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Soybean Residual Effects on a Subsequent Maize Crop[1]

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Maize (*Zea mays* L.) grown after soybean (*Glycine max* L. Merr.) consistently performs better than maize that follows itself (second year maize), irrespective of nitrogen fertilization. In previous studies of the soybean-maize rotation, there never has been an evaluation of the potentially different effects of soybean genotypes on following maize. A two-year, soybean maize rotation was initiated in Ames at 1988 with the first year planted to various soybean genotypes, a maize hybrid, and oat (*Avena sativa* L.). These were followed in the second year by a single maize hybrid with 0, 80, 160, and 240 kg/ha N fertilization levels. Results are based on three repetitions of this cycle.

Averaged over all years and N rates, maize after nodulated soybean and oat yielded 1270 and 1570 kg/ha, 16 and 20% respectively, more than second-year maize. Second-year maize was delayed in silking by 4 days. Though soybean returned 60 to 70 kg/ha of N to the soil in vegetative residue, there seemed to be no *net* N contribution from soybean to maize because soybean benefited maize less at zero N than did unharvested oat. Soybean evidently returns to the soil less N than is mineralized from soil organic matter during a cropping year. Prior soybean and oat both benefited maize even under the highest nitrogen fertilization rate.

BSR 201 soybean benefited maize more than did the other soybean cultivars or oat. Averaged for years and the two highest N rates, BSR 201 benefited maize 680 kg/ha (ca 11 bu/A) more than all the other nodulated soybean genotypes averaged. The BSR 201 effect, however, was not consistent, occurring in two of the three years. Work is continuing using other BSR types.

INDEX DESCRIPTIONS: rotations, cropping systems

Maize and soybean are the primary row crops in much of Iowa and the North-Central United States, and often, they are grown in sequence. However, 30% or more of the maize follows itself (second-year maize) in the cropping sequence (G. Benson, Iowa State Univ., pers. commun.). In the midwest, maize grown after itself regularly yields 5 to 15% less, sometimes up to 25% less, than maize that follows soybean (Benson, 1985). Although soybean provides some nitrogen (N) to a following crop [Power et al. (1986) report that almost all N in soybean residues is mineralized and available for a following crop, and Hanson et al. (1988) calculate the benefit at about 94 kg N/ha], at least some of the soybean benefit persists even under heavy nitrogen fertilization of maize (Benson, 1985; Welch, 1985). This non-N benefit often is referred to as the "rotation" effect.

Others have shown that second-year maize is less vigorous than rotated maize. Crookston et al. (1991) observed that continuous maize showed lesser dry weight at silking, which persisted until maturity. Sarobol (1986) found that maize after soybean silked earlier than continuous maize. The reason(s) for lower vigor and depressed yields of second-year maize and, likewise, for the benefits of rotation are speculative and have been extensively debated (Anderson et al., 1988; Crookston, et al., 1988, 1991; Johnson et al., 1992; Voss and Shrader, 1984). Whatever the reason, the accelerated development and greater vigor of maize resulting from rotation with soybean seems advantageous to final yields.

Knowledge of rotation effects is essential, not only for measuring these effects, but also for reducing energy use and pollution potential (Baldock et al., 1981). Excessive N application to maize following soybean could result in significant N losses leading to deleterious environmental effects. Also, without an understanding of the magnitude of rotation effects, little progress in rotation improvement can be expected (Russelle et al., 1987).

Previous work with the soybean-maize rotation, never has evaluated the potentially different effects of soybean genotypes on following maize yields. Variability in growth habit, N_2-fixation rates, and dry matter production of different soybean genotypes possibly could influence the performance of following maize. Knowledge of potentially different effects would help producers when choosing a soybean cultivar. They could choose a cultivar not only for its yield but also for degree of its positive effect on following maize. Therefore, the main objectives of this study were to (*i*) evaluate the nitrogen and rotation effects of diverse soybean genetic types on the yield of a subsequent maize crop and (*ii*) compare the performance of maize following itself vs. maize following soybean or oat in rotation.

