Assessing Micronutrients Application for Efficient Soybean Production in the Mississippi Delta (21-2023)
Annual Report

PI: Ammar B. Bhandari, 662-686-5279, Ammar.bhandari@usda.gov
Co-PI: Tulsi P. Kharel, 662-686-5234, Tulsi.kharel@usda.gov

Rationale/Justification for Research:

In recent years, the increase in soybean (*Glycine max* L.) cultivation due to higher soybean grain sale prices has increased interest in maximizing yield with high-input crop management strategies, including micronutrient application (Orlowski et al., 2016; Gasper et al., 2018). Micronutrients are essential to plants, and their deficiency may limit critical plant functions, resulting in reduced yield and quality (Orlowski et al., 2016). Moreover, high-yielding modern soybean cultivars may require more nutrients, especially in high-yield environments (Thapa et al., 2021). Therefore, it is crucial to use optimum nutrient management to maximize yield by protecting soil health, improving net farm profitability, and minimizing negative environmental impacts. However, minimal information is available on soybean micronutrient requirements and applications (Enderson et al., 2015; Gasper et al., 2018). Soybean crop yields and micronutrient requirements depend on several factors, including field conditions, soil mineralogy, variety, and environment (Gasper et al., 2018; Johnson & Fixen, 1990). Applying micronutrients and irrigation can impact the nutritional composition of soybean grains, including protein and oil content (El-Haggan, 2014; Enderson et al., 2015; Zolfaghari et al., 2019). Soybean meal, obtained as a by-product during oil processing, is a primary source of high-quality protein (amino acids) for livestock and poultry production. Maintaining constant oil content and improving protein levels by 1% would increase soybean estimated processed value by $7.70-$12.96 per acre (Cook, 2015). Thus, adopting management practices to increase soybean seeds' nutrient and protein content can result in higher economic returns for producers. Further, applying micronutrients can help mitigate the adverse effects of drought on soybean production (Heidarzade et al., 2016). However, micro-nutrients are not recommended due to insufficient research on their correlations with crop yield and quality response (Enderson et al., 2015). Limited studies have assessed, validated, and documented the current micronutrient application in the MS Delta region. To our knowledge, no specific micronutrient application guidelines are available for soybeans in the MS Delta region. With the increase in soybean production acreage from 1,956,519 in 2012 to 2,300,000 in 2023 (USDA-NASS, 2023) in MS, ensuring that the fertilizer management strategies used are effective and validated is crucial. Testing and validation of micronutrient applications effects with and without irrigation effects is necessary for optimum fertilization, and water management strategies. Therefore, this study will provide valuable insights into the effects of irrigation and micronutrient application on soybean yield, and quality parameters, helping producers devise optimum nutrient and water management strategies for growing soybeans in the MS Delta region. The objective of the study was to investigate the impact of micronutrients application on soybean yield, and quality under fully irrigated and rainfed conditions in the Mississippi Delta.

Materials and Methods

The study was conducted at a USDA-ARS research farm in Stoneville, MS, in a randomized split-plot design with four replications, where irrigation was whole and fertilizer treatment was subplots. Within each replication, irrigation treatment was randomized, and 8 rows ally were placed in between irrigated and rainfed (no-irrigation) treatments The soil was Tunica clay with 55% clay, 28% silt, and 17% sand. Soybean variety 48XFO was planted on April 18, 2023, in 200 ft. plots with 8-rows and 38-inch row spacing. The micronutrient treatments were (i) zinc (Zn), (ii) iron (Fe), (iii) Zn + Fe, and (iv) control (C). Micronutrient treatment plots were randomized within each irrigation whole plot. The Zn and Fe was applied @5 and 2.5 lbs. ac^{-1} for low rate (LR) and 10 lbs. ac^{-1}, and 5 lbs. ac^{-1} for high rate (HR), respectively. The source of micronutrients was 4% (individually formulated) Microcline™ liquid water-soluble Fe and Zn (https://www.agroliquid.com/). The first foliar application was 48 days after planting (DAP), and the second was 68 DAP. Recommended preemergence herbicides and postemergence insecticides programs were followed. Irrigation was applied on 6/8/2023, 6/27/2023, 7/27/2023, 8/4/2023 & 8/23/2023.The whole soybean plants were samples at V3, V6, R2, R4, R6 and R8 to record crop phenology. The middle four rows were harvested with 8XP two row combine for yield and seed sub-samples were collected for quality analysis.

