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Impact of Cover Crop Seeding Rate on Stand Establishment and Aboveground Biomass Production

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ABSTRACT

Cover crops offer many ecological and economic benefits to producers including reducing soil erosion and enhancing soil health which are priority resource concerns for the USDA-Natural Resources Conservation Service. Seeding rate recommendations in the West typically reflect industry or agency guidelines developed for other areas of the country characterized by greater growing season precipitation, longer growing seasons, and different cropping systems. This study investigated the effect of variable seeding rates on seedling establishment and aboveground biomass production of a cover crop mix grown under dryland conditions in a low annual precipitation area (10 to 11 inches) in 2020 and 2021. Seeding rates of 50, 75, 100, and 125% of an industry recommended rate of 18 PLS pounds per acre were tested at the Montana-Wyoming Plant Materials Center in Bridger, Montana, in a randomized complete block design. Although there was no significant difference in seedling establishment (seedlings/foot) among the 100% (6.21) and 125% (6.85) rates in 2020, there was a difference between these rates and the 50% (2.23) and 75% (4.09) rates. There were no significant differences in aboveground biomass production (lb/acre) among the 75, 100, and 125% rates with 9461, 9482, and 8848 lb/acre,

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respectively, in 2020. There were differences in biomass production between the 50% versus 75% and 100% rates. In 2021, a year receiving below long-term average growing season precipitation, seedling establishment and aboveground biomass were substantially lower than 2020. Seedling establishment was only different among the 100% rate (2.96) and 50% rate (1.56) in 2021. There were no significant differences in aboveground biomass production among the seeding rate treatments in 2021. Results suggest there might be some benefit to seedling establishment by sowing above the 50% rate but no benefit to aboveground biomass when precipitation is limited.

INTRODUCTION

Annual cover crops have been widely used across the central and eastern parts of the United States for decades to provide a variety of agronomic and ecological benefits including reduced soil erosion, reduced weed and pest competition, enhanced soil nutrition (especially Nitrogen (N)), uptake of leachable N, improved soil moisture conservation and availability, improved soil condition (i.e., enhanced organic matter, soil biota, tilth, etc.), water quality protection, biomass production, and more (Sanderson et al., 2018). Similarly, cover crops may enhance farm economics by reducing fertilizer inputs and overall cost, improving target crop production, reducing chemical costs for weed and pest control, reducing energy costs, and by producing additional forage (Clark, 2012). In Montana and Wyoming there has been limited cover crop species or variety testing, for single species or mixes. Optimum seeding rate information is largely unavailable, especially when evaluated for two important factors of cover crop services, seedling establishment and aboveground biomass production.

There have been three recent studies at the Montana-Wyoming Plant Materials Center (MTPMC) in Bridger, Montana, testing legume species seeding rate effects on stand count and biomass production. In one study, three rates (5, 10, and 20 lb/acre Pure Live Seed [PLS]) of cowpea (*Vigna unguiculata* L.) and mung bean (*Vigna radiata* L.) were added separately to a six-species cover crop mix seeded at a constant rate (Henning & Kilian, 2017). Twenty lb/acre of cowpea resulted in significantly higher biomass production than 10 lb/acre cowpea, as well as 5 and 10 lb/acre mung bean. Interestingly, there was no significant difference in cowpea biomass production when seeded at 20 lb/acre and 5 lb/acre. There were also no significant biomass differences between any of the mung bean seeding rates. There were no significant differences in total biomass between seed rate treatments indicating the legumes contributed minor amounts to the overall biomass of the mix. The second study at the MTPMC investigated whether seeding rates of 1, 2, and 4 lb/acre PLS of 'Frosty' berseem clover (*Trifolium alexandrinum* L.), when incorporated into a six-species cover crop mix maintained at a constant seeding rate, affected berseem clover density and aboveground biomass production, and total cover crop biomass production (Henning et al., 2021). Berseem clover seeding rate did not result in any significant differences in aboveground biomass production of the cover crop mix. Berseem clover at 4 lb/acre had significantly greater seedling density and aboveground biomass than the 1 or 2 lb/acre seeding rates. Frosty berseem clover, however, performed poorly in the mix at all tested seeding rates (1, 2, and 4 lb/acre PLS). The third MTPMC study investigated seeding rates of 2.5, 5, and 10 lb/acre PLS of two leguminous cover crops, guar (*Cyamopsis tetragonoloba* [L.] Taubert) and sunn hemp (*Crotalaria juncea* L.), when incorporated into a 6-species cover crop