MATERIALS AND METHODS

The experiment was conducted for four years on an Aquic Hapludoll soil (Nicollet silt loam) at the Iowa State University Agronomy Research Center, Boone County, Iowa — 40°N latitude. Precipitation amounts and distribution, as well as the prevailing temperature during the growing season, are presented in Table 1. A two-year cycle of a soybean-maize rotation was initiated in 1988, with the first year being planted to various soybean genotypes, a maize hybrid, and oat. In 1989 and 1990, a second maize and oat plot were added to improve the estimate of maize performance following these crops (Table 2). A single maize hybrid was no-till sown in the second year over all first-year plots, with an additional factor of several N levels. This cycle was repeated three times, and the last maize crop was harvested in the fall of 1991. As maize was sown, the soybean crop of the next cycle also was sown in an adjacent area.

Table 1. Mean air temperature and precipitation at the Agronomy Research Center, Boone, Co., Iowa.

	Month					
Year	May	June	July	Aug.	Sept.	Total
			Mean air temperature, °C			
Normal	16.2	21.2	23.3	22.1	17.5	
1988	19.7	23.7	24.3	24.6	18.9	
1989	16.1	20.2	23.7	21.7	16.3	
1990	14.3	21.6	22.5	22.4	19.9	
1991	18.3	23.2	23.2	21.8	17.4	
			Precipitation, mm			
Normal	114.6	131.3	97.0	98.3	85.1	526.3
1988	43.7	53.8	84.8	151.6	84.8	418.7
1989	129.0	90.2	60.7	43.2	105.6	428.7
1990	213.9	213.4	192.3	106.9	58.2	784.7
1991	129.8	107.9	43.4	91.2	60.9	433.2

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Table 2. Rotational scheme for one replication of the four-year experiment.

Year of cycle	Year			
	1988	1989	1990	1991
1st	16 soybean types	Soybean	Soybean	—
	1 Maize plot	2 Maize plots	2 Maize plots	—
	1 Oat plot	2 Oat plots	2 Oat plots	—
2nd	—	Maize	Maize	Maize

Soybean Crop (First Year of the Cycle)

The first year of the cycle consisted of the 18 treatments listed in Table 3. Treatments were arranged in a randomized complete block (RCB) design with 16 replications in the field. The soybeans included determinate, indeterminate, early-maturing, full-season, low-yielding, and high-yielding genotypes. Because of their growth habit, determinates adapted to northern latitudes produce less vegetative mass that can be returned to the soil, as do early-maturing lines. These may affect the next crop differently. Lines with different yielding potentials also might have differential effects on the following maize crop. In Iowa, it often is recommended that farmers allow 1 lb/A N credit for each bushel yield of previous soybean crop (1 kg N/ha per 66 kg soybeans).

The maize hybrid used was Pioneer 3475. First-year maize was fertilized with 45 kg N/ha as urea. This low rate was used to minimize N carryover, which might affect the evaluation of the next crop. Oat was included in the study to evaluate the effect of a crop other than soybean on subsequent maize. Oat was cut after the heading stage, and all residue remained on the plots and was incorporated with fall tillage.

Maize Crop (Second Year of the Cycle)

In the second year of the cycle, the field was planted uniformly to Pioneer 3475 maize, the same hybrid used in the first year of the cycle. An additional factor of varying N fertility was included in the second year: rates of 0, 80, 160, and 240 kg N/ha were broadcast as

Table 3. Treatments for the first year of the soybean-maize cycle.

Crop	Characteristics
1. Gnome 85	Det.[a], High-yielding, Phytoph.[b] N.B. resist.
2. Hoyt	Det., High-yielding
3. Harosoy 63	Indet., Medium-yielding, Phytoph.[b] N.B. resist.
4. L66-2470	Non-nodulated isoline of Harosoy
5. Corsoy 79	Indet., High-yielding, Phytoph. resist.
6. Century 84	Indet., High-yielding, Phytoph. resist.
7. SRF 150	Indet., High-yielding.
8. Elgin	Indet., High-yielding.
9. Elgin 87	Indet., High-yielding, Phytoph. resist.
10. Pride B216	Indet., High-yielding.
11. BSR 201	Indet., High-yielding, Brown stem rot[c] resist.
12. PI 297.545[d]	Indet., Medium-yielding
13. PI 84.673	Indet., Low-yielding
14. PI 68.439	Indet., Low-yielding
15. PI 88.355	Indet., Low-yielding
16. PI 92.592	Indet., Medium-yielding
17. Maize-Pioneer 3475	
18. Oat	

