Nitrogen and Sulfur Fertilization's Effect on Soybean Quality and Yield in Kansas

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Summary

This study evaluates the effects of nitrogen (N) and sulfur (S) fertilization on soybean yield and quality. Over three years (2021-2023), nine site-year studies in Kansas tested five fertilization strategies, including Check (no fertilization), S (30.3 lbs S ac^{-1}), N (26.8 lbs N ac^{-1}), NS (26.8 lbs N ac^{-1} + 30.3 lbs S ac^{-1}), and Full (30.3 lbs S ac^{-1} + 299.8 lbs N ac^{-1}). Seed yield was recorded, and the seeds were analyzed for protein content. Weather data was summarized into four growth periods. There were no yield or protein content differences. Seed yield and protein showed positive correlation with soil-N content, and with precipitation and average temperature from flowering to full-pod phenological stage. The study suggests that current N_2-fixation and soil-N contributions are adequate for optimal growth, pointing toward the importance of site-specific management.

Introduction

Soybean (*Glycine max* L. Merr.), the most widely cultivated legume worldwide, stands as a leading cash crop in the United States (US). In 2022, Kansas emerged as the ninth-largest soybean producer, harvesting 189.6 million bushels, as reported by the Kansas Department of Agriculture (2023). This achievement underscores the role of Kansas in the US soybean market. Historically, plant breeding efforts have primarily aimed at increasing yields, often overlooking improvements in seed quality (Borja Reis et al., 2022).

Soybean growth and production are significantly influenced by environmental factors, including soil properties and weather conditions, which impact grain yield and seed quality (Capelin et al., 2022; Assefa et al., 2019). Soybeans heavily rely on N to achieve greater yields (Salvagiotti et al., 2021; Sinclair and de Wit, 1975)seed nutrient removal, and nutrient use efficiency (yield to nutrient uptake ratio. However, yield responses to N fertilization are unlikely, mainly due to the N_2-fixation, which usually satisfies most of the crop's N requirements (Ciampitti and Salvagiotti, 2018). Recent studies in the US addressed positive effects of S fertilization on increasing yields, and more S often resulted in seeds with higher protein levels compared to standard management practices (Borja Reis et al., 2021). It is noteworthy that under specific conditions, S colimitations with other factors have already been identified (Almeida et al., 2023; Divito et al., 2016, 2015; Salvagiotti et al., 2009). Following this rationale, the current research aims to evaluate the effect of N and S fertilization on soybean seed yield and seed quality in Kansas.

Procedures

Experimental design

This study comprises nine site-year studies conducted in Kansas during the 2021, 2022, and 2023 growing seasons under contrasting conditions (Tables 1 and 2). A randomized complete block design with five replications was utilized. Five treatments, combining rates of N and S were applied1) Check (no fertilization), 2) S (30.3 lbs S ac^{-1}), 3) N (26.8 lbs N ac^{-1}), 4) NS (30.3 lbs S ac^{-1} + 26.8 lbs N ac^{-1}), and 5) Full (30.3 lbs S ac^{-1} + 299.8 lbs N ac^{-1}). Treatments N, S, and NS were applied at planting time, and Full was split between planting and the R3 phenological stage (Fehr and Caviness, 1977) (Table 3). Harvested seed samples were analyzed in a laboratory using the Near Infrared Reflection (NIR) method to evaluate dry basis protein content (Pazdernik et al., 1997). Through in-season collected phenology information, precipitation and temperature data were obtained from the *nasapower* (Sparks, 2018) database and summarized into four different periods: 20 days prior to planting, planting to R2 (full-bloom), R2 to R4 (full-pod), and R4 to R6 (full-seed) (Fehr and Caviness, 1977).

Statistical analysis

All analyses were performed using R software (R Core Team, 2023). For each site-year a mixed model was fitted to assess the impact of treatments on seed yield and protein content. Treatments were considered fixed effects, and blocks were considered random effects. The treatment effect was assessed by analysis of variance and Tukey's test with a significance level set at $\alpha = 0.05$. The correlation between soil, weather, seed yield, and protein were evaluated using the Pearson correlation coefficient. For evaluating the weather and soil factors that contributed more to protein content and yield, a correlation matrix was constructed between environmental covariates, seed yield, and seed protein. Principal component analysis (PCA) was performed to further visualize the variability of the data and the relationships among response variables and between response variables and covariates across sites.

Results

The average seed yield was recorded at 70 bu/ac^{-1} across the site-years, ranging from 41 to 93 bu/ac^{-1} (Figure 1). No significant yield differences were observed due to N and S fertilization in any of the site-year studies ($p > 0.05$), including the Full treatment. This finding suggests that N_2-fixation and soil-N were sufficient to meet attainable yields of each site. The average dry basis protein content was 35% across all site-years, with a variation from 32% to 39% (Figure 2). Likewise, no N and S fertilization effects were observed for seed protein ($p > 0.05$) in any of the sites.

