SOYBEAN BIOLOGICAL NITROGEN FIXATION AND PRODUCTION AS AFFECTED BY FERTILIZER, NITROGEN APPLICATION, AND PLANTING DATE

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ABSTRACT

Michigan spring weather variabilities and earlier planting dates may provide opportunities for starter fertilizer to influence early season soybean (*Glycine max* L. Merr.) dry matter production while simultaneously decreasing the time interval for nutrient accumulation. However, potential fertilizer impacts on inhibition of biological N fixation (BNF) are not well understood. Field studies established near Lansing, MI examined soybean total dry matter accumulation (TDM), nodulation, ^{15}N content, grain yield, and net economic return as influenced by planting dates and fertilizer strategies in both irrigated and non-irrigated environments. Studies were arranged as a randomized complete block split-plot design containing four replications. Main plots consisted of two planting dates while sub-plots consisted of six fertilizer strategies. In 2021 grain yield of April and May planted soybean ranged from 82.3 to 78.0 bushels A^{-1} respectively, at the irrigated site, and 72.8 to 69.8 bushels A^{-1} respectively, at the non-irrigated site. Non-irrigated R4 mean nodule counts per plant showed a 36% reduction as planting date was delayed from April to May. All fertilizer treatments significantly reduced nodulation compared to the non-fertilized control except for the dry 2x2 starter strategy. Percent N derived from atmosphere (NDFA) interacted with planting date and fertilizer strategy at R2 but by R6 NDFA was different only between fertilizer treatments. Preliminary results suggest that starter fertilizer may be one tool to mitigate risk during early season planting without inhibiting biological N fixation.

INTRODUCTION

High input prices (i.e., seed, fertilizer, pesticides, etc.) have practitioners reevaluating soybean fertilizer management practices. Recent occurrences of spring weather variability combined with what has become cool, abnormally wet or dry Michigan spring planting conditions have increased interest in nutrient strategies that may influence early-season dry matter production and nutrient accumulation (i.e., reducing the lag-phase of soybean growth) but not adversely impact biological N fixation (BNF) contributions to the plant. Earlier planting dates may offer additional opportunities for Michigan soybean growers to capitalize on a longer growing season and maximize investment in nutrient application strategies.

Soybean production practices are often overlooked as many critical components of soybean yield potential are limited by the uncontrollable environment. Previous studies indicated plant density influences on total dry matter (TDM) accumulation may help facilitate nutrient uptake with greater pre-R5 dry matter associated with greater yields (Purucker & Steinke, 2020). As mean farm size continues to grow, earlier planting of soybeans has gained interest and may be another opportunity to influence TDM, grain yield, and oil content (Robinson et al, 2009). However, early spring soil conditions in

Michigan are unpredictable which may provide greater opportunity for starter fertilizer to influence plant establishment. Low rates of starter N fertilizer (< 25# A^{-1}) have been found to support increased V4 DM but yield and profitability were not consistent and effects on BNF unknown (Purucker & Steinke, 2020). Although low starter N rates have not decreased BNF, more data are needed regarding the influence of greater N rates and starter fertilizer practices not only TDM and grain yield but also BNF contributions to the plant (Salvagiotti et al, 2008).

MATERIALS AND METHODS

Field trials were conducted in Lansing, MI on irrigated and non-irrigated Capac loam soil in 2021 and 2022. All sites were previously cropped to corn (*Zea mays* L.) followed by autumn chisel plowing and spring field cultivation. Pre-plant soil samples (0–8-inch depth) indicated soil characteristics ranging from: 6.7-7.4 pH, 34-155 ppm P, 86-147 ppm K, and 8-17 ppm S across site years. Plots measured 15 ft. wide by 40 ft. in length with 30 in. row spacing. Trials were arranged as randomized complete block split-plot design with four replications to evaluate two plant timings (23 April, and 17 May 2021; 29 April, and 20 May 2022) as well as six fertilizer strategies: no fertilizer, 25 lb. N, 60 lb. P_2O_5, and 15 lb. S A^{-1} (12-40-0-10S mixed with 46-0-0) applied two inches to the side and two inches below the seed (2x2) at planting, 25 lb. N, 60 lb. P_2O_5, and 15 lb. S A^{-1} (12-0-0-26S mixed with 10-34-0) applied 2x2 at planting, 100 lb. N A^{-1} (46-0-0) broadcast and pre-plant incorporated, 100 lb. N A^{-1} (28-0-0) band applied along each row at growth stage V4, and 100 lb. N A^{-1} (28-0-0) band applied along each row at growth stage R2. Variety P24T35E, a 2.4MG soybean, was planted at both locations across years. At irrigated locations, 5 in. and 7.9 in. of supplemental water was supplied in 2021 and 2022 growing seasons, respectively, using a Micro-rain traveling irrigator (Micro Rain, Yukon, OK). Grain yield was harvested from middle two from each plot using a Kincaid 8xp small plot combine (Kincaid Equipment Manufacturing, Haven, KS) and adjusted to 13.5% moisture on 20 October 2021 and 5 October 2022.

