Yield-Soil Water Relationships in Sorghum-Soybean Cropping Systems with Different Fertilizer Regimes

W. Roder, S. C. Mason,* M. D. Clegg, and K. R. Kniep

ABSTRACT

Crop rotation of soybean [*Glycine max* (L.) Merr.] with grain sorghum [*Sorghum bicolor* (L.) Moench], and application of N fertilizer or manure generally increases grain sorghum yield. Little is known about rotation and fertilization effects on soybean yield in the Great Plains. Grain yields were measured from 1981 to 1987 in a cropping experiment started in 1980 on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll). The cropping treatments included continuous soybean, continuous grain sorghum, and grain sorghum-soybean rotation. Fertilizer treatments consisted of control, manure (15.8 Mg dry matter ha^{-1} yr^{-1}1) and N (45 kg ha^{-1} for soybean and 90 kg N ha^{-1} for sorghum). Volumetric soil water content was determined with a neutron probe in 1985, 1986, and 1987. Soil water content was unaffected by fertilizer treatment. Water content in the upper 30 cm was generally greatest with continuous grain sorghum and least with continuous soybean. Soil water depletion to 120 cm in September was 10 to 36 mm greater with soybean than with grain sorghum. Crop rotation increased soybean yield, but N application did not. Manure application reduced soybean yield in 1986, but had no effect in the other years. Rotation and fertilization increased sorghum grain yield. The soybean yield advantage from crop rotation decreased as 1 April to 31 May rainfall increased. Cropping-system induced differences in soil water content early in the growing season may be partly responsible for higher soybean yield with crop rotation.

BECAUSE alternative production systems are needed to satisfy economical and environmental needs, the potential of crop rotation merits reevaluation. Soybean and grain sorghum are major dry land crops in the Great Plains. Rotation of these crops or application of N fertilizer, or both, generally increases sorghum grain yield (Clegg, 1982; Baker and Blamey, 1985). Crop rotation research has centered mostly on the potential N contribution by legumes and its effect on subsequent cereal crops, while other effects remain poorly understood (Kurtz et al., 1984).

Little information is available on the soybean response to continuous cropping or fertilization, or both, in the Great Plains. Soybeans have been grown continuously in some areas without serious yield reduction (Pendleton and Hartwig, 1973). However, recent research has shown yield advantages of 11% and 14% for rotated soybean in Illinois and Minnesota, respectively (Johnson, 1987). Continuous soybean cropping may cause adverse effects on soil physical properties reducing yield (Fahad et al., 1982).

Nitrogen fertilizer studies with soybean have shown variable results. Studies finding no effect of fertilizer N on soybean grain yield include Baldock et al. (1981), Deibert et al. (1979), Hinson (1975), and Bharati et al. (1986). Those showing increased grain yield of soybean from N application include Bhangoo and Albritton (1976), Boswell and Anderson (1976), and Sorensen and Penas (1978). Dev and Tilak (1976) reported increased soybean yield with manure treatment, whereas Criswell et al. (1976), and Johnson and Hume (1972) found no effect.

From crop harvest to canopy closure of the succeeding crop, the amount and quality of surface residue strongly affects water content of the soil (Van Doren and Allmaras, 1978; Doran et al., 1984). Compared with grain sorghum, soybean produces less residue, which decomposes more rapidly. Cropping systems affect soil porosity, which affects soil water content, water transmission properties (Skidmore et al., 1975; Fahad et al., 1982), and root growth (Kahnt et al., 1986). Fahad et al. (1982) showed cumulative water infiltration after 4 h of 6, 13, 29, and 41 cm for continuous soybean, grain sorghum after soybean, fallow after soybean, and corn after grain sorghum, respectively. Large applications of manure increased the infiltration rate and permeability of some soils (Mathers et al., 1977; Mazurak et al., 1975; Sweeten and Mathers, 1985), decreased it in some (Lehman and Clark, 1975; Weil and Kroontje, 1979), or had no effect (Sommerfeldt and Chang, 1987).

Seasonal water use for soybean grown in the midwestern USA typically ranges from 330 to 766 mm (Van Doren and Reicosky, 1987; Kanemasu et al., 1976), with maximum water use occurring during reproductive stages. Kanemasu et al. (1976) reported evapotranspiration was 13% greater for soybean than for grain sorghum.

