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Accumulation and Distribution of P, Fe, Mn, and Zn by Selected Determinate Soybean Cultivars Grown With and Without Irrigation[1]

D. L. Karlen, P. G. Hunt, and T. A. Matheny[2]

ABSTRACT

Reports on accumulation and distribution of nutrients by determinate soybeans [*Glycine max.* (L.) Merr.] when grown under field conditions have seldom included information about micronutrients or made comparisons among several cultivars grown with or without irrigation. To provide this information, we grew three or four determinate soybean cultivars with or without irrigation on a Norfolk loamy sand (fine-loamy, siliceous thermic Typic Paleudults) during 1978 and 1979. Plant samples were collected periodically throughout the growing season to measure dry matter accumulation and distribution among the leaves, petioles, stems, and pods. Plant fractions were analyzed for P, Fe, Mn, and Zn. Total P accumulation reflected total dry matter production and was greater in plants which received irrigation during periods of water stress. The total P and Zn accumulation among cultivars was generally not significantly different, although the P and Zn concentrations in the cv. Ransom were frequently higher. The concentrations and accumulations of Fe and Mn were generally not influenced by cultivar. Irrigation appeared to enhance P diffusion to plant roots and increased P concentrations at some samplings, but it rarely influenced Fe, Mn, or Zn concentration or accumulation. Total P, Fe, Mn, and Zn accumulations were greater during 1979 due to earlier planting, a shorter period of drought, and more available soil water in the lower part of the profile. Accumulation of these nutrients reflected plant growth, but seed yields did not follow the same pattern. With irrigation, 1979 seed yields averaged 1.95 metric tons/ha compared to average irrigated yields of 3.16 metric tons/ha in 1978. Nonirrigated yields averaged 1.72 and 1.62 metric tons/ha in 1978 and 1979, respectively. Seed yields did not appear to be limited by P or micronutrient accumulation. Also, for these determinate cultivars yields were not closely related to total dry matter production.

Additional index words: **Soybean varieties, Soybean production, Nutrient accumulation, *Glycine max* L. Merr., Plant analyses.**

Few studies concerning nutrient accumulation and distribution in determinate soybeans [*Glycine max.* (L.) Merr.] have included information on the micronutrients, soil water conditions, or genetic variation. DeMooy et al. (1973) presented data from Ohlrogge (1966) and Ohlrogge and Kamprath (1968) on the micronutrient accumulation by soybeans based on 10.0 and 8.7 metric tons/ha dry matter, respectively, but they did not show the distribution of these micronutrients within the plant. The effect of soil water status on nutrient accumulation by soybeans was also reviewed by De Mooy et al. (1973), but there have been few reports on the effects of irrigation on micronutrient accumulation. Viets (1967) reviewed the relationships between nutrient availability and soil water status. He discussed diffusion and mass flow relationships, the nutrient concentrating effect of decreasing soil water content, and changes in the soil solution if O_2 becomes limiting. Oliver and Barber (1966) reported that diffusion was the most important mechanism for movement of Fe, Mn, and Zn to soybean roots, while DeMooy et al. (1973) stated in their review that pH, P content, soil temperature, variety, and soil moisture content all influenced soybean response to these elements.

Genetic variation with respect to Fe accumulation, tolerance to high P, A1, or salinity was also reviewed by DeMooy et al. (1973). They found that environmental variables, including variations in the seasonal weather patterns, influenced soybean growth, nutrient accumulation, and yield, which complicated evaluations of genetic variation in field experiments. Periods of drought, which allow plant roots to deplete the available soil water, is one of the most limiting factors to soybean production in the Southeast. DeMooy et al. (1973) reported that nutrient accumulation is affected in proportion to the number of days of effective drought during the season and to the portion of the root system located in the water depleted soil.

Irrigation of soybeans in the Southeast is increasing to prevent drought related reductions in yields and nutrient accumulation because of erratic rainfall and low soil water storage. Therefore, we conducted this research to study the effects of irrigation, cultivar, and seasonal weather pattern of P and micronutrient accumulation by determinate soybeans grown on a Norfolk loamy sand (fine-loamy, siliceous thermic Typic Paleudults) in 1978 and 1979.