[a]Det., determinate; indet., indeterminate.
[b]*Phytophthora megasperma* Drech. f. sp. *glycinea* Kuan & Erwin.
[c]*Phialophora gregata* (Allington & Chamberlain).
[d]PI, unimproved soybean Plant Introductions.

urea at the V6 stage and incorporated by cultivation. The field was arranged as a split-plot in RCB with the previous year's treatments as subplots and N rates as the main plots. Thus, there were four replications the second year.

RESULTS

The Soybean Crop

The soybean genotypes performed as expected (Figure 1); i.e., those selected for higher yield (treatments 1, 2, and 5 through 11) yielded highest, as compared with those selected for their lower productivity (treatments 13, 14, and 15). Genotypes 3, 12, and 16 were considered medium yielders and performed as such. The determinates (treatments 1, 2) did not differ significantly from the indeterminates. The non-nodulating genotype (treatment 4), which was solely dependent upon soil mineral N, yielded poorly, as expected. It had the least N concentration in its vegetative tissues and, consequently, the least vegetative N content per hectare. No diseases were observed on these crops.

The Maize Crop

The analysis of variance for yield and other traits (Table 4) show that year, nitrogen, and treatment were all highly significant. The N by treatment interaction was significant only for stalk diameter, indicating that treatments performed consistently with respect to nitrogen level for most variables. The year by nitrogen interactions likely are attributable to the different amounts of rainfall for each crop year. Both 1989 and 1991 were dry years compared to 1990 and normal. Precipitation was especially low in July 1991 (Table 1). Ovule growth, pollination, and embryo development, all of which are critically important in determining potential yield and all of which are particularly vulnerable to water stress, occur in July.

The yield response of the maize crop varied, depending upon treatment–i.e., previous crop (Table 5). The overall trend for maize following soybean to be superior to second-year maize was affirmed. Non-orthogonal contrasts show that maize following itself (treatment 17) yielded less than maize following other crops, including oat. This response was consistent all three years. Following nodulated soybean, maize averaged 16%, 1270 kg/ha, greater yield; following oat, maize yield was 20%, 1570 kg/ha, greater. The percentage increase in yield of maize after nodulated soybean or oat over that of second-year maize was greater in the drier years of 1989 and 1991.

The depressed yields of second-year maize paralleled its poor performance in other agronomic traits. These plants were shorter, had smaller stalk diameter, and were delayed in silking. When fertilized with N, second-year maize took about 4 days longer to attain 75% silking, up to 5 days when no fertilizer was applied (Table 6).

Maize after nodulated soybean performed better than second-year maize at each N level (Figure 2). With no N, the advantage was about 2180 kg/ha. The advantage decreased with additional increments of nitrogen, but even at the highest N level, there was a yield advantage of ca. 500 kg/ha from having soybean as the previous crop. Maize following non-nodulating soybean also was superior to second-year maize. At zero N, the yield difference was small, 870 kg/ha in contrast to 2180 kg/ha for nodulated soybean.

Maize after oat also performed better than second year maize at each N level and followed the same trend as that of maize after soybean. The yield advantage at zero N is slightly, though not statistically significantly, greater following oat (2640 kg/ha) than following the average of all nodulated soybeans.