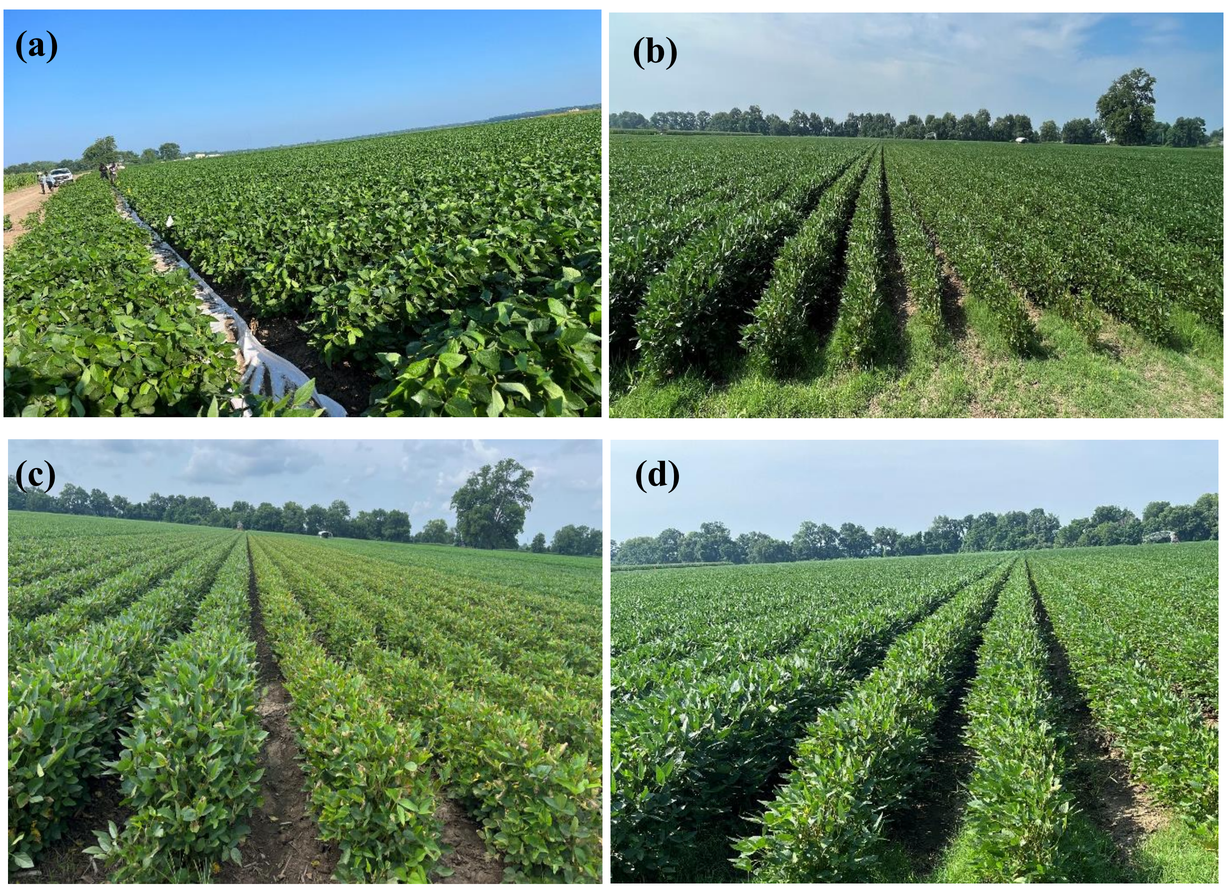

Figure 1. Soybean field. (a) Soybean growing under irrigated environment; (b) Soybean growing under rainfed (no-irrigation) environment (c) Soybean field next day after 2nd dose of zinc (left) and iron (right) fertilizer application (d) Soybean field after 2 weeks of zinc and iron treatments.

Results and Discussion

Yield:

The average soybean seed moisture was 12.5 % at harvesting. Under an irrigated production system, lower rates of Zn (5 lbs. ac^{-1}), Fe (2.5 lbs. ac^{-1}), and Zn + Fe applications increased soybean yield by 4.0%, 2.3%, and 1.4% respectively, indicating micro-nutrient application may increase yield in the high yielding environment (Figure 2; Table 1). Likewise, the higher rate of Zn and Zn + Fe increased the soybean yield by 2.3% and 1% compared to the control. There was no statistical difference in soybean yield under irrigated vs. rainfed production systems.