mix maintained at a constant seeding rate (Henning et al., 2020; Kilian, 2017b). For guar plant density, there was no significant difference between the 2.5 and 5 lb/acre rates but there was a significantly greater number of seedlings at the 10 lb/acre rate than the 2.5 and 5 lb/acre rates. Similarly, there was significantly greater aboveground biomass production of guar at the 10 lb/acre rate than the 2.5 and 5 lb/acre rates. For sunn hemp, there was no significant difference among seeding rates for plant density or aboveground biomass production. The seeding rate of guar and sunn hemp had no significant effect on the aboveground biomass production of the 6-species cover crop mix indicating these species contribute minor amounts of overall biomass to the mix.

Other USDA-NRCS Plant Materials Centers (PMC) conducted a two-year seeding rate study and are still summarizing results. The Corvallis PMC tested the effects of 20, 40, and 60 seeds/ft of a 2-species mix (50% cereal rye [*Secale cereale* L.], 50% crimson clover [*Trifolium incarnatum*]); a 4-species mix (45% cereal rye; 22.5% crimson clover; 22.5% hairy vetch [*Vicia villosa* Roth]; 10% forage radish [*Raphaus sativus*]); and a 6-species mix (22.5% each of cereal rye, oats [*Avina sativa*], crimson clover, hairy vetch; 5% each radish and turnip [*Brassica rapa*]) (Young-Mathews, 2014). After one year, there were no significant differences in total dry matter production among or between mixes or seeding rates. In a similar study at the Pullman PMC, there was significantly more dry matter production in the 2-species mix (1.53 tons/acre) than the 4-species (0.88) or 6-species (0.73) mixes (Pavek, 2014). One-year study result data from the Bismarck PMC cover crop study showed no significant differences among or between mixes or seeding rates for dry matter production (Jensen, 2014). In a separate, non-replicated cover crop study at the Corvallis PMC, three mixes (oat - vetch; cereal rye - crimson clover; triticale [*x Triticosecale*] - Austrian winter pea [*Pisum sativum*]) and four seeding rates (50, 75, 100, 150% of recommended rate) were tested. Seedling counts, percent mix composition, and biomass production were evaluated. Study results suggest the 75% seeding rate is likely adequate for canopy cover and biomass production purposes (Young-Mathews, 2017).

Trends in cover crop seeding rate research in other parts of the country may shed light on potential study directions in Montana and Wyoming. However, these studies are often of single species, planted as winter cover, in warmer and wetter environments, used in different cropping systems, and planted with different goals. In a seeding rate study using cereal ryegrass in California, averaged across years, rye population densities increased with increasing seeding rates (80, 160, and 240 lb/acre), although some increase was attributed to higher growing season precipitation in year 2 of the study (Boyd et al., 2009). In the same study, aboveground biomass increased with seeding rate the first two harvests, but not the final one, indicating that planting rye at higher seeding rates maximizes early season rye dry matter production. Dry matter increased with increasing seeding rate up to 70 to 80 days after planting, suggesting higher rates may hasten dry matter production and shorten the cover cropping period. Haramoto (2019) investigated the effects of two cover crop species (soft red winter wheat [*Triticum aestivum* L. 'Pembroke']), and cereal winter rye [*Secale cereale* L. 'Aroostook']), seeding rate (30 versus 100 lb/acre germinable seed), and planting method (drilled versus broadcast) on cover crop benefits following a corn (*Zea mays* L.) crop and prior to seeding soybean. In this study the higher seeding rate increased percent ground cover but did not consistently affect cover crop biomass production. In the case of cereal rye, the lower rate did not reduce cereal rye biomass

production. In a study in Minnesota testing seeding rate, row spacing, and nitrogen rate effects on perennial ryegrass seed production, at one location the lowest seeding rate resulted in significantly lower biomass production than the other tested rates (Koeritz et al., 2015). There was an overall linear trend of increasing biomass production with increasing seeding rate, but biomass production was more closely associated with N application levels in this study.