The correlation matrix showed that soil NH_4^+ concentration contributed mostly to seed yield and protein content (Figure 3). Aligning with these results, the PCA explained close to 50% of the variation, highlighting positive relations between yield and protein soil NH_4^+ concentration. Also, precipitation between planting and R2, and mean temperature during R2-R4 were positively related to protein and yield, for those sites (Figure 4).

References

Almeida, L.F., Correndo, A., Ross, J., Licht, M., Casteel, S., Singh, M., Naeve, S., Vann, R., Bais, J., Kandel, H., Lindsey, L., Conley, S., Kleinjan, J., Kovács, P., Dan Berning, Hefley, T., Reiter, M., Holshouser, D., Ciampitti, I.A., 2023. Soybean yield response to nitrogen and sulfur fertilization in the United States: contribution of soil N and N fixation processes. Eur. J. Agron. 145, 126791. *https://doi.org/10.1016/j.eja.2023.126791*

Assefa, Y., Purcell, L., Salmeron, M., Naeve, S., Casteel, S., Kovács, P., Archontoulis, S., Licht, M., Below, F., Kandel, H., Lindsey, L., Gaska, J., Conley, S., Shapiro, C., Orlowski, J., Golden, B., Kaur, G., Singh, M., Thelen, K., Ciampitti, I., 2019. Assessing Variation in US Soybean Seed Composition (Protein and Oil). Front. Plant Sci. 10, 298. *https://doi.org/10.3389/fpls.2019.00298*

Borja Reis, A.F. de, Rosso, L.H.M., Davidson, D., Kovács, P., Purcell, L.C., Below, F.E., Casteel, S.N., Knott, C., Kandel, H., Naeve, S.L., Carciochi, W., Ross, W.J., Favoretto, V.R., Archontoulis, S., Ciampitti, I.A., 2021. Sulfur fertilization in soybean: A meta-analysis on yield and seed composition. Eur. J. Agron. 127, 126285. *https://doi.org/10.1016/j.eja.2021.126285*

Capelin, M.A., Madella, L.A., Panho, M.C., Meira, D., Barrionuevo, F., Rodrigues, A.P.D.C., Benin, G., 2022. Physiological quality and seed chemical composition of soybean seeds under different altitude. Bragantia 81, e1022. *https://doi.org/10.1590/1678-4499.20210244*

Divito, G.A., Echeverría, H.E., Andrade, F.H., Sadras, V.O., 2015. Diagnosis of S deficiency in soybean crops: Performance of S and N:S determinations in leaf, shoot and seed. Field Crops Res. 180, 167–175. *https://doi.org/10.1016/j.fcr.2015.06.006*

Mahal, N.K., Sawyer, J.E., Iqbal, J., Sassman, A.M., Mathur, R., Castellano, M.J., 2022. Role of sulfur mineralization and fertilizer source in corn and soybean production systems. Soil Sci. Soc. Am. J. 86, 1058–1071. *https://doi.org/10.1002/saj2.20417*

Pazdernik, D.L., Killam, A.S., Orf, J.H., 1997. Analysis of Amino and Fatty Acid Composition in Soybean Seed, Using Near Infrared Reflectance Spectroscopy. Agron. J. 89, 679–685. *https://doi.org/10.2134/agronj1997.00021962008900040022x*

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. *https://www.R-project.org/*

Salvagiotti, F., Castellarín, J.M., Miralles, D.J., Pedrol, H.M., 2009. Sulfur fertilization improves nitrogen use efficiency in wheat by increasing nitrogen uptake. Field Crops Res. 113, 170–177. *https://doi.org/10.1016/j.fcr.2009.05.003*

Kansas Department of Agriculture, 2023. *https://www.agriculture.ks.gov/docs/default-source/ag-growth-summit/2023-growth-documents/soybeans.pdf?sfvrsn=ff7e9fc1_8* (accessed on 02.26.24)

Table 1. Site-year studies, their respective locations, planting date, harvest date, total seasonal precipitation (inches), and days with temperature above 95°F from full-bloom (R2) to full-seed stage (R6).