Under the rainfed production systems, although not statistically significant, the low application rate (5 lbs. ac^{-1}) Zn and Zn + Fe (5 lbs. ac^{-1} + 2.5 lbs. ac^{-1}) increased the soybean yield by 3.5% and 1.0% compared to the control (Figure 2; Table 1). However, with a high application rate, only the Zn application increased the yield by 1.2%. The Fe (-2.8%) and Zn + Fe (-1.4%) applications negatively impacted the yield under a high application rate, which might be due to leaf burning decelerating the soybean growth.

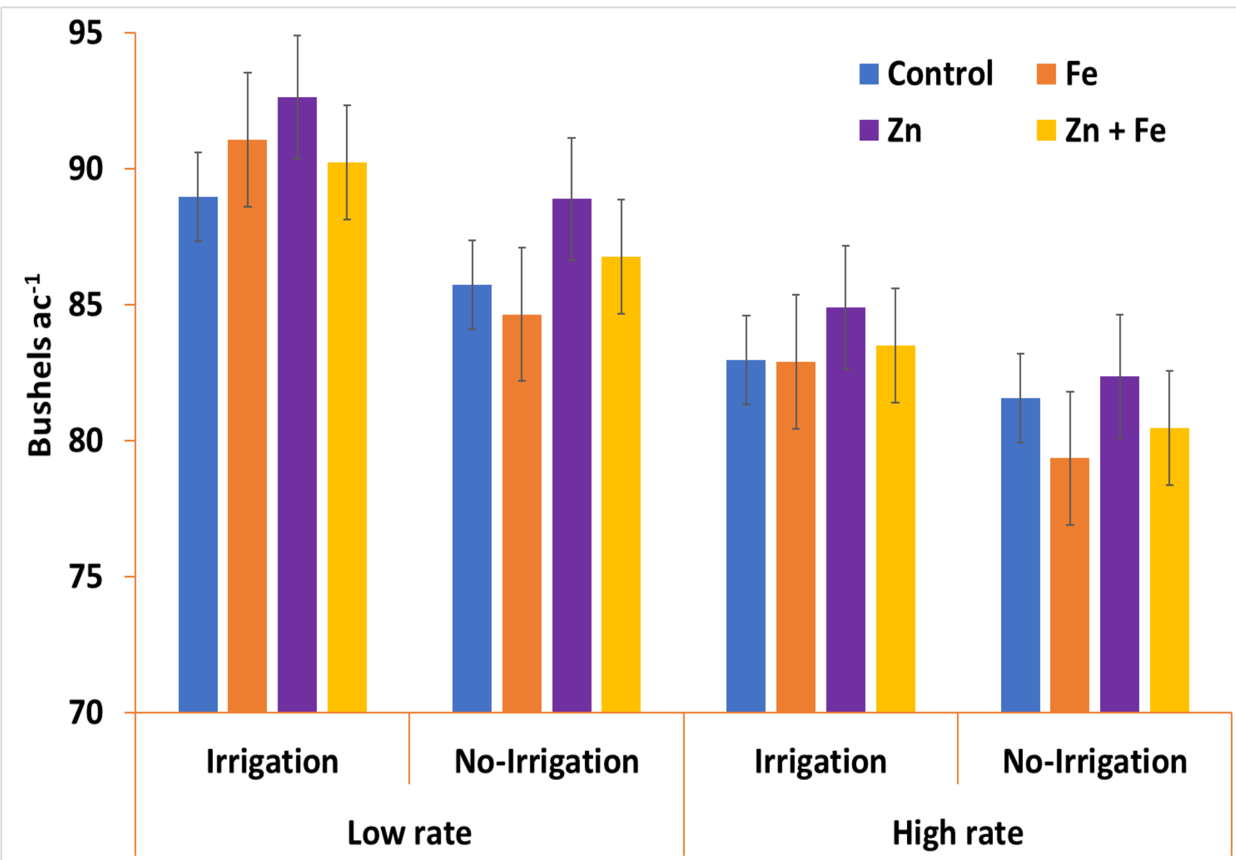

Figure 2. Soybean yield response to micronutrients application and irrigation.

