Evaluating the effects of seeding rates and inoculant performance on nodulation, weed suppression, and relative yields of different lentil varieties grown in the Northern Great Plains

Jed Eberly, Project Director

Project Summary

Lentils are important for diversifying wheat-based cropping systems and are also beneficial in enhancing soil health. These benefits have contributed to the exponential growth in pulse crop acreage in The Northern Great Plains (NGP). There are several challenges facing organic lentil production. Lack of approved herbicide for use in organic pulse crop production provides a challenge to weed management. Little is known about the optimum seeding and appropriate inoculation rates to improve; crop growth, nutrient acquisition, weed management, and yield potential for lentils in organic systems. It is hypothesized that growing lentils that tolerate high population densities could suppress weeds while maintaining and/or achieving higher yields and better economic returns to the grower. The goals of this project are to evaluate effects of seeding rates on lentil yields and weed competition. A multi-site replicated trial was established on grower's fields in three different lentil growing areas of Montana. Three lentil varieties were selected based on seed sizes; large, medium, and small, and were planted at four different rates. An inoculant containing both rhizobia and mycorrhizal fungi was applied at the recommended rate and twice the recommended rate. Yield data was not obtained at one site due to livestock encroachment before harvest. The results showed that increasing the seeding rates from 100 to 700 plants m^{-2} led to significant yield increases and reduction in weed densities regardless of lentil variety or geographic location. Furthermore, at the highest seeding rate the yield and weed density response had plateaued which suggests that optimum seeding rates may have been attained resulting in optimal yield gains and weed suppression.

Introduction

In the USA, Significant acreages of the crop are found in the low-rainfall areas of Montana (MT), North Dakota (ND), Washington (WA), and Idaho (ID). In the NGP, lentils are important for diversifying wheat-based cropping systems and are also beneficial in enhancing soil health when grown either as a cash crop or cover crop. In these areas, lentil crop is normally grown in rotation with wheat, barley, oil-seed crops such as canola and flax, and other legumes including peas and chickpeas [5,15]. The period between 2017 and 2020 saw the largest reduction in area planted into lentils across the four states. The highest reduction in acreage was in the state North Dakota at 69% followed by MT at 49%. The states of WA and ID each reduced acreage by 32% and 19% respectively (Fig.1). In spite of the reduction in area planted into lentils, yields increased by 56, 38, 31, and 27% for MT, ND, ID, and WA over the same period (Fig. 2). This could possibly be attributed to adoption of better agronomic practices by growers and favorable weather for growing lentils over the four years. The data refers to lentils grown in conventional cropping systems. To our knowledge, acreage and yields for organic lentils grown in the same region is not available in published literature.

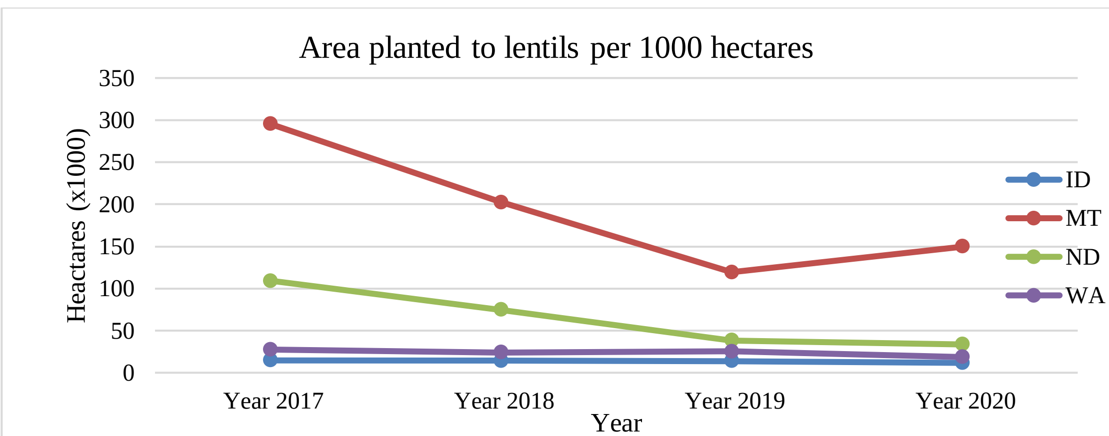

Figure 1. Trends of crop acreages for the period 2017-2020 in four states ID, ND, MT and WA (USDA: NASS 2019 and 2020)

