Enhancing Soybean Nutrient Uptake in Medium-Textured Soils
Preliminary 2019 Report to the Michigan Soybean Promotion Committee

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Location: South Campus Research Farm	**Tillage**: Conventional
Planting Date: May 28, 2019; 30 in. rows	**Replicated**: 4 replications
Harvest Date: October 18, 2019	**Population**: 60,000 – 180,000 seeds/acre
Soil Type: Capac Loam	**Variety**: S170115

Introduction

In 2019, Michigan produced 70,930,000 bushels of soybean (*Glycine max* L. Merr.) with an average yield of 41 bushels per acre. However, decreases in commodity prices and uncertainty about climatic variability have producers looking to better focus inputs for improved yield while maintaining or lowering production costs. Although producers often perceive yield loss as a greater risk than profit loss, caution needs to be taken to ensure production practices are not adopted that may have little positive impact on overall revenue.

Increases in total dry matter accumulation may partially explain some of the recent gains in soybean grain yield. Traditionally increased yield potential from greater seeding rates has reduced the risk for yield reductions. Greater seeding rates however can increase interplant competition. The ability of soybean to compensate for lower seeding rates by producing a greater number of branches and pods per plant can reduce interplant competition. As yield increases, total dry matter may also increase suggesting the manipulation of seeding rate may promote greater nutrient uptake while decreasing input costs. Although reduced seeding rates may result in similar yield to greater soybean populations, other risk factors including poor emergence and climatic factors may impart a larger influence at reduced soybean populations.

Fertilizer placement strategies including applications such as starter fertilizer applied 2 inches to the side and below the seed (2x2) may be used as a tool to decrease some risk associated with climatic variability and may help support the concept of season-long nutrient accumulation (depending on what is applied). Increasing early-season and mid-season nutrient and biomass accumulation using a subsurface banded and surface banded nutrient application may provide potential for soybean to capitalize on mid to late season environmental variability and remobilize nutrients to grain later in the season. Much of the late-season nutrient uptake and partitioning to grain comes from the soil emphasizing the importance of sufficient soil nutrient resources in the later reproductive growth stages to prevent yield limitations. Increases in total dry matter from reduced seeding rates may additionally generate a greater response to both early and mid-season nutrient applications. Early and mid-season fertilizer applications in unison with irrigation may also support additional biomass production and a greater nutrient response to subsurface and surface applied fertilizer. There is a critical need to investigate soybean grain yield, biomass accumulation, nutrient uptake and partitioning, and economic return in response to seeding rate and nutrient application across irrigated and non-irrigated environments.

Objective: Evaluate the effects of seeding rate and fertilizer application on dry matter accumulation and partitioning, nutrient uptake, grain yield, and net economic return under both irrigated and non-irrigated conditions. Our *working hypothesis* is that decreased seeding rates may have similar yield compared to greater seeding rates but the additional dry matter production due to less interplant competition will alter nutrient partitioning and response to fertilizer application. Additionally, irrigated vs. non-irrigated conditions will alter dry matter production and affect nutrient partitioning differentially.

Methods and Procedures

Field trials were initiated on May 28, 2019 in Lansing, MI on a non-irrigated and irrigated Capac Loam soil (fine-loamy, mixed, active, mesic Aquic Glossudalf). The fields were previously cropped to corn (*Zea mays* L.). Both trials were chisel plowed (20-cm depth) in the fall and field cultivated (10-cm depth) prior to planting. A Micro Rain (model MR58RLBP) traveling irrigator (Micro Rain, Yukon, OK) provided six to eight inches of supplemental water throughout the growing season at times of peak evapotranspiration and low soil moisture. Pre-plant soil samples (20-cm depth) were collected prior to nutrient application, ground to pass through a 2-mm sieve, and analyzed for soil chemical properties (Table 1). Full season pest control followed Michigan State University best management practices. Environmental data were collected using the Michigan State University Enviro-weather. Temperature and precipitation 30-year means were obtained from the National Oceanic and Atmosphere Administration.

A randomized complete block split-plot design with four replications was utilized. Whole plots measured 15 ft. wide by 200 ft. in length and each sub-plot measured 15 ft. wide by 40 ft. in length. Whole plot factor was seeding rate and the subplot factor was fertilizer application. The variety ‘S170115’ (Stine Seed Co., Adel, IA) was planted in 30-inch rows using a Monosem planter (Monosem Inc., Kansas City, KS) to achieve seeding rates of 60,000, 120,000, and 180,000 seeds per acre. Fertilizer treatments consisted of a non-fertilized control, MicroEssentials® SZ® (MESZ) (Mosaic CO., Plymouth, MN) applied 2-in below and 2-in to the side of the seed at a rate of 150 lb. MESZ A^{-1} (18 lb. N, 60 lb. P_2O_5, 15 lb. S, 1.5 lb. Zn), 16 gal. liquid potash A^{-1} (53 lb. K_2O) applied using a Y-drop applicator near V6, 15 gal. of 10-34-0 A^{-1} (17 lb. N, 59 lb. P_2O_5) applied using a Y-drop applicator near R1, and a combination of the MESZ, K_2O, and 10-34-0 fertilizer treatments referred to as the (All) treatment.