Maize following BSR 201 soybean gave the highest yield among all the treatments in two of the three years and for the three-year average (Table 5 and Figure 2). The other nodulated lines did not differ in their benefit to maize. BSR 201 is a brown-stem-rot resistant, high-yielding, indeterminate, nodulating soybean variety. With the application of N fertilizer, the yield difference did not narrow as

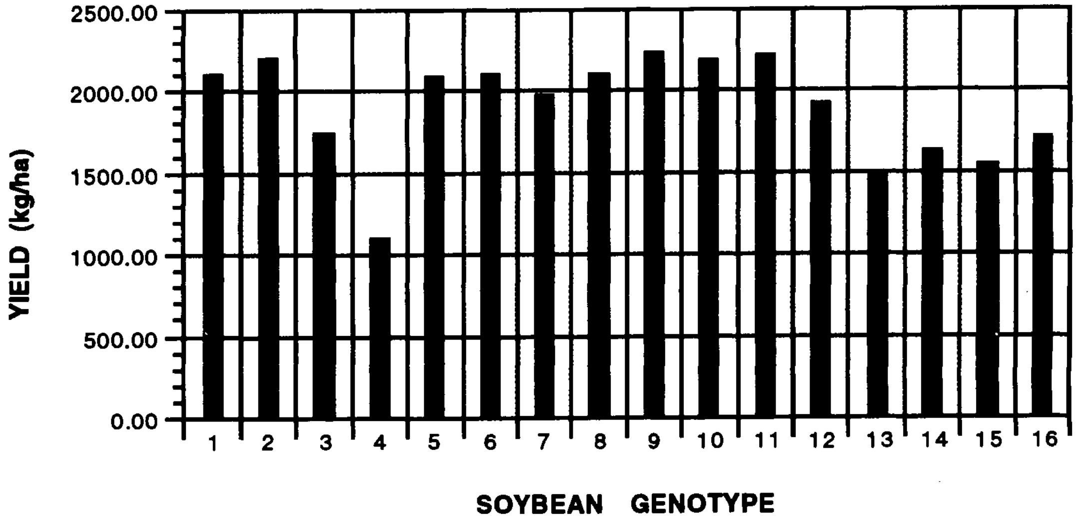

Fig. 1. Soybean yields averaged for three years. See table 3 for genotype identity. $LSD_{0.05}$ is 297.9.

much as with other soybean lines. At zero N, the difference between maize after BSR 201 and second year maize was ca. 2960 kg/ha, whereas maize after the other nodulated soybean lines averaged about 2180 kg/ha. Even at 240 kg N/ha, the yield advantage from BSR 201 was still substantial compared with the effects of all nodulated soybeans: 1700 kg/ha for BSR 201 compared with 500 kg/ha for the average of all other nodulated soybeans. Thus, even at the highest N level, the soybean benefit was enhanced if BSR 201 was the previous crop as opposed to the other nodulated soybeans tested.

DISCUSSION

Advantage of Rotation

It is very difficult, if not impossible, to ascribe specific causative effects, either positive or negative, to the previous crop in a rotation. A previous crop may benefit a subsequent one by providing a residue high in nitrogen, removing less water, by suppressing the population of insects or disease organisms, or perhaps even by contributing beneficial organic compounds, allelochemicals, through its residue or root exudates. The effects of a previous legume crop on subsequent maize often are partitioned into a nitrogen effect and a non-nitrogen "rotation" effect. The rotation effect is estimated as the yield stimulus provided by the previous crop under yield-maximizing levels of nitrogen fertilization for second-year maize–e.g., at the 240 kg/ha N rate in our study. The N benefit is estimated as the yield stimulus of the legume at zero N fertilization minus the rotation effect.

It is, however, not established that the rotation effect is wholly a non-nitrogen effect. Anderson et al. (1988) have speculated that the amount, form, or position in the profile of "readily" available organic N left by legumes may be available in a temporal way (over a longer period) to the following maize crop, which allows greater yield than that possible with fertilizer N alone. Crookston et al. (1988), on the

Table 4. Mean squares for maize yield and other traits.