Site-year	Location	Planting date	Harvest date	Total precipitation (inches)	Days with temperature above 95°F (R2 to R6)
KS1 (2021)	KRV	5/12/2021	10/4/2021	28	15
KS2 (2021)	KRV	5/12/2021	10/8/2021	24	10
KS3 (2021)	NCE	5/12/2021	10/12/2021	16	10
KS4 (2021)	ASH	5/30/2021	10/8/2021	18	13
KS1 (2022)	KRV	5/9/2022	10/18/2022	28	20
KS2 (2022)	KRV	6/13/2022	10/18/2022	22	15
KS3 (2022)	Junction City	6/20/2022	10/26/2022	15	13
KS1 (2023)	KRV	5/10/2023	10/9/2023	23	19
KS2 (2023)	KRV	6/10/2023	10/19/2023	22	13

KRV: Kansas River Valley; NCE: North Central Experiment Field; ASH: Ashland Bottoms.

Table 2. Initial soil characterization across site-year studies.

Site	pH	CEC	SOM	Sand	Silt	Clay	P	K	NO^{3-}	NH^{4+}	SO_4^{2-}
		cmolc dm-3	----------------	%	----------------		-------------------		ppm	-------------------	
KS1 (2021)	6.8	11.7	2.0	32	56	12	17	227	6.1	4.9	3.6
KS2 (2021)	5.5	23.4	3.0	16	62	22	27	420	8.9	6.8	5.3
KS3 (2021)	7.5	9.8	1.2	46	42	12	46	186	3.1	3.1	2.0
KS4 (2021)	6.0	9.5	1.4	56	36	8	36	153	3.1	2.2	2.4
KS1 (2022)	6.6	8.7	1.8	40	47	14	35	173	6.0	6.2	8.5
KS2 (2022)	6.8	7.9	1.6	46	42	12	39	138	8.2	5.4	9.1
KS3 (2022)	6.2	25.6	3.4	10	59	31	53	276	5.0	6.7	8.0
KS1 (2023)	6.8	8.5	1.8	36	52	12	23	137	5.8	9.7	5.1
KS2 (2023)	7.1	8.7	1.9	39	50	11	29	120	5.8	9.6	4.8

Table 3. Fertilizer rates (lbs/acre^{-1}) and their sources applied to the different treatments during the 2021, 2022, and 2023 growing seasons.

	Timing					
	Planting		R3 stage		Total applied	
Treatments	N	S	N	S	N	S
	lb/a					
Check	-	-	-	-	-	-
N*	27	-	-	-	27	-
S+	-	30	-	-	-	30
NS^	27	30	-	-	27	30
Full±	149	15	149	15.2	300	30

Symbols indicate fertilizer source: *(Urea, 46-0-0); +(Gypsum, 0-0-0-23.5S); ^(Ammonium sulfate, 21-0-0-24S); and ±(Urea and ammonium sulfate).

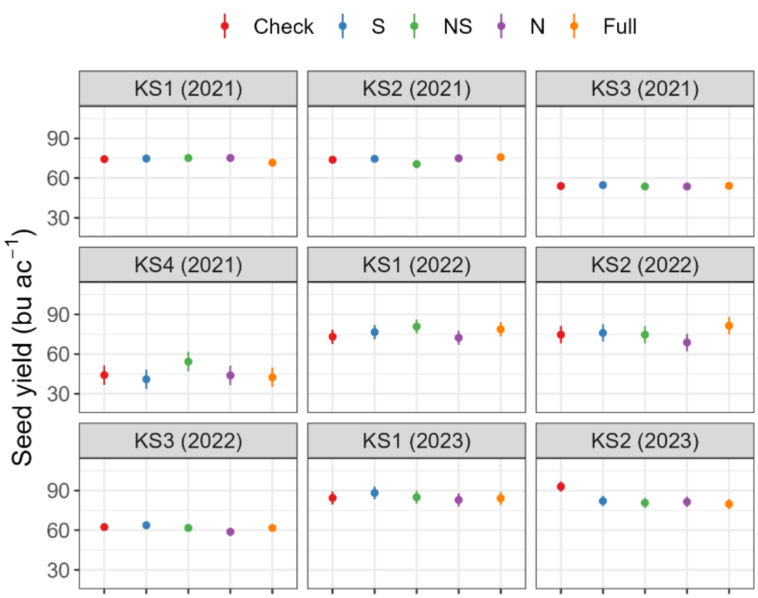

Figure 1. Seed yield (bu/ac^{-1}) responses to five fertilization strategies across nine site-year studies in Kansas during the 2021, 2022, and 2023 seasons.

