LENTIL INOCULANT, POTASSIUM, SULFUR, AND MICRONUTRIENT EFFECTS ON YIELD AND PROTEIN IN THE NORTHERN GREAT PLAINS

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ABSTRACT

Lentil (*Lens culinaris* Medikus) is an important crop, averaging more than 600,000 ac in MT and ND from 2016-20. However, relatively little is known about inoculant and fertility response in lentil in the U.S. northern Great Plains. The objective of this experiment was to evaluate the effect of rhizobial inoculant formulations (granular and seed-coat) and nutrient additions (K, S, and micronutrients), on lentil growth, yield, and seed protein. This study was conducted at six or seven university research centers in Montana and North Dakota from 2019-21, resulting in 20 site-yr of data. At the time of this report, yield results were fully available, but seed protein results were available for only 2019-20. Inoculant application increased seed yield by an average of 22% in 6 of 20 site-yr ($P<0.05$), and protein in 2 of 13 site-yr for an average 1.2 %-unit increase. Inoculant formulations affected seed yield in 5 of 20 site-yr and seed protein in 2 of 13 site-yr, but inconsistently so. Yield was greater for the granular formulation in 3 site-yr, but less in 2 site-yr. Pulse crop history among sites was not highly explanatory to inoculant response in lentil. Sulfur fertilizer (5 lb S ac^{-1}) increased seed yield in 4 of 20 site-yr, by an average of 13% in those site-years. Sulfur fertilizer increased seed protein in 3 of 13 site-yr by an average of 0.6 %-units. Potassium fertilizer affected lentil yield in 2 site-yr, but with equally opposing responses. Neither sulfate-S, nor pre-plant soil test K levels, proved highly predictive of lentil response to fertilizer. Micronutrient application was measured in 12 site-yr and had no effect on lentil yield. This research suggests greater understanding is needed for inoculant response and when and where S fertilization affects lentil yield and protein.

INTRODUCTION

Despite lentil recently becoming an important crop in the U.S. northern Great Plains (Fig. 1), little research has been conducted on best fertility management practices within this region. Since a positive response to P fertilizer has been documented in dry pea within the broader northern Great Plains region (McKenzie et al., 2001; Karamanos et al., 2003), we focused on the remaining macronutrients likely to cause a growth response in our region, K and S. The objectives of this study were to: (1) quantify lentil yield and protein response to rhizobial inoculation with granular vs seed-coat inoculant formulation, and (2) determine if K, S, or micronutrients enhance lentil growth, seed protein and yield.

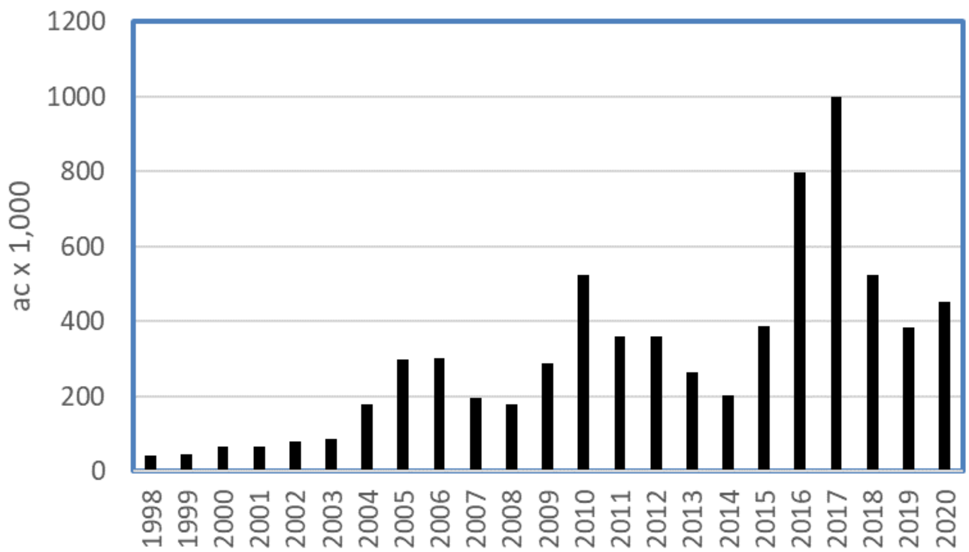

Figure 1. Acreage planted to lentils in Montana and North Dakota, 1998-2020. USDA-NASS 2020.

METHODS

Common experiments occurred at four Montana State University research center locations (Bozeman, Havre, Moccasin, and Sidney) and two or three North Dakota State University research center locations (Carrington, Hettinger, and Minot) from 2019 to 2021. Only 5/20 field sites had no pulse crop history, and another 5/20 sites had grown pulse crops more than 10 yr prior. It was presumed that K would be generally sufficient at all sites (i.e. > 250 ppm); however, the mean K content in the top 6 inches of soil was in the 200-250 ppm range at Moccasin in 2020, and in all 3 yr at Sidney, and was < 150 ppm in both years at Carrington (in 2020, lentils failed to establish). All sites were soil-tested with the aim of finding S-responsive field sites, which was not always possible, especially considering our low level of understanding with respect to measurement of critical S content in soils. The Bozeman sites generally had low soil sulfate-S levels in the top 2 ft, while Havre, Hettinger, Moccasin, and Sidney varied from low to high soil S levels among years, and Carrington and Minot had generally high soil S levels. All sites except Carrington (tilled system) were direct-seeded in cereal stubble, with a popular medium-sized green lentil cultivar (*Avondale*) grown from a common seed source. Soil nitrate-N content in the top 2 ft was consistently low at Bozeman and Sidney, and varied from low to medium among years at the remaining sites. The experimental design was a randomized complete block with eight treatments and five replicate blocks.

