FOLIAR FERTILIZATION OF SOYBEANS [1]

Antonio P. Mallarino and Mazhar Ul-Haq [2]
Iowa State University

Foliar Fertilization at Reproductive Stages

Extensive research addressed foliar fertilization of soybeans at reproductive stages during the 70s and 80s. The soybean plant has been characterized by markedly reduced root activity during late seed development and increased translocation of nutrients and metabolites from other tissue into the seed. This depletion of nutrients from leaves could result in decreased photosynthesis, leaf senescence, and lower grain yields. Researchers theorized that if nutrients were applied directly to the foliage at this time, leaf senescence could be delayed and grain yields might be increased. Field research in Iowa conducted by Garcia and Hanway (1976) seemed to confirm this hypothesis. They evaluated various nutrient combinations for foliar application at the R2 to R7 growth stages and found that a 10-1-3-0.5 NPKS ratio increased yields by 7 to 8 bu/acre. They concluded that the four nutrients were needed and that the optimum time of application was between growth stages R5 and R6.

Research conducted after Hanway published those results showed, however, that foliar fertilization of soybeans at late stages either produces insignificant yield increases, most often does not influence yield, or reduces yield. For example, in 1976 the Tennessee Valley Authority coordinated more than 200 research or demonstration field comparisons with foliar fertilization trials with soybeans at reproductive stages in 28 states. Summary reports of these studies (Gray, 1977; Peele, 1977) showed that yield responses varied from a maximum increase of 0.5 bu/acre to decreases of as much as 6 bu/acre. Later work in several states (Boote et al., 1978; Sesay and Shibles, 1980; Syverud et al., 1980; Vasilas et al., 1980; Poole et al, 1983) showed similar small and inconsistent increases but mostly no effects or negative responses that could seldom be explained by leaf damage, management practices, or several site characteristics. These results discouraged further research in foliar fertilization of soybeans and this practice has not been widely used by producers. In response to renewed interest in late foliar applications of urea, a research project was recently started in Minnesota. Data from two trials conducted in 1997 (G. Rehm, personal communication) showed no effect or yield decreases.

The Case for Fertilization at Early Stages

Little effort has been dedicated to the study of foliar fertilization of soybeans during early vegetative stages. Fertilization at early stages could increase yields by different mechanisms compared with fertilization at reproductive stages. Field observations and research with P and K in Iowa suggest that nutrient deficiencies may occur during early growth of corn or soybean when topsoil is dry in late spring or early summer, even for fields that have been fertilized. Because with chisel/disk tillage fertilizers usually are incorporated into the first 4 to 6 inches of soil or are not incorporated with no-till, deficiency symptoms may be partly explained by inhibited activity of roots when this layer is dry. This situation may occur often in soils with low P and K below the 6-inch soil layer. In these situations, foliar fertilization could result in increased growth and higher yield.

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2 Associate Professor and Postdoctoral Research Associate, respectively. Department of Agronomy, Iowa State University, Ames, IA 50011.

There are also physiological reasons for expecting positive responses of soybeans to foliar fertilization with N during early vegetative stages. Although soil N uptake and N fixation can occur simultaneously, the development over time of these processes is different. Measurable amounts of N fixation usually are first evident several weeks after emergence and N fixed increases slowly until a maximum is reached during pod set and early seed filling and then decline sharply. Soil N uptake reaches a peak at early to mid flowering stages and usually declines rapidly afterwards (see the article Soybean Nitrogen Acquisition and Utilization by R.M. Shibles printed in this publication). Responses to soil applied N have been ineffective in well nodulated soybeans and it has been shown that as soil nitrate increases nodule weight and size, and N fixation decreases. Although high rates of foliar applied N would cause serious leaf damage, small rates could stimulate growth without inhibiting nodulation. Thus, small amounts of N, P, and K applied at early critical periods could be effective if foliar fertilization is viewed as a complement for soil P and K fertilization and symbiotic N fixation.

In this presentation we present and discuss results of recent studies conducted in Iowa to evaluate the response of soybeans to foliar fertilization with macronutrients during early vegetative stages under a variety of growing conditions. Specifically, the studies assessed the effect of early season fertilization with three commercially available fertilizers varying in N, P, and K content on soybean grain yield and nutrient composition of vegetative tissues.

