1) IDPMC TN 67, which gives recommended single-species seeding rates as rule-of-thumb ranges (St. John et al., 2017); and 2) The PNW Cover Crop Selection Tool, which also gives a range of seeding rates for each cover crop species (Young-Mathews et al., 2016). These ranges are based on available literature and empirical knowledge of what has worked in the region, as well as guidelines provided by cover crop seed vendors. There is currently no Idaho NRCS guidance on narrowing those ranges.

For some producers, seed cost is a disincentive to planting cover crops. A potential solution to this problem may be to reduce the cost of planting cover crops by reducing seeding rates, so long as the benefits of the practice, such as reducing soil erosion, suppressing weeds (Meisinger et al., 1991) and providing supplemental grazing for livestock (Brummer et al., 2015) are maintained. To do this, a better understanding of performance from varying seeding rates for each species is needed. Appropriate rates can then be used to create an economical, multi-species seed mix.

The objective of this study was to compare aboveground biomass yields and percent canopy cover of 8 fall-planted cool season cover crops commonly used in Southern Idaho and surrounding cold desert areas, when seeded at 4 different rates.

MATERIALS AND METHODS

We seeded 8 species at 4 rates (Table 1). Each species was represented by a single cultivar or seed source: beardless winter barley (*Hordeum vulgare* L.) 'P919', oat (*Avena sativa* L.) 'Goliath', facultative triticale (*x Triticosecale*)'Thor', red beardless winter wheat (*Triticum aestivum* L.) 'Gore', oilseed radish (*Raphanus sativus* L.) 'Jackhammer', hybrid turnip (*Brassica rapa x B. napus)* 'Vivant', hairy vetch (*Vicia villosa* Roth) 'Villana', and Austrian winter pea (*Pisum sativum* L. ssp. *sativum* var. *arvense*) (VNS, Idaho grown). The 4 different seeding rates for each species are based on industry recommendations (Green Cover, 2021), ranges used by NRCS in Wyoming (NRCS, 2018), Missouri (NRCS 2020) and Montana (NRCS 2021), as well as the NRCS Idaho resources previously mentioned. All treatments were planted on a pure live seed (PLS) basis. Thousand-seed counts were made using a Seedburo 801 Count-A-Pack (Seedburo Equipment Co., Des Plaines, IL), and the weights of these counts were used to calculate seeds per pound (Table 1). Prior to planting, legume seeds were inoculated with the appropriate rhizobial bacteria. Seeds were wetted with a solution of molasses and water, stirred with the inoculant powder, and spread on paper to dry. Two site-years were evaluated with the same seed lots used for both years of the study.

The cool season cover crop rate trial was conducted at the Aberdeen Plant Materials center over 2 growing seasons, 2021-22 and 2023-24. In 2021, the study was planted in a Declo loam. In 2023, the study was planted in a different location on a Kimama silt loam. Plots were planted on 24 August 2021 and 17 August 2023 using an Almaco plot planter (The Almaco Company, Nevada, IA) with 6 openers on 9.5-in centers in 20-ft long plots making each plot approximately 5 x 20 ft. Planting dates were within a typical window for common crop rotations in the Aberdeen area.

Table 1. Cover crop species, seeds/lb, pure live seed (PLS), seeding rate, PLS seeds/ac, and PLS seeds/ft evaluated at the Aberdeen PMC, Aberdeen, Idaho 2021-22 and 2022-23.

Cover Crop	Seeds/lb	PLS	Seeding Rate PLS lb/ac	PLS seeds/ac[a/]	PLS seeds/ft[b/]
Barley, winter	20,000	0.94	25	500,000	9.1
Hordeum vulgare L.			50	1,000,000	18.1
'P919' beardless			75	1,500,000	27.2
			100	2,000,000	36.3
Oat	16,500	0.93	20	330,000	6.0
Avena sativa L.			40	660,000	12.0
'Goliath'			60	990,000	18.0
			80	1,320,000	23.9
Triticale, facultative	12,300	0.97	25	307,500	5.6
x Triticosecale			50	615,000	11.2
'Thor'			75	922,500	16.7
			100	1,230,000	22.3
Wheat, winter	16,500	0.89	25	412,500	7.5
Triticum aestivum L.			50	825,000	15.0
'Gore' red beardless			75	1,237,500	22.4
			100	1,650,000	29.9
Radish, oilseed	34,200	95%	2.5	85,000	1.6
Raphanus sativus L.			5	171,000	3.1
'Jackhammer'			7.5	256,000	4.7
			10	342,000	6.2
Turnip, hybrid	152,000	94%	2	304,000	5.5
Brassica rapa x B. napus			4	608,000	11.0
'Vivant'			6	912,000	16.5
			8	1,216,000	22.1
Vetch, hairy	15,500	98%	10	155,000	2.8
Vicia villosa Roth			15	232,500	4.2
'Villana'			20	310,000	5.6
			25	387,500	7.0
Pea, Austrian winter	3,600	93%	20	72,000	1.3
Pisum sativum L.			40	144,000	2.6
ssp. *sativum* var. *arvense*			60	216,000	3.9
VNS (Idaho grown)			80	288,000	5.2

[a/]PLS seeds/ac and PLS seeds/ft of row are based on 9.5-in row spacing.
[b/]PLS seeds per linear foot of row

Soil samples were lab tested each year prior to planting, and the results were used to develop fertilizer application rates. In 2021, the field had been in alfalfa the previous year and had adequate N. Prior to seeding, 30 lb P was broadcast and incorporated with a cultipacker prior to planting. In 2023, the field contained adequate P. We broadcast 50 lb N/ac as ammonium sulfate, which was incorporated with sprinkler irrigation prior to planting.

In both years of the study, plots received a total of 10.5 in sprinkler irrigation between planting and the second week of October. We chose to end irrigation in early October because this is when irrigation ditches are emptied for the winter in our area. No additional water was applied in either year of the study. Precipitation and temperature records were obtained from NOAA (2024) for the Aberdeen Experiment Station, ID weather station.