Treatments consisted of contrasting peat-based inoculant formulations (granular and seed-coat) with combinations of KCl, K_2SO_4, and a micronutrient fertilizer application (Table 1). Both rhizobial inoculant peat-based formulations were sourced from *Verdesian Life Sciences* (Cary, NC). Granular inoculant application varied from 4.4 to 6.1 lb ac^{-1} (1×10^8 CFU g^{-1}) in the seed furrow while the seed-coat formulation was applied at 0.31 lb per 100 lb of seed (2×10^8 CFU g^{-1}). *Micro 1000* (*AgroLiquid*, St. Johns, MI) contains a combination of seven micronutrients essential for plant growth plus cobalt. Although *Micro 1000* contains S, the application rate of S was about 0.3 lb ac^{-1}, and hence we call this a micronutrient solution hereafter. In 2019, *Micro 1000* was applied at well above label rates to increase the chance for a response, but this caused foliar tissue damage, and so data were omitted from 2019 analyses.

Table 1. Lentil fertility treatments.

Treatment	Fertilizer Source	Fertilizer Rate	K_2O	S
		------------- lb ac^{-1}	-------------	
1. Control	-	-		
2. Granular inoculant	-	-		
3. Seed-coat inoculant	-	-		
4. Granular with K	KCl	25.0	12.5	
5. Seed-coat with K	KCl	25.0	12.5	
6. Granular with K+S	Potassium sulfate	30.0	12.5	5.0
7. Seed-coat with K+S	Potassium sulfate	30.0	12.5	5.0
8.Granular+K+S+Micro1000[a]	Potassium sulfate + *Micro1000*	30.0	12.5	5.0

Note. Mono-ammonium phosphate (11-52-0) was used at planting at a rate of 45 lb ac^{-1} to supply 23 lb P_2O_5 ac^{-1} to all treatments, except at Moccasin in 2020.
[a] Micro1000 was applied at first flower at 32 oz ac^{-1}.

The seeding rate at all sites targeted 11 plants $ft^{-2,}$ resulting in seeding rates of 55 - 67 lb ac^{-1} among years. At planting, control plots without inoculant were seeded first, then all treatments containing granular inoculant, and then lastly treatments containing seed-coat inoculant. Treatments with the micronutrient foliar application were applied at late bud or early flowering stage with a backpack sprayer.

All plots were harvested with a combine and lentil seeds were then cleaned and weighed to determine yield. The N concentrations of all 2019 and 2020 grain samples were measured by a Kjeltec 2003 Analyzer Unit (Foss Analytical, Hilleroed, Denmark), except at Bozeman in 2020, lentil grain samples were measured by automated dry combustion analysis (LECO Corp., St. Joseph, MI). A conversion factor of N × 6.25 was used to report ‘protein’ (Coyne et al., 2005). Statistical analyses were conducted with *JMP8*, using a general linear model design, suitable for fully balanced designs. Each site-year was analyzed independently to determine site-specific responses. Linear orthogonal contrasts were used to answer four research questions:

(1) If inoculant (Control vs. Granular, Seed-coat) had an effect when other fertilizer treatments are not present;
(2) If inoculant types (Granular vs. Seed-coat) had an effect, regardless of other fertilizer treatments;
(3) If K had an effect, regardless of rhizobial inoculant;
(4) If S had an effect, regardless of rhizobial inoculant or K fertilizer
The cutoff P-value for declaring a significant effect was 0.05, meaning there is a 5% chance that differences occurred due to chance.

RESULTS AND DISCUSSION

In this study, lentil yielded an average of 1650 lb/ac across 20 site-yr, ranging from a low of <600 lb ac^{-1} at Moccasin in 2021 to two sites that had trial averages of 2610 lb ac^{-1} (Bozeman 2019 and Moccasin 2020). In 2020, lentil yielded an average of 2300 lb ac^{-1} across all sites, while in the widespread drought of 2021, the cross-site average yield was only 1100 lb ac^{-1}. Without the benefit of any formal multi-site analysis, Carrington appeared most dissimilar from the other six sites, posting the lowest ranking yield in the generally wet year of 2019, and the highest yield in droughty 2021.