Aboveground plant biomass was sampled from row two at V4, R2, R5, and R8 when at least 50% of the crop achieved each respective growth stage. Plants were partitioned into leaves, stems and petioles, flowers and pods, and grain. Netting was assembled immediately prior to the onset of leaf drop to retain senesced biomass. Dry weight was determined by drying plant tissues at 66°C (0% moisture). Total dry matter accumulation was reported as the sum of all plant components. R8 grain samples were analyzed for N, P, K, S, Zn, Ca, Mg, Mn, Fe, Cu, and B. Grain yield, moisture, and test weight with yield adjusted to 13.5% moisture was determined by harvesting the center two rows of each plot with a research plot combine (Kincaid Equipment Manufacturing, Haven, KS). Economic return was estimated using an average local cash price of \$8.73 bu^{-1} and input costs of \$44.25, \$328, and \$45 A^{-1} for MESZ, K_2O, P_2O_5, and the combination fertilizer treatment, respectively. Nutrient application costs of \$1.54 and \$12.00 A^{-1} were estimated for 2x2 starter application and Y-drop application, respectively, using Michigan State University Extension Custom Machine and Work Rate Estimates. Seed cost for 140,000 seeds was estimated at \$50.00. Net profit estimates were calculated by subtracting treatment costs from gross profit estimates. Statistical analyses were performed using PROC GLIMMIX in SAS 9.4 (SAS Institute, 2012) at $\alpha = 0.10$.

Results and Discussion

Weather

Total May to September rainfall was above the 30-year mean (Table 2). However, June rainfall was 3.7 inches above normal while August was 2.5 inches below the 30-year mean. Delayed planting because of unsuitable planting conditions in early May and limited August rainfall frequencies during the grain-fill period may have reduced vegetative growth, yield potential, and response to fertilizer applications (Figure 1). May to September mean daily air temperatures were ±3.4 degrees Fahrenheit of the 30-year mean indicating that mean air temperatures likely did not affect soybean growth and development. (Table 2).

Grain Yield and Economic Return

There was no interaction between seeding rate and fertilizer application on grain yield for the irrigated ($P = 0.77$) or non-irrigated ($P = 0.75$) sites which suggests fertilizer treatments did not require adjustment based on seeding rates (Table 3).

In 2019 seeding rate influenced grain yield at the irrigated site ($P = 0.03$) and among the tested rates was maximized at 120,000 seeds A^{-1} (Table 3). However, seeding rates did not influence yield at the non-irrigated site ($P = 0.34$) and ranged from 33.3 to 37.0 bu A^{-1} (Table 3). Greater yield at the irrigated site compared to the non-irrigated site was due in part to 0.7 inches of cumulative precipitation during August suggesting water availability during reproductive growth stages (i.e. grain-fill) decreased yield potential at the non-irrigated site. Additionally, reduced seeding rates (60,000 seeds A^{-1}) under non-irrigated conditions compensated for reduced plant density by producing additional pods. Total pod production for 60,000 seeds A^{-1} resulted in more than 5 million pods A^{-1} while only 2 or 3 million pods were produced at 120,000 and

180,000 seeds A^{-1} rates under non-irrigated conditions, respectively (Table 14). Despite significant differences in grain yield at the irrigated site, seeding rate did not affect economic return (Table 3). Yield increases were offset by greater seed costs at increased seeding rates. Economic return was also not affected by seeding rate at the non-irrigated site (Table 3).

Fertilizer application did not significantly affect grain yield at the irrigated (P = 0.32) or non-irrigated sites (P = 0.36, Table 3). Near or above critical soil test concentrations and in the environment tested, responses to fertilizer application should not have been expected (Table 1). Past research has stated yield levels of 75 bu A^{-1} or greater (i.e., high yield environments) may result in a fertilizer response due to increased nutrient uptake before and after the growth stage R5.5. Both sites failed to achieve yield levels of 75 bu A^{-1}, which may explain the lack of response to fertilizer application at above-critical soil test nutrient concentrations. Regardless of nutrient response, economic return at the irrigated and non-irrigated site was greatest with the nonfertilized treatment (Table 3). Due to the high cost of the liquid potash fertilizer, the All and K_2O treatments decreased economic return significantly for both sites (Table 3).