A rotation experiment with grain sorghum and soybean was initiated in 1980 to test the hypotheses that; (i) continuous cultivation of soybean leads to yield depression, (ii) crop rotation effects on soybean grain yield are largely caused by soil water content changes, and (iii) yield from continuous cultivation of grain sorghum or soybean can be maintained through the application of N fertilizer or manure. We expected manure application would reverse negative effects of continuous soybean cropping on soil physical properties.

MATERIALS AND METHODS

Cropping treatments consisting of continuous grain sorghum, continuous soybean, grain sorghum-soybean rotation, and soybean-grain sorghum rotation were started in 1980 on a Sharpsburg silty clay loam. Fertilizer treatments consisting of no fertilizer (control), manure (15.8 Mg dry matter ha^{-1}), or fertilizer N (45 kg ha^{-1} for soybean, 90 kg ha^{-1} for grain sorghum) were applied yearly beginning in 1981. Manure was applied before planting. Total N applied in manure was 170 $\pm$ 12 kg ha^{-1} yearly, except in 1984 when 247 kg ha^{-1} was applied. Fertilizer N was applied 3 to 4 wk

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after planting as liquid urea-ammonium nitrate from 1981 to 1985, and dry ammonium nitrate in 1986 and 1987. Treatment combinations were applied in the form of a split plot randomized complete block design with 16 replicates (Table 1). The whole plot treatments consisted of sorghum or soybean in even numbered years. This design facilitated field work in even numbered years, but reduced the power for testing previous-crop effects in the subsequent years.

Tillage was uniform for all treatments, and generally consisted of disking after manure application and double disking before planting. Plots were planted with a 6-row John Deere Max-Emerge planter (John Deere, Moline, IL). Plots were 12 rows wide, with 0.75 m row spacing and 7.8 m row length. All observations were limited to the four center rows, using the middle 5.4 m.

Soil water content was estimated in 1985, 1986, and 1987, using a neutron probe (Campbell Pacific 503 DR, Campbell Pacific, Pacheco, CA). Access tubes were installed in a central row of each plot of 4 replicates after plant emergence. Probe readings were taken once a month in 1985, and twice a month in 1986 and 1987 during the growing season, with additional readings after harvest and the following March (1986 and 1987). Readings were taken in 30-cm increments to a depth of 120 cm.

Yield data are based on results of 16 replicates, except for 1983 and 1986 when eight replicates were excluded (none of

Table 1. Degrees of freedom (df) summary for analysis of grain yield and soil water measurements from 1981 to 1987.

	Yield measurements		Soil water measurements	
	Years			
	Odd	Even	1985, 1987	1986
	df			
Replicate[1]	15	15	3	3
Crop	1	1	1	1
Replicate × crop	—	15	—	3
Previous crop	1	1	1	1
Replicate × previous crop	15	—	3	—
Fertilizer	2	2	2	2
Crop × previous crop	1	1	1	1
Crop × fertilizer	2	2	2	2
Previous crop × fertilizer	2	2	2	2
Crop × previous crop × fertilizer	2	2	2	2
Error[1]	150	150	30	30
Total	191	191	47	47

[1] Yield observations in 1983 and 1986 were limited to eight replicates consequently. Degrees of Freedom (df) for replicates and error were only 7 and 70, respectively, in these years.

