Monoculture and Rotation System Effects on Precipitation Use Efficiency of Corn

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ABSTRACT

Development and utilization of cropping systems in rainfed areas are highly dependent on their water use efficiencies, especially in subhumid areas. The objective was to evaluate the effect of crop rotation and N fertilizer rates on precipitation use efficiency by dryland corn (*Zea mays* L.). Corn was grown under rainfed conditions at Mead, NE, on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll) in four cropping systems: (i) continuous corn, (ii) a 2-yr soybean [*Glycine max* (L.) Merr.]–corn rotation, (iii) a 4-yr rotation of oat [*Avena sativa* (L.)] + clover [80% *Melilotus officinalis* Lam. and 20% *Trifolium pratense* L.]–grain sorghum [*Sorghum bicolor* (L.) Moench]–soybean–corn, and (iv) a 4-yr rotation of soybean–grain sorghum–oat + clover–corn. Nitrogen fertilizer rates used for corn were 0, 90, and 180 kg N ha^{-1} as NH_4NO_3. Corn grain precipitation use efficiency was significantly affected by year, rotation, and N fertilizer rates from 1984 through 1991. Precipitation use efficiency ranged from 36 to 137 kg ha^{-1} cm^{-1} for continuous corn and from 57 to 165 kg ha^{-1} cm^{-1} for corn grown in rotation from 1984 through 1991. Precipitation use efficiency was greater in rotation (101.8 kg ha^{-1} cm^{-1}) than in continuous corn (83.6 kg ha^{-1} cm^{-1}). In dryland production areas, cropping systems with greater and more stable precipitation use efficiency can reduce crop failures.

EFFICIENT WATER USE in rainfed cropping systems increases in importance as you move from humid to more arid production areas. Pierce and Rice (1988) stated crop rotations may affect the water available for crop growth through their effect on processes controlling available water supply, particularly infiltration and evaporation. Advances in cropping systems productivity can be accomplished by developing and using crop rotations that either are more timely in utilizing available water and/or are able to conserve more water for crop use.

Pierce and Rice (1988) also stated that, although the efficient use of water has been extensively reviewed in recent years, few reports exist regarding the effect of crop rotation on efficient water use. The one exception they found was the wheat (*Triticum aestivum* L.)–fallow rotation used in the U.S. Great Plains. Work in this region continues, because of the major importance of water in arid environment cropping systems. Recently, Black and Bauer (1990), Campbell et al. (1990), Halvorson (1990), and Peterson et al. (1991, 1992) have addressed this issue in a slightly different manner from the historical norm in the wheat–fallow production areas of the Great Plains. Their approach has been to devise cropping systems that are better able to use the greater amounts of stored soil water obtained with no-till management systems than can be attained in the wheat–fallow system. To reduce evaporation losses, they have used more intensive cropping systems to reduce fallow time and utilize the additional water stored when herbicides instead of tillage are used for weed control. Inclusion of summer crops such as corn in the rotation has doubled the water use efficiency of the cropping systems. This approach has resulted in more efficient utilization of limited water resources, and in some cases a gradual improvement in soil conditions.

This approach presents an intriguing possibility for evaluating the efficiency of cropping systems in other rainfed areas of the country. What happens when grain crops such as corn are grown in areas considered to be on the fringes of the Corn Belt because of less available precipitation? Evaluating corn on the basis of water use efficiency in these areas should provide additional information about the relative stability of corn production in the various cropping systems in this type of environment. Calculation of corn water use efficiency over a period of many years in different cropping systems will provide information that can then be used to make recommendations to producers regarding which cropping system will produce the most stable corn yields over a period of many years. In addition, this type of information can also be used to demonstrate what happens to corn production in various cropping systems in years with annual precipitation amounts either much above or much below long-term averages. Our objective was therefore to evaluate the effect of crop rotation and N fertilizer rates on precipitation use efficiency by dryland corn in a long-term study.

MATERIALS AND METHODS

The experiment was conducted on the Agronomy Farm at the University of Nebraska Agricultural Research and Development Center near Mead, NE, on a Sharpsburg silty clay loam from 1984 through 1991. Corn was grown under rainfed conditions in continuous monoculture, a 2-yr soybean–corn rotation, and two 4-yr rotations: oat + clover–grain sorghum–soybean–corn and soybean–grain sorghum–oat + clover–corn. 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. Nitrogen subplots were randomly assigned application rates of 0, 90, or 180 kg N ha^{-1} for corn throughout the duration of the study. Each phase of all rotations was grown each year.