Fields, Treatments, and Measurements

Forty-eight field trials were conducted at producers' fields from 1994 through 1996 and in several major agricultural regions of Iowa (21 in 1994, 17 in 1995, and 10 in 1996). Soil and crop management practices were those normally used by the producers, and approximately equal number of trials were established in fields under conventional, no-till, and ridge-till management. Because the vast majority of Iowa soybean fields test optimum or above in soil-test P or K, very few of the sites in this research tested below optimum. Only six fields tested low in soil-test P (9-15 ppm by the Bray-1 method) and one field tested very low (6 ppm). Only one field tested low in soil-test K (89 ppm by the ammonium acetate method), a value borderline with the optimum range (90 to 130 ppm). Consideration of these observations is very important when interpreting the results of the studies.

Six treatments were applied in 1994, which consisted of a control and rates and frequency of application of a 3-18-18 (N-P-K) fertilizer. Three treatments were single applications of 2, 3, or 4 gal./acre and two treatments were 4 or 6 gal./acre split in two applications. In 1995 and 1996, four of the treatments differed from those used in 1994. Two treatments were the same single application of 3 gal./acre and a double application of 4 gal./acre of 3-18-18 treatments that were used in 1994. The other three treatments were single applications of 3 or 6 gal./acre of 10-10-10 and 4.5 gal./acre of 8-0-8. The 3-gal. rate of 3-18-18 and 6-gal. rate of 10-10-10 applied the same P and K rates and, also, the 3-gal. rate of 10-10-10 and the 4.5-gal. rate of 8-0-8 applied approximately the same rate of N and K. The target growth stage for single applications and the first application of the double treatments was the V5 stage. The second spray was done 8 days after the first spray. The fluid fertilizers used are commercially available. The 3-18-18 and 10-10-10 fertilizers are manufactured with phosphoric acid, aqueous ammonia, potassium hydroxide, and low-biuret urea. The 8-0-8 fertilizer is manufactured by dissolving potassium nitrate in water. There were four replications at all trials. Each plot measured 40 feet in length and 15 to 19 feet in width (the width varied depending on the planter used by the producers). Treatments were sprayed with 10 gal./acre of water. The plots were sprayed after 4:30 p.m. when day temperatures were higher than 85 degrees.

Small-plant samples were collected the same day of the first spraying (before treatments were applied). The samples were analyzed for total P and K in 1994 and for N, P, and K in 1995 and 1996. Samples of the top three fully developed, trifoliate leaves were collected at the R2 to R3 stage (full bloom) from selected treatments and were analyzed for total P and K concentrations in 1994 and for N, P, and K in 1995 and 1996. In addition, in 1995 and 1996 whole-plant samples that were collected from selected treatments at the R2 to R3 growth stage were weighed and analyzed for total N, P, and K content. Visual scores of leaf damage due to the foliar spray were collected from all plots. Grain was harvested from the center two rows (or equivalent width in drilled fields) of each plot and from a length of 25 feet to eliminate border effects and drift. The grain was threshed and weighed at the field, and moisture was determined with an electronic meter.

Results and Discussion

Results for 21 trials conducted in 1994.

Fig. 1 shows the mean grain yields for the six 3-18-18 treatments used in 1994 at responsive sites and across the 21 sites. There were statistically significant responses (P#0.1) at seven sites. At four sites, all fertilization treatments increased yield. At two sites, some treatments increased yields, others decreased yields slightly, and others did not affect yield. The differences between treatments were not consistent across sites and could not be explained satisfactorily. At one site all treatments decreased yield (3.8 bu/acre). It must be noted that the results for this site are included in the means for the responsive sites shown in Fig. 1 so the mean yield increases were actually higher than those represented in the figure. The yield decreases could not be explained by leaf damage (no treatment caused visible damage), rates, or frequency of application.