We collected plot data and photographs using the Field Book app (Rife & Poland, 2014) on a Samsung Galaxy Tab tablet. Percent canopy cover was determined at monthly intervals after planting (MAP) using Foliage (Patrignani, 2020), a web-based application that classifies green

canopy cover (Figure 3). We established a photo area in each plot that included three seeded rows (approximately 30 in x 30 in) that were photographed with the tablet's camera held parallel to the ground surface at a height of approximately 2 ft above the canopy. Because the app can only distinguish green from non-green objects, weeds were hand rogued from the area so that they did not interfere with the color analysis. Monthly measurements of canopy cover were made until the cover crop was winter-killed or terminated in spring, except for when the plots were covered by snow or had little living cover. Additionally, a reference photo of each plot was taken every month from the same end in order to visually document whole-plot plant height and cover. A stake showing 1 ft vertical increments was inserted in the center of the plot for scale; however, in some months of 2021-22, frozen soil prevented the insertion of the stake. In 2023-24 a second person held a similar stake in place. No color analysis was performed on these reference photos.

All plots that survived the winter were terminated after the 8 MAP evaluation, on 5 May 2022 and 24 April 2024 with 64 oz/ac Roundup PowerMAX. Reference plot photos were taken 1 month after the plots were winter killed or terminated to record the amount of remaining cover.

Aboveground biomass was harvested at 2 times: in the fall at 2 MAP to estimate fall forage, and prior to termination. Two types of termination were considered depending on species characteristics: (1) winterkill from low temperatures for susceptible species; or (2) for winter-hardy species, termination in spring prior to area planting dates for commodity crops (April). We followed weather forecasts in the fall to anticipate killing temperatures for oat, radish, and turnip, and sampled biomass just prior to expected lethal temperatures. We evaluated biomass of radish and turnip on 16 November (1 week short of 3 MAP) in anticipation of killing temperatures (15 °F). Oat biomass was collected at 3 MAP (24 October) because plants were declining in the continued cold temperatures. Each biomass sample consisted of two adjacent row lengths of 3.25 ft that were cut at ground level at the opposite end of the plot from the photo area. The second, pre-termination (PT) biomass sample was taken near the first sample, with care taken not to sample from the "outside rows" created by previous biomass sampling. Wet and oven dry weights (48 hr at 60 °C) were determined, and dry weight (lb/ac) calculated.

Plant height and growth stage were measured at the same time biomass samples were taken. Plant height can be correlated to aboveground biomass and is also used as an indicator of how easy it will be to manage or terminate a cover crop. For each plot, we recorded the average height of canopy growth based on three random measurements. Growth stage definitions for turnip and radish are taken from Harper (1974) while growth stages for small grains (Feekes) and legumes are from Padro et al. (2022).

Each cover crop species was considered a separate experiment and analyzed using a completely randomized design (CRD) with four replications of each seeding rate with each study year being analyzed separately. Statistical analysis was performed with Statistix 10 (Analytical Software, Tallahassee, FL), using ANOVA with $\alpha = 0.05$ and means separation with Tukey HSD. In cases where the data did not meet ANOVA assumptions (normality), we used a Kruskal-Wallis One-Way AOV with means separation by Dunn's test.

RESULTS AND DISCUSSION

In 2021, heavy rain on 20 August delayed planting until 24 August. The plots received 1.3 in of rain between planting and 2 MAP and were subjected to several days of record high temperatures in early September. Lowest temperatures were in January and February 2022, with a low temperature of -10 °F and a total of 14 days with lows below 0 °F. The beginning of 2022 was colder than long-term normal, with low temperatures near 0 °F into mid-March and in the teens in April (NOAA, 2022). These cold temperatures, combined with little protective snow cover, affected the survival of some cover crop species. For example, we expected winter pea and facultative triticale to regrow in the spring, but triticale survival was patchy and very few peas survived.

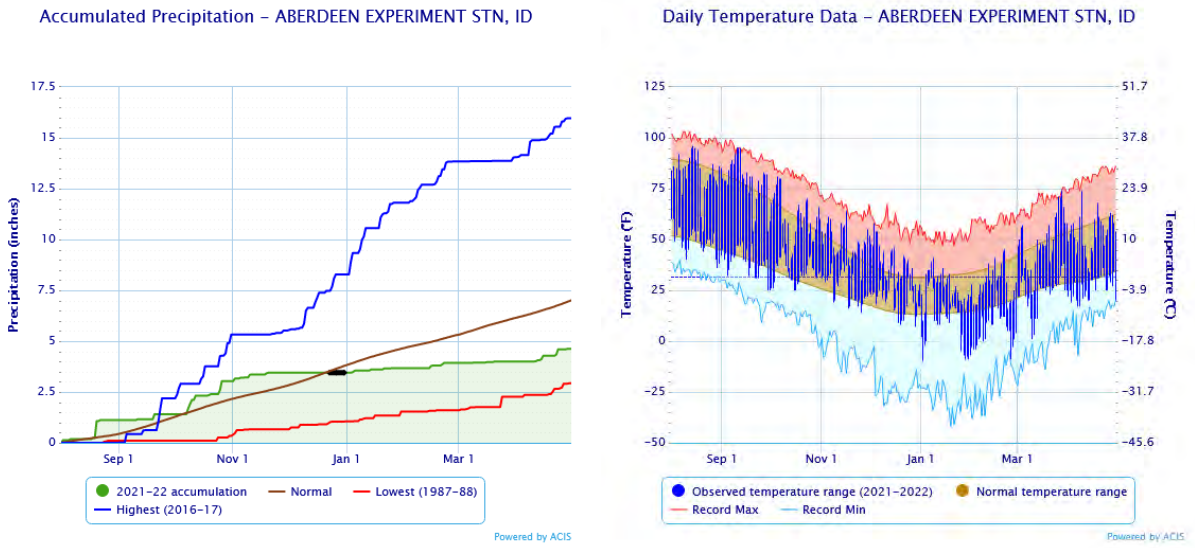

Figure 1. Accumulated precipitation (left) and observed temperature ranges at the Aberdeen Experiment Station, Idaho, for the period 1 August 2021 through 30 April 2022. NOAA (2024).