Cover crop seeding rate studies in the Intermountain West are rare but producer questions on optimum seeding rates are common. Seeding rates for individual species and mixes grown under dryland applications appear to follow specifications used in other areas of the country characterized by higher annual precipitation, longer growing seasons, greater growing degree days (GDD), and different cropping systems. In addition, much of the existing research is limited to testing small grains such as cereal rye, barley, and wheat. Industry and agency seeding calculators offer useful approximations but may over- or underestimate optimal seeding rates for a specific location, climate, or planting goal.

The objective of this study was to determine the optimal cover crop seeding rate for reducing soil surface erosion and optimizing aboveground biomass production. Specifically, we assessed cover crop seeding rate effect on seedling establishment and biomass production. We chose these response variables for their positive effects on various conservation services (ground cover, soil organic matter enhancement, improved soil health, increased target crop productivity, etc.) and farm economics (forage value, N source, reduced need for agrochemicals, etc.) (Clark, 2012). Stalk growth and leaf area are important factors in reducing soil surface erosion and guarding against soil loss (Clark, 2012). Secondly, aboveground biomass contributes to soil surface organic matter and mulching effects after termination and decomposition, reducing erosion and conserving soil moisture (Clark, 2012; Haramoto, 2019), two important considerations in dryland applications in low precipitation areas like central and eastern Montana and Wyoming. Aboveground biomass can also be a valuable farm commodity enhancing a producer's profitability and potentially improving adoption of cover crops in conventional cropping systems.

MATERIALS AND METHODS

The study was conducted on a dryland site at the USDA-NRCS Montana-Wyoming Plant Materials Center in Bridger, Montana (45º17'12.7", 108º53'9.7") in 2020 and 2021. The Bridger, Montana area is in a 11- to 12-inch annual precipitation zone with annual frost-free dates of May 19 through September 20 (NOAA, 2021). The seeding mix was a 7-species blend consisting of 'Frosty' berseem clover (*Trifolium alexandrinum* L.), 'Sweet Six' sorghum-sudangrass (*Sorghum bicolor* var. *bicolor* x *drummondii* (L.) Moench), 'Tifleaf 3' pearl millet (*Pennisetum glaucum* L.), 'Grazing BMR 84' corn (*Zea mays* L.), Impact Forage collards (*Brassica oleracea* L.), 'Bayou' hybrid kale-rape (*Brassica oleracea* x *napus* L.), and black oil seed sunflower (*Helianthus annus* L.) (Table 1). The cover crop study was seeded on June 2, 2020, and May 28, 2021, in a Haverson silty clay loam soil (Parker et al., 1975) in a clean tilled and leveled field to ensure good seed-to-soil contact and minimal weed competition. Plots were seeded 1.25 to 1.5 inches deep with a 4-row, precision cone planter (Kincaid Equipment Manufacturing®, Haven, KS) equipped with double disk furrow openers, depth bands, and double packer wheels. Each

plot consisted of eight seeded rows with 14-inch between-row spacing. Plots were 25 feet long and 9.4 feet wide. The study design was a randomized complete block with four replications. Treatments included four seeding rates of 50, 75, 100, and 125% of the industry recommended seed rate.

Table 1. Crop species, type or variety, seeding rate, and cost of the seed mix used in the Cover Crop Seeding Rate on Stand Establishment and Aboveground Biomass Production study at the 100% industry recommended rate in 2020 and 2021 at the USDA-NRCS Plant Materials Center at Bridger, MT.