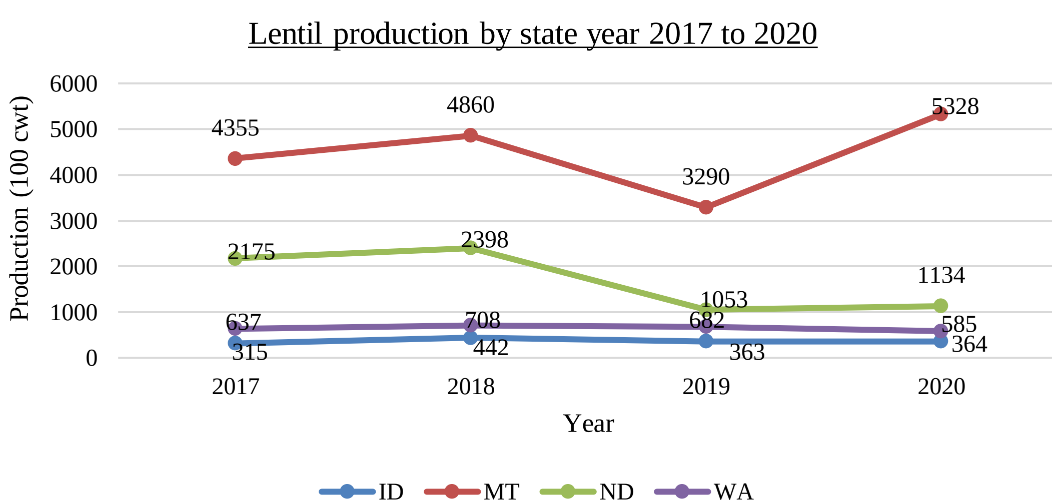

Figure 2: Trends of lentil production between 2017 and 2020 across ID, ND, MT, and WA (USDA: NASS 2019 and 2020)

Most organic lentil growers in the Northern Great Plains (NGP) base the seeding rates of all lentil varieties on a target population of 130 plants m^{-2} which is borrowed from conventional farming systems ([1] and Jim Barngrover, (*pers comm*). However, crop management strategies and inputs used in organic system differ from those used in conventional cropping systems [1]. For example, while conventional lentil growers can use a number of approved synthetic seed treatment and weed management products, these are not approved for use in organic systems. Organic growers are often encouraged to seed densely to account for the loss of stand due to seed and soil pathogens and achieve desired plant density in the field. More research is needed given the wide range of seeding rates in lentil growing regions around the world [1, 16] and there is a need for better seeding rate recommendations.

In addition to improving yield, optimal seeding rates can also enhance weed control. Lentil plants are short (averaging 30-35cm high) in stature and are poorly competitive with weeds. Conventional lentil growers have access to products for weed management. To our knowledge, there are no certified products for weed management in organic lentil fields. Therefore, organic lentil growers rely heavily on cultural practices to manage weeds in their fields. Strategic practices employed to control weeds in organic farms include use of cover crops in place of summer fallow and repeated cultivation pre-seeding. The drawback of repeated cultivation in the spring is that soil moisture is lost, and the crops will often have to contend with insufficient moisture throughout the growing season. An alternative method that can be employed to help control weeds in organic lentil fields is increasing the planting density.