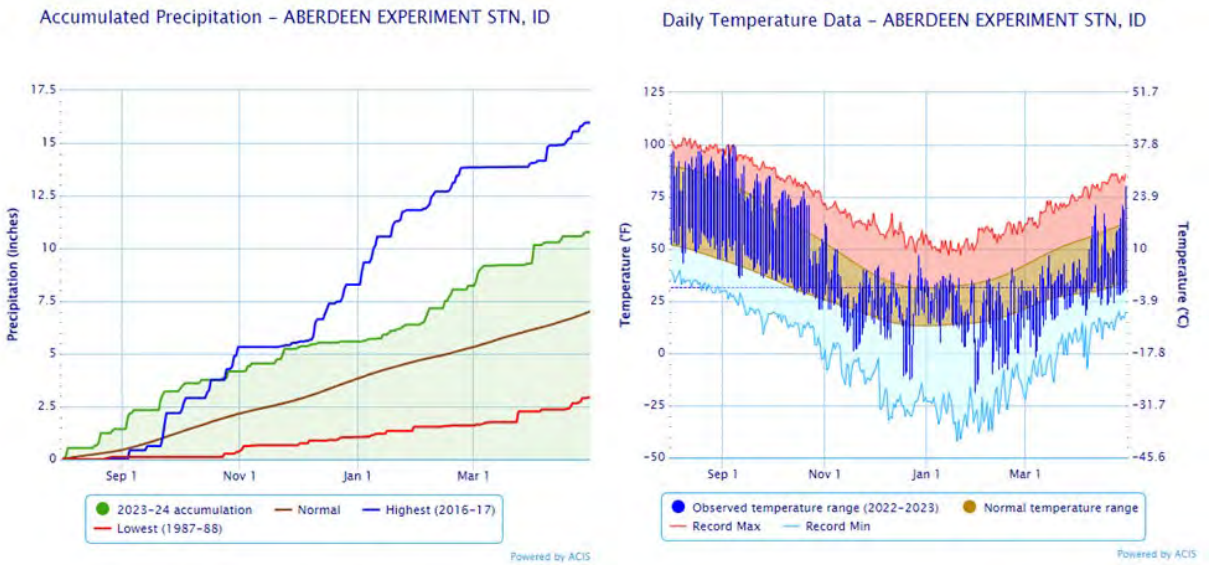

Figure 2. Accumulated precipitation (left) and observed temperature ranges at the Aberdeen Experiment Station, Idaho, for the period 1 August 2023 through 30 April 2024. NOAA (2024).

The 2023-24 growing season started off wetter than 2021-22, with 3.22 in of rain between planting and 2 MAP. Temperatures during that period were more moderate than in 2021-22, and killing

temperatures arrived earlier in the fall. Low temperatures (13 °F) at the end of October (2 weeks after 2 MAP) killed the oats, whereas in 2021 they survived until 3 MAP. Radish and turnips were damaged by the low temperatures in late October (individual leaves died) but by 3 MAP were growing new leaves from the root. Subsequent low temperatures killed the radishes, but the turnips regrew in spring. Lowest temperature of the season was -16 °F in January. There were half as many days with extreme temperatures below 0 °F than in 2021-22. Additionally, there was protective snow cover for most of the winter months in 2023-24.

Canopy Cover

Only the first 3 months of canopy growth at each seeding rate are discussed here. Ideally, a cover crop canopy should close quickly to protect the soil surface. Also, growth had slowed drastically or ceased by 3 MAP (late November) in each year of the study, and some species winter-killed around that time.

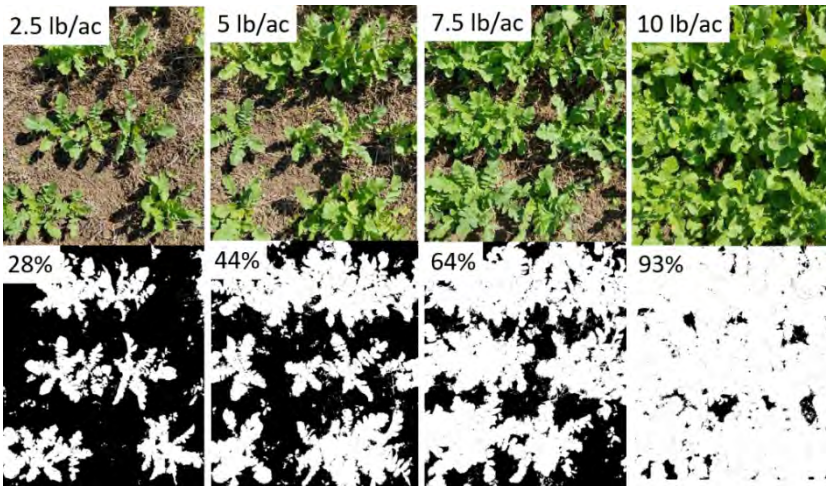

Figure 3. Example of Foliage (Patrignani, 2020) color image analysis. Top row: Radish plots were photographed at 1 month after planting (1 MAP) in 2023. From left to right, radishes were seeded at 2.5, 5, 7.5, and 10 lb/ac. Bottom row: Analysis determined living canopy cover at 28%, 44%, 64%, and 93%, respectively.

Barley

Small differences in barley cover were observed at 1 MAP, but all seeding rates of barley reached >90% cover by 2 MAP in both years of the study (Figure 4).

Oat

In 2021, the canopy reached peak cover at 2 MAP (Figure 4). All seeding rates achieved >60% cover, with the highest rate reaching >80% cover. By 3 MAP, the canopy had been damaged by hard frosts. All treatments had declined to around 60% living cover by 3 MAP. In 2023, all seeding rates achieved at least 99% cover by 2 MAP. Subsequent hard frosts completely killed the canopy; by 3 MAP there were no green leaves that could be measured with Foliage. The killed canopy was very dense.

Triticale

In 2021, the 3 highest seeding rates reached >80% cover by 2 MAP, with the lowest seeding rate at 74% cover (Figure 4). Cold temperatures caused some loss of living canopy by 3 MAP. The 2 highest seeding rates had less cover, 62% vs. ≥70% for the lower rates, with the differences caused by lodging of the thicker stands. In 2023, all seeding rates reached at least 98% cover by 2 MAP. There was a slight decline due to freezing temperatures by 3 MAP. All treatments maintained >90% cover.

Wheat

In 2021, the 3 highest seeding rates reached >90% cover by 2 MAP (Figure 4). In 2023, all rates reached >90% cover by 2 MAP. Cold temperatures before 3 MAP caused slight declines in the 3 highest seeding rates in 2021, but not in 2023.

