AGRONOMIC MANAGEMENT OF SOYBEAN WITH FOLIAR MANGANESE AND APICAL MERISTEM ALTERATIONS

BY

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THESIS

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ABSTRACT

About half of soybean [*Glycine max* (L.) Merr.] yield is attributed to genetic improvements of 12.5 kg ha^{-1} per year (Specht and Williams, 1984) with the remaining half of soybean yield being dependent upon environment, agronomic management, and the interaction of genetics and management (Rowntree et al., 2013). Many farmers have overlooked the importance of incorporating management practices into their soybean production system, which indicates they may be missing half of the potential yield of soybeans. Therefore, our objective was to quantify the impact of different agronomic management practices on soybean productivity. One study was conducted in 2014 and 2015 to determine the value of the foliar application of two different foliar manganese products to relieve “yellow flashing” in glyphosate resistant soybeans sprayed with the herbicide glyphosate. Foliar manganese applied 24 hours prior to glyphosate applications led to the greatest increase in plant manganese concentration. Although applications of either manganese formula increased plant manganese concentration, they did not result in a consistent impact on total biomass, plant chlorophyll, or final yield; however, chlorophyll measurements as well as visual observation did not indicate “yellow flashing” in either year. A second experiment in 2015 evaluated alternative practices to break apical dominance in soybean in order to facilitate plant branching or create multiple new main stems to potentially increase yield. Practices to eliminate the plant apical meristem included applying the herbicide Cobra (2-ethoxy-1-methyl-2-oxoethyl-5-[2-chloro-4-(trifluoromethyl)-phenoxy]-2-nitrobenzoate) to cause a chemical burn, as well as decapitation back to the unifoliate or first trifoliate nodes. Plant population (80,000 vs 160,000 plants $acre^{-1}$) was also a factor in this study as soybean plants tend to naturally branch more at lower populations. All apical meristem removal treatments resulted in a significant yield decrease, with greater penalties occurring at the lower plant population (80,000 plants per acre). Collectively, these findings emphasize the importance of providing the soybean plant a stress-free growing season to maximize yield.

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CHAPTER 1: ELIMINATING GLYPHOSATE 'FLASH' IN SOYBEAN WITH ENHANCED MANGANESE MANAGEMENT

ABSTRACT

The use of glyphosate resistant soybeans [*Glycine max* (L.) Merr.] has increased with the widespread intensive use of the herbicide glyphosate. Because of the broad spectrum of weed control of glyphosate, farmers have intensively used the herbicide, and occasionally soybean plant injury has occurred. Glyphosate or "yellow flash" occurs when glyphosate resistant soybeans are sprayed with a high rate of glyphosate herbicide. The "flashing" can be identified as chlorosis or yellowing in new plant growth and is typically seen where overlap of the sprayer boom occurs. In these areas of excessive glyphosate application, it is thought that the glyphosate herbicide chelates manganese in the plant, keeping it from moving to new plant growth. Manganese is important in the plant for photosynthesis, nitrogen metabolism, and nitrogen assimilation. By applying manganese in addition to the glyphosate herbicide, applicators hope to relieve any possibility of tying up manganese in the plant. In this study, we tested two different manganese sources, mixed with glyphosate, as well as seeing if one source, GR-MNC14, applied 24 hours before the glyphosate could alleviate yellow flashing and increase grain yield. All sources of manganese resulted in a higher concentration of manganese in the plant; however, when manganese was applied with the herbicide, there was no consistent impact on total biomass, plant chlorophyll, or final grain yield.

INTRODUCTION

Glyphosate (N-(phosphonomethyl) glycine) is a nonselective herbicide that controls a broad spectrum of plants. The mechanism of action of glyphosate is unique in that it only targets an enzyme called 5-enolpyruvylshikimate-3-phosphate synthesis (EPSPS) in the shikimate pathway found in plants and bacteria (Zobiole et al., 2010). Because of this mechanism, the herbicide is destructive to all plant species making it difficult to use in cropping systems (Franz et al., 1997). With the ability to alter plants through molecular biology, scientists have been able to introduce a glyphosate insensitive gene into crops; which has allowed farmers to effectively control weeds found in crop production fields (Dill, 2005). The first glyphosate resistant soybean was introduced in 1996 under the trade name Roundup Ready. The introduction of this product was very successful as within nine years after becoming commercially available, 87% of all soybeans grown in the United States were the glyphosate resistant type (Fernandez-Cornejo and Caswell, 2006).

With the introduction of glyphosate resistant crops, the use of the glyphosate herbicide increased in production agriculture. Although glyphosate resistant soybeans are insensitive to the herbicide, visual injury known as “yellow flashing” has occurred under certain conditions with different salt formulations of glyphosate (Reddy and Zablotowicz, 2003). Glyphosate is a phosphonic acid (Franz et al., 1997) as well as a strong metal ion chelator (Kabachnik et al., 1974; Glass, 1984; Coutinho and Mazo, 2005). With these qualities, the herbicide is known to reduce manganese concentrations in glyphosate resistant plants (Johal and Huber, 2009). Glyphosate also reduces the uptake and translocation of Mn in soybean plants (Huber, 2010).

Mn is an important micronutrient in plants as it is necessary for many biochemical processes. The nutrient plays a role in processes such as respiration, amino acid synthesis, lignin biosynthesis, and phytohormone levels; however, its most important role is in oxygen evolution in photosynthesis. Playing a major role in all photosynthetic organisms, Mn acts as a catalyst in the oxygen evolving reaction of photosystem II. Because photosynthesis is a vital process in providing photoassimilates and chemical energy to the plant, Mn deficiencies therefore affects plant growth, seed production, and other biochemical processes (Campbell and Nable, 1988).

Manganese deficiencies are commonly seen as interveinal chlorosis (Moraghan, 1985; Marschner and Rimmington, 1988), dark brown spots on leaves, and early senescence of older leaves (Campbell and Nable, 1988). Chlorosis symptoms are associated with the lack of chlorophyll concentration likely leading to a reduction in photosynthesis (Weiland et al., 1975). A study with tomatoes found that Mn deficiency resulted in reduced leaf thickness, smaller palisade cells that led to necrosis of cells, and xylem that became blocked by brown deposits (Eltinge, 1941). The consequences of Mn deficiency are dependent on the severity, and photosynthesis levels of manganese deficient plants can be quickly restored (approximately 24 hours later) when supplied with the nutrient (Campbell and Nable, 1988). The yield of legumes is highly dependent on the plant concentration of Mn as both deficiency and toxicity of Mn can result in decreased yield (Walton, 1978; Heenan and Campbell, 1980; Hannam et al., 1984; Mascagni and Cox, 1985). Reduction in yield results from fewer fertile nodes (and therefore seed-bearing pods) on a plant and decreased seed weight (Randall et al., 1975; Heenan and Campbell, 1980; Boswell et al., 1981; Gettier et al., 1985). When foliar Mn sulfate was applied to soybean plants deficient in Mn as late as at the prebloom stages, yield was similar to fertilizer banded with the seed at planting (Randall et al. 1975). Seed quality can also affected by moderate deficiencies of Mn, causing oil concentrations to decline from 21.4% to 17.4% (Wilson et al., 1982).

Manganese is the most available in the soil at pH levels between 5 and 6.5 as Mn^{+2}. At pH levels below 5, Mn is even more available often leading to excessive uptake and tissue toxicity. Soils high in organic matter can chelate Mn^{+2} making it unavailable to the plant. Once absorbed, manganese is immobile in the plant, causing any deficiency symptoms that develop under Mn-limited conditions to occur in the newest or youngest growth. Manganese fertilizer applications are suggested when soil test levels are less than 10 ppm, or when tissue concentrations are less than 20 ppm (Schulte and Kelling, 2004).

