Soybean Yield Potential and Management Practices Required to Achieve It

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Introduction

Crop yield potential is achieved when an adapted cultivar is grown without yield loss from nutrient deficiencies, soil toxicities, weed pressure, or disease and insect damage (Evans, 1993). For soybean, yields in excess of 100 bu/ac have been reported at various sites in the USA (Cooper, 1982; Flannery, 1983; Specht et al., 1999). It has been suggested that future average soybean yields could rise to about 80 to 90 bu/ac in favorable Corn Belt production areas (Cooper et al., 1991; Specht et al., 1999). However, consistently achieving yield potential levels with soybean is difficult because our basic understanding of soil and crop management requirements is lacking. Since 1999, our research team has attempted to quantify soybean yield potential and the management practices required to achieve it in a long-term field study on *Ecological Intensification of Irrigated Corn and Soybean Cropping Systems*. In this report we summarize our findings on soybean yield potential and management.

Materials and Methods

A long-term experiment was established in 1999 at the UN-L East Campus Agronomy Research Farm in Lincoln, NE. The soil is a deep Kennebec silt loam (fine-silty, mixed, superactive, mesic Cumulic Hapludolls). Prior to 1999, the field was in a sorghum-soybean rotation without N fertilizer for the past 10 years. Average initial soil test values in the 0-20 cm plow layer were pH 5.3, 2.7% soil organic matter, 67 ppm Bray-P, and 350 ppm exchangeable K. Lime was applied in 1999 and 2001 to maintain a soil pH of about 6.5.

The experiment was a randomized complete block design with split-split plot arrangement of treatments, which were a factorial combination of crop rotation (R) main plots, plant populations (P) as sub-plots, and level of fertilizer nutrient management regimes (M) as sub-subplots, with four replicates (Table 1). Sub-subplots were 6.1 m x 15.2 m (20’ x 50’) in size with 8 rows at 0.762 m (30’’) inter-row spacing. Details about crop and soil management in this experiment and other results have been reported previously (Arkebauer et al., 2001; Dobermann et al., 2002; Dobermann et al., 2005; Dobermann et al., 2003; Arkebauer et al., 2004). The focus of this report is on the soybean cycle of the corn-soybean rotation treatments, and a summary of the treatments applied to soybean is provided in Table 1. The experiment included two sets of treatment plots for the corn-soybean rotation such that one set began with soybean in the first year and another with corn, soybean was grown in each year under all plant population and fertility regimes. Each year the experiment was managed to avoid or mitigate stress-induced yield reductions from non-treatment factors. Weeds, insects, and diseases were controlled effectively in all years except in 2003 when large numbers of bean leaf beetles (*Certoma trifurcate*) emerged in spring and infected seedlings bean pod mottle virus (BPMV), Genus Comovirus, Virus Code VC18.0.1.0.003). Macronutrients other than N, P, and K are not limiting at this site, and micronutrients were applied as needed.

Key measurements in this field experiment include:

- Canopy environmental conditions: daily climate and intercepted solar radiation.
- Crop development rates, aboveground biomass and biomass partitioning during the growing season.
- Corn and soybean grain and biomass yield, harvest index, components of yield, and plant population at physiological maturity.
- Plant C, N, P, K, Ca, Mg, S uptake in aboveground biomass at physiological maturity (including seed and haulms for soybean).
- Soil physical and chemical characteristics, potentially mineralizable nitrogen, soil C stocks, soil nitrate in spring, irrigation water composition.
- Soil surface CO_2, N_2O and CH_4 fluxes in selected treatments.

Table 1. Fertilizer (M1 and M2) and "intended" plant population (P1, P2, P3)* treatment regimes used on soybean in the Ecological Intensification field study at the Univ. of Nebraska, Lincoln. Cultivar NE3001 was used throughout this study and has a semi-determinant habit.

Treatment level	Year					
	1999	2000	2001	2002	2003	2004
M1, no fertilizer	0	0	0	0	0	0
M2, NPK (lb/ac)	138-40-75	138-40-75	71-40-75	71-40-75	71-40-75	71-40-75
P1, (1000/ac)	150	150	105	105	150	150
P2, (1000/ac)	185	185	130	130	150	150
P3, (1000/ac)	220	220	154	154	225	225
Irrigation method	Surface drip	Surface drip	Subsurf drip	Subsurf drip	Sprinkler	Sprinkler

*Intended plant population densities were the actual seed sowing rates after adjustment for germination percentage.

