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Large applications of fertilizer N at planting affects seed protein and oil concentration and yield in the Early Soybean Production System☆

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Abstract

An inverse relationship between soybean [*Glycine max* (L.) Merr.] seed protein and oil concentration is well documented in the literature. A negative correlation between protein and yield is also often reported. The objective of this study was to determine the effect of high rates of N applied at planting on seed protein and oil. Nitrogen was surface-applied at soybean emergence at rates of 290 kg ha^{-1} in 2002, 310 kg ha^{-1} in 2003, and 360 kg ha^{-1} in 2004. Eight cultivars ranging from Maturity Group II–IV were evaluated under the Early Soybean Production System (ESPS). However, not all cultivars were evaluated in all 3 years. Glyphosate herbicide was used in all 3 years and a non-glyphosate herbicide treatment was applied in 2002. Cultivars grown in 2003 were also evaluated under an application of 21.3 kg ha^{-1} of Mn. All cultivar, herbicide, and Mn treatments were evaluated in irrigated and non-irrigated environments with fertilizer N (PlusN treatment) or without fertilizer N (ZeroN treatment). When analyzed over all management practices (years, cultivars, herbicide, and Mn treatments), the PlusN treatment resulted in a significant decrease in protein concentration (2.7 and 1.9%), an increase in oil concentration (2.2 and 2.7%), and a decrease in the protein/oil ratio (4.7 and 4.6%) for the irrigated and non-irrigated environments, respectively. However, the overall protein and oil yield increased with the application of fertilizer N at planting (protein: 5.0% irrigated, 12.7% non-irrigated and oil: 9.9% irrigated and 18.9% non-irrigated). These increases were due to the increase in seed yield with the application of large amounts of fertilizer at planting. Additionally, a significant correlation ($r = 0.45$, $P = 0.0001$) was found between seed protein concentration and seed yield. No significant correlation was found between seed oil concentration and seed yield. The data demonstrate the inverse relationship between protein and oil and indicate that large amounts of N applied at planting do not change this relationship.
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Keywords: Soybean; ESPS; Nitrogen; Fertilizer; Protein; Oil

1. Introduction

Soybean [*Glycine max* (L.) Merr.] can be used in a wide range of products from hand lotion to diesel fuel (USB, 2004), however, its primary use is as a high protein meal and secondarily as a vegetable oil source. Yaklich et al. (2002) analyzed 51 years of data from the Uniform Soybean Tests and reported that the mean seed protein and oil concentration for the Southern Region Test was 411 g kg^{-1} of protein and 209 g kg^{-1} of oil. However both protein and oil concentration can vary greatly with genotype and environment. In order for soybean to produce a high protein meal, a large amount of N is required. A 4000 kg ha^{-1} soybean crop has about 260 kg ha^{-1} of N in the harvested grain (Olson, 1978) as compared to 129 kg ha^{-1} in the harvested grain of a 9500 kg ha^{-1} corn crop (Barber and Olson, 1968; Olson, 1978). This difference in seed N concentration is reflected in seed protein concentration (≈410 g kg^{-1} soybean versus ≈100 g kg^{-1} corn).

The N source of soybean is a combination of symbiotic N_2 fixation and mineral N assimilation. Estimates vary, but N from N_2 fixation accounts for between 50 and 75% of the

Abbreviations: ESPS, Early Soybean Production System; DAP, days after planting; DTM, days to maturity; MG, maturity group

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soybean demand for N (Hardarson et al., 1984; Bergersen et al., 1985; Matheny and Hunt, 1983; Unkovitch and Pate, 2000). Large amounts ($\geq$100 kg ha^{-1}) of N fertilizer applied to soybean have been variously reported to have no effect on yield (Welch et al., 1973; Freeborn et al., 2001; Gan et al., 2003; Gutiérrez-Boem et al., 2004), mixed effects (Lyons and Earley, 1952), or to increase yield (Weber, 1966; Sorensen and Penas, 1978; Purcell and King, 1996; Purcell et al., 2004; Ray et al., 2006). In general, reports of no effect on yield are those with post-flowering or late season applications of fertilizer N. Indeed, many of the reports of increased yield with fertilizer N also indicate an increased seed number per m^2 (Weber, 1966; Purcell and King, 1996; Ray et al., 2006) upon which late season N applications would have no effect. In addition to stage of development at which the N is applied, other factors such as temperature, soil water content, soil type, and organic matter content may affect the response to fertilizer N on soybean.