Due to the importance of manganese in soybean, the objective of this study was to evaluate preventative methods of minimizing glyphosate “flash” using supplemental foliar manganese nutrition and application timing technologies. To accomplish our objective, we used two different manganese sources and looked at the effects of applying manganese either combined or separated with glyphosate.

MATERIALS AND METHODS

Experimental design and site characteristic

The experiments were implemented during 2014 and 2015 in southern, central, and northern IL at Harrisburg, Champaign, and DeKalb, respectively. These locations were maintained weed-free with a pre-emergence herbicide application of Boundary (Syngenta, Greensboro, NC) at a rate of 2 pints $acre^{-1}$. The fields at all sites were level and well-drained, and well-suited to provide evenly distributed soil fertility, pH, soil organic matter, and water availability. Experimental plots were four rows wide and 36 ft in length with 30-inch row spacing. In 2014, plots were planted on 24 May at Harrisburg (Hurst- Reesville silty clay loam, 2.2% organic matter; 12.6 meq/100g CEC, 6.4 pH, 10 ppm P, 80 ppm K, 39 ppm Mn with Mehlich-3 extraction), 10 May at Champaign (Drummer- Flanagan silt loam, 4.0% organic matter; 21.0

meq/100g CEC, 6.4 pH, 45 ppm P, 179 ppm K, 44 ppm Mn), and 20 May at DeKalb (Drummer silt loam, 3.6% organic matter; 17.1 meq/100g CEC, 6.6 pH, 28 ppm P, 139 ppm K, 38 ppm Mn). Plots in 2015 were planted on 3 May at Harrisburg (Hurst- Reesville silty clay loam, 3.1% organic matter; 20.8 meq/100g CEC, 6.1 pH, 21 ppm P, 131 ppm K, and 20 ppm Mn with Mehlich-3 extraction), 23 May at Champaign (Drummer- Flanagan silt loam, 3.5% organic matter; 17.9 meq/100g CEC, 6.2 pH, 29 ppm P, 118 ppm K, and 34 ppm Mn), and 21 May at DeKalb (Drummer silt loam, 4.6% organic matter; 23.2 meq/100g CEC, 6.9 pH, 16 ppm P, 130 ppm K, and 21 ppm Mn). Soybean cultivars adopted for each region were used, namely FS 42A12 in Harrisburg, FS 39A42 and FS 31A32 in Champaign (as two separate trials, FS 31A32 was planted at Champaign only in 2015), and FS 31A32 in DeKalb. Corn was the previous crop and conventional tillage was used. Plots were arranged using an RCBD with six replications. Herbicide and manganese treatments were applied in-season at V3 and reapplied at V6 (Table 1.1). Touchdown (Syngenta, Greensboro, NC) was the glyphosate herbicide used in 2014 at a rate of 48 fl oz. acre^{-1}. Due to no visual “flashing” of soybeans in 2014, a different herbicide was used at a higher rate in 2015. RoundUp Powermax (Monsanto, St. Louis, MO) was the glyphosate herbicide used for this experiment at a rate of 64 fl oz. acre^{-1}. The control treatment received an application of glyphosate at both V3 and V6. In this study, two different manganese sources supplied by Goëmar Laboratories (Saint Malo, Bretagne, France) were tested; the Standard Mn source being manganese chloride. Interactions of manganese and glyphosate were evaluated by applying the Mn source, GR-MNC14, tank mixed with the glyphosate or 24 hours before glyphosate applications were made. In both years, manganese products were applied at a rate of 1.5 pints acre^{-1} which was recommended by Goëmar Laboratories. Treatments were applied with a CO_2 pressurized backpack sprayer with an output of 15 gallons acre^{-1}.

Measured parameters

Biomass sampling for nutrient analysis was conducted at approximately 20 days after the V6 treatment application at each of the locations (approximately the R1 growth stage). One meter of plants were sampled from each plot; sampled plant tissues were dried, weighed, and ground for analysis of N, P, K, and Mn (only P, K and Mn in 2015) by A & L Great Lake Laboratories, Fort Wayne, IN. Total biomass is presented on a dry weight basis (0% moisture concentration). Nutrient accumulation was algebraically derived using total plant biomass and tissue nutrient concentration. At the growth stage R5, five representative plants per plot were selected for yield component assessments. The number of pods and beans on each plant were counted and used for determination of beans pod^{-1}. Crop vigor and chlorophyll (greenness) measurements were conducted using a SPAD502 plus meter (Spectrum Technologies, Aurora, IL) at approximately 7 days after both the V3 and V6 applications. Chlorophyll measurements were obtained from the middle leaf of the uppermost, fully expanded trifoliate averaged over six plants per plot. Crop vigor evaluations used a 1 to 10 scale with 1 being less vigorous and 10 being most vigorous, based on a visual assessment of overall crop greenness, stem and leaf health, and crop growth.

The center two rows of each plot were mechanically harvested at maturity for measurement of grain yield. Harvest in 2014 was on 12 October at Harrisburg, 5 October at Champaign, and 20 October at DeKalb. In 2015, plots were harvested on 2 October at Harrisburg, 1 October (31A32) and 27 October (39A42) at Champaign, and 16 October at DeKalb. Subsamples of harvested grain were analyzed for grain quality (protein and oil) by NIT using a Foss Infratec 1241 grain analyzer (Eden Prairie, WI). Subsamples of harvested grain were also used to determine individual seed weight based on a representative sub-sample of 300 seeds. Seed number on a per-area basis was calculated algebraically by dividing total grain weight by individual seed weight.

Statistical Analysis

Data were analyzed in PROC MIXED with treatment and location in the model set as fixed effects and replication nested within location as a random effect using SAS software. Because of the change in herbicide source and rate in 2015, years were analyzed separately. PROC UNIVARIATE was used to assess normality of the residuals and for removal of outliers. LSD values were determined using the PDIFF macro using α=0.10 probability level.

RESULTS

2014 Evaluation

Although not statistically significant, the GR-MNC14 treatments tended to increase the number of pods by as much as 1.9 pods per plant when averaged across all locations (Table 1.2). Applying Mn in combination with glyphosate (standard Mn or GR-MNC14 combined with glyphosate) was especially effective at Champaign resulting in a 14% increase in pod number and an 11% increase in seed number compared to the control, although these differences were not statistically significant (Table 1.2). The absence of any visual glyphosate flashing may have limited the response to the Mn treatments (Table 1.2).

Nutrient accumulation of nitrogen, phosphorus, and potassium in the plants at the R1 growth stage was not affected by the Mn applications (Table 1.3). Conversely, significant increases in manganese uptake occurred at Champaign and DeKalb, and when averaged across all three locations when GR-MNC14 was the source applied separately from the herbicide (Table 1.3). The standard Mn product only increased Mn accumulation at DeKalb, and GR-MNC14 applied with the herbicide only increased Mn accumulation at Champaign (Table 1.3). All treatments at Harrisburg numerically increased the manganese content of plants; however, this increase was not significant, nor did it lead to significant yield improvements (Tables 1.3 and 1.5).

Crop vigor and chlorophyll greenness at approximately seven days after application revealed that plants were not damaged by any of the manganese products (Table 1.4). At Harrisburg, there was an approximate 9% increase in the V6 plus 7 days SPAD values associated with GR-MNC14 applied with glyphosate, though it did not result in greater biomass, pod counts, or yield (Tables 1.2 and 1.5).