Another field experiment adjacent to the EI experiment was conducted in 2003 and 2004 to evaluate the effect of planting date on soybean yield potential (Bastidas, 2005). These studies followed optimal crop and soil management practices similar to those in the *Ecological Intensification* study for all factors other than planting date.

Results and Discussion

General Observations

There were several constraints to soybean yields in specific years despite our attempt to use optimal management throughout the duration of this study. In 2003, there was a relatively high incidence of BMPV, which reduced seed yield because the viral-infected plants had green stems with greatly reduced pod number per plant. Since that year we have used a systemic insecticide seed treatment to prevent over-wintering bean leaf beetles (the vector for this virus) from feeding on and thus infecting soybean plants during early vegetative growth. Soybean yield loss due to this virus is greatest when infection occurs early. In other years the design of our irrigation system did not allow separate irrigation of the corn and soybean treatment plots. Because soybean requires less water than corn during the vegetative and early reproductive phases, we had to overirrigate soybean in some years when we lacked the ability to apply separate irrigation regimes (e.g., 2000 and 2003). Applying excess water to soybean during early growth can lead to increased plant height and subsequent lodging. Therefore, after 2003 we have used separate sprinkler irrigation systems to allow each crop to be irrigated optimally.

Effect of plant population on seed yield

Soybean seed have difficulty in emerging because they are rich in oil and protein content, which makes them attractive to soil-borne pathogens and insects. Moreover, because the soybean seed is large, the cotelydons have a large surface area, which must push aside a relatively large mass of soil to reach the surface. These constraints cause substantial year-to-year variation in seedling emergence rates and percentages—even with the fungicide seed treatment used in our study (Fig. 1). Emergence percentages are reduced substantially in years when a heavy rainfall event causes soil slaking or when unusually cool temperatures occur soon after sowing. Even with favorable climatic conditions, however, there is typically a large attrition in soybean plant population compared to monocot crops like corn and wheat. On average, the rate of attrition was about 14% at low sowing rates (105,000 to 130,000 viable seed/ac) and 36% at high sowing rates (225,000 viable seed/ac). These data suggest that sowing rates (even after correction for germination percentage) should be about 25% greater than the intended plant population.

In general, and as observed in many other studies, soybean yields were not very sensitive to actual plant population in the range of 80,000 to 180,000 plants/ac as achieved in our study. There was a significant response to higher plant populations only in 2001, when sowing rate treatments were relatively low, and in 2004, which was a year with very favorable climate and high yield potential (Fig. 2). The probability of obtaining a yield response to higher plant density was greatest in years with high yield potential and at yield levels exceeding 75 bu/ac (Fig. 3). At yields below this level, other factors appear to be more limiting than plant population.

Effect of increased NPK fertilizer rates and NPK requirements

Soybean yields did not respond significantly to application of additional NPK (Fig. 4). Despite this general lack of response, the data suggest an increased probability for a yield increase from additional fertilizer in high-yielding years (Fig. 5). Based on our current UNL recommendations (Ferguson et al., 2003; Ferguson et al., 2003), fertilizer P and K application would not be recommended at this site because actual soil test P levels (>50 ppm Bray-1 P and >300 ppm K in all plots) by far exceeded the currently used critical soil test levels for soybean in Nebraska (12 ppm Bray-1 P, 124 ppm K). At issue is whether these recommendations hold true at high yield levels. The answer to this question requires further study as we strive to achieve higher soybean yields on a more consistent basis.