Crop	Type or Variety	Actual Seeding Rate	Percent of Full Seeding Rate	Percent by Weight	Seeds per Acre	2020 Cost per Acre
		-lb/acre-	*--%--*	*--%--*	*-seeds/acre-*	*--$--*
Berseem clover	'Frosty'	1	14	6	134,000	3.36
Sorghum-sudangrass	'Sweet Six'	5	28	28	90,000	8.15
Pearl millet	'Tifleaf III'	3	28	17	180,000	5.22
Corn	BMR 84 Day Grazing	5	28	28	12,500	3.40
Collards	Impact Forage	1	17	6	175,000	2.19
Rape/Kale	'Bayou'	1	20	6	181,000	2.97
Sunflower	black oil seed	2	35	11	16,000	1.36

The 2020 and 2021 plantings were sampled on August 26 and September 1, respectively. Plant establishment data (plants per foot) and aboveground biomass samples were collected from randomly located, 3-foot lengths of row, one sample from each of the four center rows of each plot. Aboveground biomass was cut at ground level and samples were dried in a forage drier maintained at 50°C for 168 hours (1 week) and weighed. The response variables, plant density counts and aboveground biomass, were analyzed using analysis of variance (ANOVA) with Statistix 10 software (Statistix10, Tallahassee, FL) with years analyzed separately. Tukey HSD separations were used when $P<0.05$.

RESULTS AND DISCUSSION

Analysis in 2020 indicates a significant difference in seeding rates effect on seedling establishment (plants per foot, $P<0.0001$). Seedling establishment was greater when seeded at the 100 and 125% seeding rates than when seeded at the 50 or 75% rates (Table 2). There was also a significant difference in seeding rates for aboveground biomass production ($P=0.0283$) (Table 2) in 2020. Biomass production at the 50% rate was the same as the 125% rate but lower than the 75 and 100% rates. Biomass production at the 75, 100, and 125% rates were not statistically different.

Table 2. Cover crop seedling establishment and biomass production by seeding rate in 2020 at USDA-NRCS Plant Materials Center, Bridger, MT.

Seeding Rate		Seedling Establishment	Biomass Production
--lb/acre--	*--%--*	*--plants/foot--*	*--lb/acre--*
22.3	125%	6.85 A*	8848 AB*
18.0	100%	6.21 A	9482 A
13.5	75%	4.09 B	9461 A
9.0	50%	2.23 C	6256 B

*Means within column followed by the same letters are not significantly different as determined by Tukey's HSD test at $P<0.05$.

Field observations on August 26, 2020, indicated excellent establishment and growth of seeded monocot species and marginal height and size of seeded forbs which may have been a response to the above average precipitation and adequate soil fertility levels on the site. Annual precipitation in 2020 from May through September (approximate growing season) measured 7.08 inches (NOAA, 2021) which was slightly higher than the long-term average of 6.85 inches in Bridger over that period (NOAA, 2011). Soil nitrate nitrogen in the 0 to 24-inch zone measured 84 lb/acre in 2019 (Agvise Laboratories, Northwood, ND).

Analysis in 2021 indicates a significant difference in seeding rates effect on seedling establishment (P=0.0063). Seedling establishment was greater when seeded at the 100% seeding rate than when seeded at the 50% rate (Table 3). There was no significant difference in seeding rates for aboveground biomass production (Table 3) in 2021. Both seedling establishment and biomass production were lower in 2021 than 2020 for the same treatment.

Table 3. Cover crop seedling establishment and biomass production by seeding rate in 2021 at USDA-NRCS Plant Materials Center, Bridger, MT.

Seeding Rate		Seedling Establishment	Biomass Production
--lb/acre--	*--%--*	*--plants/foot--*	*--lb/acre--*
22.3	125%	2.95 AB*	5072 A*
18.0	100%	2.96 A	6140 A
13.5	75%	1.89 AB	4513 A
9.0	50%	1.56 B	5045 A

*Means within column followed by the same letters are not significantly different as determined by Tukey's HSD test at $P<0.05$.