METHODS AND MATERIALS

The experimental designs were a split plot in 1978 and a randomized complete block in 1979. The plot size was 62 m^2. Each experiment was replicated three times. The nutrient status of the soil (Table 1) was determined by using a dilute double acid extract (0.05 *N* HCl in 0.025 *N* H_2SO_4) (Isaac, 1977). Analyses of the Ap horizon indicated very high P, adequate micronutrient concentrations, medium K, low Ca, and high Mg. Fertilizer applications included 220 kg/ha 0-14-22 in 1978 and 202 kg/ha 0-20-20 in 1979. Treflan[3] (trifluralin) was applied at 0.3 liters/ha before planting and incorporated by disking.

Three cultivars ('Ransom,' 'Bragg,' and 'Coker 338') were planted on 12 June 1978, and four cultivars ('Lee,' Ransom, Bragg, and Coker 338) were planted on 24 May 1979. The

Table 1. Chemical properties of a Norfolk loamy sand where experiments to measure P, Fe, Mn, and Zn accumulations by determinate soybeans were conducted.

			Dilute double acid extractable						
Horizon	Year	pH	K	Ca	Mg	P	Zn	Mn	Fe
			me/100 g			ppm			
A_p	1978	6.1	0.14	0.97	0.67	65	1.7	13	46
A_p	1979	5.6	0.18	0.97	0.72	61	1.5	14	40
B	1978	5.0	0.24	0.95	0.94	4	0.4	2	28
B	1979	4.7	0.17	1.18	0.73	2	0.6	2	13

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[2] Soil scientists, Florence, SC 29502.

[3] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dep. of Agric. or the S.C. Agric. Exp. Stn. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

cultivars were selected to represent Maturity Groups VI, VII, VIII. Stand counts taken approximately 2 weeks after emergence showed densities of 26 plants/m² in 1978 and 20 plants/m² in 1979. The lower plant density in 1979 was caused by planter malfunction. Supplemental irrigation was applied during pod fill, growth stage R3, in 1978 and during late vegetative (V14) and flowering (R1) growth stages in 1979. Irrigation amounts (Table 2) were determined by estimating evapotranspiration (ET) at 6 mm/day and applying supplemental water to meet this demand. Soil water tensions were monitored with vacuum gauge tensiometers placed at 30-, 60-, 90-, 120-, and 150-cm depths. On-site weather data were collected continuously starting in August 1978.

Whole plant samples were collected from approximately 30 cm of row during vegetative, flowering (R2), early (R4), and late (R6) pod development. Plants were partitioned into leaves, stems, petioles, and pods; rinsed in demineralized water; dried at 70 C; ground to pass a 0.841 mm screen in 1978 or a 0.500 mm screen in 1979; and digested with a 1:1 mixture of nitric and perchloric acids. The P concentration was measured colormetrically on a Technicon auto-analyzer using industrial method 334-74 W/B (Technicon Industrial Systems, 1977). Iron, Mn, and Zn concentrations were measured by atomic absorption spectrophotometry. Data were analyzed using Duncan's Multiple Range Test at P (0.05) as outlined by Steel and Torrie, (1960).

Table 2. Distribution and amount of rainfall and irrigation received by soybeans during 1978 and 1979.

Days after planting	Rainfall 1978	Rainfall 1979	Irrigation 1978	Irrigation 1979
	mm			
7	0	30	0	0
14	51	3	0	0
21	43	1	0	20
28	20	76	0	0
35	71	7	0	0
42	32	0	0	11
49	37	14	0	28
56	16	62	0	25
63	23	44	0	0
70	28	0	0	0
77	2	0	68	57
84	10	7	50	32
91	41	33	13	53
98	11	12	21	19
105	0	205	22	0
112	11	7	22	0
119	1	4	6	0
126	0	18	0	0
133	0	72	0	0
140	0	10	0	0
147	2	1	0	0
154	4	19	0	0

RESULTS AND DISCUSSION

The 1978 and 1979 soybean growing seasons were very different. The distribution of rainfall and irrigation (Table 2) shows that there was a prolonged drought during pod fill (119 to 154 days after planting (DAP)) in 1978, while in 1979 a short-term drought occurred during the late vegetative and early reproductive growth stages (70-84 DAP). In 1979, Hurricane David produced intense rainfall which resulted in very wet conditions throughout pod fill. The distinctly different seasonal weather patterns which occurred dur-