Soybean N requirements are especially large because of high seed protein content. We found a strong linear relationship between N uptake and seed yield over a wide range in yield (Fig. 6). A soybean crop that yields 90 bu/ac requires uptake of 430 lb N/ac in aboveground biomass. By extrapolation, a 100 bu/ac soybean crop would require uptake of 480 lb N/ac. These trends emphasize the importance of N supply—from soil, biological N_2 fixation, and applied fertilizer—to support high yield levels. Of these, N_2 fixation typically provides the greatest portion of total N supply. At issue is whether our N fertilizer management practices are effective in optimizing the N supply from biological N_2 fixation. The additional N in the M2 treatment is applied as a topdressing at the R3.5 stage. We suspect this practice reduces N_2 fixation because root nodules are concentrated in the upper topsoil layer, and high inorganic N levels in this zone could decrease nodule activity and may cause nodule senescence (Freeborn et al., 2001). Perhaps the use of controlled release N fertilizer placed at 6-8 inch depth before planting would reduce the negative impact of N application on N_2 fixation thus delaying leaf senescence and supporting a longer period of seed filling. We are planning to evaluate this practice in the M2 treatment next year.

Soybean uptake requirements for P and K are also large because the seed contains high concentrations of both P and K. Despite these large requirements, we found no evidence that uptake requirements or removal rates were affected by either plant population or fertilizer input treatments (Table 2). These findings are in contrast to high-yield corn, which had greater uptake requirements for K at higher plant populations (Dobermann et al., 2002).

Table 2. Soybean nutrient uptake and removal in relation to seed yield. Data are averaged over years (2000-2004) and plant population treatments. Neither plant population nor fertilizer treatments (M1 and M2) had a significant impact on nutrient uptake or removal. See Table 1 for details about fertilizer input treatments.

Treatment*	Total nutrient uptake (lb/bu)			Nutrient removal with seeds (lb/bu)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
M1	4.45	1.08	3.35	3.34	0.65	1.32
M2	4.39	1.08	3.32	3.34	0.66	1.34

Critical role of planting date for high soybean yields

Any solar radiation that falls on the ground surface is wasted because that energy does note contribute to plant photosynthesis and either evaporates water from the soil surface or heats up a dry soil surface. Getting a canopy of green soybean leaves covering the ground as soon as possible in the spring is easily accomplished by early planting. Many soybean producers focus first on planting their corn acres and plant soybean later. Some then use narrow rows to hasten soybean canopy closure. However, delayed planting also delays canopy closure, so narrow rows are simply a “rescue” treatment for planting late in the first place. Late plantings lead to a reduction in the number of nodes per plant. Recent data from our 2003 and 2004 planting date experiment (Bastidas, 2005) has demonstrated that a new node is produced every 3.84 (~ 4) days soon after the plants reach their V1 stage (Fig. 7), and this 4-day cycle is relatively insensitive to seasonal temperature or rainfall. Nodes are where the plant produces its flowers, pods, and seeds. So, delaying planting from May 1 to May 28 will automatically reduce node number in the later-planted soybean. Moreover, the nodes “lost” by late planting cannot be regained during the season because the 4-day node production rate was relatively constant for all planting dates.

While soybean planted in late May can be nearly as tall as those planted in early May, they will have fewer nodes, which results in lower yield potential. Regression of soybean yield on planting date over two years shows that yield potential decreases by 0.25 to 0.6 bu/ac per day of delay in planting. Still, there are three caveats to planting soybeans early. First, you have to use good quality seed (get cold-germ test from your dealer) treated with both fungicide and with a systemic insecticide to protect against early bean leaf beetle infestation. As note earlier, protection against the bean leaf beetle is not so much to protect against leaf feeding as to protect against early transmission of the bean pod mottle virus, which is a subtle but deadly yield killer (Giesler et al., 2002).

Residual Soil Nitrate

Because high-yield corn systems require greater amounts of N fertilizer than systems with average yields, it is of critical importance to use soil testing for residual nitrate and the soybean "N credit" in developing N fertilizer recommendations (Shapiro et al., 2001). Failure to do so can result in substantial losses of N, which reduce both profitability and environmental quality.

Over five years in the *Ecological Intensification* field study, residual soil nitrate ranged from 20 to 145 lb NO_3-N/acre in the top four feet (Fig. 8). In the M1 treatment without N fertilizer application to soybean, residual soil nitrate was consistently smaller following corn than following soybean. This difference likely was the result of moderate N deficiency in the M1 N fertilizer management regime on corn, which resulted in very high N fertilizer uptake efficiency in the M1 corn treatment and little residual N. It should be noted that the greater amount of residual N following M1 soybean compared to M1 corn is in addition to the soybean N credit when calculating the N fertilizer requirement. Therefore, N fertilizer use efficiency of corn following soybean in the M1 treatment is augmented by both the greater residual N and the soybean N credit.

