Precipitation Use Efficiency of Soybean and Grain Sorghum in Monoculture and Rotation

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ABSTRACT

Rainfed cropping systems are highly dependent on water use efficiency of crops in the rotation, especially in subhumid and semiarid areas. Precipitation use efficiency (PUE), an alternative to water use efficiency, is equally effective for water use evaluation in long-term rainfed studies. We hypothesized that crop rotation and N fertilizer rates altered PUE of soybean [*Glycine max* (L.) Merr.] and grain sorghum [*Sorghum bicolor* (L.) Moench]. To test this, soybean (five cropping systems) and grain sorghum (four cropping systems) were grown under rainfed conditions at Mead, NE, on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll), each at three N fertilizer rates. Precipitation use efficiency values for the 1984 through 1991 cropping seasons varied from 15.5 to 59.9 and 21.6 to 159 kg ha^{-1} cm^{-1} for soybean and grain sorghum, respectively. Soybean PUE values averaged 30 kg ha^{-1} cm^{-1} and varied from 25 to 33 kg ha^{-1} cm^{-1} for the 8 yr. Grain sorghum PUE values averaged 89 kg ha^{-1} cm^{-1} and with sufficient N fertilization varied from only 94 to 99 kg ha^{-1} cm^{-1} for the 8 yr. Similar PUE values for soybean and grain sorghum (with adequate N fertilizer) within a given year and similar PUE values during the study among cropping systems for each crop indicated that both of these crops would be excellent options for rotations in areas with similar precipitation patterns.

SELECTION AND APPLICABILITY of cropping systems for different areas of the U.S. are based on both economic and environmental concerns. Specific crops are chosen for adaptability to the climate and soil of the area, performance in relation to other crops in the cropping sequence, and economic return. Crop choice is greatly affected by the availability of water, which is generally determined by local environmental conditions. Exceptions to this rule are made in areas where water is available for irrigation.

Availability of water for crop production generally decreases from humid to more arid areas. The number of crops adapted for a particular area follows a similar pattern, with fewer options available in reduced rainfall and more arid areas without irrigation.

Efficient use of available water by crops in a particular cropping system has received little attention, according to Pierce and Rice (1988). Their review noted that efficient water use has been mainly reported for crops in monoculture systems. One exception was the wheat (*Triticum aestivum.* L.)-fallow system predominant in the U.S. Great Plains. Extensive work has been reported for this system, probably because the wheat-fallow system is used widely in arid environments where water availability is extremely important (Greb, 1979; Haas et al., 1974; Smika and Wicks, 1968).

Researchers in the Great Plains area are now investigating more intensive cropping systems because no-till management systems have increased the amount of stored soil water. Reduced and no-till management increases infiltration and reduces evaporation losses, which have allowed the use of summer crops in the rotation. These systems have resulted in much greater water use efficiency and more efficient utilization of limited water resources.

Black and Bauer (1990), Halvorson (1990), and Peterson et al. (1992, 1993) have developed more intensive rotations to utilize the additional stored soil water resulting from no-till management. Evaluation of these systems has used a modified form of water use efficiency, namely, PUE (Halvorson, 1990).

More recently this procedure was utilized to evaluate cropping system effects on PUE by corn (*Zea mays* L.) grown in an area on the drier fringes of the Corn Belt. Varvel (1994) obtained additional information about the relative stability of corn production in various cropping systems in such an environment. The study concluded that corn grown in rotation had greater and more stable PUE and decreased yield variability than monoculture corn.

Precipitation use efficiency calculations in long-term studies like the one described above can be used to evaluate water and N use efficiencies within those experiments, even though evapotranspiration and soil water depletion have not been directly measured. Precipitation use efficiency values provide information similar to water use efficiency because they evaluate the effectiveness of precipitation in individual treatments from the same experiment for a long period of time. In this study, PUE values were calculated using data for 8 yr, which encompassed two cycles of the longest cropping systems in the study.