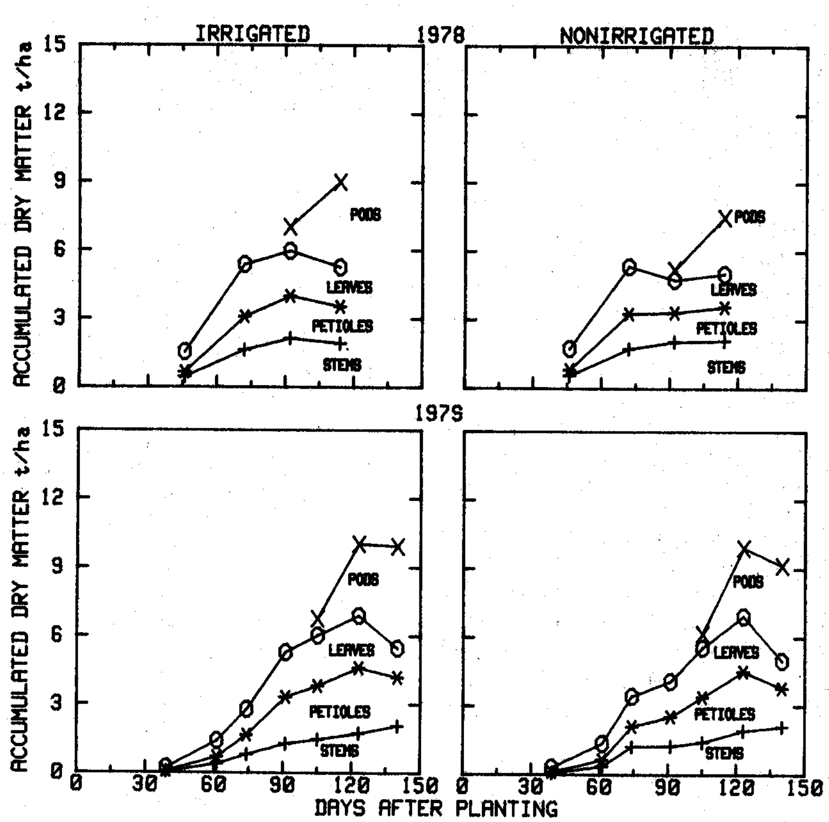

Fig. 1. Accumulation and distribution of dry matter by soybeans grown with and without irrigation. Note: The figures are cumulative over time, but do not include plant fractions which had fallen from the stem. The actual amount within any plant fraction can be obtained by subtraction of any two points.

ing the 2-year study illustrate the erratic nature of rainfall under which soybean production occurs in the Southeast.

The influence of irrigation on plant growth during periods of drought stress in these experiments was discussed in detail by Karlen et al. (1982). The growth information has been included in this manuscript so that nutrient and dry matter production can be discussed more easily. With respect to irrigation effects on soybean grain yield, we concur with Doss et al. (1974) who stated that irrigation during the pod-fill growth stage was most important.

The average plant growth for the two seasons with and without irrigation is shown in Fig. 1. Differences in total dry matter accumulation among cultivars were significant only at the sampling taken 92 days after planting in 1978. This was caused by significantly greater pod development on the Bragg and Ransom cultivars than in the Coker 338. Variations among cultivars, in the amount of dry matter accumulated in the various plant fractions, were generally nonsignificant. An exception to this was at the sampling 122 days after planting in 1979 when leaf drop, petiole abscission, and maturation of the Group VI Lee cultivar had begun. This resulted in statistically significant differences in leaf, petiole, and stem dry matter accumulation by the Lee cultivar.

Plant growth differences due to irrigation during periods of drought stress were much greater than growth differences among cultivars. Therefore, we chose to graphically present the dry matter and nutrient accumulation data averaged across cultivars. Variations in the nutrient concentrations among cultivars for selected sampling dates will be discussed.