In contrast, residual nitrate varied substantially from year-to-year in the M2 treatments (Fig. 8). In all cases, it was greater in M2 treatments than in the comparable M1 treatment. In some years residual N in M2 treatments was greater following soybean and in others following corn. These fluctuations largely followed yield trends in the previous year. In years when yields were high and the associated crop N uptake was high, residual N was relatively low and *vica versa*. Therefore, achieving consistently high yields is a crucial factor in achieving high N fertilizer efficiency when producers apply N fertilizer at rates that are required for high yields. In years when yields fall well below yield potential due to factors other than N, then N fertilizer efficiency is low, residual soil nitrate is high, and the potential for N losses to the environment are large.

Conclusions

- Maximum soybean yields obtained in the EI experiment from 1999 to 2004 ranged from 65 to 85 bu/ac with greatest yields obtained in years with favorable climate during grainfilling (2001 and 2004).
- Although there was no consistent yield response to plant population or fertilizer application above current recommended practices, there was evidence of such a response in high-yielding years when yields exceeded 75 bu/ac.
- Irrigated soybean should avoid irrigation before the R3 stage except in years with extreme early season water stress, and focus on providing adequate moisture during the critical seed filling stages (R3-R6).
- The following considerations are critical for pushing soybean yields towards the yield potential ceiling:
- Use lodging resistant varieties because high-yield systems create a heavy seed load that makes plants more prone to lodging.
- Plant early to ensure that the crop attains maximum node number because a new node is formed approximately every four days regardless of planting date. A general rule of thumb is to plant 21 days after the earliest date of frost.
- Treat seeds with both a fungicide and systemic insecticide.
- Achieve an actual plant population of at least 150,000 plants per acre.

- Ensure adequate soil P and K fertility, as well as adequate supplies of other macro- and micronutrients

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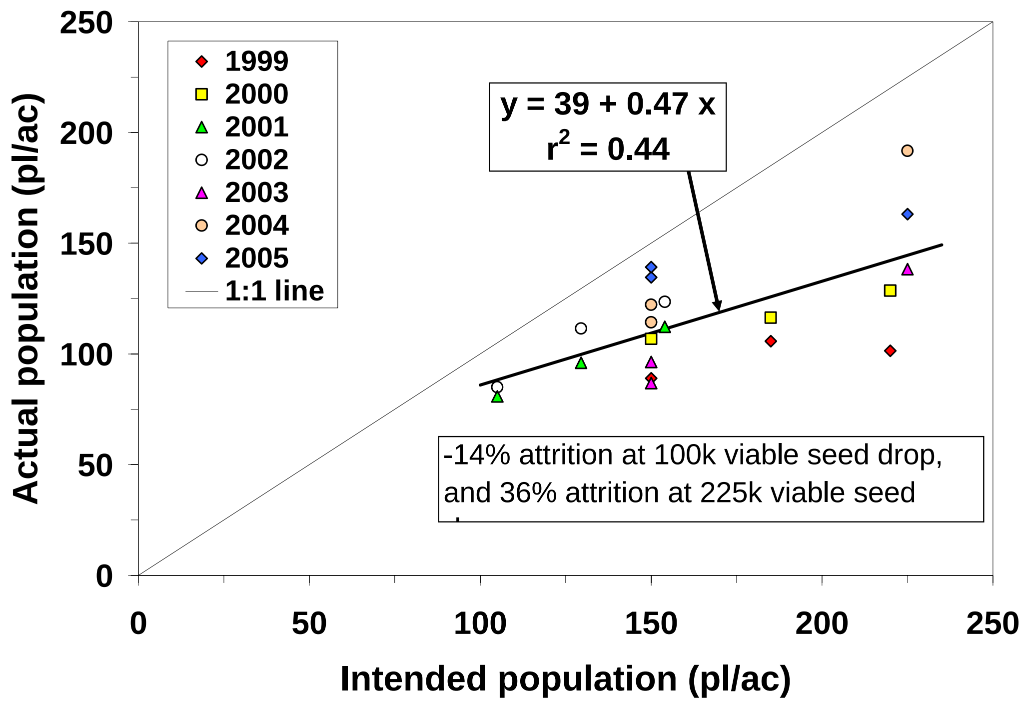


Figure 1. The attrition in soybean plant population (in units of 1000 plants per acre) as described by regression of actual plant population measured at physiological maturity on the intended plant population based on the number of viable seed sown. In all years, seed were treated with a fungicide to reduce seedling diseases.