The initial study (Varvel, 1994) did not evaluate other crops in each rotation because of the complexity involved in assessing cropping systems that contain crops with different yield potentials and essentially a forage crop [oat (*Avena sativa* L.) + clover (*Trifolium* and *Melilotus* sp.), in the case of the two 4-yr rotations. Analysis of all cropping systems required assignment of some type of economic value to each crop, or the procedure used for corn (Varvel, 1994) could be used. Assignment of economic values required choice of crop prices, which is always difficult because of market fluctuation. Using the PUE approach eliminates this dilemma and allows the producer to choose crops for a rotation system with

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Abbreviations: PUE, precipitation use efficiency; CSB, continuous soybean, C-SB(2), 2-yr corn-soybean rotation; SG-SB(2), 2-yr grain sorghum-soybean rotation; SG-SB(4), 4-yr corn-oat+clover-grain sorghum-soybean rotation; C-SB(4), 4-yr grain sorghum-oat+clover-corn-soybean rotation; CSG, continuous grain sorghum; SB-SG(2), 2-yr soybean-grain sorghum rotation; OCL-SG(4), 4-yr soybean-corn-oat+clover-grain sorghum rotation; SB-SG(4), 4-yr oat+clover-corn-soybean-grain sorghum rotation.

the greatest probability of success in terms of using the available water; the most limiting resource in this region.

The objective of this study was to determine the effects of cropping system and N rates on PUE of soybean and grain sorghum in a rain-fed environment.

MATERIALS AND METHODS

An extensive rotation study has been conducted on the Agronomy Farm at the University of Nebraska Agricultural Research and Development Center near Mead, NE, on a Sharpsburg silty clay loam since the early 1980s. The period reported in this study includes the 1984 through 1991 cropping seasons. Rotation treatments were assigned to main plots, 9 m wide (12 rows with 0.76-m spacing between rows) and 32 m long, in four randomized complete blocks. Each main plot was split into three subplots (9 by 10 m each) separated by 1-m alleys for N rate comparisons. Each phase of all rotations was grown every year.

Soybean

Soybean cropping systems included: (i) continuous monoculture, (ii) corn–soybean, (iii) grain sorghum–soybean, (iv) corn–oat+clover (80% yellow sweetclover [*Melilotus officinalis* Lam.] and 20% red clover [*Trifolium pratense* L.])–grain sorghum–soybean, and (v) grain sorghum–oat+clover–corn–soybean rotations. Nitrogen subplots, randomly assigned, had application rates of 0, 34, and 68 kg N ha^{-1} for soybean throughout the study. Adapted soybean cultivars were used and weed control consisted of a combination of preemergence herbicides and cultivation. Grain yields were determined by harvesting two rows approximately 10 m long in late September or early October with a plot combine and yields were corrected to standard moisture contents.

Grain Sorghum

Grain sorghum cropping systems included: (i) continuous monoculture, (ii) soybean–grain sorghum, (iii) soybean–corn–oat+clover–grain sorghum, and (iv) oat+clover–corn–soybean–grain sorghum rotations. Nitrogen subplots were randomly assigned application rates of 0, 90, or 180 kg N ha^{-1} for grain sorghum throughout the study. Adapted grain sorghum hybrids were used and weed control consisted of a combination of preemergence herbicides and cultivation. Grain yields were determined by harvesting two rows approximately 10 m long in October or early November with a plot combine and yields were corrected to standard moisture contents.

Cultural practices were similar to those used by local producers. Previous crop residue from corn or grain sorghum was shredded in late fall with a rotary mower. Clover from the previous oat+clover plots was killed with a tandem disk in mid-April when weather permitted. Spring tillage usually consisted of disking once or twice 10 to 15 cm deep and then harrowing just prior to planting.

The N source was NH_4NO_3 (34–0–0) in all years. Nitrogen fertilizer applications were broadcast by hand after the crop had emerged, usually 2 to 4 wk after planting and incorporated during the first cultivation.