Yield, yield components, and grain quality were primarily influenced by differences in location as opposed to treatment applications (Table 1.5). When averaged across all locations, remedial measures of supplying Mn to eliminate glyphosate flash did not increase or decrease yield. The most notable yield increase trend of 3.9 bushel acre^{-1} with GR-MNC14 applied separately from glyphosate at Champaign was associated with a significant increase in seed number (+ 5%; Table 1.5). There was also a non-significant yield response of 3.5 bushel acre^{-1} associated with the GR-MNC14 applied concurrently with glyphosate (applied at V3 and V6) at DeKalb (Table 1.5). Applying GR-MMNC14 combined with glyphosate increased seed oil concentration at all three locations and usually decreased protein levels.

2015 Evaluation

In 2015, Mn and glyphosate did not significantly impact pod and bean number or R1 biomass (Table 1.6). There were, however, significant location effects and an interaction of treatment and location effects on seeds pod^{-1}, which was most likely due to the fluctuation of pod number and seed number at each location (Table 1.6). For example, at Harrisburg, the GR-MNC14 applied separately from the herbicide tended to cause a 4.3 pod plant^{-1} increase with a concommitment decrease in seed plant^{-1} (Table 1.6). Yield is a combination of pod number, seeds pod^{-1}, and seed weight, so while applying GR-MNC14 separately from glyphosate tended to increase the pod number, the plants compensated by decreasing seed number pod^{-1}. Mn applications did not have an effect on biomass at R1 (Table 1.6).

All manganese applications tended to decrease P_2O_5 and K_2O accumulation at the R1 growth stage at DeKalb (Table 1.7). As expected, manganese applications usually increased Mn accumulation, with the amount of increase affected by the variety in Champaign and by the location. An evaluation of crop vigor and greenness at approximately seven days after each application showed that after two applications of manganese and glyphosate, plants had lower SPAD values when GR-MNC14 was applied separately from glyphosate at Harrisburg, and when GR-MNC14 was combined with glyphosate at DeKalb (Table 1.8).

At Champaign, the GR-MNC14 applied separately from the herbicide significantly increased yield by 2.9 to 4 bushel acre^{-1} depending on variety (Table 1.9). At Harrisburg, there was no effect of any Mn treatment on yield; while at DeKalb all treatments numerically decreased yield, with the GR-MNC14 applied separately from the herbicide causing a significant yield decrease of 3.6 bushel acre^{-1} (Table 1.9). The yield increases at Champaign were primarily due to an increase in seed number (Table 1.9), with the shorter season variety (31A32) also exhibiting an increase in seed weight from GR-MNC14 either combined with or separated from the glyphosate (Table 1.9). In contrast to 2014, the impact from treatments on grain quality was minimal at all locations, although when a treatment increased yield, grain protein concentration tended to decrease (Table 1.9).

DISCUSSION

Although many growers and crop consultants believe that foliar Mn applications are helpful in alleviating glyphosate-induced “yellow flashing”, there are not many consistent results supporting this practice. There are, however, a number of published reports on the use of foliar (and soil-applied) Mn to increase Mn status and grain yield; although similar to our findings, the results of these studies are inconsistent. Results from a study evaluating Mn applications across nine locations in 2013 and seven locations in 2014 found variable responses to foliar Mn application with positive yet not significant responses occurring only 50% of the time (Bluck et al., 2015). Although manganese did not have an effect on yield in our study, yield increases have been seen in previous studies evaluating the effects of manganese in glyphosate resistant soybeans. Previous work by Gordon (2006) and Huber (2007) have shown that the application of supplemental Mn increased yield by 13 to 18 bushel acre^{-1} which are drastic increases compared to the findings in our study. Randall et al. (1975) evaluated broadcast, starter, and foliar applications of MnEDTA on soybean. In this study, they found that all methods of Mn application resulted in higher concentrations of Mn in the plant which is what we would have expected with each of the Mn products in our study; however, both sources did not consistently increase Mn accumulation at all locations.

CONCLUSIONS

Although no visual “yellowing flashing” occurred in 2014 or 2015, manganese tended to have a positive impact on yield components, nutrient uptake, plant greenness, and yield; however, results from the manganese treatments were fairly inconsistent and not always significant. It is possible that plants did not experience manganese deficiency due to sufficient soil manganese levels as well as foliar manganese applications.

TABLES AND FIGURES

Table 1.1. Treatments used for the evaluation of Mn and glyphosate interactions at Harrisburg, Champaign, and DeKalb, IL in 2014 and 2015. Treatment applications were made at both the V3 and V6 soybean growth stages. In 2014, a glyphosate rate of 48 fl oz acre^{-1} was applied through the use of Touchdown (Syngenta, Greensboro, NC) at both V3 and V6. In 2015, a different glyphosate product was used (RoundUp Powermax; Monsanto, St. Louis, MO), and the rate was increased to 64 fl oz acre^{-1}.

Mn Treatment	**Mn Rate**	**Mn Application†**
	pt acre^{-1}	Timing
Glyphosate Only	0	.
Standard Mn	1.5	Applied with glyphosate
GR-MNC14	1.5	Applied with glyphosate
GR-MNC14	1.5	Glyphosate applied 24 hrs after GR-MNC14

† A symbol of '.' indicates the absence of that practice for the corresponding treatment.

Table 1.2. Effect of Mn and glyphosate treatments on physiological yield components at the R5 growth stage and soybean biomass at the R1 growth stage in 2014 at three locations. Biomass is reported on a dry weight basis (0% moisture concentration). Glyphosate was applied at a rate of 48 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

Treatment	**Pods**	**Seeds**	**Seed Pod^{-1}**	**R1 Biomass**
	pods plant^{-1}	seed plant^{-1}	seed pod^{-1}	lbs acre^{-1}
		Average Across Locations		
Glyphosate Only	47.4	120	2.5	3773
Standard Mn-Combined	49.7	125	2.5	3814
GR-MNC14-Combined	49.3	123	2.5	3743
GR-MNC14-Separated	47.1	118	2.5	3790
LSD (α=0.10)	NS	NS	NS	NS
		Harrisburg, IL		
Glyphosate Only	52.0	132	2.5	2983
Standard Mn-Combined	52.3	133	2.5	3034
GR-MNC14-Combined	50.5	131	2.6	3038
GR-MNC14-Separated	50.3	129	2.6	3083
LSD (α=0.10)	NS	NS	0.1	NS
		Champaign, IL		
Glyphosate Only	41.4	111	2.7	4859
Standard Mn-Combined	47.0	123	2.6	4793
GR-MNC14-Combined	47.1	122	2.6	4619
GR-MNC14-Separated	41.3	112	2.7	4639
LSD (α=0.10)	NS	NS	0.1	NS
		DeKalb, IL		
Glyphosate Only	48.9	117	2.4	3477
Standard Mn-Combined	49.9	119	2.4	3615
GR-MNC14-Combined	50.1	116	2.4	3572
GR-MNC14-Separated	49.8	114	2.3	3649
LSD (α=0.10)	NS	NS	0.1	NS
Source of Variation		***P* > *F***		
Treatment (T)	0.4002	0.5563	0.8223	0.9266
Location (L)	0.1616	0.1621	0.0541	<0.0001
T x L	0.6467	0.9567	0.1900	0.7843

Table 1.3. Effect of Mn treatments on nutrient uptake at R1 of N, P, K, and Mn in 2014 at three locations. Glyphosate was applied at a rate of 48 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

