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Nitrogen and Phosphorus Rates' Impact on Different Varieties of Alfalfa in Central Kansas

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Summary
The United States is the largest producer of alfalfa (*Medicago sativa* L.) in the world, with a vast area grown under rainfed conditions. Under these conditions, and especially in a transition state such as Kansas, the alfalfa crop often suffers from water deficit stress. Environments under water-limited conditions promote a decrease in crop yield when inadequate water leads to an nitrogen deficiency and reduces crop biomass. This research aimed to investigate the production of different alfalfa varieties under different nitrogen and phosphorus rates in a rainfed environment. Three nitrogen application rates (0 lb/a; 200 lb/a; 400 lb/a) and three phosphorus application rates (0 lb/a; 100 lb/a; and 200 lb/a) provided nine combinations of application rates to four alfalfa varieties (54HVX41, Pioneer 54VR10, LOL 356HQRR, and DKA43-22RR). Five harvests were executed at 10% of flowering, and the whole plant biomass was collected to determine the dry matter in ton/a. Despite the statistically significant results of treatment interaction, there was no pattern in the average values of alfalfa production among different treatments and seasons. The collected weather data provided empirical evidence to support that precipitation and evapotranspiration (specifically under water stress) influenced alfalfa yield. The four genotypes used in this field study tended to be stable in their yield in response to fertilization.

Introduction
Alfalfa is a perennial forage legume with high nutritional value (Diatta et al., 2021). As a legume, it produces its own nitrogen through the process of biological nitrogen fixation. Alfalfa yield in central Kansas is also often limited by water availability and distribution (Fink et al., 2022), which may occur in other alfalfa growing regions of the US as well (Baral et al., 2022). Water-limited conditions can also lead to N deficiency and reduce crop biomass (Kunrath et al., 2018). Diatta et al. (2021) suggested that when alfalfa plants are subjected to a severe deficit of water, the plant presents slow growth, and a delay in flowering and plant maturity once phytohormones are produced to control the plant's osmotic potential, providing stomatal closure. Consequently, biological N_2 fixation is limited, as well as nutrient absorption. All these factors lead to a significant reduction in alfalfa productivity. Moreover, recent evidence suggests that biological N fixation may not produce the total amount of N needed for high-yielding crops such as soybeans (La Menza et al., 2017). Likewise, a recent on-farm survey of alfalfa management suggested that phosphorus was among the most limiting factors for alfalfa yield in central Kansas (Fink et al., 2022). To study whether biological N fixation

is sufficient for high-yielding alfalfa in central Kansas, a region typically showing phosphorus limitation, this research investigated the forage yield of different alfalfa varieties as affected by the combination of rates of nitrogen and phosphorus in a rainfed environment.

Procedures

A rainfed field experiment was conducted on a two-year old alfalfa stand at the Kansas State University South-Central Experiment Field near Hutchinson during 2022. Field experiments were planted in April 2020 in a split-split plot design with alfalfa variety as the whole plot, nitrogen management as the sub-plot, and phosphorus rate as the sub-sub plot. Four alfalfa varieties (54HVX41, Pioneer 54VR10, LOL 356HQRR, and DKA43-22RR) were sown in combination with three nitrogen application rates (0 lb/a; 200 lb N/a; and 400 lb N/a) and three phosphorus application rates (0 lb/a; 100 P_2O_5 lb/a; 200 P_2O_5 lb/a), resulting in thirty-six treatments. The experiment had four replications. The N fertilizer source was urea (46-0-0) and the P fertilizer source was triple superphosphate (0-45-0). Two fertilizer applications were made, the first on April 4 and the second on August 29, 2022.

Sampling

A composite soil sample (consisting of 15 individual soil cores) was collected from the 0- to 6-in. and 6- to 18-in. depths before trial establishment in May 2020 for baseline fertility status and texture quantification (Table 1). Alfalfa forage yield was measured and sampled by cutting the whole plant biomass from two representative 3.2-ft rows per plot using a hand clipper. Samples were dried and weighed to determine the dry matter in ton/a. The main harvest was executed at 10% of flowering and occurred five times in the 2022 season, namely June 3, June 27, July 26, August 29, and October 3. After this main harvest yield was measured, the entire experiment was mowed to a 3-inch height using a rotary mower and alfalfa biomass was removed from the field. Additionally, to better understand the impacts of weather variables on alfalfa productivity, we sampled alfalfa biomass 1 or 2 times in between the main cuts (roughly at 10-day intervals). The sampled area was marked off to avoid re-sampling, but the experiment was not mowed.