Long-term and yearly precipitation measurements were taken from a site approximately 1 km south of the research site. Precipitation use efficiencies (Halvorson, 1990) were calculated for each cropping system and N fertilizer rate from grain yields and annual precipitation received by dividing grain yields (kilograms per hectare) by annual precipitation (centimeters). Annual precipitation was chosen after several attempts were made to use different precipitation periods that corresponded to planting to harvest (1 May–31 October) or harvest to harvest (1 November–31 October). Both of these attempts resulted in PUEs similar to those calculated from calendar-year precipitation totals because a large proportion of the annual precipitation falls from 1 May to 31 October.

Data were combined from the 8 yr of the study for an overall analysis. All statistical analyses were performed using the Statistical Analyses System (SAS Institute, 1992).

RESULTS AND DISCUSSION

The effectiveness of the PUE approach requires assumptions that all cropping systems have received the same amount of precipitation, similar amounts of runoff have occurred (especially within a replication), each particular crop has been exposed to the same evaporative demands in all cropping systems during that time, and water extraction by a crop from all rotations in a given year is the same. The first three assumptions appear to be valid because of the uniformity between experimental units for all cropping systems within a replication and all phases of each rotation are present each year. The fourth assumption appears to be valid because results published earlier show that water extraction by both crops in all the cropping systems was similar throughout the growing season (Peterson and Varvel, 1989a,b).

All differences due to year, rotation, and N rate treatments for PUE of both soybean and grain sorghum were significant (Table 1). In addition, all two- and three-way interactions were significant for the period analyzed (Table 1). These results were expected, especially given the diversity of cropping systems in the study, and the likelihood that different previous crops would cause differential responses to N applied.

The year × rotation × N rate interactions are shown for soybean (Fig. 1) and grain sorghum (Fig. 2). The results for both crops are generally similar, showing very little difference in yearly PUE among cropping systems. Two exceptions are for soybean (Fig. 1) in 1988 and grain sorghum (Fig. 2) in 1989. Results from these 2 yr are probably responsible for the significant three-way interaction for the two crops (Table 1). Erratic and reduced yields for soybean resulted from a combina-

Table 1. Mean squares and significance of year, rotation, and N rate treatment effects for soybean and grain sorghum grain precipitation use efficiency for 1984 through 1991 at Mead, NE.

	Precipitation use efficiency			
Source	df	Soybean	df	Grain sorghum
Year (Y)	7	3055.5**	7	32201.6**
Error (*a*)	21	76.6	21	400.5
Rotation (R)	4	553.1**	3	3660.6**
Y × R	28	129.5**	21	623.7**
Error (*b*)	96	51.7	72	253.6
N rate (N)	2	91.0**	2	20947.5**
Y × N	14	44.8**	14	341.2**
R × N	8	71.4**	6	3848.0**
Y × R × N	56	32.9**	42	486.3**
Error (*c*)	240	18.3	192	151.1
CV, %		13.9		13.8