Source	df	Seed Yield (x 10^{-6})	Days to 75% silk	Plant Height (x 10^{3})	Stalk diameter
Year	2	168.6**	11185.6**	350.99**	15.2**
Rep (Yr)	9	4.9	20.4	2.80	0.2
N	3	338.0**	169.6**	3.38**	5.7**
Yr x N	6	84.2**	11.5	1.56**	0.3**
Rep x N(Yr)	27	4.6	8.0	0.20	0.1
Trt.	17	6.6**	50.6**	0.13**	0.3**
nod-M vs. M-M[a]	1	72.7**			
oat-M vs. M-M[b]	1	59.3**			
nnod-M vs. M-M[c]	1	24.3**			
201-M vs. M-M[d]	1	86.9**			
Yr x Trt	34	2.0*	2.4	0.15**	0.1**
Rep x Trt (Yr)	153	1.2	1.5	0.06	0.03
N x Trt.	51	0.1	1.3	0.06	0.03*
Yr x N x Trt.	102	1.2	1.6	0.07	0.02

[a]maize after all nodulated soybeans except BSR 201 vs. maize after maize.
[b]maize after oat vs. maize after maize.
[c]maize after non-nodulated soybean vs. maize after maize.
[d]maize after BSR 201 soybean vs. maize after maize.

Table 5. Effect of previous crop on maize yields, kg/ha., x10^{-3}, averaged for all N-levels

Previous Crop	1989	1990	1991	3-yr. avg.
1. Gnome 85	9.16	9.51	8.24	9.08
2. Hoyt	9.29	9.91	8.25	9.11
3. Harosoy 63	9.44	9.54	7.71	8.91
4. L66-2470	8.59	9.99	8.04	8.87
5. Corsoy 79	9.81	9.32	8.30	9.03
6. Century 84	9.66	9.73	8.19	9.25
7. SRF 150	9.27	9.45	8.35	8.99
8. Elgin	9.47	9.81	8.46	9.24
9. Elgin 87	8.73	9.64	8.30	8.87
10. Pride B216	9.48	9.07	8.44	8.99
11. BSR 201	10.19	10.83	8.22	9.77
12. PI 297.545	9.18	9.53	8.22	8.97
13. PI 84.673	9.37	9.49	8.58	9.16
14. PI 68.439	9.55	9.56	8.36	9.18
15. PI 88.355	9.35	9.66	8.61	9.18
16. PI 92.592	9.92	9.68	8.54	9.33
17. Maize	7.78	9.19	6.50	7.87
18. Oat	9.39	10.40	8.51	9.44
LSD (.05)	1.11	0.63	0.52	0.45
% increase over maize after maize:				
for maize after nod. SB	21.6	5.0	28.0	16.1
for maize after oat	20.7	13.2	30.9	19.9