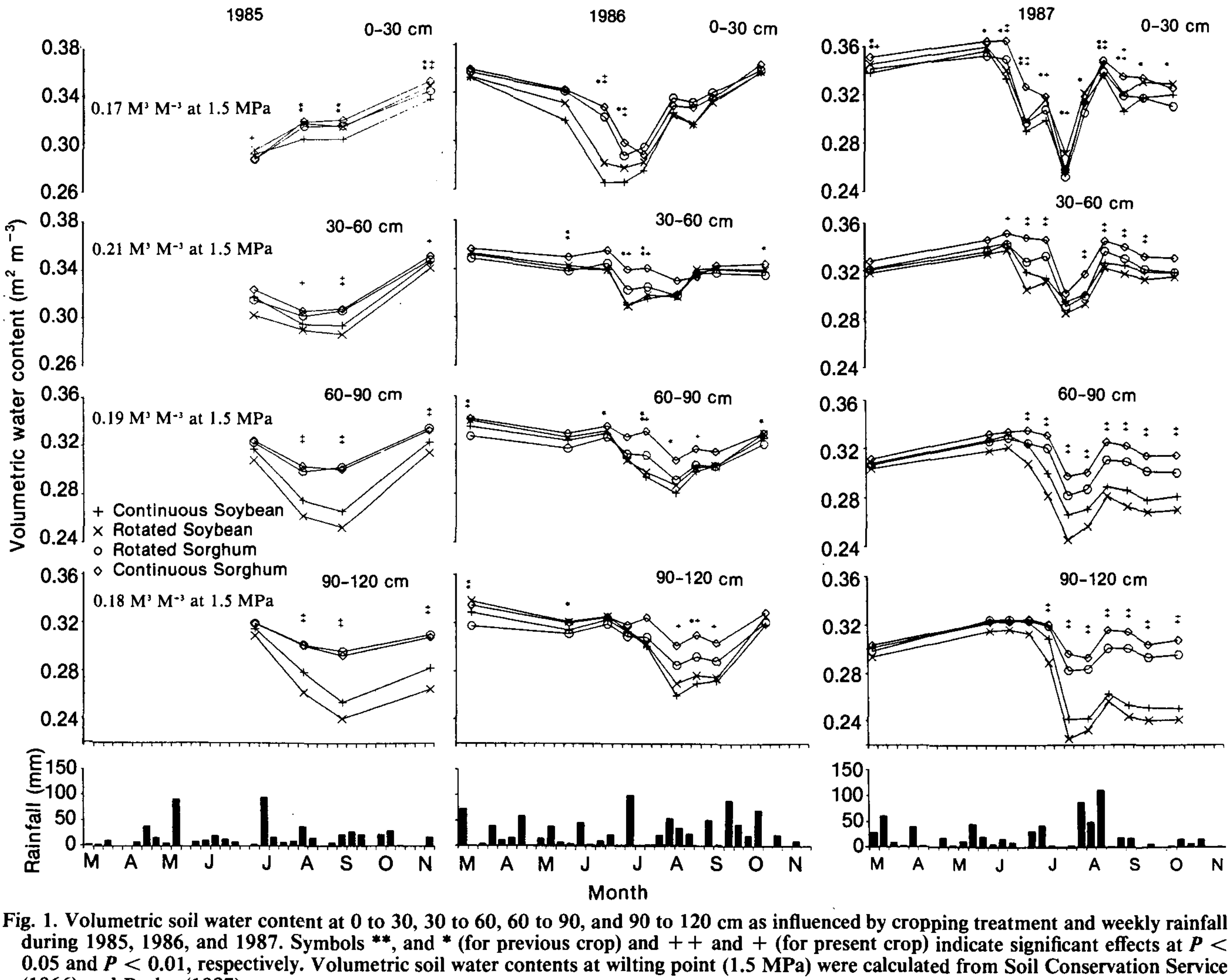

Fig. 1. Volumetric soil water content at 0 to 30, 30 to 60, 60 to 90, and 90 to 120 cm as influenced by cropping treatment and weekly rainfall during 1985, 1986, and 1987. Symbols **, and * (for previous crop) and ++ and + (for present crop) indicate significant effects at $P < 0.05$ and $P < 0.01$, respectively. Volumetric soil water contents at wilting point (1.5 MPa) were calculated from Soil Conservation Service (1966) and Roder (1987).

these were used for soil water measurements) due to problems resulting from poor weed control. Grain yields were adjusted to 120 and 140 g kg^{-1} water content for soybean and grain sorghum, respectively. Due to delayed planting, grain sorghum did not reach maturity in 1984 and was not harvested.

Crops were harvested with a plot combine, except for grain sorghum in 1985. Data were analyzed separately for each year because the design precluded analysis of two subsequent years. Single degree-of-freedom comparisons were used to test treatment variables (Steel and Torrie, 1980). The relationship between relative soybean yield increase due to rotation, and monthly precipitation or average monthly temperature was estimated by simple correlation. Relative-yield-increase (RYI) from rotation was calculated as follows:

$$RYI = [(YR - YC) \times 100]/YC$$

where YR = yield rotation and YC = yield continuous.

Based on correlation values, the variables 1 to 31 March, 1 April to 31 May, 1 to 30 June, total precipitation in the previous year, and average temperature for August were selected and tested using stepwise regression, backward elimination, and forward selection to identify the best fitting model.