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. A corn hybrid adapted to eastern Nebraska was planted with a six-row planter at a rate of 47 000 viable seeds ha^{-1} during the first 2 wk of May in all years. Weeds were controlled with a preemergence application of either alachlor [2-chloro-2,6-diethyl-*N*-(methoxymethyl)acetanilide] or metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methyl ethyl)acetamide] along

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Abbreviations: CC, continuous corn; SB–C(2), 2-yr soybean–corn rotation; SB–C(4), 4 yr oat + clover–grain sorghum–soybean–corn rotation; OCL–C(4), 4-yr soybean–grain sorghum–oat + clover–corn rotation.

with atrazine [2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine], cyanazine [2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitri le], and linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] at recommended rates. Corn plots were cultivated once during the 1st or 2nd wk of June.

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

Grain yields were determined by hand-harvesting one 5-m row in late Sept. or early Oct. from the middle row of all treatments soon after physiological maturity. Ears were removed, dried, and shelled for grain yield determinations.

Long-term and yearly precipitation measurements were taken from a site ≈1 km south of the research site. Precipitation use efficiencies (Halvorson, 1990) were calculated for each cropping system and N fertilizer rate from corn grain yields and annual precipitation received. Annual precipitation was chosen after several attempts were made to use different precipitation periods that corresponded to planting and harvest (1 May to 31 October) or harvest to harvest (1 November to 31 October). Both of these attempts resulted in precipitation use efficiencies similar to those calculated from calendar year precipitation totals, because a large proportion of the annual precipitation falls from 1 May to 31 October. Precipitation use efficiencies were also calculated using dry matter yields for corn during the 8 yr of the experiment, but the results and analyses of treatment effects were similar to those for grain yield, so they are not presented.

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

RESULTS AND DISCUSSION

Long-term studies provide opportunities to evaluate water and N use efficiencies of components in those experiments. Although direct measurements of evapotranspiration and soil water depletion have not been made, a study such as the one described above allows calculation of a modified form of water use efficiency, precipitation use efficiency. Precipitation use efficiency values were calculated for 8 yr, encompassing two cycles of the longest cropping systems in the study.

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

As noted in Table 1, all year, rotation, and N rate treatments significantly affected corn grain precipitation use efficiency. In addition, all two- and three-way interactions significantly affected corn grain precipitation use efficiencies during the 8-yr period (Table 1). These results were expected, especially given the diversity of cropping systems in the study.

Given the above results, it is important to discuss how and why the various interactions expressed themselves in precipitation use efficiencies during the 1984 through 1991 period. The year × rotation × N rate interaction (Table 1) was significant, because precipitation use efficiencies varied with N rates in rotation differently from one year to the next (Fig. 1). In those years when total precipitation was near or above the long-term average (Table 2), precipitation use efficiencies generally increased as N rate increased from 0 to 90 kg ha^{-1} in all rotations (Fig. 1), but in 1988 and 1989, when total precipitation was much lower than normal (Table 2), precipitation use efficiencies increased as N rate increased in some of the rotations and decreased or remained constant in others (Fig. 1). These differences in precipitation use efficiency responses demonstrate how rotations and N fertilizer interact to produce varying amounts of biomass where soil water reserves differ because of the previous crop in the rotation during years with below-normal precipitation. A specific case is shown in Fig. 1 for 1989, when corn following corn had the greatest precipitation use efficiency in the second of two years with below-normal precipitation, probably because of lower water use during the previous two years.

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

Source	df	Corn grain precipitation use efficiency
Year (Y)	7	20 894.0**
Error *a*	21	284.7
Rotation (R)	3	10 285.3**
Y × R	21	1 566.8**
Error *b*	72	368.4
N rate (N)	2	22 115.3**
Y × N	14	604.1**
R × N	6	2 485.9**
Y × R × N	42	583.1**
Error *c*	192	266.9
CV, %		16.8

**, Significant at the 0.01 probability level.

The three-way interaction reported above is significant and normally would preclude any discussions about the effects of two-way interactions. However, in this report it becomes imperative to present and discuss those effects important in understanding precipitation use efficiencies of corn in dryland cropping systems as they are affected in the long term.

The significant year × rotation interaction was mainly due to results from the 1989 growing season. In all the other years, the precipitation use efficiency of continuous corn was the least, but in 1989 it was the greatest (Table 3). Greater precipitation use efficiency of continuous corn in 1989 occurred because corn in this system had apparently not depleted soil water reserves as extensively as soybean or oat + clover, the previous crops in the other three rotations. This was especially critical in 1989, the second of two extremely dry years in a row (Table 2).

A significant year × N rate interaction (Table 1) mainly occurred because of slight differences in precipitation use efficiency responses to N application over the duration of the study. The significant interaction was obtained because of the slight differences between response functions for each of the years of the study, as can be seen in Fig. 2.