Research has shown that planting density can influence weed pressure. Baird *et al.,* [1] found that weed biomass was reduced by 59% when lentil planting density was increased from 100 to 229 plants m^{-2}. They suggested that organic farmers could suppress weeds and increase yield and profitability in their lentil production by increasing the seeding rate from the recommended target population of 130 plants m^{-2} to 229 plants m^{-2} in Saskatchewan, Canada. This is well above the current recommended seeding rates of 130 plants m^{-2} for the NGP. Seed size can also affect emergence patterns and ability of a crop to compete with weeds. Crawford [6] evaluated the effect of cultivar and seed size on emergence and competitiveness of edamame with weeds. The results have shown that smaller edamame seeds attained 50% emergence 0.7 days earlier than large seeds. Also, cultivar choice and seed size had significant effect on weed suppressive ability, with larger seed sizes having higher biomass and surface area covered, and greater weed tolerance 8 weeks after emergence. Place *et al*., [17] reported that soybean plants from larger seed size (~6.75 mm diameter) had more canopy coverage, more biomass, and improved competitiveness with weeds at 3-7 weeks after emergence. They suggested that using large-sized soybean seeds may be used as a better weed control strategy in organic soybean production. More research is needed to determine if similar responses will be seen with lentils and to identify cultivars that are weed suppressive or tolerant while maintaining yields.

In addition to seeding rates, inoculants can also impact the performance of pulse crops. Research has shown that the presence of endophytic rhizobia associated with pulses can have a positive impact on many soil processes and provide benefits to subsequent non-legume crops [11]. The microorganisms found in inoculants can provide a variety of plant benefits. In addition to rhizobia for N-fixation, microorganisms play a role in crop health and influence nutrient availability, provide protection against environmental stressors, and can provide protection against pathogens. Early studies with pure rhizobia isolates applied directly to the seed indicated a relationship between inoculant concentration and successful nodulation [14]. More recent studies have shown that increasing the inoculation rate to 2-4X the standard rate can result in increased nitrogen uptake and crop yield in cowpea and beans [10]. These results demonstrate the need for additional testing to determine optimum inoculation rates.

Finally, there is a need to better understand the impact of these agronomic practices on soil health in the context of the soil microbial community. Early work with rhizobia inoculants indicated that the inoculants were equally competitive with indigenous organisms and were persistent in the soil after 19 months [14]. Selection of appropriate inoculants could facilitate restoration of critical functions to degraded agricultural soils. However, more work is needed to better understand the dynamics of microbial interactions in these systems.

To our knowledge, there are no published data on the optimal seeding and inoculant rates or the performance of lentil varieties in organic systems across the different microclimates of the NGP. There is need for on-farm research to fill this knowledge gap to enhance the long-term success of organic lentil production in the region. Results from this work will help agronomists and growers understand effects of cultivar choice and seeding and inoculant rates on crop performance and will help growers make informed decisions on integrated weed management strategies for organic lentil production. By incorporating better crop management strategies, lentil growers can improve the profitability and sustainability of their operations.

Research Objectives

The objectives of the study were:

1. Evaluate the effect of seeding rate on yields of three different lentil varieties based on seed size.
2. Determine yield stability of three different lentil varieties across environments in Montana.
3. Evaluate the effects of lentils seeding rates on weed suppression.
4. Evaluate the effect of inoculant application rate on the crop performance (growth and yields).
5. Evaluate the effect of seeding and inoculant rates on the composition of the soil microbial community.

Materials and Methods

Research plots were planted on May 9 at Chester, May 11 at Geraldine, and May 15 at Great Falls. The plot size for each treatment was 1.5m x 5m (5' x 15') and all treatments were planted with 3 replicate plots. Large Green (LGL), French Green (FGL), and Black Beluga (BBL) lentils were planted at seeding rates of 100, 200, 300, 500, and 700 plants m^{-2} on a 6-inch row spacing. Previous research in 2019 demonstrated that a higher seeding rate above 500 plants m^{-2} was needed to evaluate effect of planting density on lentil yields. Therefore, a higher seeding rate of 700 plants m^{-2} was included in 2020. AGTIV granular pulse inoculant containing rhizobia and mycorrhizal fungi was applied at the label rate of 4 lbs/acre and at a 2X rate. Weed counts were performed by selecting three random quadrants measuring 0.5 m^2 in each plot. Dry weather in the months of June and July in the research fields made field conditions difficult to collect samples of root-nodules. The clay soils were too dry and therefore nodules could not be extracted from hard crusted soils without destroying and losing them. Therefore, accurate determination of nodule counts could not be done at flowering time. Also, high weed density at Geraldine and Great Falls (Fig. 3) made accurate data collection on plant heights, primary and secondary branches, number of pods per branch and number of seeds per pod difficult to be obtained.