Biomass Accumulation and Dry Matter Partitioning

Total dry matter at V4 was significantly influenced by seeding rate at the irrigated site (P = <0.01) and at the non-irrigated site (P = <0.01) (Table 4,6). As seeding rate increased, total V4 dry matter increased for both sites. However, individual plant mass data suggests decreased inter-plant competition from reduced seeding rates increased individual plant biomass compared to increased seeding rates (data not shown). Gains in individual plant biomass from reduced seeding rates did not carry over or translate to increases in total dry matter on a per acre basis. Furthermore, 60,000 seeds A^{-1} partitioned the greatest percent of aboveground total dry matter to the leaves (Table 7), while increased seeding rates of 120,000 and 180,000 seeds A^{-1} partitioned a greater percentage of total dry matter to the stems/petioles for both irrigated and non-irrigated sites (Table 7). These results may indicate how plants adapt dry matter partitioning to interplant competition, which may ultimately affect nutrient accumulation and remobilization. Previous research has stated that reduced planting densities may experience a lag phase of decreased overall growth rates for up to 30 days after soybean emergence compared to greater plant densities. Results agree with previous research and show increased seed rates achieved a greater proportion of R8 total dry matter at V4 and R2 than decreased seeding rates at the non-irrigated site (Table 11). R2 total dry matter accumulation was greatest at 180,000 seeds A^{-1} under non-irrigated conditions whereas the irrigated site resulted in an interaction between seeding rate and nutrient application (Table 5). Furthermore, a greater proportion of dry matter was allocated to the flowers and less proportioned to the leaves for 180,000 seeds A^{-1} than 60,000 seeds A^{-1} at the irrigated site (Table 8). This initial reproductive response could help explain why an increase in yield occurred for 180,000 seeds A^{-1}. Despite the possibility of less time in the lag phase at both sites, there was no difference in R5 and R8 dry matter accumulation. This may be due to accelerated crop growth rates near peak dry matter accumulation and an increase in water competition among increased seeding rates during late July and August at the non-irrigated site.

Nutrient application influenced total dry matter at V4, R2, and R5 for the irrigated and non-irrigated location (Table 4,5,6). At V4 the "All" fertilizer treatment produced the greatest amount of total dry matter under irrigated conditions (*P* = <0.01) while the All and MESZ treatment maximized total dry matter under non-irrigated conditions (*P* = <0.01, Table 4). These increases in total dry matter suggest nutrient application at planting from the "All" and MESZ treatment could potentially alleviate early season stresses affecting plant growth. Results from this study also show the application of MESZ in the MESZ and "All" fertilizer treatments increased the proportion of dry matter allocated to the stems/petioles and less to the leaves compared to all other fertilizer treatments for both sites (Table 7). Similar to increased seeding rates, the application of MESZ under irrigated conditions may have decreased the early season lag phase by increasing the V4 and R2 percentage of total dry matter (Table 11). At R2 the All and MESZ fertilizer treatments increased total dry matter between 517 and 605 lb. A^{-1} under non-irrigated conditions (Table 6). However, the MESZ fertilizer treatment may be the primary contributor towards the dry matter production within the All fertilizer treatment. In addition, the percentage of R2 and R5 irrigated and R2 non-irrigated dry matter partitioned to the stem/petiole increased with the MESZ and All fertilizer treatment (Table 8,9). Under an irrigated environment, the All fertilizer application increased R5 total dry matter compared to all other fertilizer treatments (Table 4) whereas the MESZ treatment maximized total dry matter under the non-irrigated environment (Table 6). At R8 total dry matter accumulation was significantly affected by nutrient application at the irrigated site (*P* = 0.05) but not at the non-irrigated site (*P* = 0.20) suggesting total dry matter response to nutrient application may be dependent on access to soil moisture (Table 4, 6). The All and MESZ fertilizer treatment increased total dry matter between 433 and 1,093 lb. A^{-1} at the irrigated site (Table 4). At maturity, dry matter was largely partitioned to the grain, followed by stems, pods, and leaves, respectively for both sites (Table 10),

Seeding rates did not significantly affect R1 uppermost trifoliate P, K, or Zn concentration at the irrigated site and P and K concentration at the non-irrigated site (Table 13). Under irrigated conditions sulfur concentration was greatest at increased seeding rates than decreased seeding rates but was greatest at decreased seeding rates at the non-irrigated site (Table 13). However, S concentrations were all above the generally considered critical level of 0.25%.

Nutrient application influenced R1 uppermost trifoliate P (*P* = <0.01), K (*P* = 0.03), and S (*P* = <0.01) concentration under irrigation while only K (*P* = 0.04) and Zn (*P* = 0.08) concentration were influenced under non-irrigated conditions (Table 13). Grain nutrient accumulation was significantly affected by seeding rate for N (*P* = 0.03), P (*P* = 0.06), K (*P* = 0.07), S (*P* = 0.06), and Zn (*P* = 0.10), under irrigation while no differences were realized under non-irrigated conditions (Table 12). Increased seeding rates produced the greatest N, P, K, S, and Zn grain accumulation at the irrigated site (Table 12).

Nutrient application did influence grain nutrient accumulation for P (*P* = 0.02) and K (*P* = 0.08) at the irrigated whereas no differences were observed at the non-irrigated site (Table 12).