A partial budget was used to calculate net economic return by subtracting fertilizer input cost from gross revenue (i.e., grain price multiplied by yield). Input cost included fertilizer and application costs obtained from local retail grain elevators and Michigan State University Extension Custom Machine and Work Rate Estimates. Application costs were US$2.98, $6.18, and $11.30 A^{-1} for subsurface 2x2 nutrient application, PPI broadcast application and incorporation, and surface banding, respectively (Farm Business Team, MSU, 2021). Fertilizer 2021 input costs were US$61.85, $74.78 $64.56, and $70.11 A^{-1} and in 2022 were US$104.60, $117.71 $124.97, and $131.11 A^{-1} for dry 2x2, liquid 2x2, PPI N, and V4/R2 N, respectively. Economic return was estimated by subtracting fertilizer and application cost from local cash prices of $12.02 and $13.24 Bu^{-1} in 2021 and 2022, respectively. Data were analyzed using SAS 9.4 (SAS Institute, 2012) using the GLIMMIX procedure at $\alpha=0.10$.

PRELIMINARY RESULTS AND DISCUSSION

April and May 2021 precipitation was 58% and 77% below the 30-year mean with above average totals for the remainder of the growing season. High volume 24-hour rain events in late June and early July accounted for much of the above average rainfall. Under irrigation, 5 in. of supplemental water was provided to maintain field capacity. Growing degree day (GDD, base temp 50ºF) totals 28 days after April and May plant timings were 204 and 515, respectively. Soil temperatures did not permanently remain > 50ºF until 13 May. June and July 2022 precipitation was 56% and 40% below the 30-year mean, respectively. Soil temperatures remained >50ºF after 8 May, with 28 DAP GDD totals following April and May planting reaching 291 and 445, respectively. Supplemental irrigation provided 7.9 in of additional water at the 2022 irrigated location.

Irrigated 2021 results indicated no significant interactions between planting date and fertilizer strategy. April planting averaged 82.3 bu A^{-1} as compared to 78.0 bu A^{-1} for the May planting (Table 1). Yield data agreed with the Nelson (2021) observation of a four bushel per acre increase in April planted soybeans as compared to May. Biomass accumulation at V4, R2, and R8 was significantly greater with April as compared to May planting (Table 2). Although NDFA concentration was not impacted by planting date at R2 or R6 under irrigation, planting date and fertilizer strategy interacted to impact R2 NDFA at the non-irrigated location (Table 4). Nitrogen derived from atmosphere at R6 was influenced by fertilizer strategy at both locations with PPI and V4 N applications generating less N from BNF than liquid 2x2, dry 2x2, R2 N, and untreated treatments (Table 3). Relative abundance of ureides (data not shown) at R6 indicated total N accumulation in soybean plants was only reduced 1 to 4% across fertilizer strategies in the current study. At the non-irrigated 2021 location, April planted soybean averaged 72.8 bu A^{-1} as compared to 69.8 bu A^{-1} with the May planting date. Neither planting date or fertilizer strategy influenced grain yield (Table 1).

Non-irrigated 2022 grain yield was not influenced by planting date or fertilizer strategy. Grain yield decreased 9.32 and 8.64 bu A^{-1} for April and May planting dates, respectively, from non-irrigated in 2021. Grain yield reductions in 2022 were likely caused by a lack of moisture from June to mid-August which influenced the developmental (V4-R1) and grain fill (R4-R7) periods. Irrigated 2022 grain yields were affected by fertilizer strategy. Nitrogen application PPI was significantly greater than untreated indicating N supply via BNF may not have been sufficient for achieving maximum yield. Pending 2022 ^{15}N analysis data will help quantify the level to which BNF may have been impacted by early season N application.

In 2021, neither liquid or dry 2x2 starter fertilizer reduced nodulation at R4 or contributions from BNF at R2 or R6 at either location. The opposite occurred with PPI N applications at both locations where BNF contributions were reduced (Table 3). Starter fertilizer at 25 lb. N A^{-1} band applied did not appear to have a negative impact on N accumulation and may serve as a tool for reducing the “lag phase” of soybean nutrient uptake. In the above critical P and K concentration environments tested, data suggest that pre-plant and in season V4 N fertilizer applications may negatively impact biological N fixation without consistent changes in grain yield.