Treatment	**N**	**P_2O_5**	**K_2O**	**Mn**
	lbs acre^{-1}			oz acre^{-1}
		Average Across Locations		
Glyphosate Only	125.1	27.5	114.2	2.2
Standard Mn-Combined	124.2	28.2	118.7	2.4
GR-MNC14-Combined	133.2	28.5	113.2	2.5
GR-MNC14-Separated	122.6	28.1	113.7	2.8
LSD (α=0.10)	NS	NS	NS	0.4
		Harrisburg, IL		
Glyphosate Only	85.8	20.0	86.7	1.3
Standard Mn-Combined	90.1	19.7	90.8	1.6
GR-MNC14-Combined	101.3	20.6	90.7	1.7
GR-MNC14-Separated	75.6	19.7	92.8	1.8
LSD (α=0.10)	NS	NS	NS	NS
		Champaign, IL		
Glyphosate Only	178.4	38.9	148.3	3.2
Standard Mn-Combined	158.6	38.2	156.9	2.9
GR-MNC14-Combined	187.4	41.4	144.6	3.5
GR-MNC14-Separated	173.5	39.4	138.9	3.8
LSD (α=0.10)	NS	NS	NS	0.6
		DeKalb, IL		
Glyphosate Only	111.3	23.5	107.6	2.0
Standard Mn-Combined	124.0	26.7	108.5	2.8
GR-MNC14-Combined	110.8	23.5	104.2	2.4
GR-MNC14-Separated	118.7	25.0	109.4	2.7
LSD (α=0.10)	NS	NS	NS	0.6
Source of Variation		***P > F***		
Treatment (T)	0.8228	0.9078	0.7374	0.0674
Location (L)	<0.0001	<0.0001	<0.0001	<0.0001
T x L	0.7859	0.7174	0.7763	0.4587

Table 1.4. Effect of Mn treatments on plant chlorophyll and vigor assessments in 2014 at 7 days after treatment application for three locations. The crop vigor measurements used a 1 to 10 scale with 1 being less vigorous and 10 being most vigorous. Glyphosate was applied at a rate of 48 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

	Chlorophyll		**Vigor**	
Treatment	**V3+7d**	**V6+7d**	**V3+7d**	**V6+7d**
	SPAD relative units		relative scale	
		Average Across Locations		
Glyphosate Only	30.6	30.6	8.8	9.5
Standard Mn-Combined	31.1	31.9	8.4	9.4
GR-MNC14-Combined	31.0	31.4	8.4	9.5
GR-MNC14-Separated	30.4	30.7	8.6	9.5
LSD (α=0.10)	NS	0.8	NS	NS
		Harrisburg, IL		
Glyphosate Only	31.0	30.4	9.3	10.0
Standard Mn-Combined	31.3	32.9	8.5	10.0
GR-MNC14-Combined	30.7	33.0	8.5	10.0
GR-MNC14-Separated	29.6	31.0	8.3	10.0
LSD (α=0.10)	NS	1.2	0.8	NS
		Champaign, IL		
Glyphosate Only	31.0	31.4	8.7	10.0
Standard Mn-Combined	32.3	32.4	8.7	10.0
GR-MNC14-Combined	31.8	30.4	8.8	10.0
GR-MNC14-Separated	31.6	31.1	9.5	10.0
LSD (α=0.10)	NS	NS	NS	NS
		DeKalb, IL		
Glyphosate Only	29.8	29.9	8.5	8.5
Standard Mn-Combined	29.8	30.4	8.0	8.3
GR-MNC14-Combined	30.3	30.7	8.0	8.5
GR-MNC14-Separated	30.1	30.0	8.0	8.4
LSD (α=0.10)	NS	NS	NS	NS
Source of Variation		***P > F***		
Treatment (T)	0.3756	0.0197	0.3241	0.9268
Location (L)	0.1230	0.0019	0.0749	<0.0001
T x L	0.4008	0.0358	0.1957	0.9875

Table 1.5. Effect of Mn treatments on grain yield, yield component, and grain quality in 2014. Grain yield is presented in bushel acre^{-1} at 13% moisture concentration and seed weight in mg seed at 0% moisture concentration. Glyphosate was applied at a rate of 48 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

Treatment	**Yield**	**Seed Weight**	**Seed Number**	**Protein**	**Oil**
	bu acre^{-1}	mg seed^{-1}	seed m^{-2}	%	%
			Average Across Locations		
Glyphosate Only	71.8	173.0	2303	35.7	18.8
Standard Mn-Combined	72.5	171.9	2361	35.6	19.0
GR-MNC14-Combined	72.8	173.0	2358	35.4	19.0
GR-MNC14-Separated	72.3	174.5	2327	35.6	18.8
LSD (α=0.10)	NS	NS	53	0.1	0.1
			Harrisburg, IL		
Glyphosate Only	66.1	156.2	2294	35.3	19.7
Standard Mn-Combined	65.6	156.4	2351	35.3	19.7
GR-MNC14-Combined	66.1	157.0	2356	35.0	19.9
GR-MNC14-Separated	64.2	158.7	2261	35.2	19.7
LSD (α=0.10)	NS	NS	NS	0.2	0.1
			Champaign, IL		
Glyphosate Only	78.3	196.0	2239	35.1	19.6
Standard Mn-Combined	80.9	194.0	2332	34.8	19.8
GR-MNC14-Combined	78.0	193.1	2258	34.8	19.8
GR-MNC14-Separated	82.2	195.6	2349	34.9	19.7
LSD (α=0.10)	NS	NS	91	0.2	0.1
			DeKalb, IL		
Glyphosate Only	70.8	166.8	2374	36.6	17.1
Standard Mn-Combined	71.0	165.2	2400	36.7	17.1
GR-MNC14-Combined	74.3	168.8	2460	36.5	17.3
GR-MNC14-Separated	70.6	169.1	2372	36.8	17.1
LSD (α=0.10)	NS	NS	NS	0.2	0.1
Source of Variation			***P* > *F***		
Treatment (T)	0.8593	0.3898	0.2284	0.0090	0.0145
Location (L)	<0.0001	<0.0001	0.0650	<0.0001	<0.0001
T x L	0.1481	0.7669	0.1936	0.1271	0.3607

Table 1.6. Effect of Mn treatments on physiological yield components and soybean biomass at the R1 growth stage in 2015. Biomass is reported on a dry weight basis (0% moisture concentration). Glyphosate was applied at a rate of 64 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

Treatment	**Pods**	**Seeds**	**Seed Pod^{-1}**	**R1 Biomass**
	pods plant^{-1}	seed plant^{-1}	seed pod^{-1}	lbs acre^{-1}
		Average Across Locations		
Glyphosate Only	42.9	109	2.5	4046
Standard Mn-Combined	42.7	108	2.5	3924
GR-MNC14-Combined	41.8	104	2.5	3954
GR-MNC14-Separated	41.7	105	2.5	4017
LSD (α=0.10)	NS	NS	NS	NS
		Harrisburg, IL		
Glyphosate Only	47.5	131	2.7	4595
Standard Mn-Combined	48.2	124	2.6	4437
GR-MNC14-Combined	48.3	124	2.6	4701
GR-MNC14-Separated	51.8	129	2.5	4601
LSD (α=0.10)	NS	NS	0.1	NS
		Champaign, IL (39A42)		
Glyphosate Only	46.7	108	2.3	2974
Standard Mn-Combined	46.9	116	2.4	3128
GR-MNC14-Combined	44.1	104	2.3	2927
GR-MNC14-Separated	44.8	111	2.5	3107
LSD (α=0.10)	NS	NS	0.1	NS
		Champaign, IL (31A32)		
Glyphosate Only	44.8	115	2.5	2890
Standard Mn-Combined	39.8	99	2.5	2891
GR-MNC14-Combined	41.7	103	2.6	2665
GR-MNC14-Separated	38.9	98	2.5	2838
LSD (α=0.10)	NS	NS	0.1	NS
		DeKalb, IL		
Glyphosate Only	32.6	82	2.5	5725
Standard Mn-Combined	36.2	95	2.6	5238
GR-MNC14-Combined	32.9	82	2.5	5526
GR-MNC14-Separated	31.2	83	2.7	5524
LSD (α=0.10)	NS	NS	0.1	NS
Source of Variation		***P > F***		
Treatment (T)	0.7993	0.4160	0.3922	0.7309
Location (L)	<0.0001	0.0004	0.0014	<0.0001
T x L	0.4250	0.2638	0.0007	0.7217