RESULTS AND DISCUSSION

Soil Water Dynamics

Rainfall from 1 May to 30 September in 1985, 1986, and 1987 was 75, 116, and 88% of the 30-yr average precipitation of 842 mm. Soil water content and rainfall distribution are shown in Fig. 1. Because fertilizer treatment effects were absent only average values for crop and previous crop are shown. Soil water content generally decreased at all depths during the growing season. Water depletion shortly after planting occurred predominantly from the surface 30 cm of soil. As the season progressed, water depletion shifted to lower depths. During the 1985 and 1987, and the initial part of the 1986 growing season, soil water content of the 0 to 30-cm depth was generally greatest with continuous grain sorghum and least with continuous soybean. Increased residue cover with grain sorghum as a previous crop may be largely responsible for this effect in spring and early summer. Other factors, such as increased water infiltration rate following grain sorghum as previous crop, increase in importance as the growing season progresses (Fahad et al., 1982). Previous crop water use was reflected in 1986; the soil was drier at all depths at planting time when soybean was the previous crop.

During 1985, water reserves were least in September, whereas the driest levels in 1986 and 1987 occurred in August (Fig. 2). Stored soil water in August, ranked from least to greatest, showed rotated soybean < continuous soybean < rotated grain sorghum < continuous grain sorghum in all three seasons. Differences in soil water content between cropping treatments of the same crop remained constant over the season. Soybean used more water than grain sorghum in all three seasons. The amount of stored water in September of 1985, 1986, and 1987 was 34, 10, and 36 mm less, respectively, for soybean than for grain sorghum. Assuming a water use of 400 mm for soybean (Johnson, 1987), this difference represents 3 to 9% of the total water use, and is comparable to differences in evapotranspiration between the two crops (Kanemasu et al., 1976).

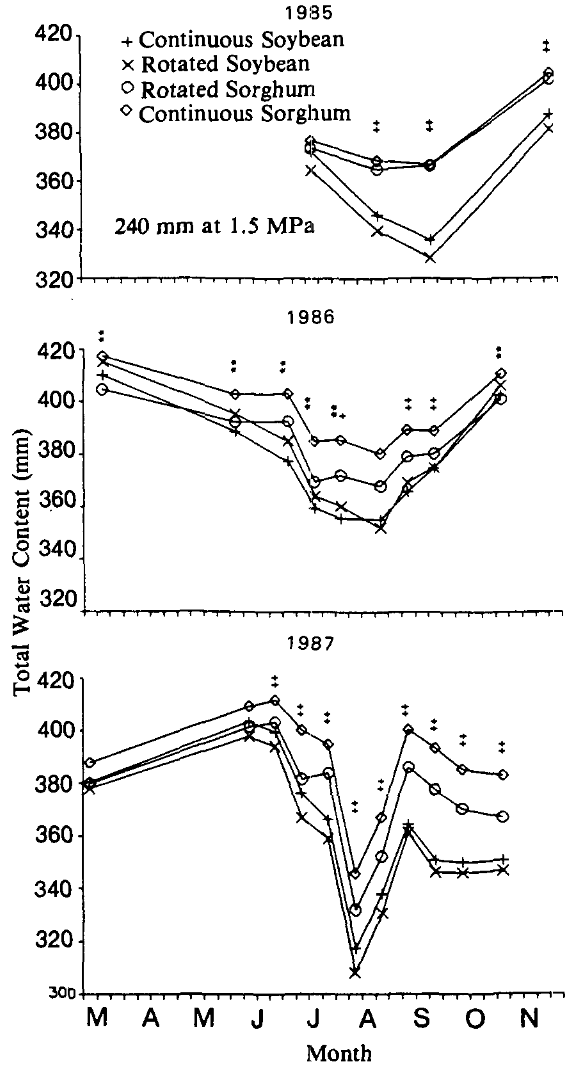

Fig. 2. Soil water content in the 0 to 120-cm profile as influenced by cropping treatment during 1985, 1986, and 1987. Symbols ** and * (for previous crop) and + and ++ (for present crop) indicate significant differences at $P < 0.05$ and $P < 0.01$, respectively. Soil water contents at wilting point (1.5 MPa) are as presented by Fahad (1979).

Grain Yield

Treatment effects on grain yield of both crops varied with year (Table 2). Cropping and fertilizer effects were absent in 1981; lack of effects were attributed to high initial inorganic soil N and only 1 yr of cropping history.