Figure 3. High weed populations at Great Falls (left) and Geraldine (right)

Lentils were harvested in Chester on 2 August 2020 and at Great Falls on August 20, 2020. At Geraldine, harvest data was not obtained after livestock breached the fences and damaged the lentil trial just before harvest. Plant biomass was determined by collecting whole lentil plants above crown from three random quadrants each measuring 0.5 m^2 in each plot at harvest. Total biomass and yield were measured for each cultivar and averaged across all sowing densities. The harvest index (HI) was determined by dividing seed yield by the total biomass. The differences in yields among treatments was determined using analysis of variance (ANOVA) performed using R statistical software (R Core Team, 2013). Where treatment effects were significant, a post hock analysis was conducted using Fishers, LSD to determine the differences among significant mean values.

Results

Similar to 2019, differences in weed densities could be observed between different lentil seeding rates at flowering time in early July (Fig.1). However, unlike in the previous year, differences in weed suppressibility among the lentil varieties was not clearly distinguishable. Both FGL and LGL showed growth advantage compared to the smaller BBL early in the season. This led to earlier canopy closure among the two varieties and higher yields compared to the small seeded BBL variety but did not contribute significantly to better weed suppression relative to the smaller BBL. Total precipitation between the months of April – August 2020 was 5.6 inches at Chester and 9.5 at Great Falls. At both locations, low rainfall levels were recorded in the months of July which is a critical period of early flowering. During period of peak flowering, which occurs in early July, only 0.57 inches of rain was recorded at Chester. The total amount of precipitation received at time of flowering and podding (July and August) was 0.6 and 0.3 inches in Chester, and 0.6 and 0.1 inches at Great Falls (Table 1). The growing degree days (GDD) were 88 and 87 at Chester and Great Falls respectively during the 2020 growing period. The GDD at both locations were the same but the amount of precipitation received at Chester was 0.2 inches higher than at Great Falls at the period of podding. High weed density in Great Falls provided a strong competition for resources including nutrients, water, and sunlight to the lentil crops and therefore contributed to lower yields at the same site in 2020.

Figure 4. Lentil study at Geraldine in early July. Differences in weed density could already be observed between seeding rates among lentil varieties. The boxes A and B shows plot seeded at 500 and 300 seeds m^{-2} and the C box shows a plot planted at 100 plants m^{-2}.

Table 1. Precipitation, Temperature and Growing Degree Days (GDD) summaries for Great Falls and Chester in 2020 growing season.

Great Falls					
	APR	MAY	JUN	JUL	AUG
Precipitation (in.)	0.73	3.34	4.73	0.6	0.1
Temps (Ave) (°F)	39.15	51.305	60.215	66.48	68.935
Ave. Max (°F)	52.37	64.45	72.9	82.77	86.81
Ave. Mins (°F)	25.93	38.16	47.53	50.19	51.06
GDD	-0.85	11.305	20.215	26.48	28.935
Chester					
Precipitation (in.)	0.41	1.89	2.38	0.58	0.3
Temps (Ave) (°F)	38.62	51.76	61.15	66.37	68.34
Ave. Max (°F)	51.97	64.71	73.97	82.61	85.74
Ave. Mins (°F)	25.27	38.81	48.33	50.13	50.94
GDD	-1.38	11.76	21.15	26.37	28.34

Figure 5. Close up view of differences in weed density between 100 seeds m^{-2} (D), 300 seeds m^{-2} (E), and 700 seeds m^{-2} (F) seeding rates. Rows of lentils are more visible on plots with high seeding rates on the right than on the left (low seeding rates).