Table 1.7. Effect of Mn treatments on nutrient uptake at R1 of P, K, and Mn averaged across all locations in 2015. Glyphosate was applied at a rate of 64 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

Treatment	**P_2O_5**	**K_2O**	**Mn**
	lbs acre^{-1}	lbs acre^{-1}	oz acre^{-1}
		Average Across Locations	
Glyphosate Only	27.5	127.2	2.6
Standard Mn-Combined	26.4	119.3	2.9
GR-MNC14-Combined	24.6	117.6	2.8
GR-MNC14-Separated	25.8	124.9	2.9
LSD (α=0.10)	1.6	8.8	0.3
		Harrisburg, IL	
Glyphosate Only	36.7	167.2	1.9
Standard Mn-Combined	34.7	167.2	2.6
GR-MNC14-Combined	34.3	166.1	2.6
GR-MNC14-Separated	35.5	174.7	2.0
LSD (α=0.10)	NS	NS	NS
		Champaign, IL (39A42)	
Glyphosate Only	23.3	106.5	2.9
Standard Mn-Combined	27.4	112.6	3.6
GR-MNC14-Combined	21.6	102.4	3.5
GR-MNC14-Separated	24.8	116.4	4.1
LSD (α=0.10)	3.0	NS	0.5
		Champaign, IL (31A32)	
Glyphosate Only	22.4	93.9	2.9
Standard Mn-Combined	20.3	88.4	3.0
GR-MNC14-Combined	20.4	93.0	3.0
GR-MNC14-Separated	21.2	96.9	3.1
LSD (α=0.10)	NS	NS	NS
		DeKalb, IL	
Glyphosate Only	27.5	141.2	2.2
Standard Mn-Combined	23.1	108.9	2.4
GR-MNC14-Combined	21.9	108.8	2.2
GR-MNC14-Separated	21.8	111.6	2.3
LSD (α=0.10)	3.4	18.9	NS
Source of Variation		***P > F***	
Treatment (T)	0.0293	0.2272	0.1884
Location (L)	<0.0001	<0.0001	<0.0001
T x L	0.0881	0.2579	0.1332

Table 1.8. Effect of Mn treatments on plant chlorophyll and vigor assessments in 2015. The crop vigor measurements were based off of a 1 to 10 scale with 1 being less vigorous and 10 being most vigorous. Glyphosate was applied at a rate of 64 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

	Chlorophyll		**Vigor**	
Treatment	**V3+7d**	**V6+7d**	**V3+7d**	**V6+7d**
	relative units		relative scale	
		Average Across Locations		
Glyphosate Only	36.1	40.3	10	10
Standard Mn-Combined	36.8	40.8	10	10
GR-MNC14-Combined	36.5	39.6	10	10
GR-MNC14-Separated	36.6	39.8	10	10
LSD (α=0.10)	NS	NS	NS	NS
		Harrisburg, IL		
Glyphosate Only	42.9	39.1	10	10
Standard Mn-Combined	42.9	41.5	10	10
GR-MNC14-Combined	42.5	39.1	10	10
GR-MNC14-Separated	43.3	36.4	10	10
LSD (α=0.10)	NS	1.5	NS	NS
		Champaign, IL (39A42)		
Glyphosate Only	32.4	37.7	10	10
Standard Mn-Combined	32.6	37.2	10	10
GR-MNC14-Combined	32.4	37.5	10	10
GR-MNC14-Separated	32.7	37.7	10	10
LSD (α=0.10)	NS	NS	NS	NS
		Champaign, IL (31A32)		
Glyphosate Only	36.1	39.8	10	10
Standard Mn-Combined	38.4	40.2	10	10
GR-MNC14-Combined	38.2	39.6	10	10
GR-MNC14-Separated	37.0	40.2	10	10
LSD (α=0.10)	NS	NS	NS	NS
		DeKalb, IL		
Glyphosate Only	33.2	44.7	10	10
Standard Mn-Combined	33.2	44.3	10	10
GR-MNC14-Combined	33.0	42.4	10	10
GR-MNC14-Separated	33.4	44.8	10	10
LSD (α=0.10)	NS	1.5	NS	NS
Source of Variation		***P* > *F***		
Treatment (T)	0.3742	0.0244	1.0	1.0
Location (L)	<0.0001	<0.0001	1.0	1.0
T x L	0.2014	0.0005	1.0	1.0

Table 1.9. Effect of Mn treatments on grain yield, yield component, and grain quality in 2015 season. Grain yield is presented in bushel acre^{-1} at 13% moisture concentration and seed weight in mg seed at 0% moisture concentration. Glyphosate was applied at a rate of 64 fl oz acre^{-1}, either combined with one of the two Mn sources or separated by 24 hours. Treatments were repeated at both the V3 and V6 stages. Values are the average of 6 replications.

Treatment	**Yield**	**Seed Weight**	**Seed Number**	**Protein**	**Oil**
	bu acre^{-1}	mg seed^{-1}	seed m^{-2}	———%———	
			Average Across Locations		
Glyphosate Only	63.8	137.0	2934	34.7	18.9
Standard Mn-Combined	64.0	136.4	2954	34.6	19.0
GR-MNC14-Combined	64.4	136.3	2970	34.7	19.0
GR-MNC14-Separated	64.6	138.7	2917	34.6	19.0
LSD (α=0.10)	NS	1.4	NS	NS	NS
			Harrisburg, IL		
Glyphosate Only	74.1	125.4	3563	34.5	20.1
Standard Mn-Combined	75.4	126.7	3608	34.4	20.1
GR-MNC14-Combined	74.7	125.8	3592	34.6	20.1
GR-MNC14-Separated	73.7	133.2	3352	34.9	20.0
LSD (α=0.10)	NS	3.2	139	0.3	NS
			Champaign, IL (39A42)		
Glyphosate Only	60.7	145.4	2703	35.5	18.6
Standard Mn-Combined	61.6	144.3	2762	35.3	18.7
GR-MNC14-Combined	61.8	143.6	2779	35.4	18.7
GR-MNC14-Separated	63.6	145.0	2835	35.1	18.8
LSD (α=0.10)	2.8	NS	111	0.3	NS
			Champaign, IL (31A32)		
Glyphosate Only	64.4	140.1	2803	34.2	19.1
Standard Mn-Combined	64.5	140.7	2797	34.2	19.1
GR-MNC14-Combined	65.9	141.5	2838	34.4	19.1
GR-MNC14-Separated	68.4	141.1	2951	34.1	19.2
LSD (α=0.10)	2.8	2.5	111	NS	NS
			DeKalb, IL		
Glyphosate Only	56.2	137.3	2666	34.6	17.9
Standard Mn-Combined	54.6	134.2	2649	34.7	18.1
GR-MNC14-Combined	55.1	134.4	2671	34.5	18.1
GR-MNC14-Separated	52.6	135.6	2532	34.4	18.0
LSD (α=0.10)	3.2	2.9	129	0.3	0.1
Source of Variation			***P* > *F***		
Treatment (T)	0.8537	0.0224	0.5075	0.6394	0.4178
Location (L)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T x L	0.1829	0.0211	0.0067	0.0216	0.0138

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CHAPTER 2: CAN SOYBEAN YIELD BE INCREASED BY INDUCING BRANCHING?