The All and 10-34-0 fertilizer treatment maximized grain P accumulation in addition to the All fertilizer treatment achieving the greatest grain K accumulation (Table 12).

Summary

The objective of this study was to evaluate the effects of seeding rate and fertilizer application on dry matter accumulation and partitioning, nutrient uptake, grain yield, and net economic return. Current commodity prices and inconsistent results from nutrient applications at above critical soil test concentrations has led many Michigan soybean producers to place more emphasis on profitability. Findings of this study are aimed towards growers targeting intensive nutrient management strategies including in-season applications or for those looking to reduce production costs without sacrificing yield.

Results from 2019 indicate there was no interaction between seeding rate and fertilizer application on grain yield for the irrigated or non-irrigated sites, which suggests fertilizer applications did not require adjustment based on seeding rates. However, 120,000 seeds A^{-1} increased grain yield among the tested seeding rates at the irrigated site but did not influence net economic return. Irrigation likely decreased inter-plant competition for water at increased seeding rates (> 120,000 seeds A^{-1}) and increased yield in comparison to the non-irrigated site. Grain yield and economic return were not affected by seeding rate at the non-irrigated site. Reduced seeding rates (60,000 seeds A^{-1}) under non-irrigated conditions compensated for reduced plant density by producing additional pods. Total pod production for 60,000 seeds A^{-1} resulted in more than 5 million pods A^{-1} while only 2 or 3 million pods were produced at 120,000 and 180,000 seeds A^{-1} rates under non-irrigated conditions, respectively.

Fertilizer application did not significantly affect grain yield at the irrigated or non-irrigated sites. Nutrient application did not elicit a fertilizer response when soil test values were at or above critical under the conditions tested. Soil test values should be considered prior to implementing fertilizer applications.

The 60,000 seeds A^{-1} rate partitioned the greatest percent of aboveground total dry matter to the leaves while increased seeding rates of 120,000 and 180,000 seeds A^{-1} partitioned a greater percentage of total dry matter to the stems/petioles for both irrigated and non-irrigated sites. These results may indicate how plants adapt dry matter partitioning to interplant competition, which may ultimately affect nutrient accumulation and remobilization. Subsurface placement of fertilizer (i.e., 2x2) reduced the “lag phase” associated with reduced early season growth and promoted increased dry matter production. At R8, total dry matter accumulation was significantly affected by nutrient application at the irrigated site but not at the non-irrigated site suggesting total dry matter response to nutrient application may be dependent on access to soil moisture. The All and MESZ fertilizer treatment increased total dry matter between 433 and 1,093 lb. A^{-1} at the irrigated site. At maturity, dry matter was largely partitioned to the grain, followed by stems, pods, and leaves, respectively for both sites. Despite increased dry matter production and grain nutrient accumulation from nutrient applications, yield gains did not occur. Thus growers should not confuse increases in plant biomass with greater grain yield.

Appendix

Figure 1. Rainfall frequency and average daily air temperature (˚F), Lansing, MI, 2019.