Table 1. Grain yield in bushels per acre of irrigated and non-irrigated soybeans, 2021 and 2022, Lansing, MI.

Site	Treatment	Irrigated 2021	Irrigated 2022	Non-irrigated 2021	Non-irrigated 2022
Irrigated	Planting Date	Bushel A^{-1}			
	April	82.3 a†	69.2 a	72.8 a	63.5 a
	May	78.0 b	68.3 a	69.8 a	61.2 a
	P > F	**0.07**	**0.81**	**0.19**	**0.55**
	Fertilizer				
	None	79.1 a	64.7 bc	72.6 a	61.3 a
	Dry 2x2	81.5 a	68.6 abc	75.7 a	64.5 a
	Liquid 2x2	78.1 a	64.1 c	70.7 a	61.4 a
	PPI N	82.2 a	72.8 a	68.9 a	63.0 a
	V4 N	78.4 a	71.0 abc	70.4 a	61.2 a
	R2 N	81.5 a	71.2 ab	69.5 a	62.5 a
	P > F	**0.18**	**< 0.01**	**0.20**	**0.90**

† Values followed by the same lowercase letter in the same column are not significantly different at α=0.1.

Table 2. Biomass accumulation at growth stages V4, R2 and R8 of irrigated 2021 soybeans.

Site	Treatment	V4 Biomass	R2 Biomass	R8 Biomass
Irrigated	Planting Date	lb A^{-1}		
2021	April 23	255 a†	1652 a	8830 a
	May 17	158 b	1242 b	6381 b
	P > F	**0.02**	**0.09**	**0.05**
	Fertilizer			
	None	178 b	1096 b	7372 a
	Dry 2x2	257 a	1633 a	7189 a
	Liquid 2x2	206 ab	1622 a	7290 a
	PPI N	185 ab	1518 ab	8527 a
	V4 N	-- ‡	1366 ab	8211 a
	R2 N	--	--	7045 a
	P > F	**0.09**	**0.04**	**0.82**

† Values followed by the same lowercase letter in the same column are not significantly different at α=0.1.

‡ Treatment not in effect at time of sampling.

Table 3. Nodule count and percentage of nitrogen derived from atmosphere at R2 and R6 of irrigated and non-irrigated soybeans, Lansing, MI, 2021.

Site	Treatment	Nodules $Plant^{-1}$	% NDFA R2	% NDFA R6
Irrigated 21'	Planting Date			
	April 23	94 a†	25.13 a	56.57 a
	May 17	73 b	19.78 a	55.02 a
	P > F	**0.09**	**0.25**	**0.59**
	Fertilizer			
	None	86 a	28.30 a	57.67 a
	Dry 2x2	93 a	28.39 a	60.32 a
	Liquid 2x2	88 a	25.64 a	57.77 a
	PPI N	73 a	13.50 b	50.13 b
	V4 N	72 a	16.44 b	48.36 b
	R2 N	89 a	-- ‡	60.53 a
	P > F	**0.53**	**<0.001**	**<0.001**
Non-Irrigated 21'	Planting Date			
	April 23	88 a	§	36.73 a
	May 17	56 b		36.10 a
	P > F	**0.03**		**0.77**
	Fertilizer			
	None	94 a		41.40 a
	Dry 2x2	76 ab		47.94 a
	Liquid 2x2	69 ab		48.32 a
	PPI N	59 b		12.68 b
	V4 N	70 ab		19.68 b
	R2 N	65 ab		48.58 a
	P > F	**0.07**		**<0.001**

† Values followed by the same lowercase letter in the same column from the same site are not significantly different at α=0.1.
‡ Treatment not in effect at time of sampling.
§ See Table 3 for non-irrigated % NDFA R2 interaction.

Table 4. Interaction of planting date and fertilizer strategy on percentage of nitrogen derived from atmosphere at R2 of non-irrigated soybeans, Lansing, MI, 2021.

Site	Fertilizer	Planting Date		***P > F***
		23-Apr	17-May	
Non-irrigated 21’		%		
	None	37.53 a†A‡	30.86 aA	**0.3**
	Dry 2x2	31.20 aBA	37.70 aA	**0.31**
	Liquid 2x2	35.40 aA	39.47 aA	**0.52**
	PPI N	22.69 aB	7.50 bB	**0.05**
	V4 N	24.33 aB	34.31 aA	**0.12**
	R2 N	--*	--	**--**
	P > F	**0.044**	**<0.0015**	

* Treatment not in effect at time of sampling.
† Means in the same row followed by the same lowercase letter are not significantly different at α=0.10.
‡Means in the same column followed by the same uppercase letter are not significantly different at α=0.10.

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