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N, P, and K accumulation by high yielding irrigated maize grown on a Typic Paleudult in the southeastern US

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Abstract

The nutrient and water management requirements for high yield maize (*Zea mays* L.) production in the southeastern Coastal Plains of the US must be quantified in order to achieve levels of production that are profitable. Research was conducted to determine if yields could be increased by refining nutrient, water, and cultural management practices. Average grain yields for the 2 years exceeded 12,5 t/ha with maximum average yields of 14,8 t/ha. Grain yields were significantly greater both years when plant populations exceeded 98 000 plants/ha and the plant distribution was made more uniform by planting in twin rows. Total dry matter accumulation exceeded 22,0 t/ha both years with an average total accumulation of N, P, and K of 242, 52, and 320 kg/ha/year, respectively. Other nutrients which appear to require careful management for maize production on these soils include B, S, and Zn. These experiments have shown that by carefully managing water, nutrient applications, plant population, and row configuration, high and profitable maize yields can be produced in the Coastal Plains of the southeastern US.

Introduction

Irrigation can increase crop production in the southeastern US by preventing water stresses which are caused by intermittent droughts and low water-holding capacities of the soils. To justify their investment in irrigation, landowners are multiple cropping and planting more hectares to water responsive crops such as maize (*Zea mays* L.), but failure to change cultural and nutrient management practices has often resulted in irrigated yields which are insufficient to offset the increased production costs. *Zublena et al.* (1981) reported that the 'breakeven' yield for irrigated maize production in South Carolina was 9,4 t/ha of shelled grain provided prices were $118/t (150 bu/A @ $3/bu).

Rhoads (1981), and *Rhoads* and *Stanley* (1978, 1981) have evaluated several cultural and nutrient management practices and have shown that maize yields exceeding 12,5 t/ha (200 bu/A) were possible in the Coastal Plains of Florida.

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Langdale et al. (1981) evaluated N requirements for various tillage systems in the Atlantic Coastal Plain and produced 12,6 t/ha with 295 kg/ha of N when in-row subsoiling was utilized. The objectives of our research were to (a) compare some new management concepts with those currently recommended for maize production, (b) to measure nutrient accumulation by maize grown on a Typic Paleudult (red and yellow podzolic), and (c) to determine if plant nutrition was limiting maize yields in the southeastern Coastal Plain.

Materials and methods

This experiment was initiated in 1980 on a Norfolk loamy sand (fine loamy, siliceous, thermic, Typic Paleudult). Variables included water management, row configuration, plant population, and fertility program in a 3×2×2×2 factorial arranged in a completely randomized block design with 4 replicates.

In 1980 tensiometers were used to manage irrigation. Water was applied when soil water tensions exceeded either 250 or 500 millibars (mb). In 1981 the 250 mb scheduling treatment was retained, but the 500 mb treatment was replaced with a computerized water balance scheduling program *(Lambert et al.,* 1981) that maintained the volumetric water content of the root zone between 50 and 100% of total available water. The 2 row configurations were conventional, 'single rows' spaced 96 cm apart and a 'twin-row' concept which improves plant distribution, but allows the use of conventional equipment. In 1980 the twin rows were spaced 35 cm apart with each pair of rows spaced 112 cm apart. In 1981 the twin rows were spaced 30 cm apart with each pair of rows spaced 96 cm apart. Plant population was intended to be 68 or 105 thousand plants/ha (pph) in 1980. Stand counts at harvest showed that average populations were 65,0, 72,2, 82,4, and 98,4 thousand pph for the conventional low, twin-row low, conventional high, and twin-row high treatments, respectively. Analysis of 1980 plot data showed that yields were still increasing at the highest plant population (103 000 pph), so in 1981 populations were intended to be 68 or 112 thousand pph. At harvest average populations were 70,8, 70,6, 109,1, and 116,9 thousand pph for the above treatments, respectively. Preplant fertilization rates were uniform for all treatments with 67–29–168 kg/ha N, P, and K being applied in 1980 and 67–29–168–53–6,7–3,3–2,8 kg/ha N, P, K, S, Cu, Zn, and B in 1981. In 1980 supplemental N was applied through the irrigation system in 2 or 4 equal applications so that a total of either 202 or 303 kg/ha of N was applied. In 1981 135 kg/ha of supplemental N was applied through the system to one fertility treatment making the total N application 202 kg/ha while the other treatment received supplemental N and K through the system making the total application of those nutrients 303 and 249 kg/ha, respectively.