Statistical Analyses

Analysis of variance (ANOVA) was conducted using linear mixed model procedures in R Studio statistical software. Alfalfa varieties, nitrogen rates, phosphorus rates, and their interaction were considered as fixed factors. The harvests were evaluated individually and replication was a random factor. Interaction effects, when found significant, were also calculated. Tukey's post-hoc test was used to compare significant differences between treatment means. Non-linear regression was used to explore the relationship between precipitation and alfalfa yield, whereas linear regressions explored the relationship between alfalfa yield under different fertilization regimes.

Results

Soil fertility and texture results are shown in Table 1. Based on these soil test results, no nutrient deficiency was expected in this trial.

Alfalfa Yield and Weather Conditions

Cumulative precipitation during the cutting interval explained 86% of alfalfa forage yield (Figure 1). Expectedly, there were greater precipitation amounts in the first and second cuts than in the remaining three cuts (2.5 to 9.4 inches versus 0.7 to 1.6 inches), resulting in greater alfalfa yield (mean yield of 1.4-1.5 versus 0.3-0.6 tons per acre). We also noted that temperatures during the first and last harvests were colder than the three middle median harvests (Table 2).

Effects of Variety, Nitrogen Rate, Phosphorus Rate, and Their Interactions on Alfalfa Yield

Analyses of variance of main effects and interactions suggested different driving factors of alfalfa yield depending on harvest. During the highest-yielding first harvest, the main effects of N rate and P rate were significant on alfalfa yield (Table 3). Here, the 200 lb N/a rate resulted in the highest yield (1.6 ton/a), whereas the zero N control had the lowest yield (1.4 ton/a). Likewise, phosphorus applied at 100 or 200 lb/a out-yielded the zero P control (1.5 versus 1.4 ton/a, respectively). During the second cut, N was still a significant effect as the 400 lb N/a rate resulted in 1.4 ton/a versus ~1.3 ton/a in the lower or absent N rates (Table 3). During the third and fourth cuts, there were significant interactions between alfalfa variety and N rate (Figure 2). The third cut interactions suggested that the 400 lb N/a rate usually resulted in the highest yields, even though the variety 54HVX41 did not increase yield as N rates increased. Pioneer 54VR10 increased yields from 0 to 200 lb N/a and then stabilized, while the other two varieties continued to increase yields until 400 lb N/a rate. The fourth cut interactions suggested similar trends although at lower yield levels. In the fifth cut, the only significant effect was P rate, as the 200 lb P/a rate out-yielded the 0 lb P/a (0.53 versus 0.47 ton/a).

Across all sources of variation, alfalfa fertilized with 400 lb N/a had a 0.04 ton/a greater yield than alfalfa not fertilized with N, and this benefit was irrespective of yield environment (Figure 3). Meanwhile, alfalfa yield when fertilized with phosphorus was the same as that of non-fertilized alfalfa at lower yielding environments, but the yield advantage of the fertilized crop increased at greater yielding environments (slope of 1.05; Figure 3).

Preliminary Conclusions

This experiment only reports on one site-year of data, so conclusions are preliminary. Nonetheless, the weather data collected provided empirical evidence to support that precipitation was a decisive factor in modulating alfalfa forage yield. The addition of N increased yields consistently in the highest yielding cuts (first and second) and depending on variety in the third and fourth cut, which suggested that biological N fixation may not be enough under the determined conditions in Kansas. Phosphorus fertilizer increased alfalfa yield in the first and last cuts of the season.