Fiber, oil and protein content:

The soybean seeds were analyzed for different quality parameters such as fiber, oil, protein, fatty acid compositions (palmitic acid, stearic acid, Oleic acid, and linolenic acid), and essential amino acids content (arginine, isoleucine, leucine, lysine, methionine, cysteine, threonine, tryptophan, valine). Under the irrigated environment, the low-rate (LR) zinc (Zn) application significantly increased the oil content compared to the control (Table 1). The protein content also trended higher with Zn and iron (Fe) application compared to the control but was not statistically different. There was no significant micronutrient treatment effect on fiber content (Table 1). With a high application rate of micronutrients, the fiber content was reduced, while protein content was not affected in irrigated environment (Table 1). Under rainfed (no-irrigation) environment, the application of micronutrients did not impact the fiber, oil, and protein content with both high and low application rates. The oil content (%) under rainfed (22.0%) was significantly greater than irrigated environment (21.5%).

Table 1. Micronutrient application effect on soybean yield and seed composition under irrigated and rainfed production system.

Treatments	Low application rate, Irrigated				Low application rate, No-irrigation			
	Yield (lbs. ac^{-1})	Fiber (%)	Oil (%)	Protein (%)	Yield (lbs. ac^{-1})	Fiber (%)	Oil (%)	Protein (%)
Control	89.0[a]	6.41[a]	21.1[b]	38.3[a]	85.7[a]	6.11[a]	21.6[a]	37.7[a]
Iron (Fe)	91.1[a]	6.19[a]	21.4[ab]	38.9[a]	84.6[a]	6.53[a]	22.0[a]	38.0[a]
Zinc (Zn)	92.6[a]	6.53[a]	21.8[a]	38.7[a]	88.9[a]	6.26[a]	22.1[a]	38.1[a]
Fe + Zn	90.2[a]	6.41[a]	21.6[ab]	38.9[a]	86.8[a]	6.28[a]	22.3[a]	38.2[a]
	High application rate, Irrigated				High application rate, No-irrigation			
Control	82.9[a]	5.64[a]	21.8[a]	38.9[a]	81.4[a]	6.13[a]	22.2[a]	38.3[a]
Iron (Fe)	83.0[a]	5.95[a]	21.6[a]	38.8[a]	79.5[a]	6.14[a]	22.1[a]	37.9[a]
Zinc (Zn)	84.9[a]	5.57[a]	22.0[a]	38.4[a]	82.3[a]	6.22[a]	22.2[a]	37.7[a]
Fe + Zn	83.5[a]	6.06[a]	21.7[a]	38.1[a]	80.5[a]	6.34[a]	21.7[a]	37.9[a]

Means within the within the column with different letters indicate significant difference with micronutrient treatments and irrigation at *$p \leq 0.05$*.

Fatty acid composition:

Under both irrigated and rainfed production environment, the application of Fe, Zn, and Fe + Zn had no significant effect on the fatty acids composition compared to the control except in rainfed low application environment (Table 2). similarly, when comparing the irrigated vs. rainfed environment, the low application rate of Fe + Zn significantly increased the oleic acid. Although not statistically significant, the linoleic acid trended higher in irrigated and rainfed environments with both the lower and higher application rates of Fe, Zn, and Fe + Zn. Likewise, the stearic acid was significantly greater with rainfed (4.32%) compared to irrigated (4.21%) environment. Overall, stearic acid content trended greater with high micronutrient application rate and in both irrigated and rainfed environment (Table 2).

Table 2. Micronutrient application effect on soybean seed fatty acid compositions in percent under irrigated and rainfed production system.

Treatments	Low application rate, Irrigated				Low application rate, No-irrigation)			
	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid
Control	10.4[a]	4.24[a]	20.2[a]	9.20[a]	10.4[a]	4.24[a]	20.1[a]	9.21[a]
Iron (Fe)	10.4[a]	4.12[a]	20.3[a]	9.48[a]	10.4[a]	4.26[a]	20.2[a]	9.56[a]
Zinc (Zn)	10.3[a]	4.26[a]	20.2[a]	9.32[a]	10.5[a]	4.21[a]	20.3[a]	9.73[a]
Fe + Zn	10.3[a]	4.15[a]	20.2[a]	9.45[a]	10.5[a]	4.22[a]	20.8[a]	9.51[a]
	High application rate, Irrigated				High application rate, No-irrigation			
Control	10.3[a]	4.11[a]	20.6[a]	9.07[a]	10.2[a]	4.30[a]	20.6[a]	9.14[a]
Iron (Fe)	10.3[a]	4.23[a]	20.1[a]	8.90[a]	10.3[a]	4.31[a]	20.2[a]	9.03[a]
Zinc (Zn)	10.3[a]	4.17[a]	20.4[a]	8.92[a]	10.3[a]	4.35[a]	20.2[a]	9.01[a]
Fe + Zn	10.3[a]	4.33[a]	20.2[a]	8.88[a]	10.3[a]	4.31[a]	20.2[a]	9.10[a]