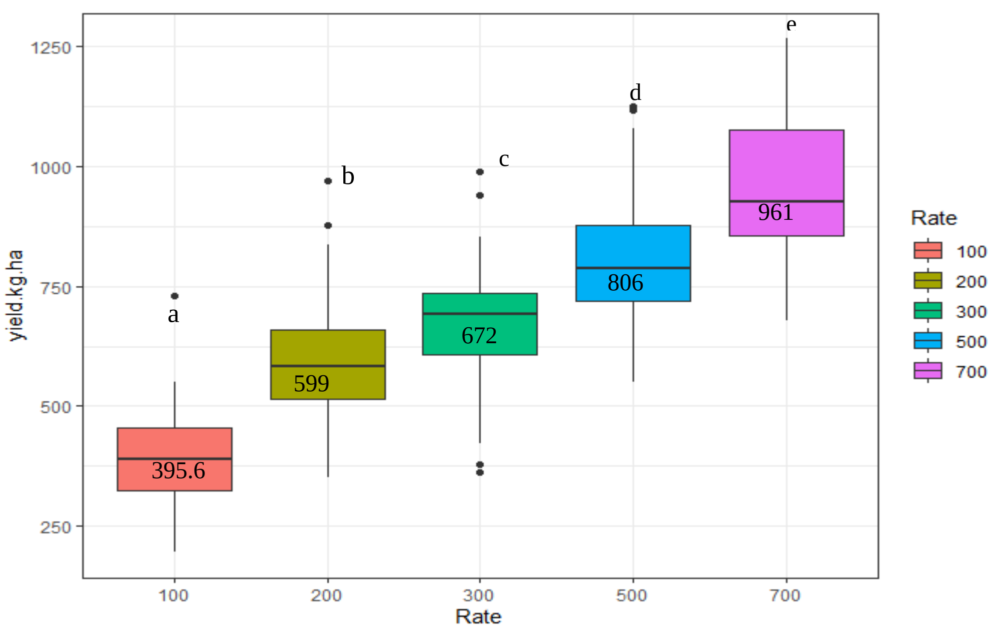

Figure 6. Box plots of the average yield across all varieties and locations for each seeding rate. The dark line represents the mean, boxes represent the interquartile range, and whiskers represent the minimum and maximum values in the data set. Values in the boxplots represents average yields for the. Letters indicate a significant difference in yield at $p<0.05$.

Increasing the seeding rates increased lentil yields across the sites in 2020 (Fig. 6). The highest planting density of 700 plants m^{-2} had 58% greater yield than 100 plants m^{-2}. Although a similar trend was observed among the seeding rates in 2019, overall yields in 2020 were lower compared to 2019.The highest seeding rate in 2020 (700 m^{-2}) yielded the same as the highest seeding rate in 2019 (500 m^{-2}).

Analysis of yield by location and variety in 2020 showed relatively consistent results among lentil varieties in one of the two locations (Table 2). In Great Falls, lentil yields were the same across all varieties in 2020 but significantly lower compared to the yields in 2019. This could be attributed to presence of a strong weed competition and dry weather at pod fill at Great Falls site in 2020. At Chester, the LGL variety yielded higher in 2020 compared to 2019 and this may have been due to favorable growing conditions at the end of the growing season that favored the growth habits of the LGL variety. Overall, the mean yields across all varieties were the same for the two years in Chester but lower yields were observed in Great Falls in 2020 compared to 2019. LGL yielded 12.1% and 16.4% higher than FGL and BBL respectively across the two sites. Also, LGL and FGL yields were comparable but higher than that of BBL across the two locations.

Table 2. Effect of Variety by location and year on yield in 2019/20 for Chester and Great Falls sites

Variety	Chester		Great Falls		Mean
	2019	2020	2019	2020	
BBL	533.8 a	581.4 a	1140.3 d	578.0 a	708.4 b
FGL	645.4 b	607.4 b	1455.4 e	593.3 a	825.4 c
LGL	709.0 b	804.7 c	1462.2 e	543.5 a	879.9 c
Mean	629.4 b	664.5 b	1352.6 e	574.6 a	

Weed density

Increasing the lentil seeding rates led to an increase in crop biomass across all seeding rates and at all three locations (Fig.7). This also resulted in a significant decrease in weed biomass among all lentil varieties (Fig. 7).