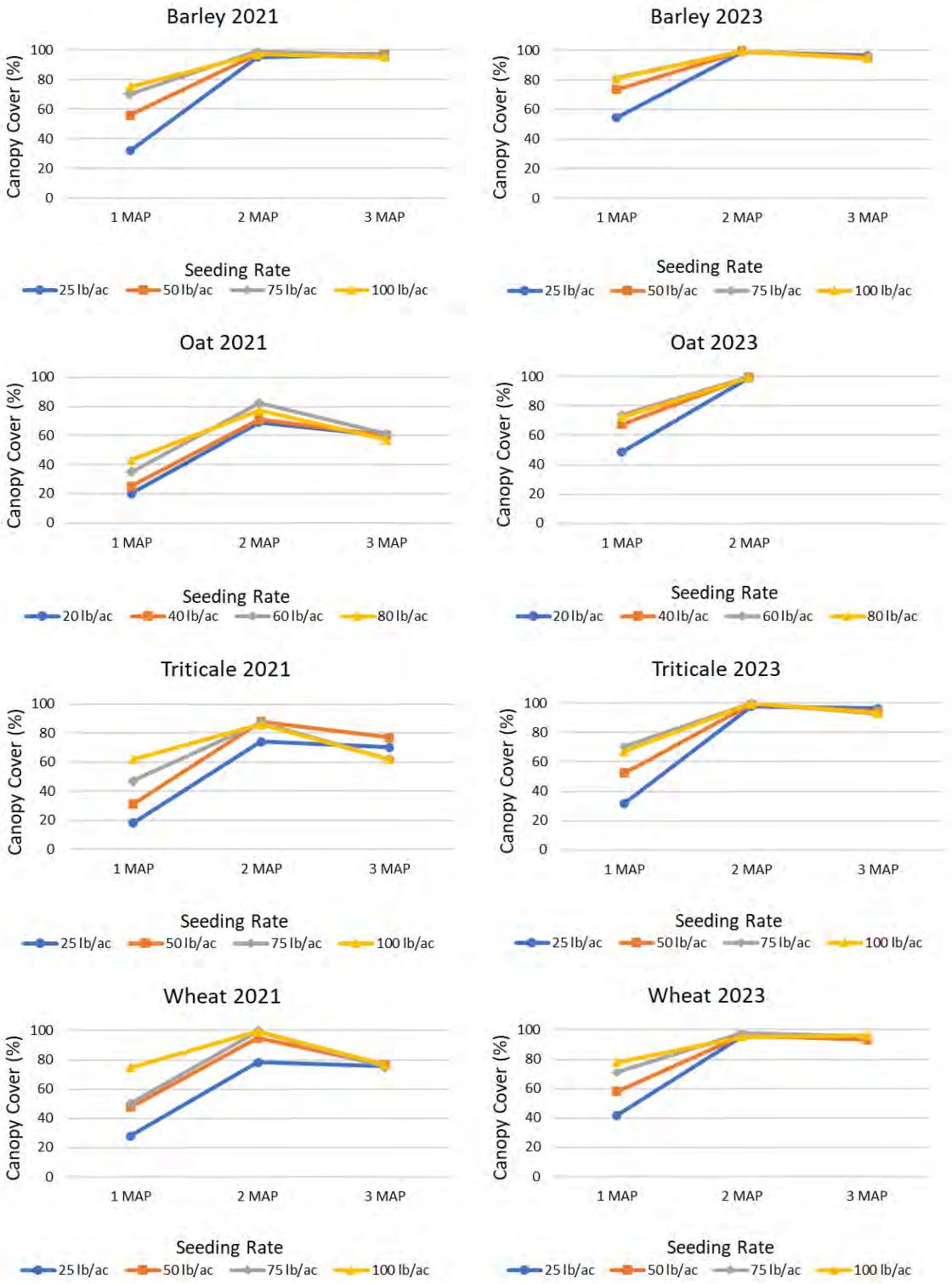

Figure 4. Canopy cover (%) for winter barley ‘P919’, oat ‘Goliath’, facultative triticale ‘Thor’, and winter wheat ‘Gore’ at 1, 2, and 3 months after planting (MAP) in 2021 and 2023, Aberdeen Plant Materials Center, Aberdeen, Idaho.

Figure 5. Canopy cover (%) for radish 'Jackhammer', hybrid turnip 'Vivant', hairy vetch 'Villana', and Austrian winter pea VNS at 1, 2, and 3 months after planting (MAP) in 2021 and 2023, Aberdeen Plant Materials Center, Aberdeen, Idaho.

Radish
In 2021, the 3 highest seeding rates reached >90% cover by 2 MAP (Figure 5). All rates reached over 90% cover by 3 MAP and were winter killed shortly after. In 2023, all rates reached >90% cover by 2 MAP. At 3 MAP, hard frosts had partially killed the canopy. There was not enough exposed green canopy to use the Foliage app, so green + dead cover was measured by point-intercept to obtain total cover. All but the lowest rate maintained at least 90% total cover.

Turnip
In 2021, all treatment rates reached >60% cover by 2 MAP (Figure 5). All reached >90% cover by 3 MAP and were winter killed shortly after. In 2023, the highest rate reached 90% cover at 1 MAP. All rates reached >90% cover by 2 MAP. They maintained this cover at 3 MAP, although many leaf tips had been killed by frost.

Hairy Vetch
In 2021, hairy vetch developed slowly after emergence (Figure 5). By 2 MAP, none of the seeding rates had reached 25% cover. At 3 MAP, the second highest rate had reached 40% cover, and the highest rate had reached 38% cover. In 2023, hairy vetch cover was similar to 2021 at 1 MAP, but by 2 MAP, the 2 higher seeding rates had achieved >90% cover, while the lower rates were around 60% cover. By 3 MAP, all seeding rates had achieved >80% cover, with the 2 higher rates both reaching 97% cover.

Winter pea
In 2021, only the 2 highest seeding rates reached 25% cover by 2 MAP (Figure 5). By 3 MAP, the 3 highest rates had reached >50% cover, with the 2 highest rates reaching >60% cover. In 2023, winter pea performed better than in 2021. By 2 MAP, all but the lowest rate had reached at least 50% cover, and the 2 highest rates had >80% cover. By 3 MAP, the lowest rate reached 61% cover, and the two highest rates were 94% and 95% cover.

Biomass at 2 MAP
All 2 MAP biomass values are reported in Table 2.