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Table 1. Soil fertility and texture results for the 0- to 6-in. and 6- to 18-in. depths at the site where the alfalfa trial was established

Element	Unit	0–6 inches	6–18 inches
Al	ppm	<0.00	<0.00
Ca	ppm	2,541	4,790
Cu	ppm	1.1	0.7
Mg	ppm	307	354
Mn	ppm	21.1	5.1
Na	ppm	318	1,063
OM	%	2.8	1.6
P-M	ppm	36.7	10.4
CECS	meq/100g	17.42	32.03
pH		6.8	8
NO_3-N	ppm	4.2	2.8
NH_4-N	ppm	4.8	2.9
K	ppm	301	198
Zn	ppm	0.8	0.3
Fe	ppm	58.5	18
S	ppm	26.8	190.3
Cl	ppm	268	433
Sand	%	30	18
Silt	%	44	42
Clay	%	26	40

OM = organic matter. CECS = cation exchange capacity of soil.

Table 2. Weather data from the Hutchinson meteorological station for the alfalfa season in 2022

Harvest date	Tmax	Tmin	RH	Precip.	Rs
	°F	°F	%	Inches	MJ m-2 d-1
6/3/2022	78.4	56.3	67.0	9.7	12277.4
6/27/2022	93.7	69.2	61.4	2.5	6589.7
7/26/2022	99.5	69.9	50.8	1.3	6229.1
8/29/2022	93.2	63.0	54.0	0.7	4594.4
10/19/2022	73.4	42.4	47.6	1.6	5786.7

Data reflect mean maximum (Tmax) and minimum temperatures (Tmin), mean relative humidity (RH), and cumulative precipitation and solar radiation (Rs) for the period preceding each respective harvest period.

Table 3. Mean alfalfa forage yield as affected by the main effects variety, N rate, and P rate for each harvest cut

	Treatments	Alfalfa dry matter yield (ton/a) at each harvest cut				
		1	2	3	4	5
Variety	54HVX41	1.49	1.37	0.60	0.32	0.48
	DKA43-22RR	1.41	1.37	0.59	0.30	0.54
	LOL 356HQRR	1.47	1.37	0.64	0.31	0.49
	Pioneer 54VR10	1.52	1.36	0.55	0.30	0.50
N	0	1.38 b	1.38 ab	0.51 b	0.28 b	0.51 b
	200	1.56 a	1.29 b	0.56 b	0.31 ab	0.51 ab
	400	1.48 ab	1.44 b	0.70 a	0.34 a	0.50 a
P	0	1.38 b	1.35	0.59	0.32	0.48 b
	100	1.56 a	1.36	0.59	0.30	0.50 ab
	200	1.48 a	1.40	0.60	0.31	0.53 a

Data are presented as an average of four replicates. Different lowercase letters indicate significant differences between treatment means based on Tukey's significant difference test ($P \leq 0.05$).