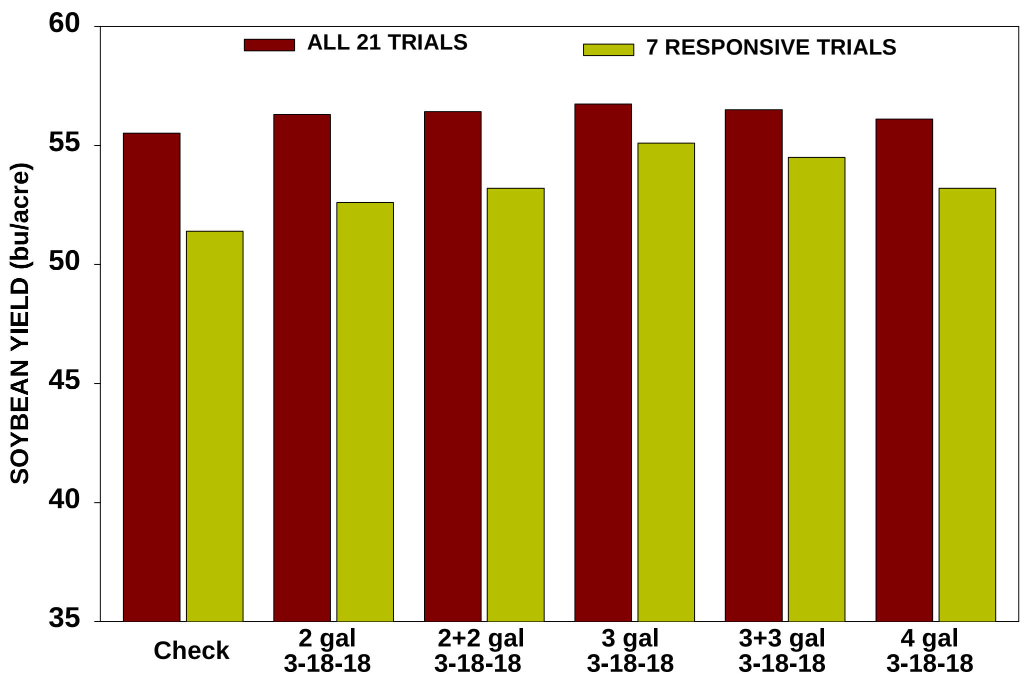

Fig. 1. Yield response of soybeans to early foliar fertilization for 21 trials conducted in 1994.

Fertilization had no statistically significant effects across the 21 sites and the mean effect of all treatments was less than one bu/acre. The 3-gal. rate produced higher yields than the other treatments and increased yield by about 2 bu/acre, although this increase was not statistically significant. At responsive sites, this treatment increased yield by an average of 6 bu/acre. There was no advantage for the highest single rate (4 gal./acre) or the double applications compared with the single 3-gal. rate.

Results for 17 trials conducted in 1995.

Fig. 2 shows the mean grain yields for all sites and responsive sites for each of the new set of treatments applied this year. There were statistically significant treatments effects at five sites but differences between treatments were inconsistent across trials. All treatments increased yield at one site (a

6 bu/acre mean increase) and most treatments (except for the double application of 3-18-18 and the 6 gal. rate of 10-10-10) increased yield at another site (a 5 bu/acre mean increase). At two sites the 3-18-18 fertilizer increased yield by an average of 3 bu/acre but the other mixtures either did not affect or decreased yield slightly. At one site all treatments decreased yield (a 4 bu/acre mean decrease). The results for this site are included in the means for the responsive sites shown in Fig. 2. The average response across all sites and treatments was essentially zero, although fertilization with 3 gal./acre of 3-18-18, the treatment that produced the highest yields in 1994, increased yields by about one bu/acre across all sites. When means for only the responsive sites were calculated, the yield advantage for the 3 gal. rate of 3-18-18 was about 5 bu/acre.