Barley
Seeding rates had a significant effect on barley biomass at 2 MAP of in both years of the study. At 2 MAP in 2021, the 3 highest seeding rates all produced over 3500 lb/ac and 2 highest rates produced over 4000 lb/ac. In 2023, we saw no significant difference in biomass from the 3 highest rates with all producing just over 3800 lb/ac. The lowest rate however produced significantly lower biomass with only 2884 lb/ac. Barley was also notable in its production relative to the other small grains in the study. In both years of the study, the lowest rate of barley exceeded 2400 lb/ac at 2 MAP, which was not the case for any other small grain except for oat in 2023.

Oat
There were notable differences in oat performance at 2 MAP in the 2 years of the study, even though the same seed lot was planted. At each seeding rate, 2023 2 MAP biomass was at least twice what it was in 2021. The lowest seeding rate in 2023 produced 3581 lb/ac, which was greater than the biomass produced by the highest seeding rate in 2021, 2852 lb/ac. Weather conditions in 2021 were less favorable, with 1.3 in of rain between planting and 2 MAP (in addition to irrigation) and record

Table 2. Mean cover crop biomass lb/ac (dry weight) at 2 months after planting (2 MAP) and prior to termination (PT) for the 2021-22 and 2023-24 study years at the Aberdeen PMC, Aberdeen, Idaho. For PT biomass, barley, triticale, wheat, vetch and pea were evaluated at 8 months after planting (MAP), prior to chemical termination. Oat, radish, and turnip were evaluated prior to killing temperatures in the fall. ANOVA (P = 0.05) with means separation by Tukey HSD unless otherwise indicated.

		2021-2022						2023-2024					
Cover Crop	Seeding Rate PLS lb/ac	2MAP Biomass lb/ac		SE Mean[1/]	PT Biomass lb/ac		SE Mean	2MAP Biomass lb/ac		SE Mean	PT Biomass lb/ac		SE Mean
Barley, winter	25	2425	c	196	951[2/]	ns[3/]	365	2884	b	78	5355	ns	441
'P919'	50	3506	b	127	522		67	3884	a	173	5114		269
	75	4067	ab	242	433		92	3871	a	232	5144		341
	100	4360	a	150	348		59	3837	a	141	4847		316
Oat	20	1564	b	269	3871[4a/]	ns	456	3581	b	337	3581[4b/]	b	337
'Goliath'	40	1844	ab	280	4254		459	4869	ab	255	4869	ab	255
	60	2852	a	200	5512		516	5043	ab	581	5043	ab	581
	80	2646	ab	399	5755		563	5667	a	272	5667	a	272
Triticale	25	1147	b	73	wk[5/]		--	1732	b	109	2423	a[6/]	579
'Thor'	50	1989	ab	419	wk		--	2465	ab	398	486	ab	92
	75	2961	a	201	wk		--	2939	a	217	166	b	36
	100	3321	a	553	wk		--	2716	ab	230	442	ab	134
Wheat, winter	25	1161	b	174	1765[2/]	ns	247	1822	c	200	4731	ns	583
'Gore'	50	2631	a	264	2422		345	2188	bc	157	5277		271
	75	3427	a	417	2108		151	2603	ab	79	5687		304
	100	3776	a	207	1774		462	2791	a	90	5360		366
Radish	2.5	1797	ns	145	2234[4a/]	ns	231	1287	b	235	1287[4b/]	b	235
'Jackhammer'	5	2179		267	2528		71	1510	b	143	1510	b	143
	7.5	2379		160	2927		100	2095	ab	271	2095	ab	271
	10	2830		388	2630		368	2830	a	422	2830	a	422
Turnip, hybrid	2	2541	ns	273	4254[4a/]	ns	534	4134	ns	967	3793[4c/]	ns	333
'Vivant'	4	3524		401	4295		407	5613		590	5102		191
	6	3807		190	4068		575	3356		148	3726		163
	8	3582		681	4684		379	4656		298	4223		286
Vetch, hairy	10	152	ns	27	598[2/]	ns	86	405	b	96	4350	ns	261
'Villana'	15	219		55	562		79	844	a	100	4584		229
	20	290		50	763		165	1184	a	77	5028		199
	25	397		123	709		228	1121	a	79	5371		397
Pea, Austrian	20	526	ns	67	wk[5/]		--	593	b	66	1708	ns	419
Winter	40	397		101	wk		--	567	b	122	2442		522
VNS	60	357		170	wk		--	1006	ab	274	2072		480
	80	549		156	wk		--	1580	a	178	1237		38

[1/]Standard error of the mean.
[2/]Plots heavily grazed by deer and rodents (2021-22 only).
[3/]Not significant at P = 0.05.
[4a/]Biomass collected one week before 3 MAP in 2021 in anticipation of killing temperatures.
[4b/]Winterkill two weeks after the 2 MAP biomass evaluation. The 2 MAP biomass data was used for pre-termination biomass.
[4c/]Collected at 3 MAP prior to expected winterkill.
[5/]Unexpected winterkill; no data collected.
[6/]Kruskal-Wallis nonparametric AOV (P = 0.05) with means separation by Dunn's Test where significant.

high temperatures in early September. In 2023, the plots received 3.22 in of rain and more moderate temperatures between planting and 2 MAP, which undoubtedly contributed to rapid biomass accumulation.

Triticale
The highest seeding rate of triticale produced approximately 300% greater biomass than the lowest rate in 2021 (3321 and 1147 lb/ac, respectively). In 2023, the 2 highest rates produced nearly double that of the lowest rate. Triticale produced similar amounts of biomass in both years of the study. In 2023, the 2 lowest seeding rates produced more biomass than in 2021, but the highest rate produced less, 2716 lb/ac vs. 3321 lb/ac in 2021. The 3 highest rates exceeded 2400 lb/ac in 2023, but only the 2 higher rates reached this mark in 2021.

Wheat
Wheat biomass at 2 MAP increased with increasing seeding rate in both years of the study. In 2021, the 3 highest seeding rates produced significantly more biomass (2631, 3427, and 3776 lb/ac) than the lowest rate (1161 lb/ac). Less biomass was produced at 2 MAP than in 2023, except at the lowest seeding rate. Biomass from the highest seeding rate (2791 lb/ac) was significantly higher than the lowest and second lowest seeding rates (1822 lb/ac and 2188 lb/ac, respectively).