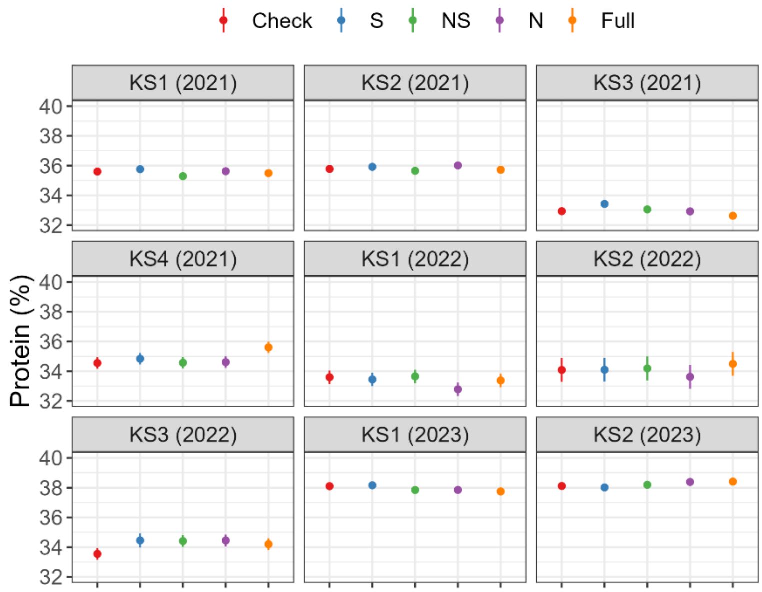

Figure 2. Seed protein (%) responses to five fertilization strategies across nine site-year studies in Kansas during the 2021, 2022, and 2023 seasons.

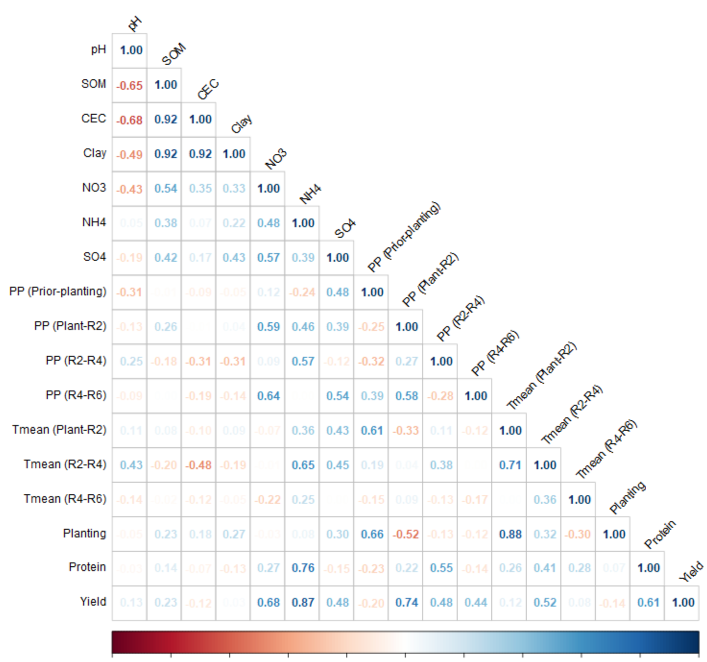

Figure 3. Correlation matrix between environmental covariates, seed yield, and seed protein.

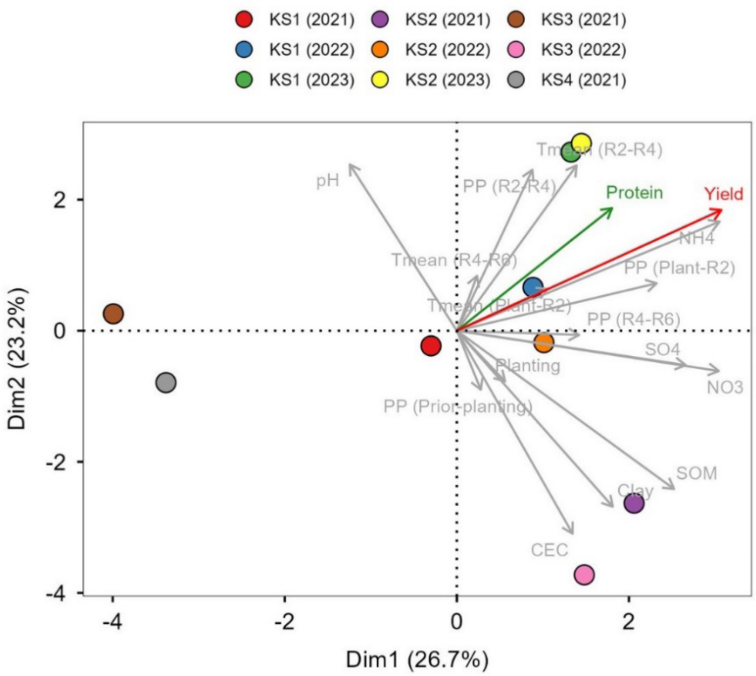

Figure 4. Principal component analysis depicting the variability of the data and the relationship among response variables and between response variables and covariates across sites.