Phosphorus

Phosphorus accumulation and distribution within the soybean cultivars grown with and without supplemental irrigation are shown in Fig. 2. The maximum amounts of P accumulated with and without irrigation were 26 and 18 kg/ha in 1978 and 42 and 39 kg/ha in 1979, respectively. The higher P accumulation in 1979 reflected both greater total dry matter production and higher P concentrations in the various plant fractions (Tables 3 and 4). Total P accumulation was significantly greater in the irrigated plants at samplings taken 92 days after planting in 1978 and 90 days after planting in 1979. In 1978 this reflected greater pod development (Fig. 1) rather than a difference in P concentration within the plant fractions (Table 4), but in 1979 the difference was due to greater leaf, petiole, and stem growth and to higher P concentrations in all fractions of the irrigated plants. The effect of water stress on P accumulation was most evident 63 to 91 days after planting in 1979. During this period, non-irrigated plants received 4 cm of rainfall while irrigated plants received an additional 14.2 cm of water (Table 2). Plant growth was influenced slightly by this period of drought (Fig. 1), but P accumulation in all vegetative plant fractions was significantly lower. During other periods of water stress, the P concentrations in all plant fractions of the nonirrigated plants were also generally significantly lower than in the irrigated

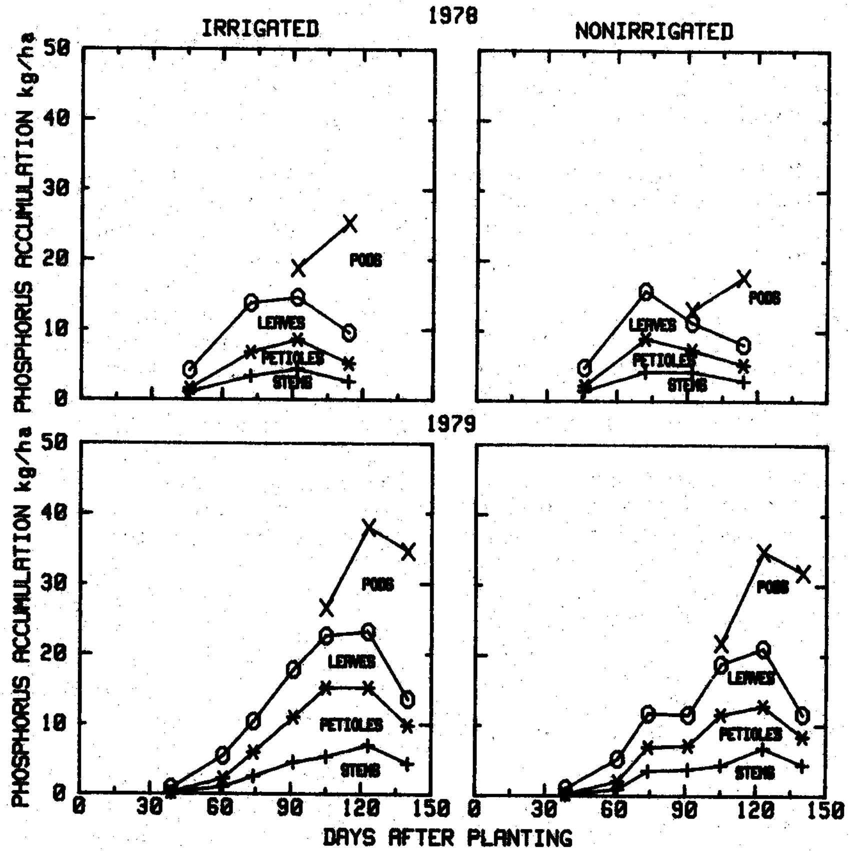

Fig. 2. Accumulation and distribution of P by soybeans grown with and without irrigation. See Note, Fig. 1.

Table 3. Concentrations of P in various fractions of determinate soybean cultivars at selected growth stages.†