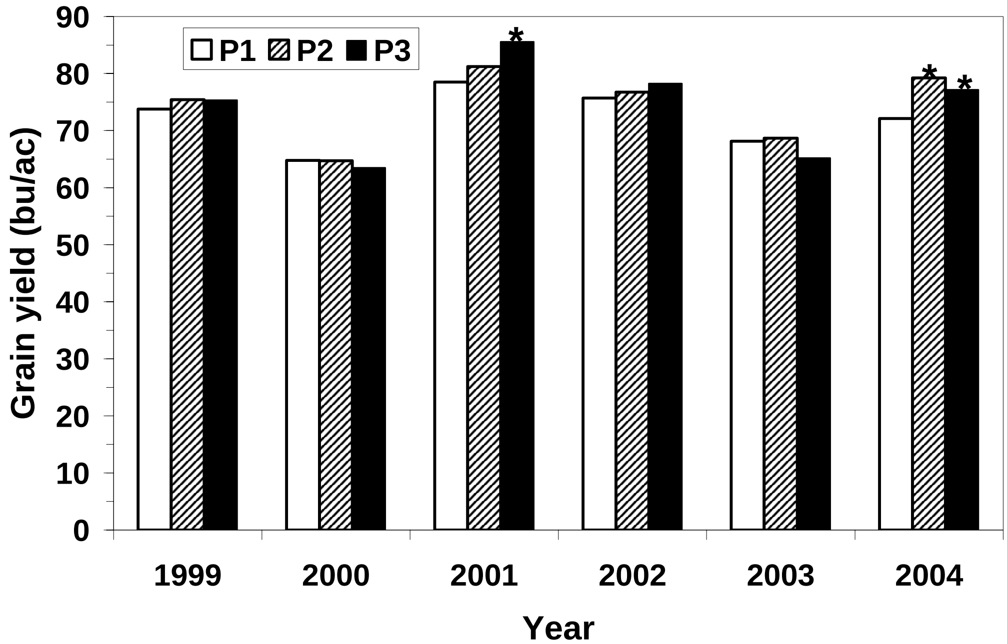


Figure 2. Effect of plant population, averaged over fertilizer input treatments, on soybean seed yield. Statistical significance: *P<0.05.