The effects of large amounts of fertilizer N on protein and oil concentrations of soybean seed are not as well documented. Weber (1966) reported small increases in seed protein concentration and decreases in oil concentration with 56 and 168 kg ha^{-1} of N applied at planting. Purcell et al. (2004) reported a general trend of decreasing protein concentration and increasing oil concentration with 112 kg ha^{-1} of N applied at V6, full bloom (R2), or V6 and R2 (stages according to Fehr et al., 1971). Gutiérrez-Boem et al. (2004) found that late season (beginning pod, R3 and beginning seed fill, R5) applications of fertilizer N (50 or 100 kg N ha^{-1}) had no effect on protein concentration. On the other hand, maintenance of N_2 fixation through full pod (R6) has been associated with high seed–protein concentration (Leffel et al., 1992; Fabre and Planchon, 2000). Although normally not recommended as an economical practice, application of fertilizer N on soybean can be used to provide N at higher levels and/or for longer periods than can be achieved through symbiotic N-fixation alone. In this report we describe the effect of large amounts of fertilizer N (290–360 kg ha^{-1}) applied at planting on soybean protein and oil concentration for irrigated and non-irrigated Early Soybean Production System (ESPS) planting at Stoneville, MS in 2002, 2003, and 2004.

2. Materials and methods

In order to describe the effects of large fertilizer N applications on soybean across a broad range of conditions, a series of experimental factors were included in this study. An overview of the experiment can be found in Table 1 (from Ray et al., 2006 and is reproduced here to orient the reader). Ray et al. (2006) provides a more detailed discussion of the experimental design and conduct, however the essential materials and methods are summarized here. Field experiments with four replications were conducted over a 3-year period (2002–2004). In each year, either no fertilizer N (ZeroN treatment) or large amounts of fertilizer N (PlusN treatment) were applied to soybean grown in irrigated and non-irrigated environments. As shown in Table 1, weed populations were managed with either non-glyphosate or glyphosate treatments in 2002, whereas, in 2003 and 2004 only the glyphosate treatment was used. A granular, surface applied, Mn fertilizer treatment (21.3 kg ha^{-1}) was applied in 2003 but not in 2002 and 2004 (Table 1). In each year four cultivars were grown, however, not every cultivar was grown every year (Table 1). To simplify discussion, years, herbicide treatments, Mn treatments, and cultivars are collectively referred to as ‘‘management practices’’. Data analysis was

Table 1
Description of the factors analyzed over the 3 years of the study

MG[a]	Management practices (random effects)[b]				Fixed effects[c]	
	Cultivar	Year grown[d]	Herbicide[e]	Added Mn[f]	Irrigation[g]	Added nitrogen[h]
II	A 2703	2002	G,C	N	N,I	P,Z
III	A 3702	2003, 2004	G	Y,N	N,I	P,Z
IV	A 4702	2002–2004	G,C	Y,N	N,I	P,Z
IV	AP 4882	2002	G,C	N	N,I	P,Z
III	DK 3964	2003, 2004	G	Y,N	N,I	P,Z
IV	HBK 4820	2003	G	Y,N	N,I	P,Z
IV	HBK 4920	2004	G	N	N,I	P,Z
II	Jack	2002	G,C	N	N	P,Z

Although some factors varied from year to year, all were replicated four times and were evaluated with and without fertilizer N (ZeroN and PlusN treatments).

[a] Maturity Group classification.

[b] In the text, cultivar, year, herbicide and Mn treatments are collectively referred to as ‘‘Management Practices’’ which were treated statistically as random effects.

[c] Irrigation environment and nitrogen treatment were treated statistically as fixed effects.

[d] Year(s) of the study when the cultivar was evaluated.

[e] Herbicide treatments, G = glyphosate all 3 years, C = conventional in 2002.

[f] Whether or not the cultivar was grown with the additional treatment of 23.1 kg ha^{-1} of Mn in 2003, Y = Yes and N = No.

[g] Irrigation environment under which the cultivar was grown, N = non-irrigated and I = irrigated.

[h] Added N, P = PlusN treatment (290 kg ha^{-1} in 2002, 310 kg ha^{-1} in 2003 and 360 kg ha^{-1} in 2004), Z = ZeroN treatment (no fertilizer N).