** Significant at the 0.01 probability level.

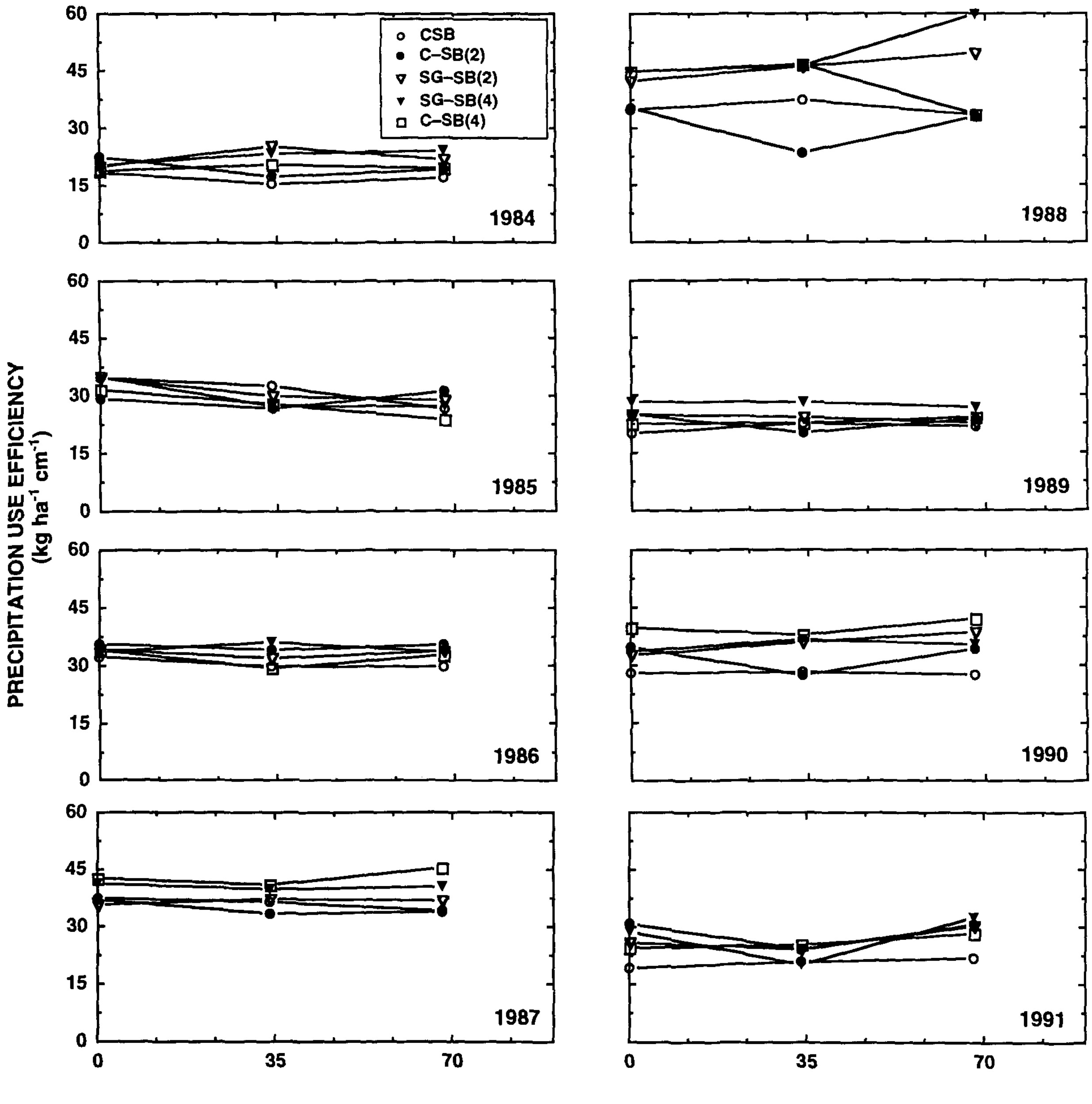

Fig. 1. Precipitation use efficiencies for soybean as affected by N fertilizer in all cropping systems each year from 1984 through 1991 at Mead, NE.

tion of less-than-normal precipitation in 1988 (Table 2) and extensive crop water use during the previous calendar year in continuous soybean, corn–soybean, and grain sorghum-oat+clover–corn–soybean cropping systems. Precipitation use efficiency for grain sorghum in the soybean–corn–oat+clover–grain sorghum rotation during 1989 was significantly lower than for other rotations. This occurred because yields were reduced by extensive water use by the clover crop before it was killed in the spring. Extensive water use in this cropping system, and little if any precipitation after planting (Table 2), severely delayed and reduced germination and final stands of grain sorghum and severely reduced yields. Low rainfall was not a problem in the other cropping systems in 1989 because enough water was available for germination and stand establishment.

Since the three-way interaction (Table 1) was significant, this normally would preclude any discussion about two-way interactions, but without 1988 for soybean and 1989 for grain sorghum, the results are fairly consistent. These same two cases probably also caused all of the significant two-way interactions for both soybean and grain sorghum (Table 1).