In 2021 during study evaluation, no berseem clover was observed in any sample area and all broadleaf cover crop species except sunflower were limited in number and size, i.e., broadleaf species contribution to seedling density or aboveground biomass was negligible. The lower biomass and seedling establishment is likely a reflection of below average precipitation in 2021. Annual precipitation in 2021 from May through September measured 3.06 inches (NOAA, 2021), well below the long-term average of 6.85 inches and less than half the amount in 2020. Soil nitrate nitrogen in the 0 to 24-inch zone measured 54 lb/acre in April 2021 (Agvise Laboratories, Northwood, ND).

A cost analysis by seeding rate found the total cost per acre differential between the 75% and 100% seeding rates ranges from approximately $6.26 to $4.35/acre (1-acre and 100-acre quantities, respectively) and does not include inoculant, mixing, bagging, shipping, or costs

associated with planting (Table 4). Legumes are often an expensive component in a cover crop mix. The cost of berseem clover, which did not establish or produce well, is provided to demonstrate the potential savings of species that do not perform well or contribute to the intended conservation goal.

Table 4. Cover crop mix actual seed costs by seeding rate in 2020 at the USDA-NRCS Plant Materials Center in Bridger, MT.

Seeding Rate		Actual Seeded Cost per Acre[1]	Large Volume Seeded Cost per Acre[2]	Berseem Clover Cost per Acre[3]
--%--	*--lb/acre--*	*--$/acre--*	*--$/acre--*	*--$/acre--*
125	22.5	31.31	29.75	3.69
100	18.0	25.05	17.85	2.95
75	13.5	18.79	13.50	2.21
50	9.0	12.53	11.90	1.48

[1] Actual seeded cost per acre is the price for 1-acre worth of seed and does not include inoculant, mixing, bagging, or shipping*.
[2] Large volume seeded cost per acre is the price for 100 acres worth of seed and does not include inoculant, mixing, bagging, or Shipping*.
[3] Berseem clover cost per acre is for 100 acres worth of seed and does not include inoculant, mixing, bagging, or shipping*.
* Green Cover Seed, Bladen, Nebraska.

CONCLUSION

Results suggest there may be opportunities to fine tune commercial cover crop seeding rates for optimizing seedling establishment and aboveground biomass production resulting in savings to producers. The potential for these benefits is site and climate specific. Available soil moisture over the growing season is an expected and important variable in optimizing seeding rate relative to aboveground biomass production. Individual species seeding rates and costs must also be considered during mix development in the context of likely services provided and the priority goals of the producer. Some benefits not assessed with this study such as wildlife habitat, soil health enhancement, and soil nitrate uptake may be maximized with different and potentially greater seeding rates. Further testing to identify which species and varieties establish well and provide the intended conservation benefits versus which do not would allow producers to avoid unproductive species thereby reducing per acre costs, i.e., eliminate poor performing species. Actual costs will be higher for all seeding rates when inoculant, mixing, bagging, and shipping costs are included, and should be proportionally greater when higher seed rates are used with correspondingly greater volumes of seed. Seeding goals should be considered so that targeted conservation benefits are optimized for the lowest possible cost.

In summary, for NRCS applications under conditions similar to the test site at Bridger, MT:

- Optimum cover crop seeding rates for maximizing seedling density and aboveground biomass production will vary by location, reflecting growing season precipitation, soil characteristics, management, and planting goals.
- In this study increasing the seeding rate above 100% did not result in statistically significant greater cover crop seedling establishment or aboveground biomass production.
- Under test conditions in 2020, the 75% seeding rate resulted in statistically similar

aboveground biomass as the 100% rate. Additional research is needed on optimal cover crop seeding rates used in NRCS planning tools.

- Both seedling establishment and aboveground biomass appear strongly influenced by growing season precipitation.
- With the exception of sunflower, broadleaved species did not compete well with aggressive monocot species such as sorghum-sudangrass and millet. Broadleaves are often relatively expensive and may be best planted alone or with few non-aggressive grass species.

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