The significant two- and three-way interactions described above are not as critical in an agronomic sense from a producer's standpoint as is the stability of corn

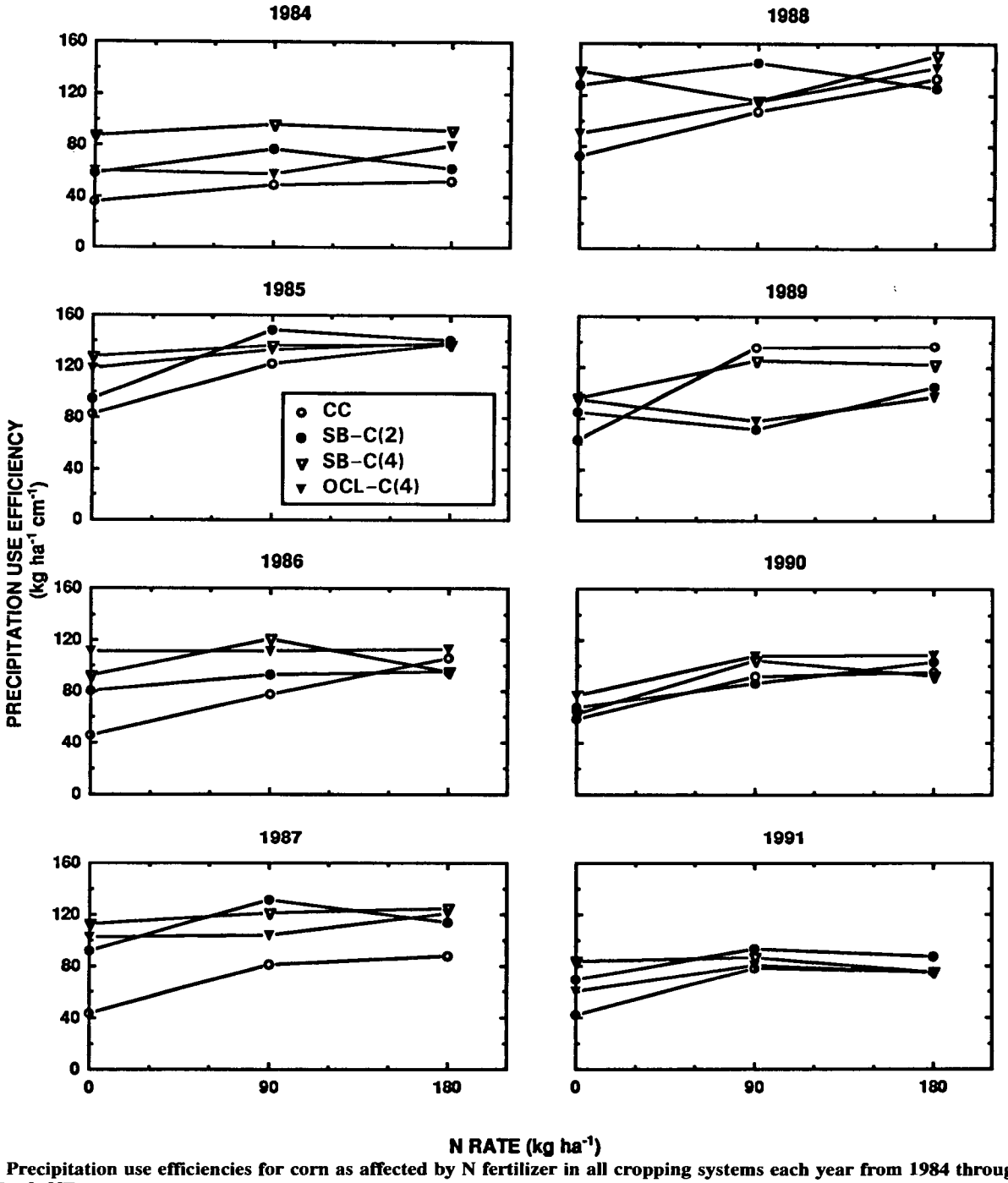

Fig. 1. Precipitation use efficiencies for corn as affected by N fertilizer in all cropping systems each year from 1984 through 1991 at Mead, NE.

grain precipitation use efficiency as affected by N fertilizer in each cropping system over the long term. Precipitation use efficiency varied with rotation and N rate when averaged over years (Table 1). Although the interaction was statistically significant, differences were not great. Corn grain precipitation use efficiency was similar at the highest N rate in all the cropping systems (Fig. 3). The main differences in precipitation use efficiency occurred where no N fertilizer was applied (Fig. 3). Precipitation use efficiency in all three rotation systems increased slightly with the addition of N fertilizer, while N fertilizer greatly increased precipitation use efficiency in the continuous corn system, especially with the 90 kg N ha^{-1} application (Fig. 3). As noted by Power and Evans (1962), similar results have been obtained with various other crops in monoculture systems. These reports include those of Weaver and Pearson (1956) on grass, Hanks and Tanner (1952) on corn and oat, Kiesselbach (1916) on corn, Penman (1948) on turf, and Power et al. (1961) on spring wheat that present experimental results indicating whenever fertilization increased plant growth, water use efficiency was increased.