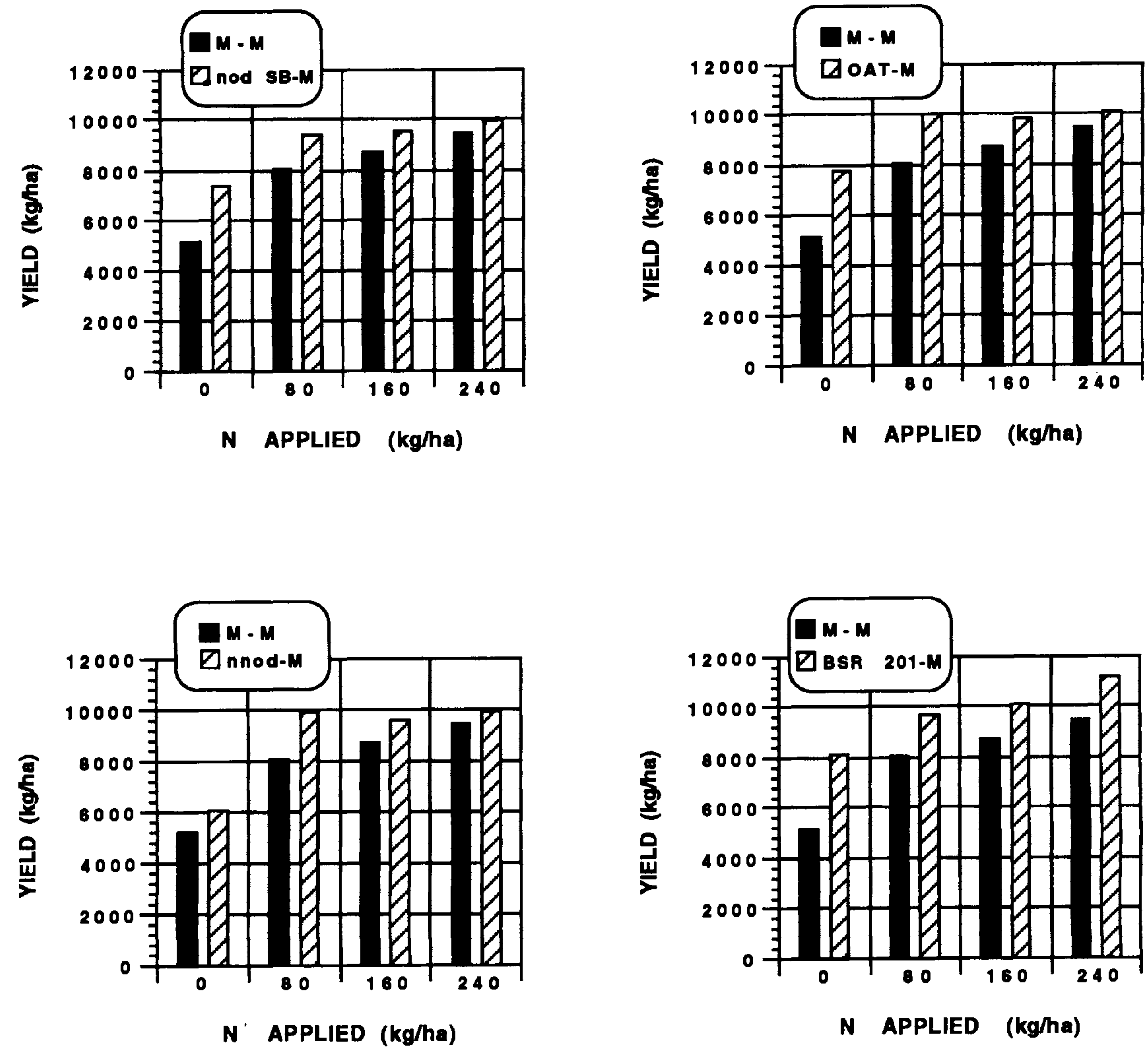

Fig. 2. Yield performance of second-year maize vs. maize following other crops under various N rates. Average of three years' data. M-M means maize following maize; nodSB-M is maize following nodulated soybean, averaged for all 15 nodulated soybean lines; nnod-M is maize following non-nodulated soybean; BSR201-M is maize following BSR201 soybean; and Oat-M is maize following oat.

other hand, believes that the rotation effect is due not to some lingering positive effect of the previous crop but, rather, that an alternate crop evidently serves to relieve "negative effects" of continuous cropping and does not make any positive, growth-regulatory contribution to the yield of a following crop. It is difficult to identify whether allelochemicals might be associated with grain yield reduction (Crookston, 1982), but there is an indication that the maize root system may produce a factor in the surface 15 cm of soil that is toxic to young maize plants (Garica, 1983). On the other hand, Johnson et. al. (1992) postulate that continuous cropping may lead to proliferation of detrimental mycorrhizal fungi. They found that mycorrhizal fungi populations that proliferated under maize were negatively correlated with maize yield and tissue mineral concentration but positively correlated with the following year's soybean yield and tissue mineral concentration, and vice versa. Whatever the cause(s) of yield reduction in second-year maize, it seems that it is due to the roots of plants growing in the soil and is not primarily due to the residue of the plant tops left by previous maize (Anderson, et al., 1988; Crookston and Kurle, 1989). Blackmer (A. Blackmer, Iowa State University, pers. commun.) has observed rootworm (*Diabrotica* sp.) damage on second-year maize that received an insecticide treatment to eliminate rootworms and speculates that insecticides amy not give full control of the rootworm in second-year maize. If having maize as a previous crop results in a root system with less growth and vigor, this then leads to poorer uptake of nutrients and especially moisture, which, as suggested by Benson (1985), could be a reason second-year maize shows greater yield depression in dry years. Our experience was that there were larger yield differences in dry years (Table 5).