Radish
Radish biomass did not differ significantly between seeding rates in 2021. At 2 MAP, 2021 radish biomass was 1797 lb/ac at the lowest seeding rate and exceeded 2100 lb/ac at the 3 highest seeding rates. The highest recorded biomass in 2021 was 2830 lb/ac from the highest seedng rate, nearly twice the biomass of the lowest rate. In 2023, the two lowest seeding rates were 1287 lb/ac and 1510 lb/ac, significantly less than the highest seeding rate, which tied with 2021 at 2830 lb/ac.

Turnip
Seeding rate did not significantly affect 2 MAP biomass in either year of the study. In 2021, the three highest seeding rates produced similar biomass at 2 MAP, >3500 lb/ac. In 2023, biomass was greater overall, with >4000 lb/ac except for the third highest seeding rate which produced 3356 lb/ac. We noticed some patchy areas with smaller plants in the part of the field where turnip was grown in 2023. There may have been an uneven distribution of nutrients in this area that affected plant growth.

Hairy vetch
In early fall 2021, hairy vetch grew slowly. At 2 MAP the highest seeding rate produced 397 lb/ac. Conditions in 2023 were more favorable, and the two highest seeding rates produced over 1100 lb/ac, and the three highest seeding rates produced three times more biomass than they did in 2021.

Winter pea
In 2021, all pea seeding rates produced similar 2 MAP biomass ranging from 357 to 549 lb/ac with no statistical difference between values. The lowest and highest seeding rates produced more biomass than the middle rates, although this difference was not significant. In 2023, peas responded to more favorable conditions and all seeding rates produced more 2 MAP biomass than in 2021. The two highest seeding rates produced 1006 lb/ac and 1580 lb/ac, respectively.

Figure 6. ‘Goliath’ oats seeded at 80 lb/ac in 2023. The image on the left was taken 2 months after planting (2 MAP). The image on the right is the same plot one month later (3 MAP) after hard frost. Scale stick shows 1 ft increments. Photo by IDPMC.

Biomass at Pre-termination

Termination date depended on whether a species was terminated by cold (winterkilled), or survived the winter and was terminated with a herbicide application after the 8 MAP evaluation. All pre-termination biomass is reported in Table 2.

Barley

Biomass was collected at 8 MAP in both years of the study, prior to chemical termination. In the spring of 2022, barley stands had been severely affected by deer and rodent grazing over the winter. The lowest seeding rate produced 951 lb/ac, while the highest seeding rate produced only 348 lb/ac; however, there was no statistical difference between seeding rates. In spring 2024, barley biomass values were not affected by any grazing and were much greater than in 2022. Mean biomass values ranged from 4847 to 5355 lb/ac with no significant difference between seeding rates. In both years of the study, the highest seeding rate of barley did not produce as much biomass as the lower rates. While this is not statistically significant, it shows that planting a higher rate of barley may not provide a spring biomass benefit.

Oat

In both years of the study, oats were the first cover crop to terminate (winterkill) in the fall. Oats winterkilled just before 3 MAP on 17-18 November 2021. Biomass values ranged from 3871 lb/ac at the lowest seeding rate to 5755 lb/ac at the highest seeding rate, with no significant difference between rates. In 2023, winterkill occurred on 29-31 October (Figure 6).and we therefore used the 2 MAP biomass values to represent pre-termination biomass. In spite of the 2 MAP oat biomass differences between the 2 years of the study, we found that by pre-termination the differences had evened out.

Triticale
We had fully expected 'Thor', a facultative triticale, to be winter hardy. However, in the winter of 2021-22, it winter killed and did not regrow in the spring. During the winter of 2023-24, the triticale plots were protected under several inches of snow. When the snow melted in spring, we found that the lowest seeding rate was the only one to regrow. In plots with higher seeding rates, the heavier stands had fallen over under the weight of snow, creating a thick mat of residue that inhibited spring regrowth. At 8 MAP, we collected biomass prior to chemical termination of the study. The lowest seeding rate, which had less biomass in the fall, stayed upright under the snow, was not covered with thick residue and had much more spring regrowth and biomass. Because the pre-termination data was not normally distributed, Kruskal-Wallis test used, and the means separations with Dunn's are extremely conservative. The lowest seeding rate had a mean biomass of 2423 lb/ac, while the biomass of the higher seeding rates ranged from 166 to 486 lb/ac.

Winter wheat
Biomass was collected at 8 MAP in both years of the study, prior to chemical termination. In 2021-22, winter wheat regrowth was affected negatively by weather conditions as well as by heavy grazing from deer and rodents. As with 2021-22 barley, we suspect that differences between the treatments reflect areas of snow cover and grazing, rather than treatment effects. The highest and lowest seeding rates were 1774 and 1765 lb/ac, respectively, while the two middle seeding rates were higher, (2422 and 2108 lb/ac). There were no statistically significant differences between the seeding rates. In 2023-24, snow cover and absence of deer led to more favorable regrowth in the spring. The lowest seeding rate produced a mean of 4731 lb/ac, while the highest rate produced 5630 lb/ac. There was no statistically significant difference between the seeding rate treatments.

Radish
In 2021, we expected killing temperatures one week before 3 MAP, so we collected at that time. Pre-termination biomass ranged from 2234 lb/ac at the lowest seeding rate, to 2927 lb/ac at the second highest seeding rate. There was no statistically significant difference between the treatment rates. In 2023-24, killing temperatures occurred 2 weeks after the 2 MAP biomass collection. Because plant growth had stopped in the cold temperatures, we used the 2 MAP biomass data as the pre-termination biomass amount rather than sampling again. There was no spring regrowth of radishes in either year of the study.

Turnip
In 2021, we collected pre-termination biomass one week before 3 MAP, following the same reasoning as for radishes. Pre-termination biomass ranged from a mean of 4068 lb/ac at the second highest seeding rate, to 4684 lb/ac at the highest seeding rate. There were no statistically significant differences between the 4 seeding rates. In 2023, we collected pre-termination biomass at 3 MAP, before an anticipated snowstorm and single-digit temperatures. Over the winter, the turnips were protected under the snow, and unlike in 2021-22, they regrew in the spring. We collected another pre-termination biomass at 8 MAP, along with the other cover crops that regrew after winter. Fall pre-termination values were greater than spring, ranging from 3726 to 5102 lb/ac at the second highest and second lowest seeding rates, respectively. Spring biomass ranged from 1559 lb/ac at the second highest rate to 2119 lb/ac at the highest rate (not shown in table). There were no statistically significant differences in biomass between the seeding rates in either fall or spring. Performance over the 2 years of the study shows that turnip provides no or little spring biomass and should be considered for fall biomass only in our area.