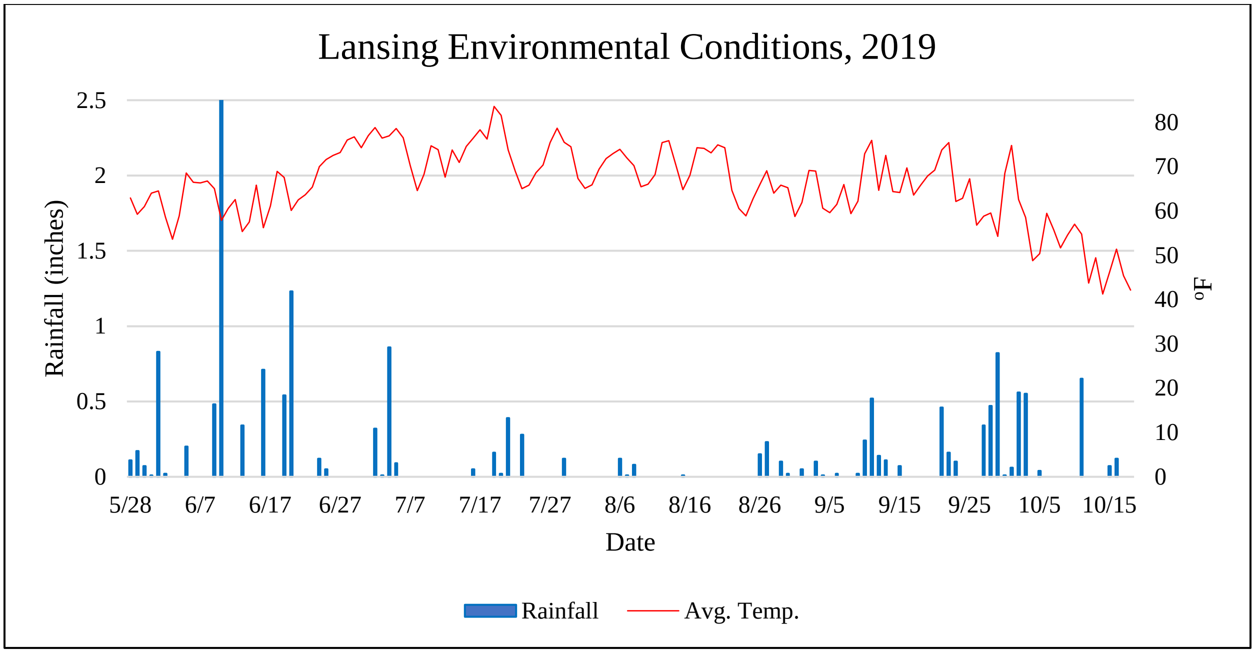

Table 1. Soil chemical properties and mean nutrient concentrations (0 to 20-cm depth) for the irrigated and non-irrigated site, Lansing, MI, 2019

	Soil test values†						
Site	pH	CEC	SOM	P	K	S	Zn
		meq/100 g^{-1}	%	ppm			
Irrigated	6.8	7.5	2.1	38	80	6	2.1
Non-irrigated	7.5	13.7	2.7	86	94	7	3.8

†pH (1:1, soil/water), SOM soil organic matter (loss-on-ignition), P Phosphorus (Bray-P1), K potassium (ammonium acetate method), S sulfur (monocalcium phosphate extraction), Zn Zinc (0.1 M HCl extraction).

Table 2. Monthly† and 30-year mean‡ air temperature (T avg) and cumulative precipitation (Ppt) for the soybean-growing season (May-September), Lansing, MI, 2019.

	Month					
Location	May	June	July	August	September	Total
Lansing						
Ppt, in	3.4	7.2	2.3	0.7	3.6	17.2
30-yr mean	3.4	3.5	2.8	3.2	3.5	16.4
T avg, ˚F	56.1	64.9	73.8	68.5	65.3	328.6
30-yr mean	57.7	67.6	71.5	69.8	61.9	328.4

†Monthly precipitation and air temperatures collected from MSU Enviro-weather (https://enviroweather.msu.edu).
‡30-year means collected from the National Oceanic and Atmosphere Administration (https://www.ncdc.noaa.gov/cdo-web/datatools/normals).

Table 3. Soybean grain yield (bu A^{-1}) and net economic return† (US\$ A^{-1}) as affected by seeding rate and fertilizer application, Lansing, MI, 2019. Grain yield adjusted to 13.5% moisture.

	Site			
Treatment	Irrigated	Non-irrigated	Irrigated	Non-irrigated
	bu A^{-1}		US\$ A^{-1}	
Seeding rate (seeds A^{-1})				
60,000	60.9 b‡	33.3 a	510 a	269 a
120,000	64.1 ab	37.0 a	517 a	280 a
180,000	67.0 a	34.0 a	520 a	233 a
P* > *F	0.03	0.34	0.77	0.15
Fertilizer				
Unfertilized	64.0 a	35.7 a	516 a	268 a
MESZ	63.5 a	35.6 a	466 b	222 b
K_2O	62.0 a	37.8 a	158 c	-53 c
10-34-0	63.8 a	32.6 a	457 b	184 b
All	66.6 a	32.2 a	94 d	-207 d
P* > *F	0.32	0.36	<0.01	<0.01

† Net economic return calculated as gross profit (soybean grain price x grain yield) minus total input costs.
‡ Values followed by the same letter are not significantly different at α=0.10.

Table 4. Impact of seeding rate and fertilizer application on irrigated dry matter (DM) accumulation at growth stages V4, R5, and R8, Lansing, MI, 2019. All values are reported at 0% moisture.

Treatment	Growth Stage V4	R5	R8
	——lb. A^{-1}——		
Seeding rate (seeds A^{-1})			
60,000	141 c†	3983 a	5836 a
120,000	205 b	4357 a	5658 a
180,000	277 a	4709 a	6743 a
P* > *F	<0.01	0.22	0.17
Fertilizer			
Unfertilized	156 c	3980 b	5671 b
MESZ	263 b	4347 b	6346 ab
K_2O	159 c	3783 b	5458 b
10-34-0	132 d	4067 b	5913 b
All	328 a	5571 a	7006 a
P* > *F	<0.01	0.04	0.05

† Values followed by the same letter are not significantly different at α=0.10.

Table 5. Interaction (*P* < 0.01) between soybean seeding rate and fertilizer application on irrigated R2 dry matter production, Lansing, MI, 2019. All values are reported at 0% moisture.