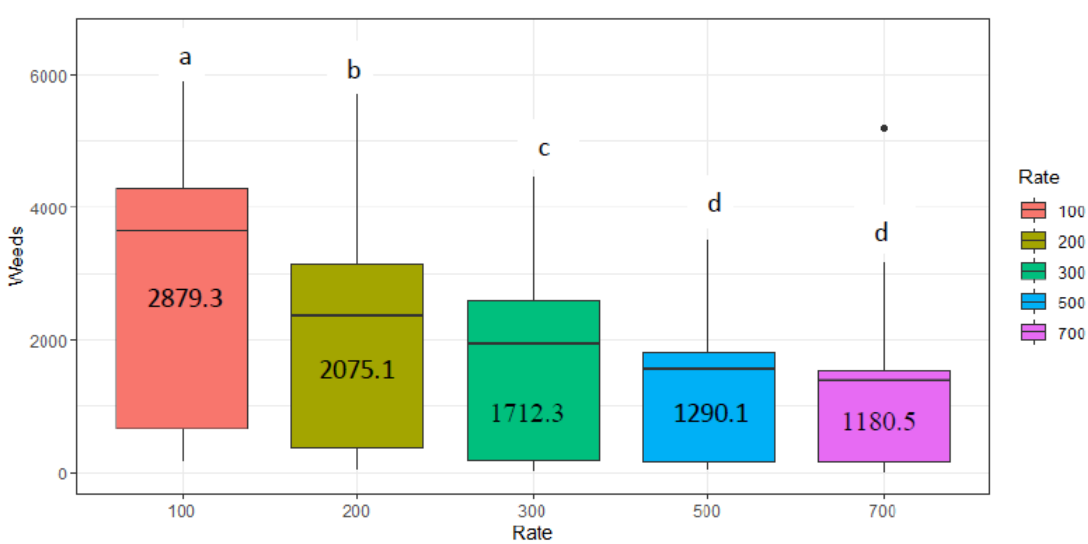

Figure 7. Increasing the seeding rates decreased weed biomass across all three locations

Weed biomass was very high in Great Falls in 2020 compared to Chester site. The average weed biomass across all lentil varieties and locations was 2193, 1549, 1166, 969, and 829 kg ha^{-1} for seeding rates of 100, 200, 300, 500, and 700 plants m^{-2}, respectively (Fig. 7). This translates to a 62% reduction in weed density when the seeding rates were increased from 100 to 700 plants m^{-2}. Analysis of weed density by location and variety showed a similar trend of decreased weed density with increasing seeding rate, regardless of the variety or location. Overall, weed densities were lowest at Chester and decreases in weed densities were not significant. This was likely due to drought conditions that occurred in that region.

Other factors

Analysis of variance (ANOVA) was performed to identify factors and interactions between factors that were significant with respect to yield, biomass, and weed biomass components. Total biomass, yield, weed count, and HI were significantly different ($p < 0.001$) between seeding rates. Total biomass, protein, yield, and HI were also significantly different ($p < 0.001$) between lentil varieties. Highest planting density of 700 plants m^{-2} yielded 3%, 12%, 11% and 21.5% higher HI than 500, 300, 200 and 100 plants m^{-2}. Nodulation data were not obtained in 2020 due to difficulty in whole root removal and nodule separation in hard crusted field soils following severe drought at flowering. Weed density was also significantly reduced by seeding rate x location interactions. Additional interaction terms including Rate x Inoculant x Variety x Location were also tested but were not significant.

Table 3. Mean Harvest Index (HI) values of lentil varieties across the two sites

	Location	
Variety	Chester	Great Falls
BBL	27.9 a	20.7 c
FGL	27.5 a	20.7 c
LGL	32.4 b	20.2 c

Average protein content among varieties was 30%, 27%, and 26% for BBL, FGL, and LGL varieties, respectively (Fig. 8). Similar trends were observed in 2019 across the three sites. The protein content among all lentil varieties was not affected by the seeding rates or rate of applied inoculate at all sites (Fig. 9). Average 1000 seed weight was 17.2 g, 23.1 g, and 50.8 g for BBL, FGL, and LGL varieties, respectively. The differences in 1000 seed weight was significant ($p < 0.001$) between lentil varieties but was not affected by seeding or inoculation rates.