Prior to planting a commercial maize hybrid[1] (Pioneer Brand 3382), the experimental site was subsoiled in 2 directions (each diagonal to the row direction but perpendicular to each other) at a depth of 45 cm and at spacings of 96 cm to eliminate root restrictions caused by an Ae horizon. The site was subsequently disked 2 times to incorporate the preplant fertilizer, Butylate (S-Ethyl diisobutylthiocarbamate) and Atrazine (2-chloro-4 ethylamino-6-isopropylamino-1,3,5-triazine) herbicides. Planting dates were 10 April 1980 and 7 April 1981.

Whole plant samples were collected frequently until pollination and at physiological maturity to determine nutrient accumulation, leaf area, plant height, and weight. Whole plant samples were dried at 70 °C, ground to pass a 0,5 mm

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[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the US Dept. of Agr. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

stainless steel screen and wet digested. Total Kjeldahl N was measured using procedures outlined by *Technicon Industrial Systems* (1977). Phosphorus was measured colorimetrically while K was measured by flame emission. Nutrient accumulation in kg/ha was calculated by multiplying nutrient concentrations by plant dry weight. Yields and yield components were measured at maturity. Yields were adjusted to uniform moisture content of 15,5%. Data were analyzed statistically using methods described by *Steel* and *Torrie* (1960).

Results and discussion

A detailed chemical characterization of the soil horizons at the experimental site is presented in table 1. As is characteristic of Typic Paleudults in the southeastern US, the organic matter content and cation exchange capacity were very low. Aluminum concentrations in the surface horizons were insignificant because of a good liming history for the site.

Table 1 Soil chemical characteristics

Horizon	pH	CEC	Al	K	Ca	Mg	P	Zn	Mn	M.O.
		me/100 g					ppm			%
Ap	5.8	1.5	0.0	0.12	1.75	0.46	52	2.8	14	0.52
Ap/Ae	6.2	1.4	0.0	0.17	1.46	0.48	30	1.2	12	0.30
B21t	4.7	3.3	0.0	0.21	1.61	0.53	0	0.3	1	0.02
B22t	4.6	4.2	1.9	0.07	0.34	1.58	0	0.2	1	0.00
C	4.4	4.2	2.8	0.06	0.28	1.28	0	0.4	1	0.00

Statistical analyses of nutrient concentration, dry matter, and yield data showed that the 2 fertility treatments and 2 irrigated water management treatments were generally not significantly different. The plant population and row configuration treatments were generally significantly different; however, for brevity in this presentation, only mean data for these treatments will be discussed. The total dry matter accumulation, yield, and yield components are presented in table 2.

Table 2 Dry matter accumulation, yield, yield components, and grain/nutrient accumulation ratios for irrigated maize

	Row configuration and plant population*							
	1980				1981			
	TR-H	TR-L	SR-H	SR-L	TR-H	TR-L	SR-H	SR-L
Dry matter (t/ha)	27.4	25.4	25.8	23.3	24.8	24.2	22.2	23.6
Grain (t/ha)	14.8	13.3	13.2	12.4	12.3	11.5	11.6	11.3
Grain/ear (g)	154	184	166	191	114	162	114	160
Kernel weight (g)	0.26	0.27	0.27	0.27	0.26	0.27	0.27	0.28
% Barren (%)	1.9	1.6	2.4	1.2	7.0	1.5	6.0	1.0
Thousand plants/ha	98.4	72.2	82.4	65.0	116.9	70.6	109.1	70.8
Maximum LAI	6.0	4.5	5.0	4.2	6.9	4.4	6.6	4.2
GNR	63	55	56	55	47	42	48	44
GPR	238	204	227	285	286	250	323	298
GKR	54	53	45	50	28	30	29	31

* TR = twin-row configuration; SR = single-row configuration.
H = high population; L = low population.

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The pattern of dry matter accumulation was similar to that reported by *Hanway* (1962), but the total quantity accumulated each year exceeded 22 000 kg/ha. The quantity of dry matter accumulation also exceeded that reported by *Rhoads* and *Stanley* (1981) and was probably due to hybrid differences. The rate of dry matter accumulation per unit area (data not shown) was greater in the high population treatments, although dry matter per plant and grain yield per plant were lower. At the low population, leaf area index (LAI) measurements were similar and averaged 4,3 for both row configurations. In 1980 maximum LAI at the high population was 5,0 for the single-row configuration and 6,0 for the twin-row configuration, but in 1981 maximum LAI exceeded 6,5 for both row configurations. This very high LAI may have approached the point where yields begin to decrease because of mutual shading *(Duncan,* 1972), since the percentage of barren stalks at the high population averaged 6,5% in 1981 compared to 2,2% in 1980.