Differences in precipitation use efficiency responses to N fertilizer between the various cropping systems

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

Year	Month													Deviation from 30-yr average†
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	
	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 average‡	16	22	45	74	105	108	88	108	82	50	31	17	745	

† Deviation of yearly precipitation totals from 30-yr average.
‡ 30-yr average: 1956–1986.

Table 3. Precipitation use efficiencies averaged over all N rates for corn in four cropping systems at Mead, NE, from 1984 through 1991.

Year	Precipitation use efficiency			
	CC†	SB–C(2)	SB–C(4)	OCL–C(4)
	kg ha^{-1} cm^{-1}			
1984	45.9	65.7	91.6	65.8
1985	113.9	127.8	133.6	129.7
1986	76.3	89.5	102.4	111.9
1987	70.6	112.3	119.4	108.9
1988	106.4	136.6	141.5	114.6
1989	108.7	76.5	104.9	98.8
1990	80.3	82.2	91.7	97.2
1991	66.3	83.9	82.4	74.1

† CC, continuous corn; SB–C(2), 2-yr soybean–corn rotation; SB–C(4), 4-yr oat + clover–grain sorghum–soybean–corn rotation; OCL–C(4), 4-yr soybean–grain sorghum–oat + clover–corn rotation.

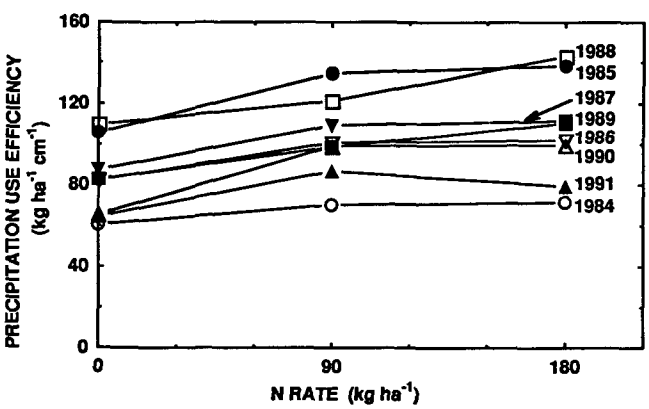

Fig. 2. Precipitation use efficiencies for corn averaged across all cropping systems as affected by N fertilizer each year from 1984 through 1991 at Mead, NE.

demonstrate why certain cropping systems are used in various areas of the country. In areas with greater annual precipitation, as in most areas of the Corn Belt, the dominant cropping system is monoculture corn. This system has provided excellent returns, and with sufficient N fertilizer, it has a very high and stable precipitation use efficiency. The grower does not have to worry about excessive growth using all the available water early in the growing season because the probability of sufficient rainfall throughout the growing season is usually fairly

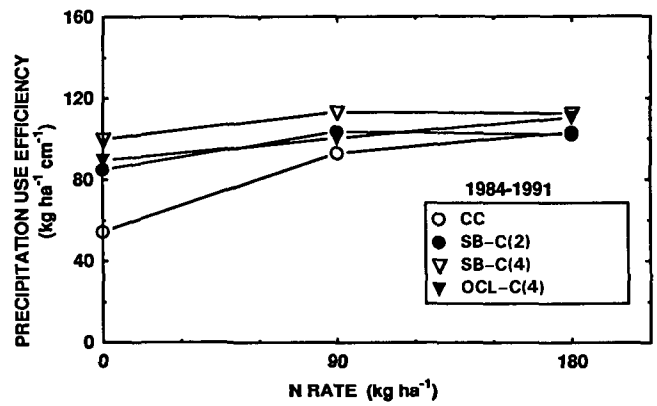

Fig. 3. Precipitation use efficiencies for corn as affected by N fertilizer in each cropping system averaged over years from 1984 through 1991 at Mead, NE.

high. In contrast, in the Western Corn Belt where this study was conducted, monoculture corn with large amounts of N fertilizer applied greatly increases the risk of crop failure, because the probability of sufficient and timely precipitation throughout the growing season is less and this study provides evidence of that variability.

Greater and more stable precipitation use efficiency over the long term with corn in rotation as compared with continuous corn provides additional reasons why rotations present a more stable option to producers. Selection of a cropping system with a more stable corn precipitation use efficiency reduces chances of crop failure over the long term.

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