Cultivar	P			
	Leaf	Petiole	Stem	Pod
	%			
1978		45 Days after planting		
Bragg	0.308 a‡	0.228 a	0.231 a	–
Coker 338	0.299 a	0.237 a	0.238 a	–
Ransom	0.330 a	0.301 b	0.283 b	–
1978		72 Days after planting		
Bragg	0.312 b	0.242 a	0.184 a	–
Coker 338	0.286 a	0.231 a	0.201 a	–
Ransom	0.342 c	0.326 b	0.281 b	–
1978		92 days after planting		
Bragg	0.288 a	0.200 a	0.182 a	0.363 a
Coker 338	0.259 a	0.189 a	0.172 a	0.401 a
Ransom	0.311 a	0.293 b	0.273 b	0.420 a
1979		38 Days after planting		
Bragg	0.394 a	0.306 a	0.255 a	–
Coker 338	0.425 a	0.305 a	0.291 a	–
Lee	0.400 a	0.307 a	0.296 a	–
Ransom	0.420 a	0.327 a	0.277 a	–
1979		90 Days after planting		
Bragg	0.304 a	0.282 a	0.305 a	–
Coker 338	0.296 a	0.273 a	0.312 a	–
Lee	0.317 ab	0.298 a	0.342 a	–
Ransom	0.340 b	0.339 a	0.362 a	–
1979		122 Days after planting		
Bragg	0.320 a	0.330 a	0.336 a	0.479 b
Coker 338	0.336 a	0.338 a	0.378 a	0.443 a
Lee	0.324 a	0.398 b	0.370 a	0.470 b
Ransom	0.369 a	0.432 b	0.425 a	0.479 b

† Average values across three replicates with and without supplemental irrigation.
‡ Values within a plant fraction and sampling date followed by the same letter are not significantly different at P (0.05) using Duncan's Multiple Range Test.

Table 4. Effects of supplemental irrigation on P concentrations in determinate soybeans at selected growth stages.†

Cultivar	P			
	Leaf	Petiole	Stem	Pod
	%			
1978		45 Days after planting		
Irrigated	0.313 a‡	0.240 a	0.235 a	–
Nonirrigated	0.312 a	0.271 a	0.266 a	–
1978		72 Days after planting		
Irrigated	0.303 a	0.243 a	0.203 a	–
Nonirrigated	0.323 a	0.289 a	0.241 a	–
1978		92 Days after planting		
Irrigated	0.299 a	0.223 a	0.213 a	0.406 a
Nonirrigated	0.273 a	0.231 b	0.204 a	0.383 a
1979		38 Days after planting		
Irrigated	0.422 a	0.325 a	0.301 a	–
Nonirrigated	0.398 a	0.297 a	0.258 a	–
1979		90 Days after planting		
Irrigated	0.342 b	0.319 b	0.354 b	–
Nonirrigated	0.286 a	0.277 a	0.307 a	–
1979		122 Days after planting		
Irrigated	0.336 a	0.387 a	0.395 a	0.473 a
Nonirrigated	0.338 a	0.363 a	0.359 a	0.463 a

† Average values across three replicates and three or four cultivars.
‡ Values within a plant fraction and sampling date followed by the same letter are not significantly different at P (0.05) using Duncan's Multiple Range Test.

plants. This may indicate that irrigation enhanced diffusion of P to the plant roots. It also indicates that for nutrient translocation models, such as the one developed by Scott and Brewer (1980), water stress must be absent or uniform throughout the entire growth period being investigated so that constant uptake rates can be assumed.

Figure 2 shows that P accumulated more rapidly in the leaf fraction during the early part of the growing season than in the petiole and stem fractions. During pod fill, translocation from the leaves was also more rapid than translocation from the petioles and stems. Phosphorus accumulated very rapidly in the pod fraction during bean formation.

In 1979 varietal differences in total P accumulation were significant only at the sampling taken 90 days after planting. This was the result of higher P concentrations in the leaf fractions of the Ransom cultivar (Table 3). Among cultivars, Ransom frequently had the highest P concentration in all plant fractions. These data on P accumulation and distribution agreed very well with that reported by Henderson and Kamprath (1970), and at all sampling dates the concentrations were within the ranges reported by Small and Ohlrogge (1973).

Iron

The accumulation and distribution of Fe within soybean cultivars grown with and without irrigation are shown in Fig. 3. Accumulation in the leaves increased most rapidly during the vegetative growth stages. Although the amount of Fe accumulated in the leaf fraction declined during pod fill, this loss was less than that being accumulated in the pods, indicating that there was limited translocation and that Fe uptake was continuing during pod fill. Accumulation in the stem and petiole fractions increased throughout the growing season. Maximum Fe accumulation averaged 0.7 kg/ha in 1978 and 1.2 kg/ha in 1979. The higher Fe accumulation in 1979 reflected greater total dry matter production (Fig. 1) and higher concentrations in the various plant fractions (Table 5). For brevity, we averaged this micronutrient concentration data across irrigation and cultivars which were generally not significantly different at P (0.05).