Soybean

Soybean yield was higher following grain sorghum than soybean, except in 1984 (Table 2). The yield increase from rotation ranged from 5 to 16%, and averaged 9% for the period 1981 to 1987. Neither manure nor N fertilizer application overcame the adverse effect of continuous cropping. While manure increased soil microbial biomass and total soil nitrogen sub-

Table 2. Previous-crop and fertilizer effects on soybean and grain sorghum yield.

Category		Year 1981	1982	1983	1984	1985	1986	1987	Avg.
		Mg ha^{-1}							
		Soybean							
Previous crop	Fertilizer								
Soybean	Control	3.11	2.76	2.68	1.87	2.79	2.49	2.29	2.57
	Manure	3.21	2.71	2.83	1.72	2.66	2.34	2.29	2.54
	Nitrogen	3.28	2.94	2.62	1.80	2.85	2.64	2.22	2.62
	Avg.	3.20	2.80	2.71	1.79	2.76	2.49	2.27	2.57
Sorghum	Control	3.35	2.91	2.91	1.88	3.15	2.64	2.63	2.78
	Manure	3.41	2.98	3.22	1.77	3.07	2.62	2.52	2.79
	Nitrogen	3.34	2.95	3.26	1.89	3.07	2.69	2.55	2.82
	Avg.	3.36	2.95	3.13	1.85	3.09	2.65	2.57	2.80
		PR > F							
Contrasts and F-test probabilities									
Previous crop (PC)		0.03	<.01	0.04	0.43	<.01	<.01	<.01	
Fertilizer									
Control vs. others		0.30	0.15	0.37	0.26	0.27	0.90	0.56	
Manure vs. nitrogen		0.86	0.03	0.71	0.25	0.12	0.01	0.87	
PC × Fertilizer		0.56	0.03	0.68	0.88	0.21	0.20	0.30	
C.V. (%)		9.9	6.6	22.4	17.4	7.6	7.6	12.0	
		Sorghum							
Previous crop	Fertilizer								
Soybean	Control	7.63	5.87	3.72		7.00	7.41	5.09	6.12
	Manure	7.70	6.22	4.66		7.74	7.71	4.92	6.49
	Nitrogen	7.52	6.14	3.53		7.69	7.89	5.24	6.34
	Avg.	7.62	6.08	3.97		7.48	7.67	5.09	6.32
Sorghum	Control	7.56	5.02	3.17		5.75	4.62	3.25	4.89
	Manure	8.05	5.74	3.32		7.50	7.18	4.47	6.04
	Nitrogen	7.29	5.97	2.13		6.98	8.04	5.52	5.99
	Avg.	7.63	5.58	2.87		6.73	6.61	4.44	5.64
		PR > F							
Contrasts and F-test probabilities									
Previous crop (PC)		0.91	<.01	0.20		<.01	<.01	<.01	
Fertilizer									
Control vs. others		0.73	<.01	0.92		<.01	<.01	<.01	
Manure vs. nitrogen		<.01	0.57	0.01		0.24	0.04	<.01	
PC × Fertilizer		0.18	0.69	0.57		0.05	<.01	<.01	
C.V. (%)		8.4	8.6	36.5		11.0	9.8	15.3	

stantially (Roder et al., 1988), soybean yields with manure were only equal to or less than those of the unfertilized control.

Soybean yield increases associated with crop rotation over the period 1981 to 1987 were negatively correlated with 1 April to 31 May rainfall (r^2 = 0.84, P = 0.02). Regression analysis showed a best fit for a linear model (Fig. 3). The manure and N treatments had higher variability than the control, but showed similar trends.

Rainfall from 1 April to 31 May equals 25% of the total annual precipitation, and is likely to affect stored soil water content for the entire growing season. Previous crop effects on soil water content were most pronounced in the surface 30 cm of soil. Water content was generally greater when grain sorghum rather than soybean was the previous crop. It is speculated that cropping-induced differences in soil water content related to residue cover and water infiltration affected crop development, mainly during the initial period when the root system had not yet reached lower depths. Total root length observed in 1986 and 1987 was 24 and 19 km m^{-2} for soybean following sorghum and 15 and 13 km m^{-2} for continuous soybean, respectively (Roder, 1987). Similar effects of continuous cropping on soybean root development were reported by Fahad (1979). Cropping effects on root development would accentuate soil water differences. It can only be speculated that the rotation advantage with reduced 1 April to 31 May precipitation resulted jointly from cropping effects on soil water content and soybean root development.