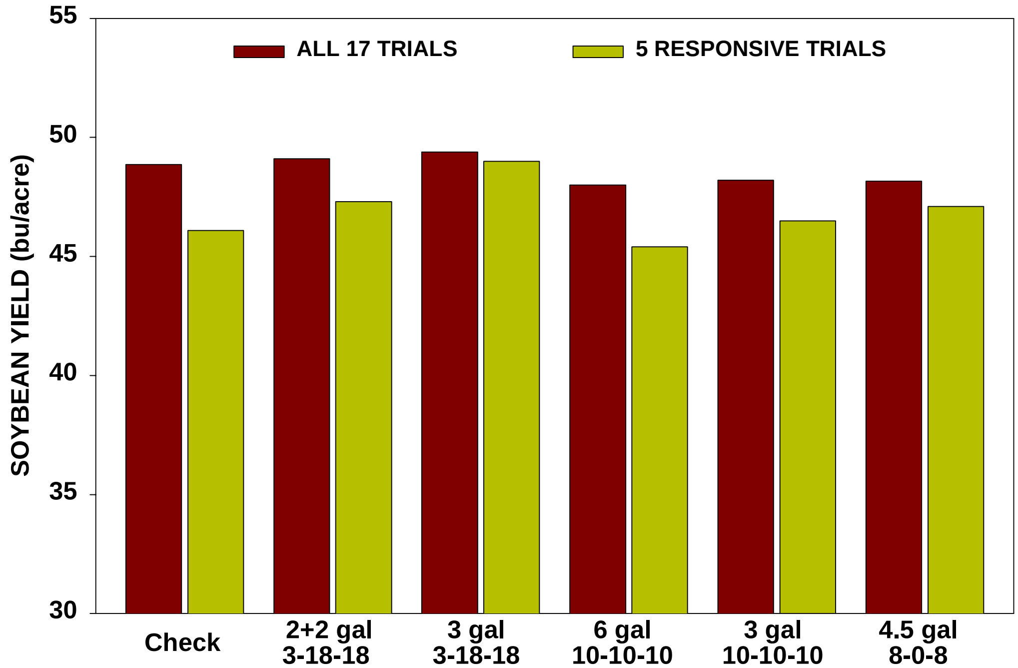

Fig. 2. Yield response of soybeans to early foliar fertilization for 17 trials conducted in 1995.

The 3-18-18 fertilizer caused no leaf damage. Although the 10-10-10 and 8-0-8 fertilizers caused slight leaf damage, the only really meaningful burning occurred for the 6-gal. rate of 10-10-10. This may explain the yield decreases observed for this treatment at several sites. The fact that the 8-0-8 has no P and the 6-gal. rate of 10-10-10 applies the same P and K as the 3-gal. rate of 3-18-18 but applies more N did not help explain the responses.

Results for 10 trials conducted in 1996.

Fig. 3 shows the mean grain yields for all 1996 sites and for the responsive sites. There were statistically significant treatments effects only at one site, where only the 3-gal. rate of 10-10-10 and the 4.5-gal. rate of 8-0-8 increased yields (a 6 bu/acre mean increase). This greater response to the low rate of 10-10-10 and the 8-0-8 fertilizer (which produced insignificant burning this year) compared with the 3-18-18 was not observed in 1995. The high rate of 10-10-10 (6 gal./acre) did not reduce or increased yield and produced significant leaf damage. There was no leaf damage due to the 3-18-18 fertilizer, and the lack of response to this fertilizer compared with the others cannot be explained. The response across all sites was not statistically significant although there was an average yield advantage of about one bu/acre over all treatments.

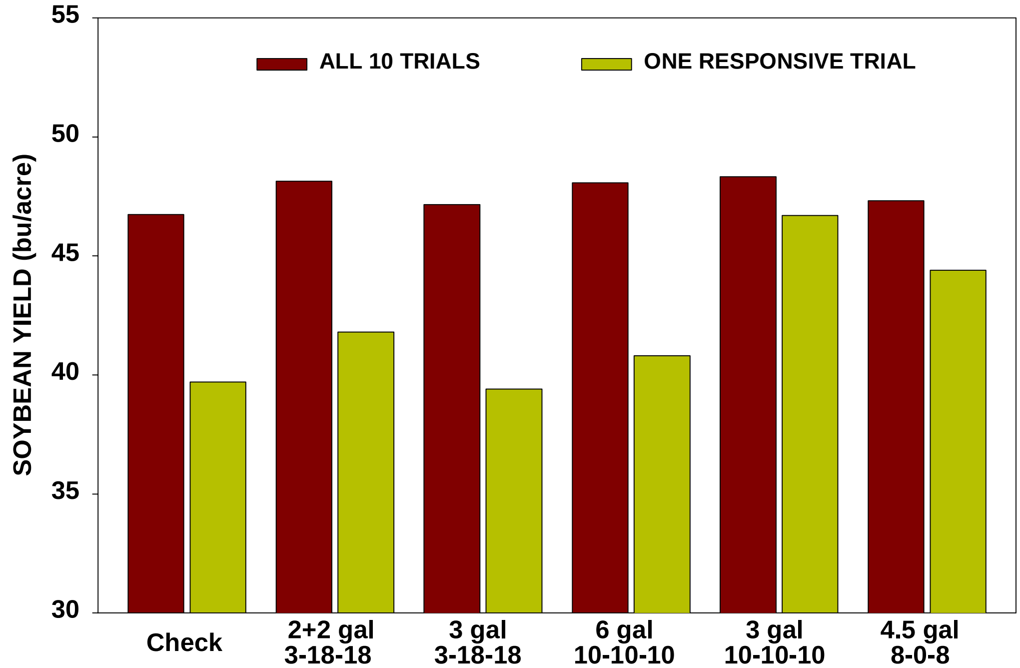

Fig. 3. Yield response of soybeans to early foliar fertilization for 10 trials conducted in 1996.