Irrigation significantly increased total Fe accumulation at the sampling 90 days after planting in 1979 when nonirrigated plants were suffering from water stress (Fig. 3). This difference was also the result of greater dry matter production (Fig. 1) because neither irrigation nor cultivar significantly influenced the Fe concentrations (Table 5). At all sampling dates, the Fe concentrations were within the range reported by Small and Ohlrogge (1973).

Manganese

Manganese accumulation and distribution within the soybean cultivars grown with and without irrigation are shown in Fig. 4. Maximum Mn accumulation averaged approximately 0.3 kg/ha in both years with and without irrigation. Accumulation by the various cultivars was not significantly different. Irrigation significantly influenced accumulation only at the sampling 90 days after planting in 1979 when water stress significantly reduced the petiole and leaf dry matter produced by the nonirrigated plants (Fig. 1). Manganese concentrations in the leaf, petiole, and stem fractions were relatively constant throughout the growing season. Although the Mn concentrations in the pod fraction declined steadily during bean formation, approximately one-third of the total Mn accumulated by the soybean plants was found in the pod fraction. The Mn concentration in the vegetative plant fractions did not decline during pod fill which indicated that Mn uptake occurred throughout pod fill or that Mn in the pods was translocated from the vegetative plant fractions which had senesenced and fallen to the ground. The Mn concentrations in the various cultivars grown with or without irrigation were generally not significantly different at any of the sampling dates in either year, so these data were averaged in Table 5. The concentrations of Mn in all plant fractions were within the ranges reported by Small and Ohlrogge (1973).

Zinc

The Zn accumulation and distribution within the soybean cultivars grown with and without irrigation are shown in Fig. 5. With or without irrigation, the maximum total Zn accumulation averaged 0.15 and 0.22 kg/ha for 1978 and 1979, respectively.

Total accumulation was not significantly influenced by either cultivar or irrigation. These levels of Zn accumulation agreed with the values found by Ohlrogge (1966) and Ohlrogge and Kamprath (1968). Zinc concentrations in all plant fractions (Table 5) declined throughout the growing season, but at all times they were within the ranges reported by Small and Ohl-

Table 5. Mean Fe, Mn, and Zn concentrations in various plant fractions of determinate soybeans grown on a Norfolk loamy sand.†

		Fe				Mn				Zn			
Year	Days after planting	Leaf	Petiole	Stem	Pod	Leaf	Petiole	Stem	Pod	Leaf	Petiole	Stem	Pod
		ppm											
78	45	--	131	98	--	52	26	15	--	35	14	14	--
78	72	178	53	39	--	59	24	12	--	33	15	9	--
78	92	179	63	46	98	60	25	14	42	34	12	6	38
78	114	187	57	38	76	63	29	13	31	24	7	4	28
79	38	325	172	164	--	51	24	17	--	25	19	16	--
79	60	335	214	161	--	60	25	14	--	34	17	14	--
79	73	340	112	85	--	53	24	13	--	35	16	14	--
79	90	251	77	63	--	56	21	10	--	30	19	10	--
79	104	169	81	53	200	50	22	14	39	30	16	12	46
79	122	156	65	50	146	56	27	14	36	26	9	10	34
79	139	207	106	97	112	58	30	14	30	23	10	7	39

† These values are averaged across 3 replicates, irrigated and nonirrigated water management, and three or four cultivars because treatment and interaction means were generally not significantly different at P (0.05) using Duncan's Multiple Range Test.