Grain sorghum

The highest sorghum yields were obtained with rotation and fertilizer combined (Table 2). Yield increases from rotation for unfertilized grain sorghum were 17, 22, 60, and 57% in 1982, 1985, 1986, and 1987, respectively. Effects of previous crop did not affect yield in 1983, probably because of variation created by poor weed control. Weed competiton in 1983 also appeared to be the cause of a yield reduction with N fertilization. Except for 1986 and 1987, yields of unfertilized rotated sorghum were equal to or greater than yields of continuous sorghum receiving 90 kg N ha^{-1}. No consistent relationship existed between increased grain sorghum yield due to rotation and climatological variables.

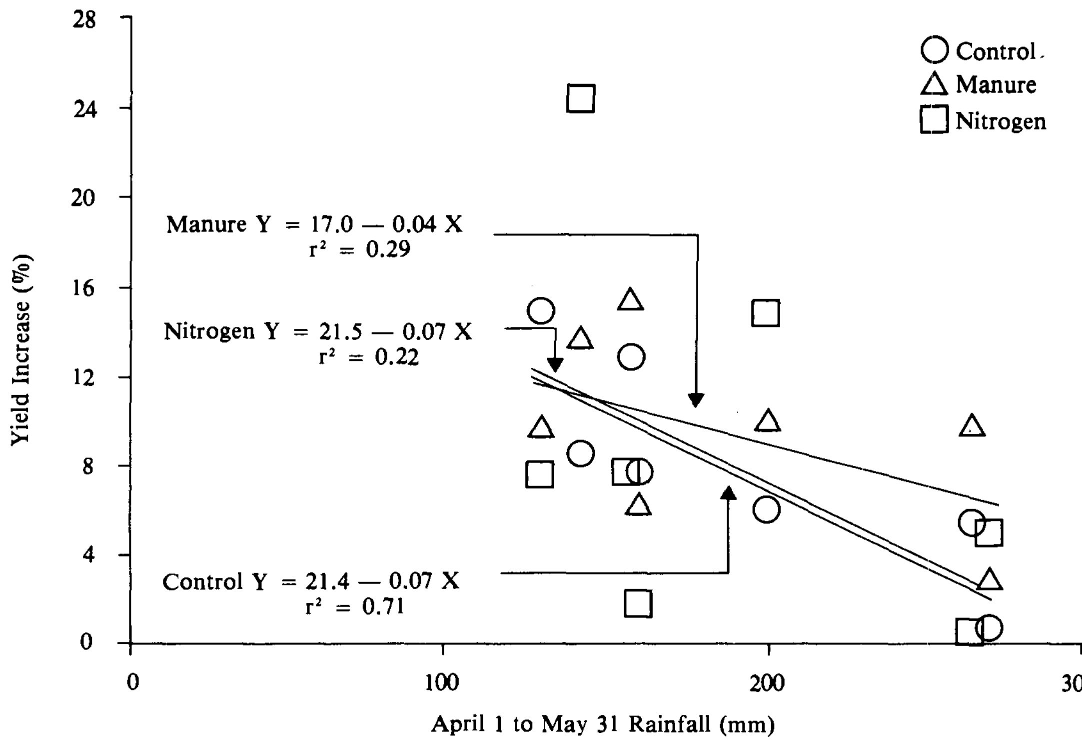

Fig. 3. Relationship between relative grain yield increase of soybean and 1 April to 31 May rainfall during the 1981 to 1987 period.

CONCLUSIONS

Soybean rotation offers yield advantages over continuous soybean cropping in eastern Nebraska. However, the yield advantage was smaller than those found in other regions. Neither manure nor N fertilization alleviated the negative effects of continuous cropping on soybean yield. The soybean yield advantage due to rotation may result partly from the degree of soil water depletion by the previous crop. Crop-specific evapotranspiration, the quantity of residue from the previous crop, and crop rotation effects on water infiltration were probably the main factors affecting soil water content in this study. The yield contribution of soybean in rotation to the succeeding sorghum crop was equivalent to 90 kg N fertilizer ha^{-1}.

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