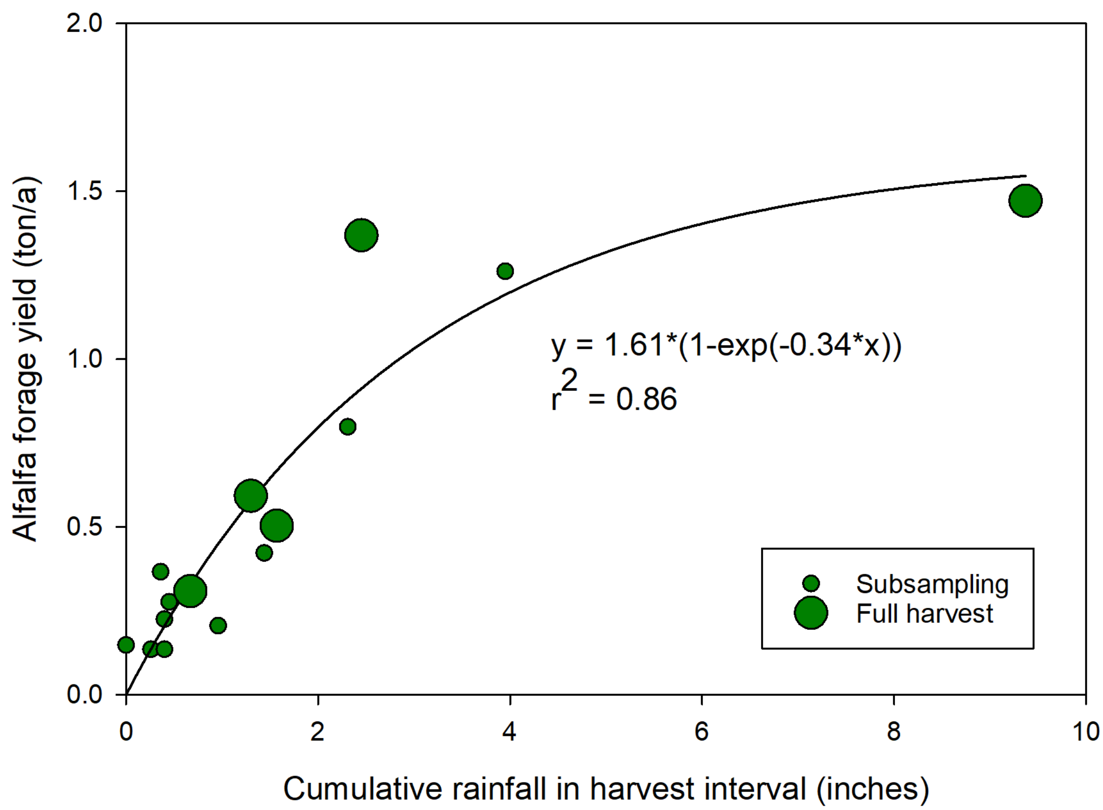

Figure 1. Relationship between cumulative rainfall prior to alfalfa harvest and alfalfa forage yield during the 2022 season near Hutchinson, KS. Data reflect full harvest as well as subsampling within harvest periods.

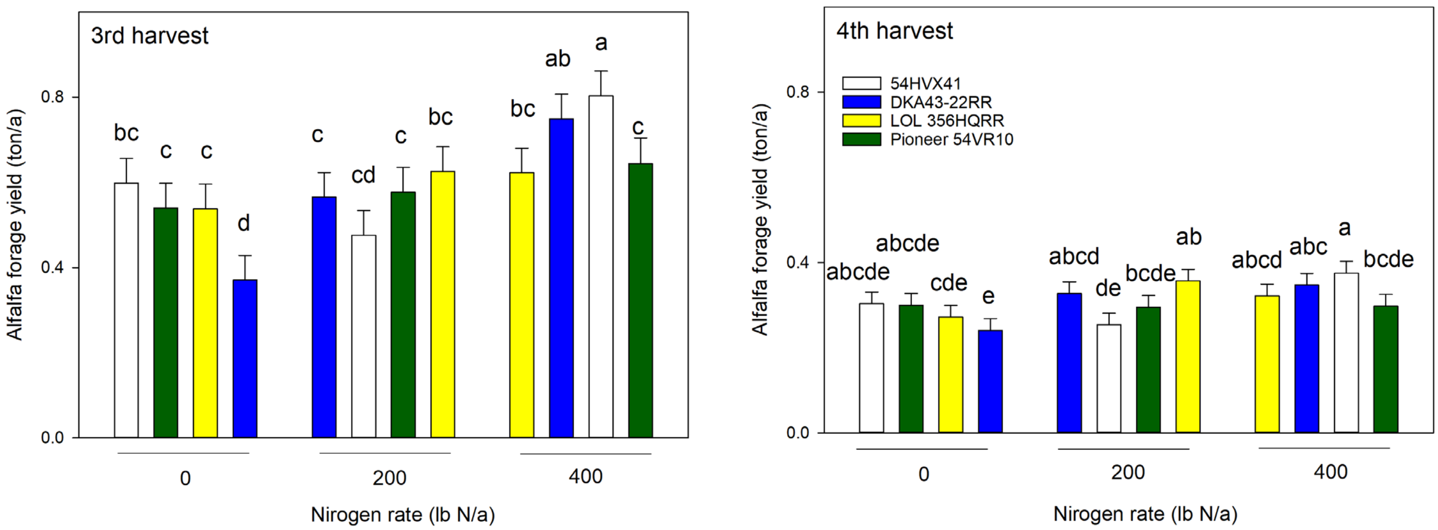

Figure 2. Alfalfa forage yield as affected by the interaction between alfalfa variety and nitrogen rate for the 3rd and 4th harvests of the 2022 season near Hutchinson, KS. Data are presented as an average of four replicates. Different lowercase letters indicate significant differences between treatment means based on Tukey's significant difference test (*P* ≤ 0.05).