ABSTRACT

Soybean [*Glycine max* (L.) Merr.] plants are known for the ability to compensate for stresses such as hail damage, wildlife feeding, etc. through branching. The soybean's ability to branch is based on the plant's growth structure. Soybean plants have a single axillary bud at each node of the main stem where the trifoliate leaves are attached (i.e., where the leaf petiole is attached to the stem) and two axillary buds where the unifoliate leaves and the cotyledons are attached at the base of the plant. Dormancy occurs when the stem apex exhibits apical dominance and suppresses the transformation of axillary buds into branches or flowers. By removing the apical meristem, the axillary buds are released from apical dominance and can develop into new stems or branches. The goal of this research was to test that stress or removal of the apical meristem will promote branching or new stem development of soybean plants, effectively doubling the number of main branches, and as a result, the number of pods per plant and the final seed yield. Branching treatments consisted of a Cobra (2-ethoxy-1-methyl-2-oxoethyl-5-[2-chloro-4-(trifluoromethyl)-phenoxy]-2-nitrobenzoate) herbicide application (12.5 oz acre^{-1}), and low (leaving the unifoliate leaves) and high (leaving the first trifoliate leaf) levels of plant decapitation; achieved by hand cutting. Plant population (80,000 vs. 160,000 plant acre^{-1}) was also included as a treatment as soybean tends to compensate for lower population through increased branching. By stressing the soybean plant with branching treatments, yield was significantly reduced by 5 to 22 bushel acre^{-1} with greater penalties occurring at the lower plant population (80,000 plants per acre). Results show the importance of reducing stress to the soybean plant in early season vegetative stages.

INTRODUCTION

Apical dominance is a common occurrence in soybean. Axillary buds of the soybean plant can develop into a branch, flower, or remain dormant (Pedersen, 2009). The development of axillary buds is dependent on the production and translocation of indole-acetic acid (IAA) produced in the apical meristem of the plant. Phytohormones including cytokinins, gibberellic acid, and benzyladenine are known to break apical dominance. Inhibited axillary buds can also resume growth after loss of the apical meristem (Sorokin and Thimann, 1964; Ali and Fletcher, 1971). When apical dominance is released, branch development in soybean commonly occurs at the cotyledonary node before V2 and the unifoliate node after V2 (Ali and Fletcher, 1970).

Practices such as mowing, rolling, and herbicide application have been used on soybean in order to kill the apical meristem of the plant and as a result promote branching. Practices to promote branching became more popular due to its success in soybean yield contests where the use of the herbicide Cobra (Valent, Walnut Creek, CA) has become a common practice in attempts to increase soybean yields. Cobra is a protoporphyrinogen oxidase (PPO) inhibitor herbicide that, when applied to soybean, will kill the apical meristem of the soybean plant (Silverman et al., 2004). Cobra is a herbicide that causes damage to plant tissues on contact (Gunsolus and Curran, 2007). Injury is typically seen as bronzing of plant tissues leading to chlorosis followed by necrosis (Harris et al., 1991; Wichert and Talbert, 1993). This injury makes the herbicide effective at killing the apical meristem of soybean.

The soybean canopy can be divided into four canopy subsections: bottom (nodes 1 to 7), middle (nodes 8 to 14), top (nodes 15+), and branches (all pods derived from branches). While relieving apical dominance increases branching in soybean, soybean branches only contribute about 17.8% of yield, showing that yield is largely dependent on the main stem (82.2%) (Bender, 2015). Throughout the main stem, the soybean canopy varies in pod distribution with the majority of pods in the middle subsection (52%). Of the remaining pods, 14.3% come from the bottom subsection and 15.9% from the top (Bender, 2015). Since the main stem produces most of the yield in soybean, a primary focus for yield improvement is to increase the number of main stems rather than branches.

A typical soybean plant consists of one main stem with branches developing from the cotyledonary or unifoliate nodes. However, at these cotyledonary and unifoliate nodes the soybean plant has two opposite axillary buds that have the potential to develop into stems making it possible for the soybean plant to produce two main stems if the apical bud is damaged (Pederson, 2009). As the plant develops trifoliate nodes, axillary buds become alternate which would suggest that the plant would resume growth with one main stem. Because soybean plants can readily branch, they can overcome early stress by to the growth of these axillary buds.

Plant population is known to have a large effect on the branching of soybean. Research looking at effects of population on branching suggests that higher plant populations cause shading which reduces photosynthesis, ultimately resulting in a shortage of carbon that could be used for the production of branches (Acock and Acock, 1987). Work by Carpenter and Board (1997) found that at lower plant populations, branch pods accounted for 75-87% of the total yield, and branch dry matter increased by 162% when populations were decreased. When plant populations were increased, dry matter production per plant decreased by reducing the number of branches on the main stem (Enyi, 1973).

The goal of this research was to determine if soybean yield can be increased through manipulating the soybean plant’s ability to branch. Branching was induced through the application of the herbicide Cobra, as well as decapitation back to the unifoliate or first trifoliate nodes.

MATERIALS AND METHODS

Experimental design and site characteristic

The experiment was implemented in 2015 at Champaign, IL. This location has been maintained weed- and disease-free, is level and well-drained, and well-suited to provide evenly distributed soil fertility, pH, soil organic matter, and water availability (Drummer-Flanagan silt loam, 4.0% organic matter; 21.0 meq/100g CEC, 6.4 pH, 45 ppm P, 179 ppm K, 44 ppm Mn). Plots were four rows wide and 16 ft. in length with 30-inch row spacing. Plots were planted with a Croplan R2C3783 soybean variety on 23 May. Corn was the previous crop and conventional tillage was used. Treatments were arranged using an RCBD with six replications. Two populations of 80,000 and 160,000 plants acre^{-1} were evaluated. Soybean plants were induced to branch by cutting plants by hand or by spraying with Cobra (Valent, Walnut Creek, CA) at a rate of 12.5 fl oz on 21 June (V3 growth stage) (Table 2.1). To generate the low decapitation treatment, plants were cut directly above the unifoliate leaves, while the high decapitation treatment cut the stems above the first trifoliate. All plots received an application of fungicide and insecticide (Priaxor and Fastac; BASF, Raleigh, NC) at R3 on 20 July at labeled rates with a commercial spray applicator.

Measurements

At R6, five representative plants per plot were selected for yield component assessments. In addition to total pods and beans, branches per plant were enumerated as well as the positioning of the pods and beans on the main stem vs. the branches.

The center two rows of each plot were mechanically harvested at physiological maturity (27 October) for determination of grain yield. Subsamples of harvested grain were analyzed for grain quality (protein and oil) by NIT using a Foss Infratec 1241 grain analyzer (Eden Prairie, MN). Subsamples of harvested grain were further evaluated to determine yield components (individual seed weight and seed number) for each plot as described in Chapter 1.

Statistical Analysis

Data were analyzed in PROC MIXED with treatment and population in the model set as fixed effects and replication as a random effect using SAS software. PROC UNIVARIATE was used to assess normality of the residuals and for removal of outliers. LSD values were determined using the PDIFF macro using α=0.10 probability level.

RESULTS AND DISCUSSION

Weather Conditions

With below-average temperatures and above-average precipitation throughout much of the 2015 growing season, the crop experienced little weather-induced heat or moisture stress (Figure 2.1). Alternatively, the cool, wet conditions following implementation of the treatments potentially impeded the regrowth and branching response, as the ideal daytime temperature for soybean is 85^{o}F (Figure 2.1).