Hairy vetch
Biomass was collected at 8 MAP in both years of the study, prior to chemical termination. In 2021-22, hairy vetch suffered from cold temperatures and grazing by deer and rodents. Pre-termination biomass ranged from 562 lb/ac at the second lowest seeding rate to 763 lb/ac at the second highest rate, with no significant difference found between the four seeding rates. In 2023-24, hairy vetch was protected from extreme temperatures and grazing, and biomass ranged from 4350 lb/ac at the lowest seeding rate to 5371 lb/ac at the highest seeding rate. There were no statistically significant differences between the four treatment rates.

Winter pea
Peas winterkilled during the winter of 2021-22. By spring, there were only a few plants in each plot, and those had been grazed by deer. We expected this locally-produced and presumably adapted pea to survive our winters. In 2023-24, the peas survived the winter, probably due to insulating snow cover. Biomass collected at 8 MAP was lowest at the highest seeding rate, 1237 lb/ac. The highest biomass, 2442 lb/ac, was produced at the second lowest seeding rate; however, there was no statistically significant difference in biomass between the four seeding rates.

Heights and Growth Stages.

Heights
Mean plant heights at 2 MAP and pre-termination are reported in Table 3. Heights were measured in cm and can be converted to inches by dividing the cm value by 2.54. In general, higher seeding rates produced taller plants by 2 MAP. Where there was less space between plants, the physical support of, and competition with, neighboring plants produced more upward growth. At lower seeding rates, plants had more room to spread out and did not get as tall.

By the time each species reached its pre-termination measurement (whether in fall or spring) significant height differences between seeding rates had been erased. This was the case in both years of the study. The only exception was triticale after spring regrowth in 2022, where there were significant differences ($P = 0.028$) between seeding rates. However, there were no significant pairwise differences among the means. Given the lack of significant pre-termination differences in height, only 2 MAP heights are discussed below.

Barley
There were significant differences in height at 2 MAP in 2021, with the lowest seeding rate at 32.3 cm and the second highest and highest rates at 39.3 cm and 38.8 cm, respectively. At 2 MAP in 2023, barley was taller than in 2021 with heights ranging from 45 cm at the lowest seeding rate to 50 cm at the second lowest seeding rate. There was no significant difference between heights in 2023.

Oat
In 2021, 2 MAP oat heights ranged from 33.8 cm at the lowest seeding rate to 42.8 cm at the highest seeding rate, with a significant difference between the lowest and highest rates. The 2023 2 MAP heights reflected the large difference in biomass between the two years, with heights ranging from 80 cm at the lowest seeding rate to 90.8 cm at the highest rate. There was a significant difference in height between the lowest and highest seeding rates.

Table 3. Cover crop mean plant height (cm) and growth stage at 2 months after planting (MAP) and prior to termination (PT) in the study years 2021-22 and 2023-24 at the Aberdeen PMC, Aberdeen, Idaho. To convert to inches, divide the cm value by 2.54. ANOVA (P = 0.05) with means separation by Tukey HSD unless otherwise indicated.

		2021-2022						2023-2024					
	Seeding Rate	2 MAP Height		SE	PT Height		SE	2 MAP Height		SE	PT Height		SE
Cover Crop	PLS lb/ac	cm		Mean[1/]	cm		Mean	cm		Mean	cm		Mean
Barley, winter	25	32.3	b	0.9	14.5[4/]	ns[3/]	0.7	45.0	ns	1.5	31.3[4/]	ns	1.5
'P919'	50	35.8	ab	1.0	13.8		0.5	50.0		0.7	29.8		0.7
	75	39.3	a	0.9	14.8		0.3	47.8		1.7	31.3		1.7
	100	38.8	a	1.0	14.3		0.5	47.0		0.7	33.5		0.7
Oat	20	33.8	b	2.6	36.5[5/]	ns	3.3	80.0	b	3.3	wk[7/]	-	-
'Goliath'	40	36.3	ab	2.2	39.5		2.3	88.0	ab	1.4	wk	-	-
	60	41.3	ab	1.7	40.0		0.8	89.0	ab	2.1	wk	-	-
	80	42.8	a	1.4	35.8		1.8	90.8	a	1.5	wk	-	-
Triticale	25	26.0	b	2.0	17.5[4/]	a	2.1	50.3	b	1.9	27.3[4/]	-	1.1
'Thor'	50	29.3	b	3.1	18.0	a	2.1	59.0	a	1.3	wk[6/]		-
	75	39.3	a	1.1	11.0	a	1.8	61.8	a	1.0	wk		-
	100	40.5	a	1.3	11.3	a	1.3	62.8	a	0.9	wk		-
Wheat, winter	25	22.3	b	1.7	25.3[4/]	ns[3/]	0.9	26.3	b	2.3	33.0[4/]	ns	1.6
'Gore'	50	27.8	ab	2.7	25.8		0.9	33.8	a	0.9	34.5		1.2
	75	29.8	ab	1.5	24.3		0.3	36.0	a	0.9	36.0		1.4
	100	34.3	a	0.9	25.3		0.8	38.3	a	1.3	33.5		0.9
Radish	2.5	30.3	ns[2/]	0.5	31.8[5/]	ns[3/]	1.6	49.8	ns	3.3	25.3[5/]	ns	1.8
'Jackhammer'	5	33.8		1.0	33.7		0.6	43.5		2.1	22.5		1.4
	7.5	32.8		1.4	33.7		1.2	50.0		4.7	24.3		2.3
	10	28.5		2.2	30.5		2.3	52.0		5.4	26.0		2.7
Turnip, hybrid	2	29.8	ns	1.3	43.2[5/]	ns[3/]	3.4	53.3	ns[3/]	5.2	34.3[5/]	ns	2.4
'Vivant'	4	32.8		1.6	42.5		1.2	59.8		1.0	33.5		0.9
	6	30.0		2.1	41.9		3.9	50.5		5.3	32.3		1.7
	8	30.8		2.5	41.9		3.4	58.3		2.3	32.0		1.8
Vetch, hairy	10	6.8	ns[3/]	0.3	3.7[4/]	ns	0.3	12.0	b[3/]	0.8	20.5[4/]	ns	1.3
'Villana'	15	6.5		0.5	4.1		0.3	12.0	b	0.0	18.0		0.9
	20	6.8		0.3	4.1		0.2	13.0	ab	0.6	19.0		1.1
	25	7.8		0.3	3.7		0.5	16.8	a	0.9	22.3		0.5
Pea, Austrian	20	12.5	ns[3/]	1.0	wk[6/]	-	-	21.8	b	0.5	14.8[5/]	ns	1.9
Winter	40	13.0		1.0	wk		-	29.3	a	0.9	14.0		1.7
VNS	60	12.8		1.1	wk		-	31.0	a	1.4	13.5		0.9
	80	14.0		1.4	wk		-	32.3	a	1.6	16.0		0.4