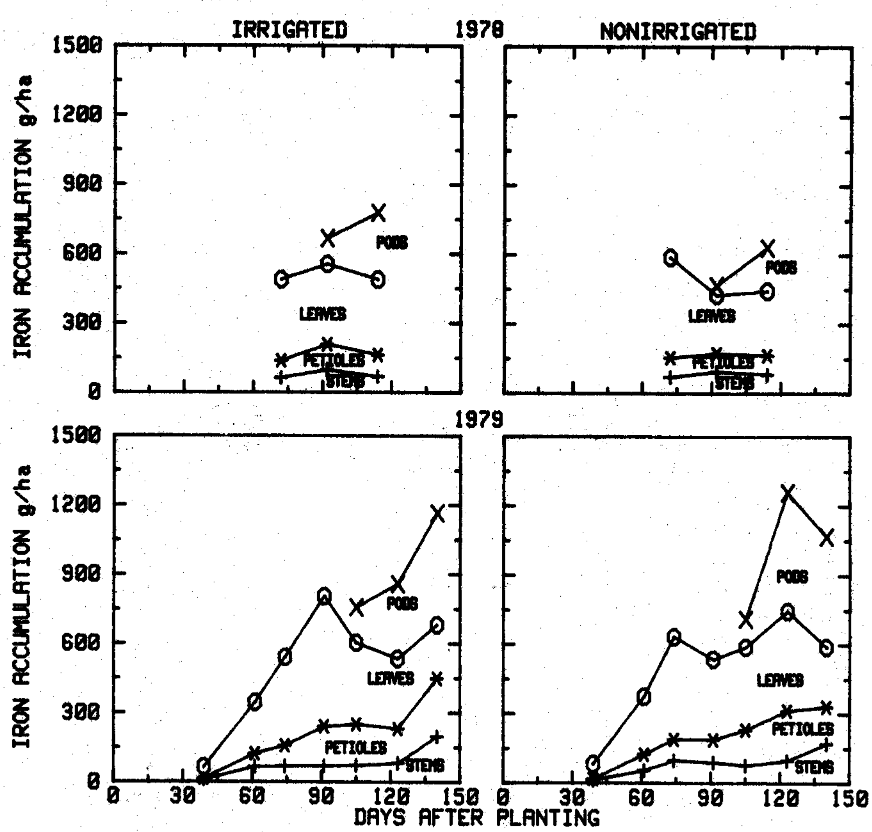

Fig. 3. Accumulation and distribution of Fe by soybeans grown with and without irrigation. See Note, Fig. 1.

rogge (1973). Irrigation did not significantly influence the Zn concentrations in any of the plant fractions. The differences among cultivars were generally not significant, although when they were, the Ransom cultivar had the highest Zn concentration.

Zinc accumulation was most rapid in the leaf fraction during the vegetative growth stage and in the pods during grain formation (Fig. 5). During pod fill, Zn accumulation in the leaf and petiole fraction declined rapidly. This reflected the translocation of Zn from the vegetative tissue to the pods during the reproductive growth stages in addition to leaf and petiole drop, because the Zn concentration in all vegetative fractions was declining during pod fill (Table 5).

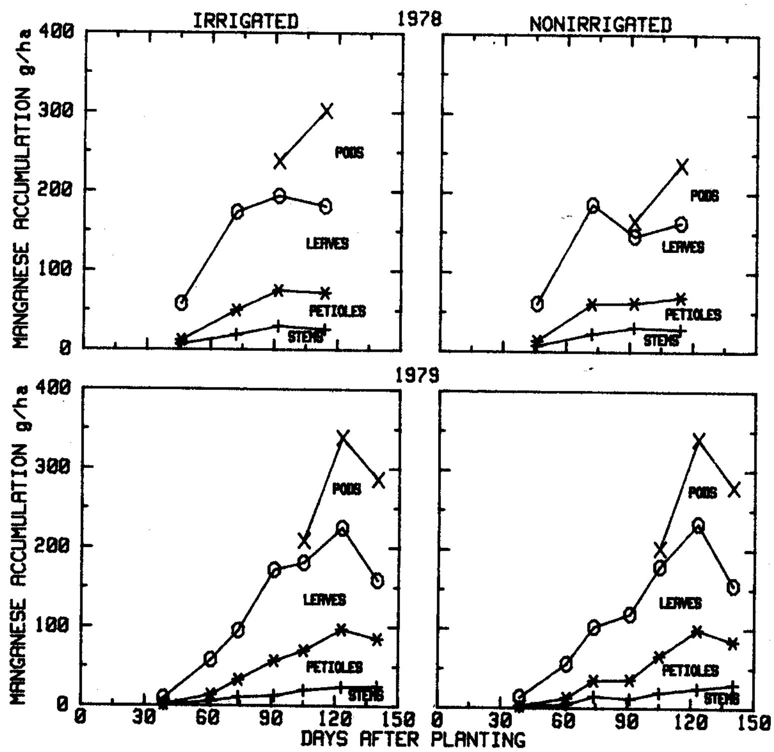

Fig. 4. Accumulation and distribution of Mn by soybeans grown with and without irrigation. See Note, Fig. 1.