Branching, yield components, grain yield, and seed quality

Decapitation treatments were successful in creating new growth from axillary buds; with 100% of low decapitation resulting in two main stems that developed from the remaining opposite axillary buds, and the first trifoliate (high decapitation) resumed growth with one main stem from the alternating node at the first trifoliate (Figure 2.2). The Cobra treatment resulted in burning of the young leaves at V3 as was seen by Gunsolus and Curran (2007) (Figure 2.2). Contrary to our expectations, plants that received a decapitation treatment had fewer branches than the control or Cobra treatment (Table 2.2). With less interplant competition at 80,000 plants acre^{-1}, branch number per plant increased (+ 50 to 67%) compared to the higher population (Table 2.2) which was similar to reports published by Enyi (1973) and Carpenter and Board (1997). The decreased population greatly increased the total amount of pods by 47%, 48%, 36%, and 45% and total beans by 51%, 48%, 34%, and 48% for the control, Cobra, low, and high decapitation treatments, respectively (Table 2.2). Previously, Gregg et al. (2015) found that when Cobra was applied to soybean, branch pods and branch beans were not affected. Although the Cobra treatment did not alter branching, pods, or beans per plant, both decapitation treatments caused a decrease in pods and beans per plant when compared to the control (Table 2.2). Contrary to these findings, Orlowski (2015) found that when plants were treated with Cobra, or when the apical meristem was removed, the total number of pods per plant did not differ from the control. While neither the Cobra nor the decapitation treatments affected beans pod^{-1} (Table 2.2), the low decapitation at the low population decreased the number of branches, pods, and beans per plant (Table 2.2). Although not significant, all branching treatments at the higher population tended to decrease beans pod^{-1} (Table 2.2).

Similar to the control, the Cobra treatment tended to result in more pods and beans on the branches than the decapitation treatments (Table 2.3) which is most likely due to the decapitation treatments developing fewer branches for pods and beans to develop on than the control and Cobra treatments (Table 2.2). On the other hand, the decapitation treatments resulted in more pods and beans on the main stem of the plant than the control or Cobra- treated plants (Table 2.3). Alternatively, Orlowski (2105) found that Cobra applications increased the production of pods and beans on the main stem of the plant. When plants were grown at 50% of the high population (a reduction from 160,000 to 80,000 plants acre^{-1}), pod number per main stem increased by 19% for the control, 29% from Cobra, and 33% and 23% from the low and high decapitation treatments, with a corresponding increase in main stem beans of 19%, 29%, 31%, and 24%, respectively (Table 2.3).

Unfortunately, interfering with the natural growth of the soybean plant (Cobra application, low decapitation, and high decapitation) significantly reduced grain yields, by 5 to 23 bushel acre^{-1} (Table 2.4). The control treatment of the higher population resulted in a 7 bushel acre^{-1} increase in yield over the lower population which was associated with more seeds per land area and similar individual seed weight (Table 2.4). These results for early season Cobra application contradict the results found by Harris et al., 1991; Wichert and Talbert, 1993; Nelson et al., 2002; and Gregg et al., 2015 who reported that there were no yield differences between Cobra treated plants and non- Cobra treated plants. For the cutting treatments (low and high decapitation), yield was most likely decreased due to the reduction in beans produced by the plant (Table 2.4). At the lower population, the Cobra treatment caused a significant decrease in seed weight; however, seed number was comparable to that of the control (Table 2.4), possibly due to less overall plant damage with this technique. Population did not affect bean quality, and there was no interaction of population and bean quality. However, the cutting treatments resulted in higher protein concentration and lower oil concentration regardless of population, Table 2.4, which was also found by Orlowski (2015).

CONCLUSIONS

The goal of this research was to determine whether damage or removal of the apical meristem could promote branching or additional stem development of soybean plants.

Treatments were successful at removing the apical meristem; however, these treatments did not increase branch number when compared to the control. Additional stem development occurred in low decapitation treatments with 100% of the plants resulting in two main stems. All branching treatments resulted in a significant decrease in soybean yield. The lower plant population did cause plants to increase branch production; however, this branching was insufficient to result in yield increases. This study shows that damage to the apical meristems of soybean plants is potentially harmful and should not be used to increase yield in soybeans.

TABLES AND FIGURES

Table 2.1. Treatments designed to alter soybean branching at Champaign, IL in 2015.

Branching Treatment	**Plant Population**
	Plants acre^{-1}
Control	80,000
Cobra†	80,000
Low Decapitation	80,000
High Decapitation	80,000
Control	160,000
Cobra†	160,000
Low Decapitation	160,000
High Decapitation	160,000

† Applied at 12.5 fl oz acre^{-1}

All treatments were made at V3 growth stage.

Low decapitation consists of leaving only the unifoliate leaves on the plant.

High decapitation consists of leaving one trifoliate on the plant.

Table 2.2. Effect of branching treatments at V3 on branching and physiological yield components (pods, beans, and beans pod^{-1}) at two planting rates at Champaign, IL in 2015. Treatment and population were included in the ANOVA model as fixed effects and replication was added as a random effect.

Treatment	**Main Stems**	**Branches**	**Total Pods**	**Total Beans**	**Beans Pod^{-1}**
	stems plant^{-1}	branches plant^{-1}	pods plant^{-1}	beans plant^{-1}	beans pod^{-1}
			80,000 Plants Acre^{-1}		
Control	1.0	4.0	81.6	224.4	2.8
Cobra	1.0	4.0	76.4	211.3	2.8
Low Decapitation	2.0	1.0	61.8	163.1	2.6
High Decapitation	1.0	3.0	72.5	200.7	2.8
LSD (α=0.10)	0.1	0.5	7.6	17.4	NS
			160,000 Plants Acre^{-1}		
Control	1.0	2.0	43.0	110.4	2.8
Cobra	1.0	2.0	39.7	110.1	2.7
Low Decapitation	2.0	0.0	39.3	107.1	2.7
High Decapitation	1.0	1.0	39.8	104.7	2.7
LSD (α=0.10)	0.1	0.5	NS	NS	NS
			Average of Populations		
Control	1.0	3.0	62.3	167.4	2.8
Cobra	1.0	3.0	58.0	160.7	2.7
Low Decapitation	2.0	1.0	50.5	135.1	2.7
High Decapitation	1.0	2.0	56.2	152.7	2.8
LSD (α=0.10)	0.1	0.4	5.4	12.3	NS
Source of Variation			***P > F***		
Treatment (T)	<.0001	<.0001	0.0071	0.0006	0.2959
Population (P)	0.5559	<.0001	<.0001	<.0001	0.7131
T x P	0.7868	0.0508	0.0697	0.0023	0.5488

Table 2.3. Effect of branching treatments at V3 on physiological yield determinants per main stem vs. branches at two planting rates at Champaign, IL in 2015. Treatment and population were included in the ANOVA model as fixed effects and replication was added as a random effect.

	Main stem		**Branches**	
Treatment	**Pods**	**Beans**	**Pods**	**Beans**
	pods stem^{-1}	beans stem^{-1}	pods branch^{-1}	beans branch^{-1}
		80,000 Plants Acre^{-1}		
Control	35.9	98.9	40.5	112.4
Cobra	40.3	110.9	41.3	113.6
Low Decapitation	57.6	152.2	4.2	10.9
High Decapitation	43.6	120.3	28.9	80.4
LSD (α=0.10)	4.6	10.5	6.4	13.6
		160,000 Plants Acre^{-1}		
Control	29.0	79.7	9.2	30.4
Cobra	28.6	78.3	10.6	32.0
Low Decapitation	38.7	105.7	0.5	1.4
High Decapitation	33.4	91.3	6.3	13.4
LSD (α=0.10)	4.6	10.5	7.5	13.6
		Average of Populations		
Control	34.5	89.3	25.6	71.4
Cobra	32.5	94.6	25.3	72.8
Low Decapitation	48.2	129.0	2.4	6.1
High Decapitation	38.5	105.8	17.6	46.9
LSD (α=0.10)	3.2	7.4	4.9	9.6
Source of Variation		***P > F***		
Treatment (T)	<.0001	<.0001	0.0043	<.0001
Population (P)	<.0001	<.0001	0.0008	<.0001
T x P	0.0263	0.0318	0.0194	<.0001

Table 2.4. Effect of branching treatments at V3 grain yield, yield component, and grain quality at two planting rates at Champaign, IL in 2015. Grain yield is presented in bushel acre^{-1} at 13% moisture concentration and seed weight in mg seed at 0% moisture concentration. Treatment and population were included in the ANOVA model as fixed effects and replication was added as a random effect.