Means within the within the column with different letters indicate significant difference with micronutrient treatments and irrigation at *$p \leq 0.05$*.

Essential amino acids:
Under the irrigated production environment, with the low application rates of Fe, Zn, and Fe + Zn, the essential amino acid parameters were not statistically different compared to the control (Table 3). However, when comparing the irrigated vs. rainfed production environment, the arginine, and tryptophan content in irrigated environment were significantly greater compared to rainfed (no irrigation) production environment (Table 3).

Table 3. Micronutrient application effect on soybean seeds essential amino acids content (%) under irrigated and rainfed production system.

Amino acids	Low application rate, Irrigated				Low application rate, Rainfed (no irrigation)			
	Control	Iron (Fe)	Zinc (Zn)	Fe + Zn	Control	Iron (Fe)	Zinc (Zn)	Fe + Zn
Arginine	2.68[a]	2.75[a]	2.70[a]	2.73[a]	2.65[a]	2.66[a]	2.66[a]	2.69[a]
Isoleucine	1.74[a]	1.81[a]	1.75[a]	1.79[a]	1.74[a]	1.74[a]	1.78[a]	1.77[a]
Leucine	2.72[a]	2.82[a]	2.74[a]	2.80[a]	2.71[a]	2.70[a]	2.75[a]	2.78[a]
Lysine	2.60[a]	2.64[a]	2.64[a]	2.63[a]	2.58[a]	2.60[a]	2.60[a]	2.64[a]
Methionine	0.47[a]	0.49[a]	0.47[a]	0.48[a]	0.47[a]	0.47[a]	0.48[a]	0.48[a]
Cysteine	0.42[a]	0.48[a]	0.40[a]	0.44[a]	0.43[a]	0.40[a]	0.46[a]	0.43[a]
Threonine	1.38[a]	1.42[a]	1.38[a]	1.41[a]	1.38[a]	1.37[b]	1.39[a]	1.40[a]
Tryptophan	0.38[a]	0.40[a]	0.38[a]	0.40[a]	0.38[a]	0.38[a]	0.37[a]	0.39[a]
Valine	1.73[a]	1.82[a]	1.74 [a]	1.79[a]	1.74[a]	1.72[a]	1.78[a]	1.78[a]
	High application rate, Irrigated				High application rate, Rainfed (no irrigation)			
Arginine	2.79[a]	2.69[a]	2.72[a]	2.66[a]	2.67[a]	2.63[a]	2.61[a]	2.64[a]
Isoleucine	1.83[a]	1.79[a]	1.81[a]	1.76[a]	1.77[a]	1.74[a]	1.73[a]	1.75[a]
Leucine	2.87[a]	2.78[a]	2.82[a]	2.75[a]	2.75[a]	2.70[a]	2.68[a]	2.75[a]
Lysine	2.55[b]	2.60[ab]	2.65[a]	2.61[ab]	2.56[a]	2.56[a]	2.64[a]	2.56[a]
Methionine	0.49[a]	0.47[a]	0.49[a]	0.45[a]	0.46[a]	0.46[a]	0.46[a]	0.45[a]
Cysteine	0.46[a]	0.49[a]	0.48[a]	0.44[a]	0.40[a]	0.40[a]	0.38[a]	0.42[a]
Threonine	1.44[a]	1.42[a]	1.43[a]	1.39[a]	1.39[a]	1.38[a]	1.36[a]	1.38[a]
Tryptophan	0.37[b]	0.39[ab]	0.40[a]	0.38[ab]	0.36[b]	0.38[ab]	0.39[a]	0.37[ab]
Valine	1.85[a]	1.81a	1.82[a]	1.79a	1.76[a]	1.74[a]	1.71[a]	1.79[a]

Means within the within the column with different letters indicate significant difference with micronutrient treatments and irrigation at $p \leq 0.05$.