The percentage of total N, P, and K accumulated by the maize before reaching a particular growth stage was similar both years and was also similar to the accumulation patterns reported by *Hanway* (1971). The N, P, and K concentrations and the quantities accumulated (table 3) were similar to those reported by *Rhoads* and *Stanley* (1981), but the N and P concentrations in these samples and in the ear leaf tissue (data not shown) were in the lower part of the sufficiency range suggested by *Jones* and *Eck* (1973). The fertility variable was not significant, therefore the higher K concentrations and greater total K accumulation in 1981 probably reflected 'luxury consumption' during the early growth stages when rainfall was much more favorable than in 1980. The lower P concentration early in the 1981 growing season probably reflected the greater plant population and a slight reduction in soil test P concentrations. The Mehlich No. 1 (double acid) extractable P concentration decreased from 95 to 58 ppm after 2 years of continuous maize production. The reduced grain yield in 1981 may have also contributed to the lower total P accumulation because of the high percentage of P which maize accumulates during grain formation.

Table 3 Nutrient concentrations in and accumulation by irrigated maize

Years	Days after emergence	N	P	K	N	P	K
		%			kg/ha		
81	21	3.88	0,38	5,02	7	1	10
80	33	3,14	0.45	5.18	25	4	42
81	36	3,02	0,31	5,36	40	4	73
80	40	3.01	0,33	4.14	60	6	82
81	44	2.66	0,28	4,82	88	10	161
80	47	2,18	0,27	4,53	121	15	161
81	51	2,16	0,31	4,67	137	20	298
80	53	1,80	0,31	3.07	140	24	240
80	60	1,29	0,35	2,22	132	36	227
81	66	1,60	0.23	2.80	209	30	367
80	71	1,76	0,28	1,88	211	30	224
80	103	0,89	0,25	1,50	226	63	265
81	107	1,09	0,17	1,58	259	41	374

Grain yields were very good in 1980 with maximum average yields of 14 800 kg/ha (236 bu/A). In 1981 yields decreased approximately 12% to 11 400 kg/ha at the lower plant population even though LAI values were similar to those found in 1980. The maximum yield in 1981 decreased approximately 14% averaging 12 700 kg/ha (202 bu/A). Grain yields were significantly greater when populations exceeded 98 000 plants/ha. Planting in the twin-row configuration

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generally increased yields significantly. In both years, the yields from all treatments were well above the economical 'breakeven' level of 9400 kg/ha of shelled grain.

Jong et al. (1982) reported that reduced solar radiation was a contributing factor to low maize yields in the low land tropics. A preliminary review of on-site solar radiation records indicates that this may have been a factor that contributed to reduced yields in this experiment in 1981. The largest difference in solar radiation occurred during growth stages 2,5 to 3,5 (35 to 49 days after emergence) which is the period when the primordial ear and potential kernel number is established in maize *(Hanway,* 1971). The kernel weight was nearly identical in both years (table 2) indicating that a major difference in the grain yield per plant was in the number of kernels produced. Visual observations of ear fill indicated that there were very little differences between ears, but the ear size was substantially smaller in 1981.

Grain yield to nutrient uptake ratios (GNR for N, GPR for P, and GKR for K) can be calculated and used to compare the nutrient utilization efficiency for management systems that involve different hybrids, tillage systems, fertility programs, and soil textures. Ratios for this experiment are presented in table 2. The GNR values were within the range of 30 to 60 reported by *Kurtz* and *Smith* (1966) and were similar in 1980 to those reported by *Rhoads* and *Stanley* (1981). In 1981 the GNR values were much lower, indicating less efficient utilization of the N which was accumulated. The GPR values were generally greater than those cited by *Caldwell* and *Ohlrogge* (1966) and probably reflected the lower P concentration in these plants. The GKR values in 1980 were similar to those reported by *Rhoads* and *Stanley* (1981), but the very low values in 1981 were probably caused by luxury consumption of K during the vegetative growth stages and the lower grain yields.

Other plant nutrients which analyses of 'ear leaf' tissue have shown to need careful management when producing irrigated maize on Typic Paleudult soils include B, S, and Zn. In 1981 applying 5 cm of additional water prior to silking significantly reduced the B concentration in the leaves opposite and below the primary ear (data not presented). The S concentration in those samples was slightly less than 0,2%, and the N:S ratios were approximately 15:1.

These experiments have confirmed that producing high and profitable irrigated maize yields on Typic Paleudult soils in the southeastern US is feasible. Water, nutrient and cultural management practices including tillage system, hybrid selection, plant population, and row configuration are some of the practices which must be carefully managed to achieve high and profitable irrigated maize yields. Although nutrient accumulations were not significantly different from those previously reported, the coarse texture, low cation exchange capacity, low water-holding capacity, and related strength characteristics of these soils emphasize the importance of fertilizer management practices including placement and timing of application. Further research is being conducted to refine these management systems so that they can be readily and profitably implemented by the producers.

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