Treatment	**Yield**	**Bean Weight**	**Bean Number**	**Protein**	**Oil**
	bu acre^{-1}	mg bean^{-1}	bean m^{-2}	———%	———
			80,000 Plants Acre^{-1}		
Control	81.0	129.0	3675	33.0	19.6
Cobra	75.4	124.0	3563	33.3	19.6
Low Decapitation	58.3	136.2	2506	35.2	18.8
High Decapitation	72.4	130.0	3265	34.3	19.2
LSD (α=0.10)	3.7	2.9	187	0.3	0.2
			160,000 Plants Acre^{-1}		
Control	88.3	129.8	3990	33.1	19.5
Cobra	83.9	127.3	3861	33.3	19.5
Low Decapitation	70.3	133.1	3095	34.9	18.8
High Decapitation	83.2	135.6	3593	34.3	19.1
LSD (α=0.10)	3.6	2.9	187	0.3	0.2
			Average of Populations		
Control	84.7	129.4	3833	33.1	19.6
Cobra	79.7	125.6	3712	33.3	19.5
Low Decapitation	64.3	134.6	2801	35.1	18.8
High Decapitation	77.8	132.7	3429	34.3	19.2
LSD (α=0.10)	2.6	2.1	132	0.2	0.1
Source of Variation			***P > F***		
Treatment (T)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Population (P)	<0.0001	0.0658	<0.0001	0.5601	0.2444
T x P	0.4403	0.0078	0.2182	0.3220	0.6677

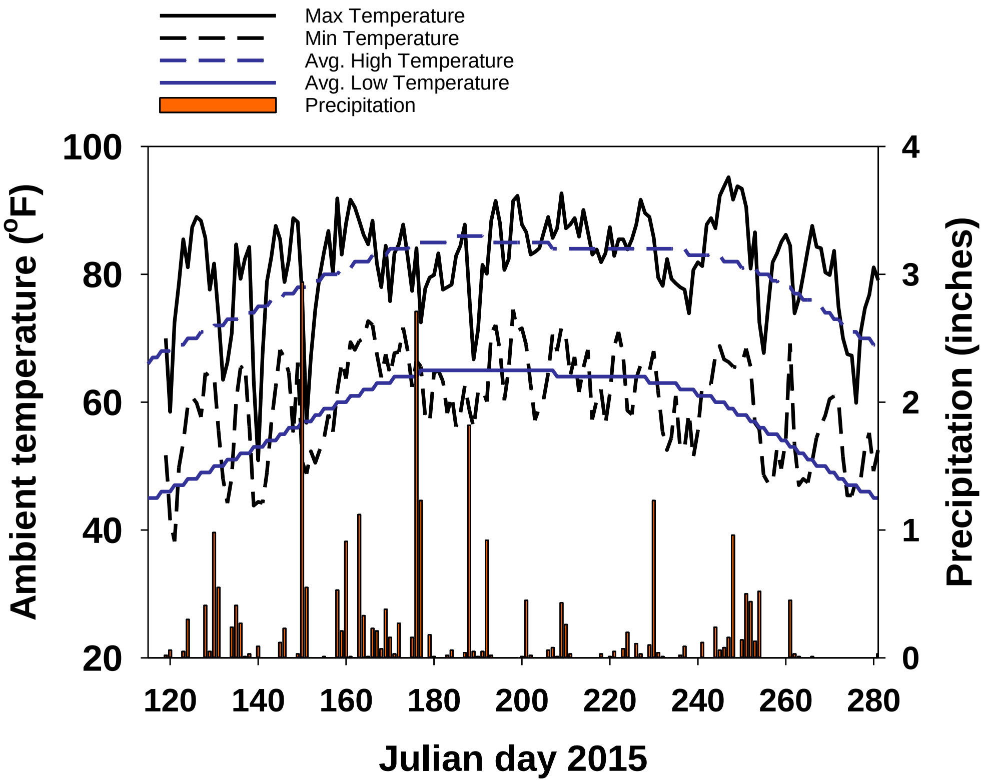

Figure 2.1. Maximum and minimum temperatures (^oF), average high and low temperatures, and daily precipitation (inch) at Champaign, IL in 2015.

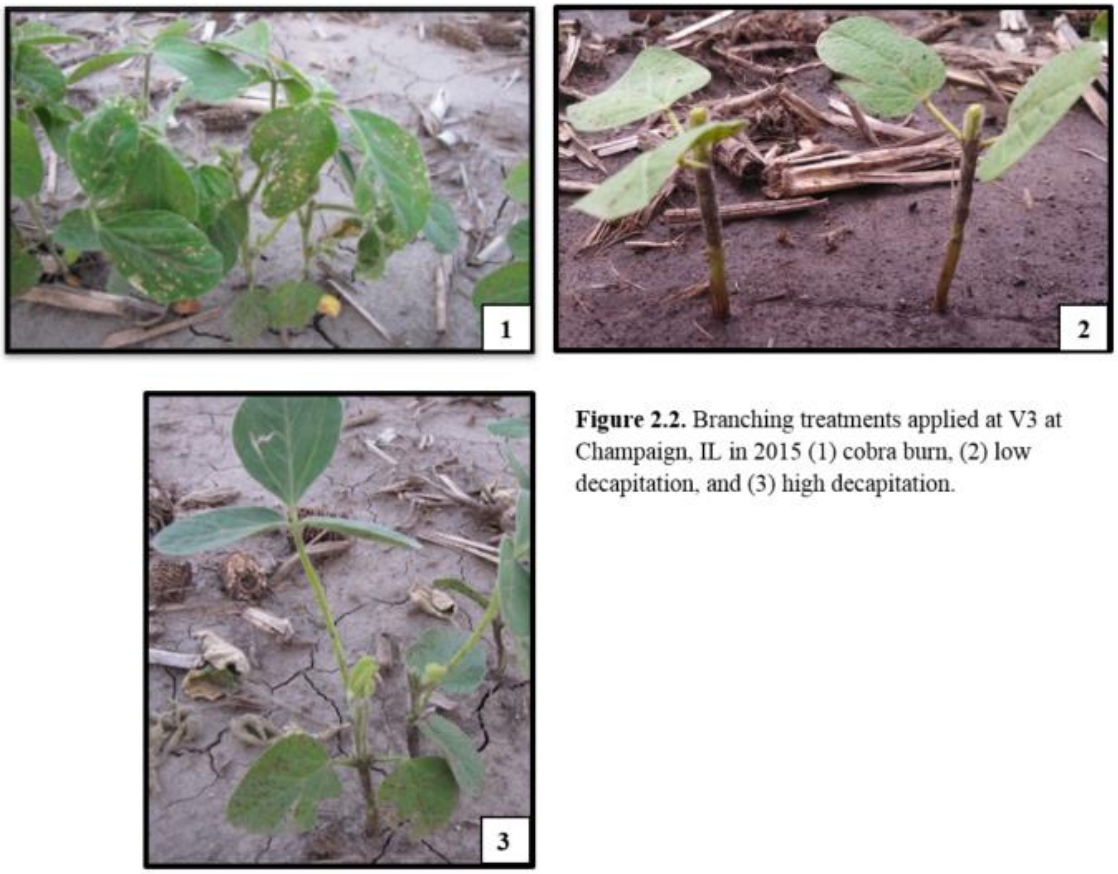

Figure 2.2. Branching treatments applied at V3 at Champaign, IL in 2015 (1) cobra burn, (2) low decapitation, and (3) high decapitation.

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