Relationship between yield response and site characteristics or management.

The study of the relationships between yield response and site variables such as variety, soil type, and others were of no help for explaining the occurrence of responses. The only apparent relationship observed, which cannot be statistically confirmed, was observed in 1994. This year responses were higher and more frequent at ridge-till and no-till fields compared with fields managed with chisel or disk tillage. The mean increase over all fertilized treatments and trials was 3 bu/acre in ridge-till, 2 bu/acre in no-till, and there was no increase at fields managed with chisel or disk tillage. It is likely that foliar fertilization alleviated problems with early nutrient uptake, which sometimes occur even in high testing soils managed with these systems.

The relationship between yield response and continuous numerical site variables (such as soil tests, plant analyses, rainfall, temperature, planting date, etc.) across sites was studied by simple correlation and multivariate factor analyses. As expected, simple correlation coefficients (not presented) showed that yield response sometimes was positively or negatively correlated with some measurements and that many site variables were intercorrelated. In some instances the correlations seemed logical but in others they were difficult to explain or absurd. This result is commonly observed in field research, because a significant correlation could be a random result or could result from the correlation of a measured variable with a nonmeasured variable that actually affected yields. Previous research has shown that fitting multiple regression models directly to sets of data with many intercorrelated measurements is not appropriate because the tests of significance are not reliable. The use of factor analysis partly overcomes this limitation. This technique can be used to identify groups of correlated site variables. New variables created on the basis of these groups can be correlated with the yield response across sites.

Analysis of responses to 3-18-18 across all 48 sites showed that although several groups of correlated site variables were identified, only a group that included soil Ca, Mg, cation exchange capacity (CEC), and rainfall during April was significantly correlated with yield response. The response was higher when the soil cations increased and rainfall in April decreased. This group, however, explained only 14% of the variation in responses. It is important to consider that the correlations between rainfall in April and each of the soil cations was negative, which has no obvious explanation and probably was a random result for this data set. Also, interpretation is complicated by likely relationships of CEC (which represents mostly Ca and Mg) with other physical (texture, water holding capacity, rooting depth) and chemical (pH, calcareous content) soil properties. An analysis that excluded the 1996 data (because this year there was only one responsive site and all trials were conducted in central Iowa) showed that yield response was significantly related to two groups of variables. One group was similar to that described for the 3-year analysis and the other included small-plant P concentration, leaf P concentration at the R2 to R3 stage, and rainfall during June and July. Yield responses were higher when the values of those variables were low. A multiple regression model with both groups explained 23% of the variation in responses. Although an explanation of the effect of the first group of variables is not straightforward, there is a likely reason for the effect of the second group. It is likely that drier topsoil conditions during these months reduced P availability for the soybeans independently of the soil-test P level.

Analysis of responses in 1995 and 1996 showed that three groups of strongly correlated site variables explained 37% of the observed yield response. One group included soil P and K, small-plant P and K concentrations, and leaf K concentration. Another group included total plant weight, N uptake, and P uptake at the R2 to R3 stage. The other group included leaf P and rainfall during July. The study of these relationships suggested that yield responses were higher or more frequent when soil P and K availability, nutrient uptake, plant weight, and rainfall in late spring or summer were low. It is important to realize that "P and K availability" refers to actual availability for the plant not necessarily soil-test P and K. These results tend to coincide with results discussed for the 3-18-18 dataset. These complex relationships suggest that growth factors that inhibit growth and nutrient uptake during the first half of the growing season increase the likelihood of positive responses to foliar fertilization. Indeed, observations of overall yield levels show that the responsive sites often had lower overall yields than nonresponsive sites.

Conclusions

Foliar fertilization of soybeans with macronutrients at early vegetative stages is likely to increase yields under some conditions, even in high testing soils. There were no consistent differences between products, rates, or frequencies of application except for two considerations. The high rate (6 gal./acre) of the 10-10-10 fertilizer did not affect or reduced yield. A single application of 3 gal./acre of 3-18-18 usually produced the highest yield increases.

No simple set of measurements can be used to predict responses. The results suggest, however, that responses will be more likely when the effective early nutrient availability is low (which not necessarily means low soil tests) and/or climatic factors limit plant growth in late spring and early summer. The results for one year also suggest that responses are more likely in ridge-till or no-till fields. In these instances, responses as high as 10 bu/acre are possible. Across all conditions, especially with predominantly high testing soils as those used in this study, the expected average response is about one bu/acre.

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