It is also possible that the inhibitory effect of previous maize is due to the large amount of organic carbon (and low N) left in the soil, which may immobilize soil ammonium N (Anderson et al., 1988; Kohl et al., 1980). Any or all of these factors could explain the poorer performance of maize after maize. It is probable that the cause is not a single factor but a combination of several factors.

The percentage increase in yield due to oat or soybean as a previous crop was greater in dry years (Table 5). Because oat was cut early

Table 6. Effect of nitrogen on days to 75% silking. Average for three years.

N level	Days to 75% Silk M-M[a]	Days to 75% Silk SB-M[b]	No. of Days Delay in silking
(kg/ha)			
0	83.1	78.2	4.9
80	81.0	76.8	4.2
160	80.9	76.5	4.4
240	80.2	76.3	3.9

[a]maize after maize
[b]maize after all soybean crops

and the residues left on the ground, it may be assumed that more moisture was conserved under oat than with maize as a previous crop. This could have contributed to the rotation effect from oat. Because soybean is a full season deep-rooted crop, we believe it unlikely that the soybean crop left a greater moisture reserve than a maize crop for the succeeding year. Indeed, Shaw and Laing (1965) have shown maize and soybean to have very similar seasonal evapotranspirational profiles. We believe that the reasons for the soybean rotation effect lie elsewhere.

Does Soybean Contribute Nitrogen to Following Maize?

Assuming that the rotation effect is a non-nitrogen effect, the direct nitrogen contribution of a previous crop can be estimated from the yield differences between rotated maize and second-year maize at 240 kg/ha vs. those differences at zero N fertilization. We emphasize and caution that this interpretation rests on the assumption that the rotation effect is similar in absolute terms at both the zero and high N fertilization rates. Evidence from our experiment that this may be true is that non-nodulated soybean, the residues of which were very poor in nitrogen, gave about the same yield stimulation at zero and high N fertilization.

Comparison at 0 and 240 kg N/ha of the yield differences between maize following soybean vs. second-year maize–2180 vs.520 kg/ha–implies that soybean contributed the fertilizer N equivalent of 1660 kg/ha of maize yield. However, the same comparison method seems to suggest that oat contributed N to subsequent maize also, because it gave an even greater yield contrast at zero compared with 240 kg N – 2640 vs. 660 kg/ha or a difference attributable to an apparent N contribution of 1980 kg/ha of maize; 320 kg more than soybean. Of course, the apparent N effect from oat cannot be due to any actual input of nitrogen by oat because oat received no N fertilizer and the grain and straw were not removed from the plot. On the other hand, mineralization of soil organic-N occurred under oat and this N was available to following maize. Thus, the putative N input of oat is apparent, not real.

The N-response of maize to soybean at zero N probably is due to the return to the soil of soybean vegetative N in amounts, we estimate 60 to 70 kg/ha fertilizer-N equivalents, almost equal to the N mineralized from soil organic matter. Assuming that mineralization of N under soybean would be similar to that under oat, we conclude that soybean does not make a *net* nitrogen input to the nutrition of following maize. Its N input is about the same as the normal mineralization rate.

The BSR-Effect

Overall, maize after BSR 201 gave the highest yields. At the two highest N fertilization levels, the yield advantage was 680 kg/ha, or approximately 11 bu/A, more than the average or the other nodulating soybean lines. The BSR 201 superiority was not consistent, however, occurring in two of the three years. Currently, we are verifying whether the BSR-effect is real using BSR 201 and other brown-stem-rot resistant types.

CONCLUSIONS

Maize that follows itself in the cropping sequence yields less than maize after soybean or oat, even at a high nitrogen fertilization rate. The "rotation" benefit to maize from soybean averaged about 720 kg/ha (ca. 11.5 bu/A), from oat it averaged about 840 kg/ha (ca. 13.4 bu/A).

Soybean provides a N fertilizer equivalence benefit to following maize of about 60 to 70 kg/ha, about the same amount of N as would be expected to occur from normal mineralization of soil organic-N in this soil. Thus, soybean probably does not make a *net* N input to following maize.

BSR soybean may provide a greater rotation benefit to following maize than other soybean lines.

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