Fertilizer	Seeding rate (seeds A^{-1}) 60,000	120,000	180,000	***P* > *F***
	——lb. A^{-1}——			
Unfertilized	2432 bC†	2656 abB	3209 aB	0.01
MESZ	3432 aB	3905 aA	3460 aB	0.34
K_2O	2037 bC	2662 aB	2869 aB	0.07
10-34-0	2176 bC	2334 bB	3411 aB	<0.01
All	4049 bA	3843 bA	5418 aA	<0.01
P* > *F	<0.01	<0.01	<0.01	—

† Lowercase letters are specific to each row (fertilizer treatment) and uppercase letters are specific to each column (seeds A^{-1}). Values followed by the same lowercase or uppercase letter are not significantly different at α = 0.10.

Table 6. Impact of seeding rate and fertilizer application on non-irrigated dry matter accumulation at growth stages V4, R5, and R8, Lansing, MI, 2019. All values are reported at 0% moisture.

	Growth Stage			
Treatment	V4	R2	R5	R8
	——————lb. A^{-1}——————			
Seeding rate (seeds A^{-1})				
60,000	132 c†	2129 b	3189 a	4544 a
120,000	212 b	2417 b	3345 a	5305 a
180,000	283 a	3150 a	3617 a	4797 a
P > F	<0.01	<0.01	0.48	0.44
Fertilizer				
Unfertilized	171 b	2357 b	2989 b	4388 a
MESZ	256 a	2874 a	3958 a	5644 a
K_2O	178 b	2356 b	3271 b	4681 a
10-34-0	179 b	2278 b	3199 b	4683 a
All	260 a	2962 a	3501 ab	5013 a
P > F	<0.01	0.05	0.04	0.20

† Values followed by the same letter are not significantly different at α=0.10.

Table 7. Impact of seeding rate and fertilizer application on irrigated and non-irrigated V4 dry matter partitioning, Lansing, MI, 2019.

Site	Treatment	Dry Matter Partitioning	
		Leaves	Stems/Petioles
		—Percent (%) of aboveground dry matter—	
Irrigated	Seeding rate (seeds A^{-1})		
	60,000	77 a†	23 c
	120,000	73 b	27 b
	180,000	70 c	30 a
	P* > *F	<0.01	<0.01
	Fertilizer		
	Unfertilized	76 a	24 d
	MESZ	70 d	30 a
	K_2O	73 bc	27 bc
	10-34-0	76 ab	24 cd
	All	71 cd	29 ab
	P* > *F	<0.01	<0.01
		Dry Matter Partitioning	
Site	Treatment	Leaves	Stems/Petioles
		—Percent (%) of aboveground dry matter—	
Non-irrigated	Seeding rate (seeds A^{-1})		
	60,000	72 a	30 b
	120,000	69 b	31 a
	180,000	68 b	32 a
	P* > *F	0.03	0.03
	Fertilizer		
	Unfertilized	72 a	28 c
	MESZ	68 c	32 a
	K_2O	71 ab	29 bc
	10-34-0	69 bc	31 ab
	All	68 c	32 a
	P* > *F	<0.01	<0.01

†Values followed by the same letter are not significantly different at $\alpha = 0.10$.

Table 8. Impact of seeding rate and fertilizer application on irrigated and non-irrigated R2 dry matter partitioning, Lansing, MI, 2019.

Site	Treatment	Dry Matter Partitioning		
		Leaves	Stems/Petioles	Flowers
		―Percent (%) of aboveground dry matter―		
Irrigated	Seeding rate (seeds A^{-1})			
	60,000	52 a†	46 a	2 b
	120,000	51 ab	47 a	3 b
	180,000	50 b	46 a	4 a
	P* > *F	0.06	0.20	0.03
	Fertilizer			
	Unfertilized	52 a	45 c	3 a
	MESZ	49 b	48 b	3 a
	K_2O	53 a	45 c	3 a
	10-34-0	52 a	45 c	3 a
	All	48 b	49 a	3 a
	P* > *F	<0.01	<0.01	0.75

Site	Treatment	Dry Matter Partitioning		
		Leaves	Stems/Petioles	Flowers
		―Percent (%) of aboveground dry matter―		
Non-irrigated	Seeding rate (seeds A^{-1})			
	60,000	54 a	44 b	3 a
	120,000	52 a	45 b	3 a
	180,000	51 b	47 a	2 a
	P* > *F	0.03	0.02	0.17
	Fertilizer			
	Unfertilized	52 bc	45 bc	3 a
	MESZ	51 c	47 a	2 a
	K_2O	54 a	44 c	2 a
	10-34-0	53 ab	44 bc	2 a
	All	51 bc	46 ab	3 a
	P* > *F	0.02	0.02	0.2

†Values followed by the same letter are not significantly different at α = 0.10.

Table 9. Impact of seeding rate and fertilizer application on irrigated and non-irrigated R5 dry matter partitioning, Lansing, MI, 2019.