Thus it is justifiable to examine the main effects of rotation and N as is done for soybean (Fig. 3) and grain sorghum (Fig. 4). Few if any differences in PUE between cropping systems occurred for either crop. These results demonstrate that soybean and grain sorghum are less

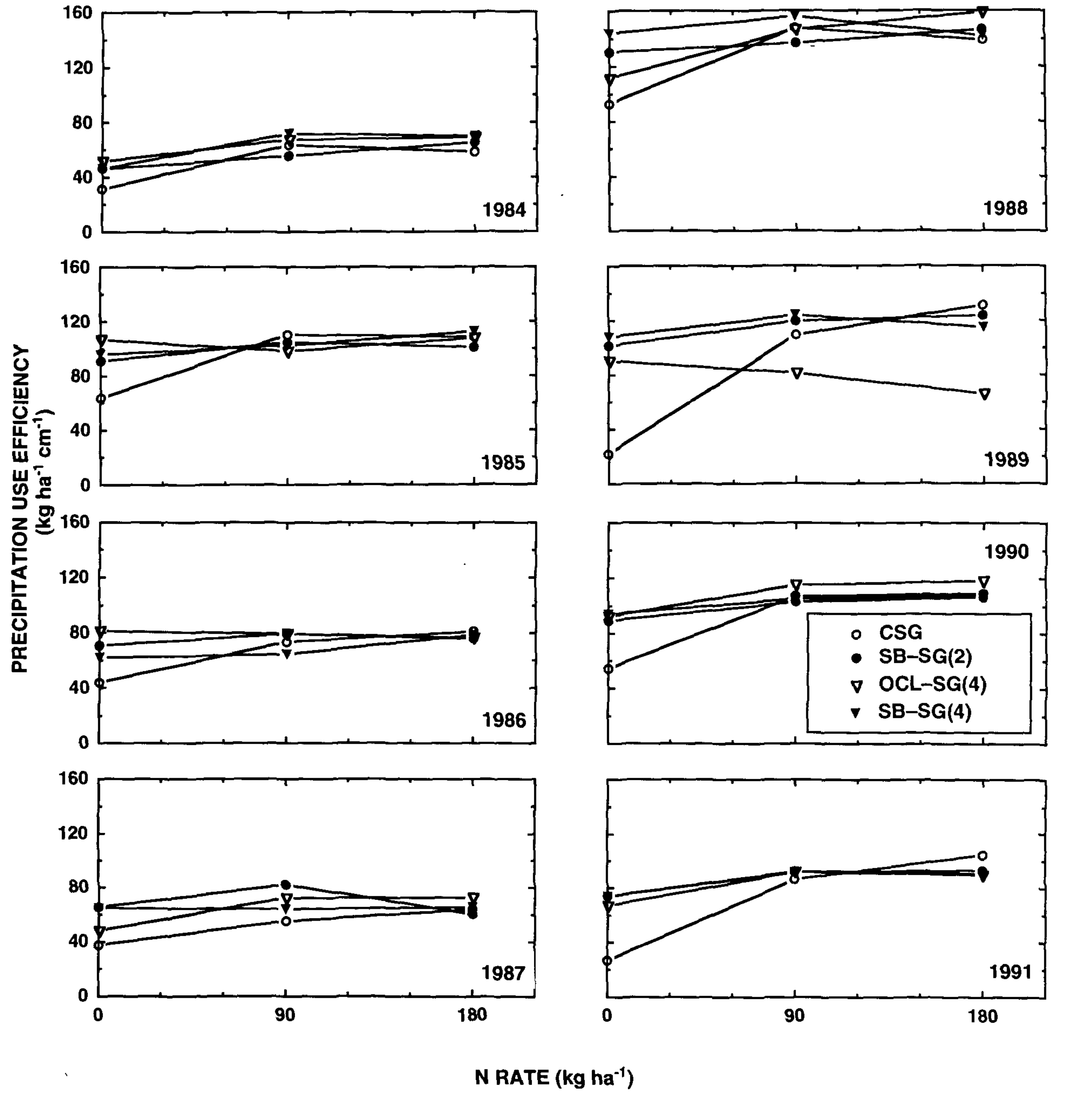

Fig. 2. Precipitation use efficiencies for grain sorghum as affected by N fertilizer in all cropping systems each year from 1984 through 1991 at Mead, NE.