[1/]Standard error of the mean.
[2/]Not significant at P = 0.05.
[3/]Kruskal-Wallis nonparametric AOV (P = 0.05) with means separation by Dunn's Test where significant.
[4/]After spring regrowth.
[5/]Prior to expected winterkill in fall.
[6/]Unexpected winterkill.
[7/]Winterkill two weeks after the 2 MAP measurement.

Triticale
In 2021, the 2 lowest seeding rates (26.0 cm and 29.3 cm) were significantly shorter at 2 MAP than the 2 highest seeding rates (39.3 cm and 40.5 cm). In 2023, 2 MAP heights at all seeding rates exceeded the tallest 2 MAP height measured in 2021. The lowest seeding rate reached 50.3 cm, significantly shorter than the 3 highest seeding rates, which were all >59.0 cm.

Wheat
Winter wheat 2 MAP heights were similar in both years of the study. In 2021, the lowest seeding rate was 22.3 cm, significantly less than the highest seeding rate, which reached 34.3 cm. Heights in 2023 were slightly greater overall, with the lowest seeding rate at 26.3 cm, significantly shorter than the higher seeding rates which ranged from 33.8 to 38.3 cm tall.

Radish
There was no significant difference in radish heights at 2 MAP in 2021 or 2023. Heights ranged from 28.5 cm at the highest seeding rate to 33.8 cm at the second highest seeding rate. In 2023, plants were slightly taller at 2 MAP than in 2021 and ranged from 43.5 cm at the second highest seeding rate to 52.0 cm at the highest seeding rate.

Turnip
There was no significant difference in turnip heights at 2 MAP in 2021 or 2023. In 2021, heights ranged from 29.8 cm at the lowest seeding rate to 32.8 cm at the second lowest seeding rate. All 2021 heights were exceeded in 2023. Heights ranged from 50.5 cm at the second highest rate to 59.8 cm at the second lowest rate. There was no significant difference in heights in 2023.

Hairy Vetch
Hairy vetch 2 MAP heights in 2021 ranged from 6.5 cm at the second lowest seeding rate to 7.8 cm at the highest seeding rate, with no significant differences. In 2023, the 2 lowest seeding rates were both 12.0 cm tall, significantly shorter than the highest seeding rate at 16.8 cm tall.

Winter pea
Winter pea heights at 2 MAP in 2021 were between 12.5 cm at the lowest seeding rate and 14.0 cm at the highest seeding rate, with no significant differences. In 2023, the lowest seeding rate reached 21.8 cm and was significantly shorter than the 3 higher seeding rates, which were ≥29.3 cm.

Growth Stage
Seeding rate did not affect growth stage in any of the cover crop species at any time (data not shown). By 2 MAP, all small grains had reached Feekes Stage 5, with leaf sheaths strongly erected and the stems formed starting to grow in length. For small grains that survived the winter, the plants were observed to still be at Stage 5 in late April prior to termination. At 2 MAP, both turnip and radish had reached Stage 2 (Harper, 1973) forming rosettes but not yet initiating stem elongation. Neither species advanced beyond Stage 2 before being killed by cold temperatures. Turnip regrowth in spring 2024 was much weaker than the fall growth and remained at Stage 2 until termination at 8 MAP. Hairy vetch and winter pea remained at Stage 1 (vegetative, no flowers) (Padro et al., 2022) throughout both years of the study.

Discussion

The appropriate seeding rate for each species depends on the goals of a cover crop mix seeding and what resource concern it is designed to address. Where seeding rate had little effect on canopy cover and/or biomass production, lower seeding rates can meet conservation goals while keeping seed costs at a minimum.

Canopy

All seeding rates of small grains provided similar amounts of 2 MAP canopy cover in both years of the study, although there was less 2 MAP canopy cover overall in 2021 due to environmental conditions. Small grain canopy cover did not increase after 2 MAP. Radish and turnip seeding rates showed little difference in canopy cover by 2 MAP, and by 3 MAP all seeding rates had achieved >90% cover in both years. If the goal of the cover crop seeding is to rapidly cover the soil surface and prevent erosion, this was achieved with lower seeding rates of small grains and brassicas in our study.

The early growth of hairy vetch and winter pea was comparatively slow, particularly in 2021 when environmental conditions were less favorable. Because small grain and brassica species can produce rapid, dense canopy cover, legume species are more appropriate as a minor component of cover crop mixes designed for erosion control.

Biomass

For all species in both years of the study, the highest seeding rate did not produce significantly more fall biomass than the second highest seeding rate. The lowest seeding rates produced significantly less fall biomass than higher seeding rates of barley and wheat in both years and of hairy vetch in 2023. For cover crop species that survived winter and regrew in the spring, biomass appeared to be affected more by environmental conditions than by seeding rate in most cases. There were no significant differences in spring biomass for regrowth species in either year except for triticale in 2024, when only the lowest seeding rate survived being buried by snow. If biomass is for grazing or if building soil health is a conservation objective, this goal may be better achieved by avoiding the lowest seeding rates for each species, while also avoiding the highest seeding rates that do not provide additional biomass or a return on investment.

CONCLUSION

An important step to successful cover crop planting is to seed at a rate that balances the economic needs and the stated conservation goals. The results of this 2-year evaluation of 4 seeding rates of fall-planted winter barley, oat, facultative triticale, winter wheat, radish, hybrid turnip, hairy vetch, and winter pea provides a base of information on canopy cover and biomass production. For many species, seeding at the highest rate did not provide additional benefit in terms of biomass or canopy cover. Seeding at the lowest rate generally produced less biomass but generated similar cover by 3 MAP as higher seeding rates. Producers and conservation planners can use the results of this study to determine the appropriate single-species seeding rates for their objectives, to generate a mix that is both effective and economical.

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