		Dry Matter Partitioning		
Site	Treatment	Leaves	Stems/Petioles	Flowers/Pods
		—Percent (%) of aboveground dry matter—		
Irrigated	Seeding rate (seeds A^{-1})			
	60,000	40 a†	50 a	10 a
	120,000	38 b	50 a	14 a
	180,000	37 b	51 a	11 a
	P* > *F	<0.01	0.17	0.44
	Fertilizer			
	Unfertilized	40 a	49 d	12 a
	MESZ	38 b	51 a	11 a
	K_2O	40 a	50 cd	12 a
	10-34-0	40 a	50 bc	11 a
	All	37 c	51 ab	13 a
	P* > *F	<0.01	<0.01	0.35
		Dry Matter Partitioning		
Site	Treatment	Leaves	Stems/Petioles	Flowers/Pods
		—Percent (%) of aboveground dry matter—		
Non-irrigated	Seeding rate (seeds A^{-1})			
	60,000	40 a	46 b	13 a
	120,000	39 ab	47 b	14 a
	180,000	38 b	48 a	14 a
	P* > *F	0.06	0.03	0.67
	Fertilizer			
	Unfertilized	40 a	46 a	14 a
	MESZ	38 a	47 a	15 a
	K_2O	39 a	47 a	14 a
	10-34-0	40 a	47 a	13 a
	All	39 a	47 a	14 a
	P* > *F	0.21	0.41	0.52

†Values followed by the same letter are not significantly different at $\alpha = 0.10$.

Table 10. Impact of seeding rate and fertilizer application on irrigated and non-irrigated R8 total dry matter partitioning, Lansing, MI, 2019.

		Dry Matter Partitioning			
Site	Treatment	Leaves	Stems/Petioles	Pods	Grain
		Percent (%) of aboveground dry matter			
Irrigated	Seeding rate (seeds A^{-1})				
	60,000	13 a†	30 a	18 a	38 a
	120,000	15 a	29 a	16 b	39 a
	180,000	14 a	30 a	16 b	39 a
	P* > *F	0.11	0.71	<0.01	0.64
	Fertilizer				
	Unfertilized	15 a	29 a	17 a	39 a
	MESZ	15 a	31 a	16 a	38 a
	K_2O	13 a	30 a	18 a	40 a
	10-34-0	15 a	30 a	17 a	38 a
	All	12 a	31 a	17 a	39 a
	P* > *F	0.31	0.19	0.18	0.7
		Dry Matter Partitioning			
Site	Treatment	Leaves	Stems/Petioles	Pods	Grain
		Percent (%) of aboveground dry matter			
Non-irrigated	Seeding rate (seeds A^{-1})				
	60,000	16 a	23 c	17 a	44 a
	120,000	16 a	25 b	17 a	43 a
	180,000	15 a	27 a	15 b	43 a
	P* > *F	0.57	0.01	0.1	0.66
	Fertilizer				
	Unfertilized	15 a	24 b	17 a	44 a
	MESZ	14 a	25 ab	16 a	45 a
	K_2O	16 a	24 b	17 a	43 a
	10-34-0	16 a	25 b	16 a	43 a
	All	16 a	27 a	15 a	42 a
	P* > *F	0.17	0.09	0.66	0.55

†Values followed by the same letter are not significantly different at α = 0.10.

Table 11. Impact of seeding rate and fertilizer application on irrigated and non-irrigated percentage of R8 total dry matter, Lansing, MI, 2019.

		Growth Stages		
Site	Treatment	V4	R2	R5
		———Percent (%) of R8 total dry matter———		
Irrigated	Seeding rate (seeds A^{-1})			
	60,000	3 b†	52 a	74 a
	120,000	4 a	56 a	80 a
	180,000	4 a	56 a	73 a
	P* > *F	0.04	0.72	0.67
	Fertilizer			
	Unfertilized	3 b	50 b	73 a
	MESZ	4 a	60 a	72 a
	K_2O	3 b	48 b	73 a
	10-34-0	2 c	49 b	77 a
	All	5 a	66 a	84 a
	P* > *F	<0.01	0.01	0.78
		Growth Stages		
Site	Treatment	V4	R2	R5
		———Percent (%) of R8 total dry matter———		
Non-irrigated	Seeding rate (seeds A^{-1})			
	60,000	3 c	52 b	73 a
	120,000	4 b	50 b	68 a
	180,000	6 a	65 a	78 a
	P* > *F	<0.01	0.07	0.42
	Fertilizer			
	Unfertilized	4 a	56 a	70 a
	MESZ	5 a	59 a	76 a
	K_2O	4 a	51 a	74 a
	10-34-0	4 a	50 a	72 a
	All	5 a	61 a	73 a
	P* > *F	0.17	0.47	0.99

†Values followed by the same letter are not significantly different at $\alpha = 0.10$.

Table 12. Soybean grain nutrient accumulation at physiological maturity (R8) as affected by seeding rate and fertilizer application presented across irrigated and non-irrigated sites, Lansing, MI, 2019.