Inoculant Response

Six of 20 site-yr showed a positive response to rhizobial inoculation, with an average yield increase of 344 lb ac^{-1} at those sites (Table 2). There were zero negative responses. The largest site response occurred in 2019 at Sidney, MT, where the control yielded 50% of the average of the two rhizobial inoculant formulations. At three of the responsive sites, pulses had not been grown before (Sidney 2019, Hettinger 2020, Havre 2021) and at a fourth site (Havre 2019) it is suspected that the only pulse crop grown 3 yr prior was uninoculated. However, positive responses were also observed at Bozeman in 2019 on a site with frequent pulse crop history, and at Moccasin in 2020, where pulses had been grown in 2014. Thus, presence or absence of pulse crop history was not highly explanatory. The effect of inoculant formulation, as applied, was significant at 5 of 20 site-yr. The peat powder seed coat formulation induced higher lentil yields in 2 site-yr, by an average of 107 lb ac^{-1}, while the peat granular soil-applied formulation induced higher lentil yields in 3 site-yr, by an average of 440 lb ac^{-1}. The single most remarkable response occurred at Sidney in 2019 where peat granular inoculant induced yields that were 1110 lb ac^{-1} greater than with seed coat inoculant.

Table 2. Frequency of treatment effects amid 20 site-yr and mean lentil yield response (lb ac^{-1}) for each condition. nd = No Data.

	Ctrl < Inoc	Ctrl = Inoc	Ctrl > Inoc
Frequency	6	14	0
Control	1531	1538	nd
Inoculant	1875	1571	nd
	Gran < SC	Gran = SC	Gran > SC
Freqency	2	15	3
Granular	1619	1547	2261
Seed coat	1726	1552	1821
	K < No K	K = No K	K > No K
Frequency	1	18	1
K	2183	1648	1336
No K	2388	1645	1252
	S < No S	S = No S	S > No S
Frequency	0	16	4
S	nd	1555	2266
No S	nd	1569	2011

Fertilizer Response

Potassium fertilizer increased lentil yield in 1 site-yr and decreased yield in 1 site-yr. The positive response to K was observed at Sidney in 2019, with a mean soil test value of 214 ppm. However, a negative response was observed at Carrington in 2021 with a low mean soil test value of 155 ppm. Sulfur fertilizer showed greater crop response, increasing lentil yield in 4 site-yr by an average of 255 lb ac^{-1}, with zero negative responses. Bozeman had generally low pre-plant soil sulfate-S levels but the S treatment increased lentil yield only in 2020. Notably, N_2-fixation was increased by 30 lb N ac^{-1} in 2020 at Bozeman (Baber et al. 2022). Three other positive S responses occurred at sites where mean soil sulfate-S levels in the top 2-ft of soil were sufficiently high (i.e. Moccasin 2020 = 10.5 ppm, Sidney 2021 = 3.9 ppm, and Carrington 2021 = 5.6 ppm), such that a crop response would not be expected. At Minot in 2019 and 2021, soil-test sulfate-S levels tested high out of measurement range, and yet no negative crop response occurred. Since several positive yield responses were induced by an inexpensive 5 lb S ac^{-1} fertilizer addition it is tempting to recommend this practice broadly. However, further research is needed to make reliable S recommendations for lentil based on soil test values. No effect was observed from micronutrient application.

Lentil Seed Protein

Judging from the 2019-2020 data, protein responses were less frequent than yield responses, and related mainly to presence/absence of rhizobial inoculant and S fertilizer application. Seed protein was increased by inoculation at 2 of 13 site-yr by an average 1.2 %-unit. Seed protein was increased by S fertilizer at 2 of 13 site-yr, but decreased at 1 site-yr.

CONCLUSION

Rhizobial inoculant increased lentil yields at 30% of our site-years, but without clear relation to previous pulse crop history. Peat granular inoculant formulation increased lentil yield over the peat powder seed coat formulation at 15% of our site-years, once remarkably (Sidney 2019), but also reduced lentil yields at 10% of our site-years compared with the seed coat formulation. A low rate of S fertilizer (5 lb ac^{-1}) increased lentil yield markedly at 20% of our site-years, but seemingly without regard to pre-plant sulfate-S levels in the top 2 ft of soil. A focused and well networked research effort is needed to more fully understand the potential benefits of S fertilizer for lentil yield.

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REFERENCES

Baber, K., C. Jones, P. Miller, and S. Koeshall. 2022. Lentil nitrogen fixation response to fertilizer and inoculant in the northern Great Plains. In Great Plains Soil Fertility Conference Proceedings. March 8-9 2022.

Coyne, C., Grusak, M., Razai, L., & Baik, B. 2005. Variation for pea seed protein concentration in the USDA *Pisum* core collection. Pisum Genetics 37: 5-9.

Karamanos, R., Flore, N., & Harapiak, J. 2003. Response of dry peas to phosphate fertilization. Can. J.Plant Sci. 83:283-289.

McKenzie, R., Middleton, A., Solberg, E., DeMulder, J., Flore, N., Clayton, G., & Bremer, E. 2001. Response of pea to rate and placement of triple superphosphate fertilizer in Alberta. Can. J. Plant Sci. 81:645-649.

USDA-NASS. 2020. State agriculture overview. Retrieved from National Agricultural Statistics Services (NASS): https://www.nass.usda.gov/Statistics_by_State/Ag_Overview/