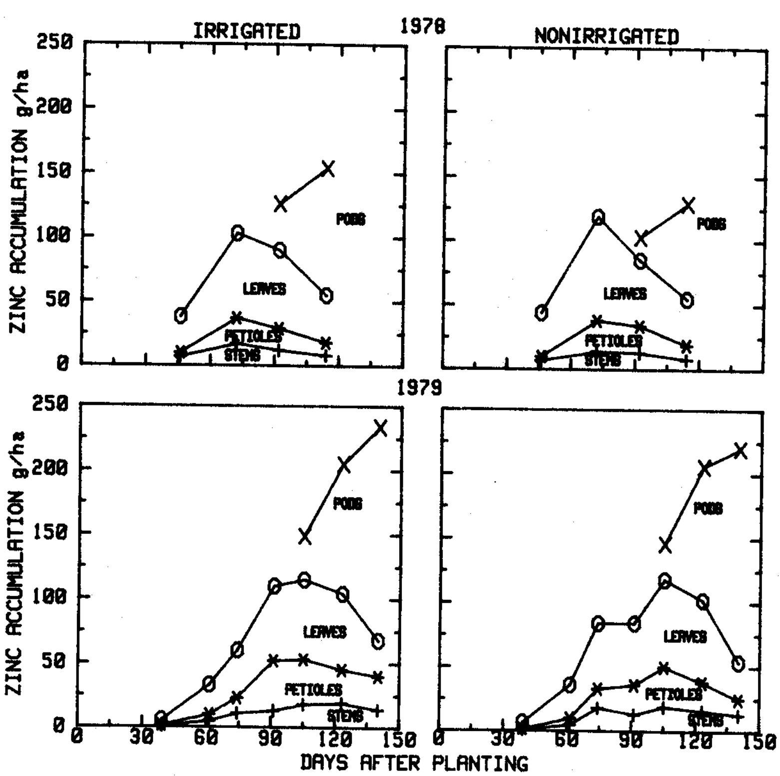

Fig. 5. Accumulation and distribution of Zn by soybeans grown with and without irrigation. See Note, Fig. 1.

Table 6. Yields of selected determinate soybean cultivars grown with and without irrigation in experiments where P, Fe, Mn, and Zn accumulation and distribution were measured.

	1978		1979	
Cultivar	Irrigated	Nonirrigated	Irrigated	Nonirrigated
	metric tons/ha			
Bragg	2.89 b†	1.55 d	1.96 a	1.67 a
Coker 338	3.07 b	1.59 f	1.73 a	1.44 a
Lee	--	--	1.80 a	1.65 a
Ransom	3.51 a	2.02 c	2.32 b	1.74 a

† Values within a year followed by the same letter are not significantly different at P (0.05) using Duncan's Multiple Range Test.

Grain yields (Table 6) were not closely related to the total dry matter production or the total amount of P, Fe, Mn, or Zn accumulated. Even with irrigation during the short-term drought, the 1979 grain yields were much lower than the irrigated grain yields in 1978. A large number of factors including a lower plant density and possible O_2 stress during pod fill may have contributed to the lower yields in 1979, but the P, Fe, Mn, and Zn concentrations and levels of accumulation did not appear to have been the yield-limiting factors in either year.

SUMMARY AND CONCLUSIONS

The accumulation and distribution of P, Fe, Mn, and Zn in selected cultivars of determinate soybeans grown with and without supplemental irrigation was measured in these experiments. Total nutrient accumulation reflected dry matter accumulation which was influenced by seasonal soil water status. Phosphorus concentrations within the irrigated plants were generally greater than in the nonirrigated plants. Irrigation increased P accumulation by increasing plant growth and perhaps by enhancing P diffusion to the plant roots. Nutrient concentration within the cultivars studied generally did not differ significantly, although the Ransom variety generally had higher P and Zn concentrations in all plant fractions. The Ransom cultivar also produced the highest grain yield in both years. These data indicate that under nutrient-limiting conditions deficiencies might occur more rapidly with some soybean cultivars than with others.

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