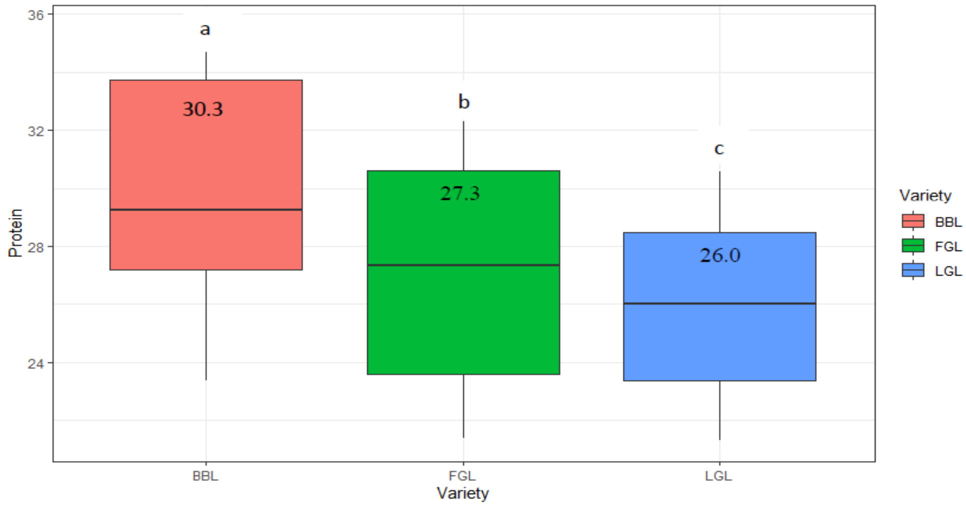

Figure 8. Protein content (%) in lentil differed by variety at Chester and Great Falls in 2020

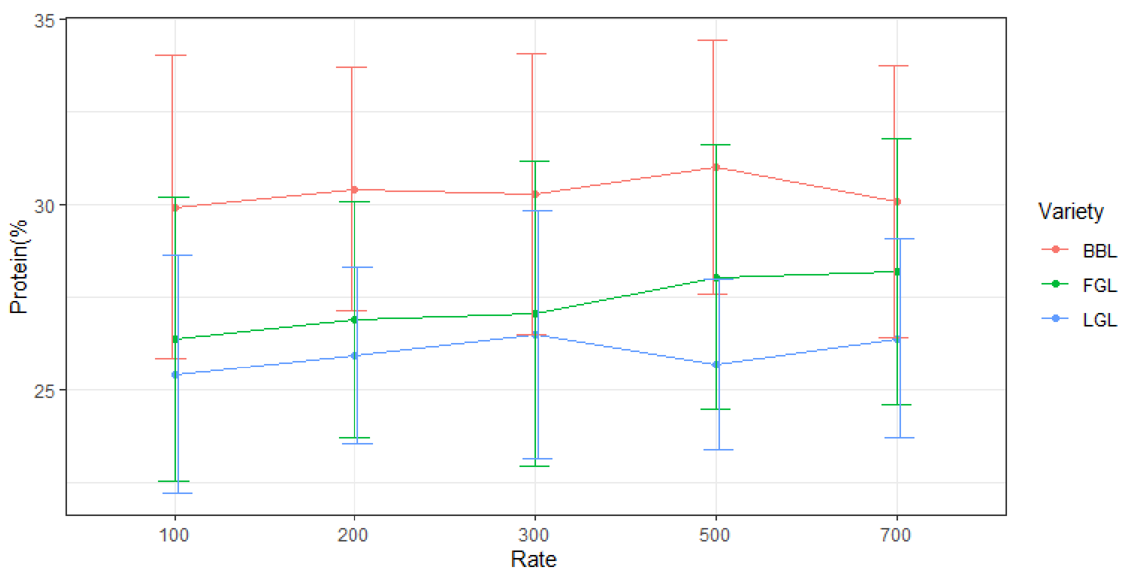

Figure 9. Protein content (%) by seeding rate.