Under the irrigation production environment and with higher application rates, the lysine and tryptophan were significantly higher with Zn application compared to the control (Table 3). All other amino acid parameters were statistically similar with Fe, Zn, and Fe + Zn application rates compared to the control (Table 3). However, when comparing the irrigated vs. rainfed, the higher application rate significantly increased cysteine in irrigated (0.47) compared to rainfed (0.40) production systems. Likewise, the arginine, isoleucine, leucine, threonine, tryptophan, and valine were significantly increased with higher application rates and irrigation compared to rainfed production systems (Table 3).

Summary and future work

Micronutrient applications, especially Zn and Zn + Fe increased soybean yield in both irrigation and rainfed production environments. The micronutrient application and irrigation showed some synergetic impact on soybean yield. However, the lack of significant difference in yield with irrigation vs. rainfed environment suggests that there is potential to save irrigation water and total production cost. Further research is needed to quantify the impacts of micronutrient application rates and irrigation on soybean yield. Regarding soybean seed quality, the application of Fe and Zn showed mixed results. The lower rate of Zn application with irrigation had a significant impact on oil content compared to control, while the higher application rate with irrigation had a significant impact on amino acids such as Lysine, and Tryptophan. Although, the amino acid quality parameters were affected by Fe and Zn application with irrigation, but the mixed results indicate that more research is needed to quantify the impact of micronutrient application and irrigation on soybean seed quality. The research findings can help the soybean producers in MS develop a new strategy to grow quality soybeans successfully in the region whether with or without irrigation, in combination with micronutrient application.

References

Cook, W. J. (2015). Three reasons why high protein soybeans pay. BigYield.US. https://www.bigyield.us/three-reasons-why-high-protein-soybeans-pay/ (accessed on March 20, 2024).

Enderson, J. T., Mallarino, A. P., & Haq, M. U. (2015). Soybean yield response to foliar-applied micronutrients and relationships among soil and tissue tests. *J. Agron*, 107(6), 2143-2161. https://doi.org/10.2134/agronj14.0536.

Gaspar, A. P., Laboski, C. A. M., Naeve, S. L., & Conley, S. P. (2018). Secondary and micronutrient uptake, partitioning, and removal across a wide range of soybean seed yield levels. *Agronomy Journal*, 110(4), 1328–1338. https://doi.org/10.2134/agronj2017.12.0699

El-Haggan, E. A. L. M. A. (2014). Effect of micronutrients foliar application on yield and quality traits of soybean cultivars. *International Journal of Agriculture and Crop Sciences*, 7(11), 908–914.

Heidarzade, A., M. Esmaeili, M. Bahmanyar, and Abbasi, R. (2016). Response of soybean (Glycine max) to molybdenum and iron spray under well-watered and water deficit conditions. J. Exp. Biol. Agric. Sci. 4: 38-46. doi: 10.18006/2015.4(1).37.46.

Johnson, G.V., & Fixen, P.E. (1990). Testing soils for sulfur, boron, molybdenum, and chlorine. In: R.L. Westerman, editor, Soil testing and plant analysis. 3rd ed. SSSA, Madison, WI. p. 265–273.

Orlowski, J.M., Haverkamp, B.J., Laurenz, R.G., Marburger, D.A., Wilson, E.W., Casteel, S.N., Conley, S. L., Naeve, S. L., Nafziger, E.D., Roozeboom, K. L., Ross, W.L., Thelen, K.D., & Lee, C.D. (2016). High-Input management systems effect on soybean seed yield, yield components, and economic Break-Even probabilities. *Crop Sci.*, 56 (4), 1988-2004.

Thapa, S.; Bhandari, A.; Ghimire, R.; Xue, Q.; Kidwaro, F.; Ghatrehsamani, S.; Maharjan, B.; Goodwin, M. (2021). Managing Micronutrients for Improving Soil Fertility, Health, and Soybean Yield. *Sustainability*, 13, 11766. https://doi.org/10.3390/su132111766

Zolfaghari, M. G., Pasari, B., Shams, K., Rokhzadi, A., & Mohammadi, K. (2019). The effect of micronutrient foliar application on yield, seed quality and some biochemical traits of soybean cultivars under drought stress. Journal of Plant Nutrition, 42:20, 2715-2730, DOI: 10.1080/01904167.2019.1655034