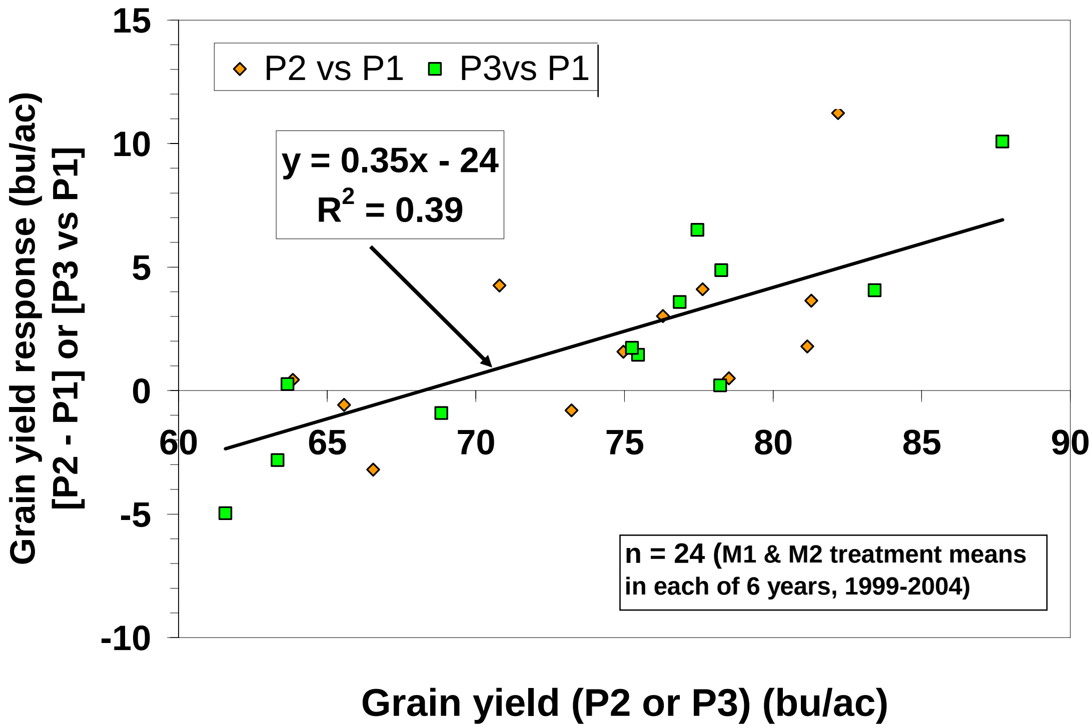


Figure 3. Yield response to increased plant population versus the grain yield at the higher plant population treatment. Regression is significant at $P<0.01$.

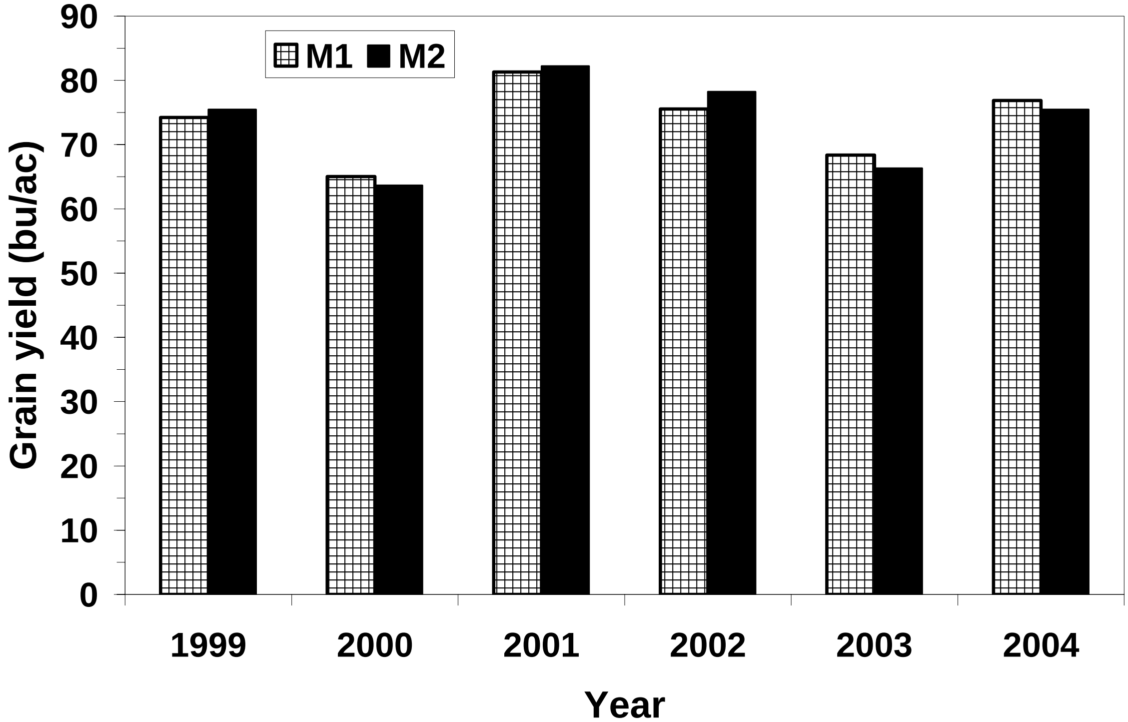


Figure 4. Effect of NPK addition on soybean yields. Rates of addition are given in Table 1. There was no significant effect of NPK addition on yield in any of the six years.