		Grain Nutrient Accumulation†				
Site	Treatment	N	P	K	S	Zn
		lb. A^{-1}				g A^{-1}
Irrigated	Seeding rate (seeds A^{-1})					
	60,000	205 b‡	19 b	61 b	12 b	51 b
	120,000	220 a	20 ab	63 ab	12 ab	51 b
	180,000	230 a	21 a	66 a	13 a	55 a
	P* > *F	0.03	0.06	0.07	0.06	0.10
	Fertilizer					
	Unfertilized	217 a	19 c	62 b	12 a	53 a
	MESZ	221 a	19 bc	62 b	12 a	53 a
	K_2O	211 a	19 bc	62 b	12 a	51 a
	10-34-0	217 a	20 ab	63 b	12 a	51 a
	All	225 a	21 a	68 a	13 a	55 a
	P* > *F	0.32	0.02	0.08	0.56	0.44
		Grain Nutrient Accumulation				
Site	Treatment	N	P	K	S	Zn
		lb. A^{-1}				g A^{-1}
Non-irrigated	Seeding rate (seeds A^{-1})					
	60,000	180 a	16 a	52 a	9 a	50 a
	120,000	178 a	16 a	50 a	9 a	50 a
	180,000	181 a	16 a	51 a	9 a	49 a
	P* > *F	0.59	0.48	0.48	0.49	0.80
	Fertilizer					
	Unfertilized	181 a	16 a	50 a	9 a	50 a
	MESZ	181 a	16 a	52 a	9 a	50 a
	K_2O	175 a	16 a	52 a	9 a	49 a
	10-34-0	180 a	16 a	50 a	9 a	49 a
	All	181 a	16 a	51 a	9 a	50 a
	P* > *F	0.43	0.94	0.50	0.11	0.84

†Grain nutrient accumulation calculated as nutrient concentration x grain dry matter accumulation.
‡Values followed by the same letter are not significantly different at $\alpha = 0.10$.

Table 13. Impact of soybean seeding rate and fertilizer application on irrigated and non-irrigated R1 uppermost trifoliate nutrient concentrations, Lansing, MI, 2019.

		R1 Uppermost Trifoliate Nutrient Concentrations			
Site	Treatment	P	K	S	Zn
		(%)			ppm
Irrigated	Seeding rate (seeds A^{-1})				
	60,000	0.47 a†	2.18 a	0.30 b	34.6 a
	120,000	0.48 a	2.27 a	0.32 a	32.7 a
	180,000	0.48 a	2.33 a	0.32 a	31.9 a
	P* > *F	0.74	0.45	0.02	0.11
	Fertilizer				
	Unfertilized	0.45 c	2.19 bc	0.31 b	32.6 a
	MESZ	0.49 a	2.14 c	0.32 a	33.7 a
	K_2O	0.48 ab	2.22 ab	0.32 a	33.4 a
	10-34-0	0.46 bc	2.28 b	0.31 b	32.3 a
	All	0.50 a	2.38 a	0.32 a	33.4 a
	P* > *F	<0.01	0.03	<0.01	0.47
		R1 Nutrient Concentrations			
Site	Treatment	P	K	S	Zn
		(%)			ppm
Non-irrigated	Seeding rate (seeds A^{-1})				
	60,000	0.51 a	2.12 a	0.31 a	41.5 a
	120,000	0.49 a	1.95 a	0.30 b	39.6 b
	180,000	0.48 a	1.96 a	0.29 b	37.4 c
	P* > *F	0.28	0.15	<0.01	<0.01
	Fertilizer				
	Unfertilized	0.49 a	2.00 bc	0.30 a	39.8 ab
	MESZ	0.51 a	1.98 bc	0.30 a	38.5 b
	K_2O	0.49 a	2.17 a	0.29 a	38.8 b
	10-34-0	0.51 a	2.05 ab	0.30 a	40.8 a
	All	0.48 a	1.87 c	0.30 a	39.6 ab
	P* > *F	0.41	0.04	0.35	0.08

†Values followed by the same letter are not significantly different at $\alpha = 0.10$.

Table 14. Number of soybean pods per acre as affected by seeding rate and fertilizer application across irrigated and non-irrigated sites, Lansing, MI, 2019.

	Site	
Treatment	Irrigated	Non-irrigated
	———pods A^{-1}———	
Seeding rate (seeds A^{-1})		
60,000	4,931,562 a†	5,094,421 a
120,000	4,768,885 a	2,223,567 b
180,000	5,254,021 a	3,111,618 b
P* > *F	0.51	0.04
Fertilizer		
Unfertilized	4,679,642 a	3,271,790 a
MESZ	4,965,587 a	3,886,526 a
K_2O	4,782,143 a	3,351,403 a
10-34-0	4,810,181 a	3,284,167 a
All	5,686,559 a	3,588,792 a
P* > *F	0.11	0.27

†Values followed by the same letter are not significantly different at α = 0.10.