Conclusions and Discussion

The results of this work suggest that the standard seeding rate of 130 plants m^{-2} used in conventional systems is less than optimum for organic systems in semi-arid regions of the Northern Great Plains. Yields and crop biomass increased and weed density decreased with increasing seeding rate across all locations and varieties. In a year with favorable growing conditions i.e., 2019, yield showed a linear increasing trend that did not plateau or begin to decline at the 500 plants m^{-2}. However, seeding at higher densities 700 plants m^{-2} in a year with less-than-ideal growing conditions (drought and higher weed pressure) in 2020 resulted in similar yields to highest seeding rate in 2019. Higher seeding rates resulted in higher plant biomass which may have provided a stronger competition against weeds especially on a weedy field. Further research is needed to determine competitiveness of different lentil genotypes against weeds and their tolerance to high plant density across different environments.

The results of this work suggest that by increasing planting rates, organic lentil growers can suppress weeds and benefit from higher yields. A robust crop growth that results in early canopy closure will minimize available moisture, nutrients, and light for weed growth. In addition to weed suppression, identification of appropriate lentil varieties and seeding rates for improved ground-cover characteristics, i.e., early branching, foliage development, and early canopy cover can potentially lead to reduced lodging. This will make it easier to harvest the crop and minimize dirt-tag which could adversely affect quality and price.

Research outreach and potential impact

COVID-19 restrictions reduced the opportunities for presenting research findings. Research findings have been presented at three meetings attended by pulse growers, university research scientists, and representatives from different pulse industries and seed organizations from Montana and the surrounding locations in the Pacific Northwest and the Northern Great Plains. The meetings where the findings of this research have been presented are shown in Table 4. The Q and A at the end of each of these sessions was very positive and is indicative that the project is attracting the interest and attention of the target audience. This work is expected to have a direct impact on grower practices and will result in growers using higher seeding rates for organic lentils in the Northern Great Plains.

Table 4: Research dissemination

Event	Date	Location
Timeless Seeds Inc. winter growers meeting	02/26/2021	Great Falls, MT
MSU Plant Science and Plant Pathology Departmental seminar	02/23/2021	Bozeman, MT
OFRF Virtual Expo West	05/11/2021	Online

Financial Accounting

Appendix A on page 13 details budget expenditures for the project.

Leveraged Resources

Results from this work were instrumental in obtaining funding for a new 3-year project from the Montana Specialty Crop Block grant which is focused on evaluating effects of different seeding rates and integrated weed management practices on lentil yield.

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Appendix A: Detailed Budget Expenditures

Organic Farming Research Foundation Research Grant: Final Financial Report			
PI NAME: Jed Eberly			
INSTITUTION/ORGANIZATION NAME: Montana State University			
PROJECT NAME: Evaluating the effects of seeding rates and inoculant performance on nodulation, weed suppression, and relative yields of different lentil varieties grown in the Northern Great Plains			
EXPENSES			
Item	**Budgeted Amount**	**Actual Spent**	**Detail**
eg: Labor of graduate student researcher	***$1,500***	***$1,500***	***75 hours @ $25/hr***
Personnel Costs and Fringe	$16,100.00	$16,815.00	
Equipment rental or purchases			
Stipends for farmer/rancher cooperatives or student labor	$1,500.00	$1,500.00	
Travel/Mileage	$1,679.00	$0.00	3,168 miles x $0.53/mile (state rate)
Other: supplies	$121.00	$0.00	
Other: MSU Environmental Lab	$600.00	$1,685.00	Protein analysis
Other:			
TOTAL EXPENSES:	$20,000.00	$20,000.00	
FIRST PAYMENT AMOUNT RECEIVED:		$18,000.00	
TOTAL OWED FOR FINAL PAYMENT:		**$2,000.00**	

Justification for Variances: COVID-19 travel restrictions necessitated several changes from original plans. We were unable to travel for meetings in 2020 as planned. Personnel costs were also higher. Previously it was planned to have a research associate, who is funded from a separate source, assist with the fieldwork. Due to COVID-19 travel restrictions, the research associate was not able to assist in the field work and consequently more funds were needed for student labor. No additional field supplies were purchased since we had enough remaining from a different project. Costs related to protein analysis were also higher than initially budgeted.