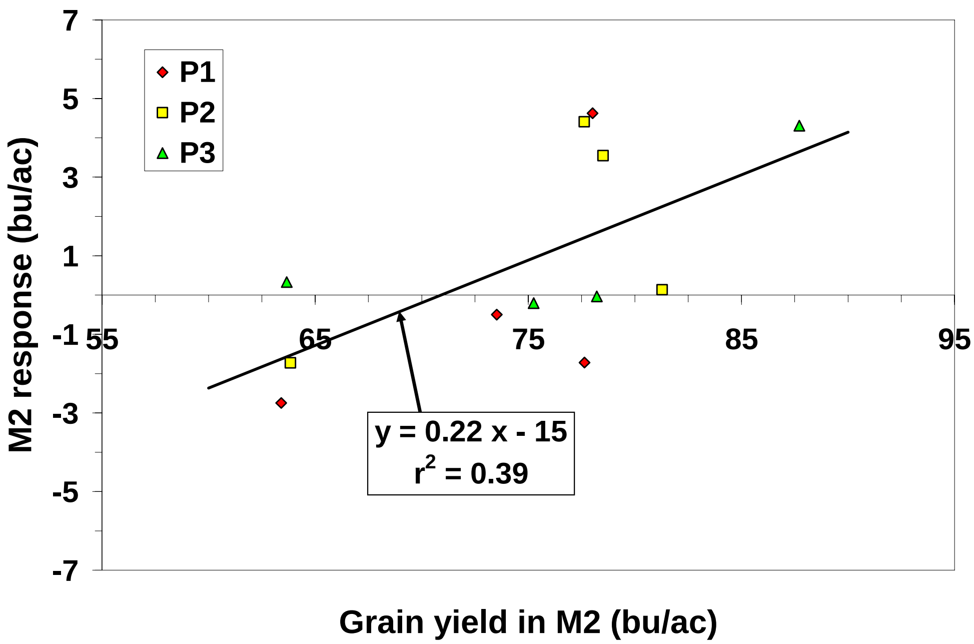


Figure 5. Relationship between the response to application of additional NPK fertilizer (yield in M2 minus yield in M1) and the yield of the treatment receiving additional NPK (M2). Regression is significant at $P<0.05$.