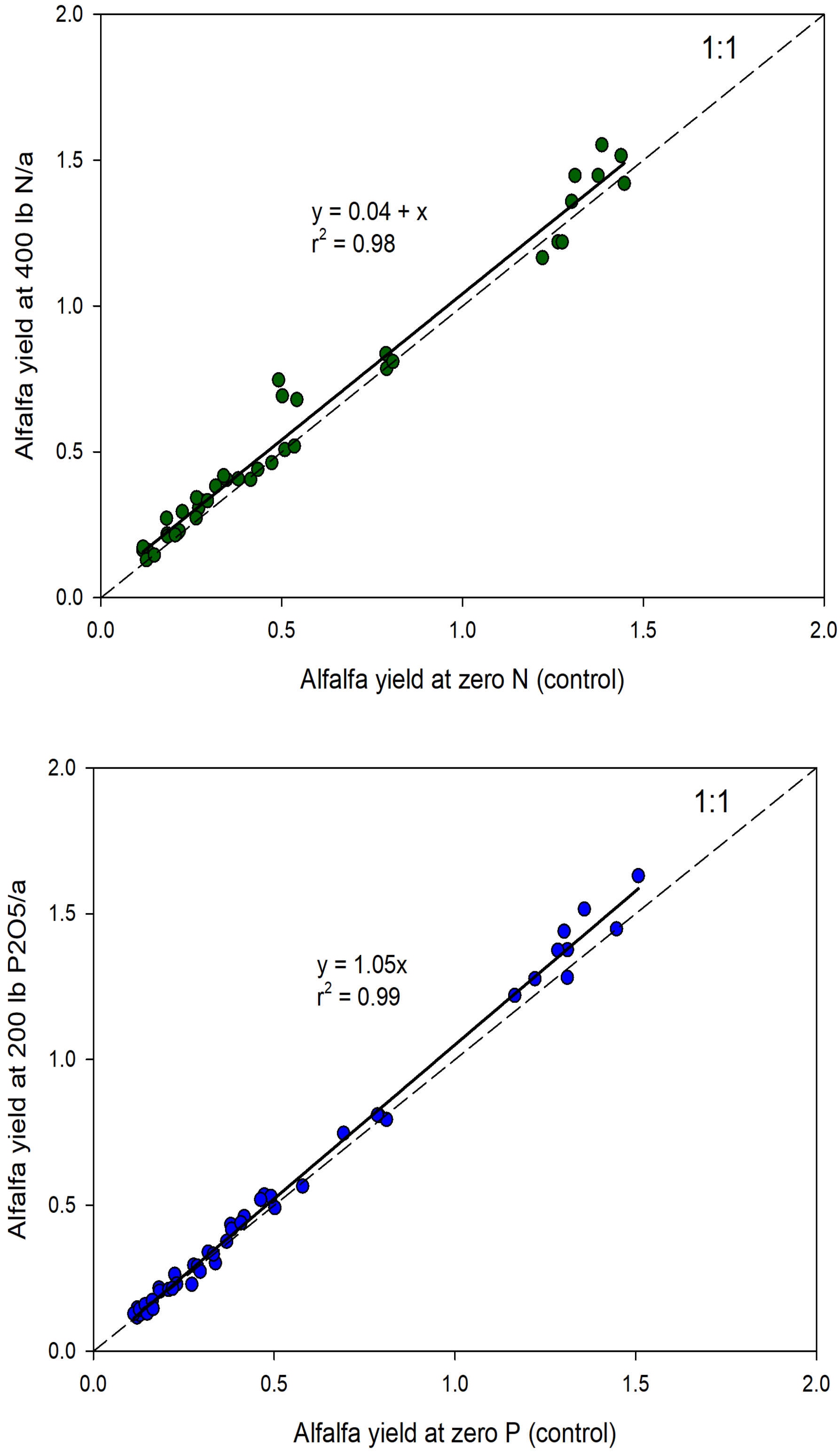

Figure 3. Comparisons across all sources of variation between fertilized and unfertilized alfalfa yield for nitrogen (upper panel) and phosphorus (lower panel) for the trial conducted near Hutchinson, KS, during the 2022 season.