Table 2. Monthly precipitation received at Mead, NE, from 1984 through 1991, 30-yr averages, and deviations from 30-yr average.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Deviation†
	mm													
1984	8	17	50	151	125	166	42	25	43	141	13	88	869	+124
1985	3	14	22	75	154	58	93	77	85	60	22	5	668	−77
1986	0	11	75	134	70	81	112	142	193	118	13	19	968	+223
1987	0	2	105	36	158	42	98	221	47	17	31	15	772	+27
1988	12	2	1	36	83	26	91	18	122	2	41	12	446	−299
1989	20	15	2	25	22	105	106	41	114	22	1	17	490	−255
1990	13	7	82	9	116	112	180	20	21	43	26	15	644	−101
1991	22	7	89	67	73	253	78	46	64	26	66	51	842	+97
30-yr avg.‡	16	22	45	74	105	108	88	108	82	50	31	17	745	

† Deviation of year precipitation totals from 30-yr average.
‡ 30-yr averages (1956 through 1986).

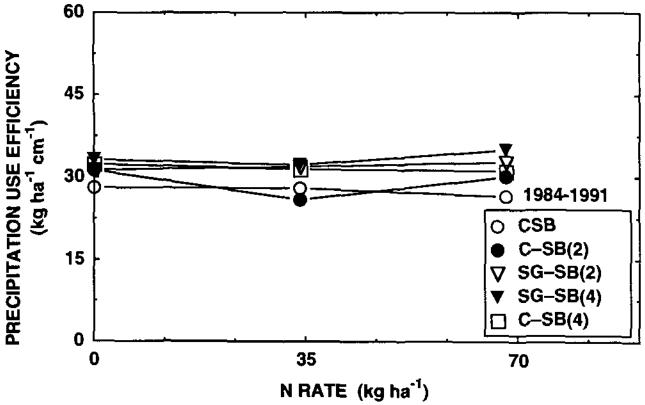

Fig. 3. Precipitation use efficiencies for soybean as affected by N fertilizer in each cropping system averaged across years from 1984 through 1991 at Mead, NE.

affected by the previous crop than corn in these same cropping systems (Varvel, 1994). The only situation where they are not the same is for unfertilized continuous grain sorghum (Fig. 4). However, with sufficient N fertilizer, PUE was identical in all cropping systems.

It is critical from a producer's standpoint that PUE be stable over the long term. These results demonstrate that PUE is stable for soybean and grain sorghum in the cropping systems included in this study. In contrast to results obtained for corn (Varvel, 1994), soybean and grain sorghum PUE values indicate that these crops are less sensitive to previous crop (rotation) in the western Corn Belt. The results, therefore, suggest that in a subhumid environment, where annual precipitation varies widely, both grain sorghum and soybean will have much more stable production than a crop such as corn.

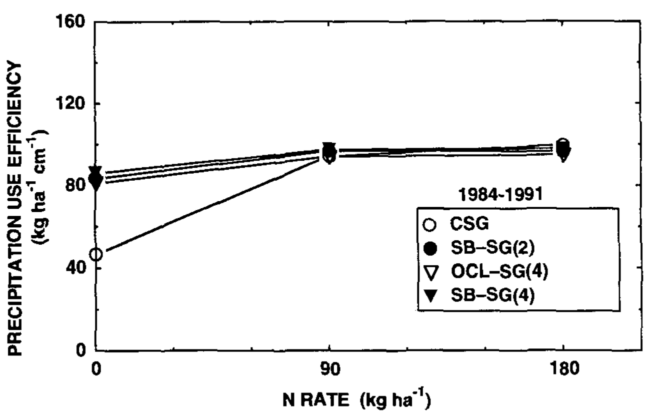

Fig. 4. Precipitation use efficiencies for grain sorghum as affected by N fertilizer in each cropping system averaged across years from 1984 through 1991 at Mead, NE.

SUMMARY AND CONCLUSIONS

Similar long-term PUE for soybean in five cropping systems and for grain sorghum in four cropping systems indicates that both of these crops would be excellent options for these and similar rotations in subhumid areas with similar precipitation patterns. Selection of a cropping system from an agronomic standpoint appears to depend to a greater extent on economics and other crops in the rotation, such as corn, which has a greater yield and PUE response to crop rotation.

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