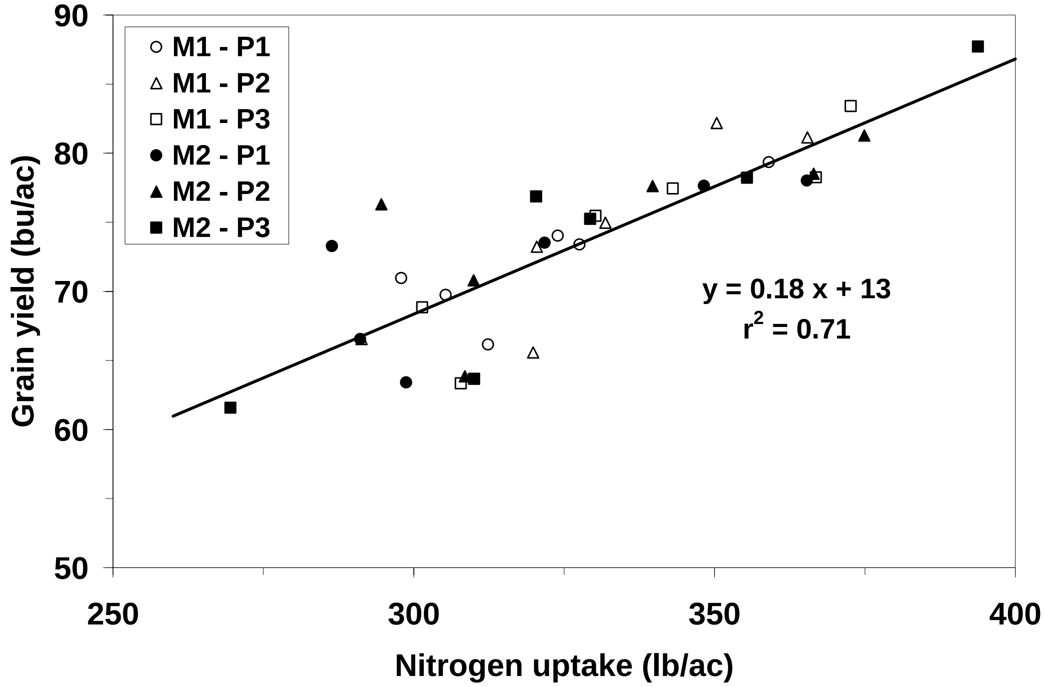


Figure 6. Soybean grain yield in relation to nitrogen uptake. Data points represent fertilizer x plant population treatment means over five years, from 2000-2004.

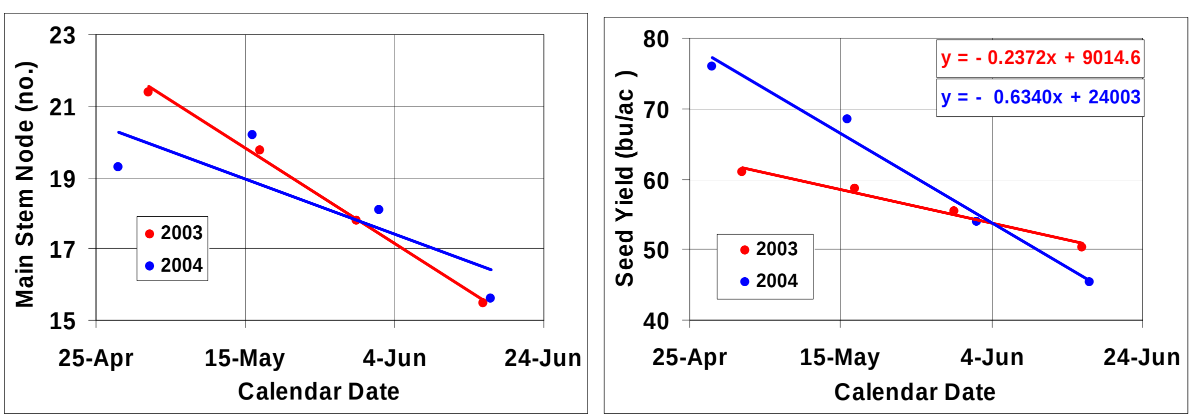
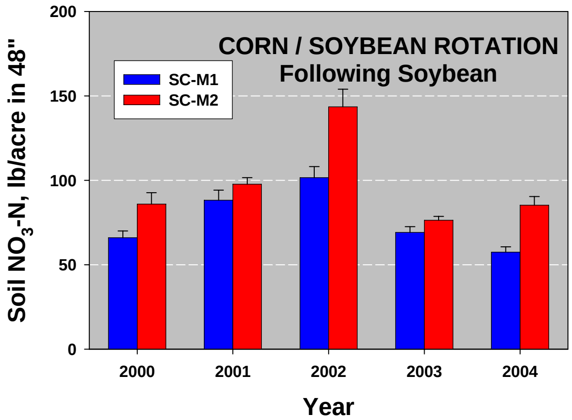


Figure 7. Soybean yield and node number as affected by planting date. Values shown represent means of 14 cultivars in maturity groups 2 to 3.



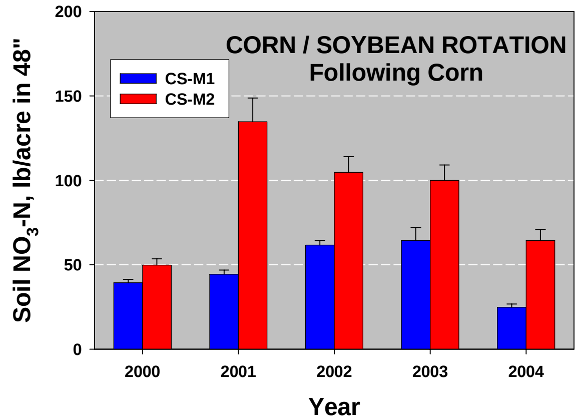


Figure 8. Residual soil nitrate to four-foot depth as affected by cropping system and fertilizer input treatments. Data are averaged over plant population treatments.