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Row Spacing, Plant Population, and Water Management Effects on Corn in the Atlantic Coastal Plain[1]

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ABSTRACT

Lack of water because of erratic rainfall frequently limits corn (*Zea mays* L.) production on Typic Paleudults in the Atlantic Coastal Plain. Traditionally, wide (96 cm) row spacing and low plant population have been used to prevent water stress, but recently landowners have begun to invest in irrigation systems. Changes in row spacing, plant population, or fertilization practices may be required to achieve maximum water-and nutrient-use efficiency with those systems. We evaluated plant population treatments averaging 7.0 and 10.1 plants m^{-2} in single and twin rows on a Norfolk (fine-loamy, siliceous, thermic Typic Paleudult) loamy sand during 1980, 1981, and 1982. Three water management [nonirrigated, irrigated using tensiometers (TENS) to measure soil-water potential for scheduling, and irrigated using a computer-based water balance (CBWB) for scheduling], and two fertilization programs were also evaluated in a four-factor split-plot design. Water management and plant population interacted significantly. Planting in twin rows increased grain yield an average of 0.64 Mg ha^{-1} (10 bu/A), but planting more than 7.1 plants m^{-2} significantly increased grain yield only in 1980. Irrigation increased grain yield 150, 161, and 8% in 1980, 1981, and 1982, respectively, as a result of increased kernel weight and number of kernels per ear. Increasing total N, P, and K application beyond 200, 30, and 167 kg ha^{-1}, respectively, did not significantly influence grain yield or yield components. Yield advantages of narrow rows can be obtained on Coastal Plain soils which require subsoiling by using a twin-row planting configuration. Irrigation can be scheduled using either tensiometers (soil-water potential) or a computerized water balance without significantly changing corn grain yield, nutrient accumulation, or yield components.

Additional index words: **Irrigation, Maize, Nutrient accumulation, Yield components, *Zea mays* L.**

DESPITE an average annual precipitation which exceeds 1100 mm, corn (*Zea mays* L.) grain yields in the Atlantic Coastal Plain are frequently limited by water shortages. Yield reductions occur because seasonal rainfall distribution is erratic, and soils have low water-holding capacities. Compacted tillage pans or genetic horizons also restrict root growth and further limit plant available water. To compensate for erratic rainfall, wide row spacing and low plant population are used. To further minimize impact of intermittent drought, landowners have also begun to invest in irrigation systems. This change encourages planting more hectares of corn, but costs associated with irrigation must be offset by increased grain yields. Currently, 9.4 Mg ha^{-1} of grain are needed to ensure profitability (35), but failure to properly manage irrigation (18) or to change traditional cultural practices may prevent profitable irrigated corn production.

Corn grain yield can be increased by raising plant population (19), but this relationship is parabolic (10). At low populations, yield is limited by the number of plants, while at high populations, yield is limited by the number of barren plants. Intrarow spacing and competition for water, light, and nutrients determine optimum plant densities for each growth environment (3,11,21,22,27,31).

Plant population can usually be increased by decreasing row spacing. However, for many Atlantic Coastal Plain soils, subsoiling is required to disrupt pans which restrict rooting and stress plants by reducing water and nutrient uptake (6,34). Subsoiling is energy intensive but, even with irrigation, it has been shown to increase corn yield on Typic Paleudults (6). Therefore, to reduce plant row spacing, major changes in tillage, planting, cultivating, and harvesting equipment are needed. Those requirements economically reinforce reluctance to change traditional practices. We therefore, investigated a twin-row planting configuration (31) which can accommodate subsoiling and provide advantages of narrow row spacing.

Irrigation in the Atlantic Coastal Plain can be scheduled or managed in several ways (7,13). Management based on soil-water potential is widely recognized and recommended for this region (4), but this technique is not widely utilized (18). Rhoads (26) and Rhoads and Stanley (28) have concluded that "plow layer" soil-water management and programmed fertilization are effective for increasing corn production on Florida Ultisols, but those management practices have also not been widely adopted. Computers are used in arid regions to schedule irrigation water applications, but for several reasons this technology is neither recommended nor practiced by irrigation managers in the humid region (7,13,18). The objectives of this research were to (i) determine if planting corn in twin rows at higher plant populations would increase grain yield; (ii) evaluate effects of row configuration, plant population, and water management on yield components and nutrient accumulation; and (iii) compare current N-P-K recommendations with an increased fertilizer program based on plant population.

METHODS AND MATERIALS

Soil Characteristics

Three water management, two row spacing, two plant population, and two fertilization programs for corn were evaluated in a four-factor split-plot experiment on Norfolk (fine-loamy, siliceous, thermic Typic Paleudult) loamy sand near Florence, SC, during 1980, 1981, and 1982. Soil profile descriptions were made by USDA-SCS personnel for two pits excavated to a depth of 2 m in border areas between field replicates. Water retention and bulk density were measured on undisturbed core samples (29). Cation exchange capacity (CEC) was estimated by summation of 1 *M* NH_4OAc (pH 7.0) exchangeable Ca, Mg, K, and Na plus 1 *M* KCl exchangeable Al (14). Total organic carbon, 1:1 soil:water pH, and Mehlich No. 1 extractable P, K, Ca, Mg, Mn, and Zn were determined on representative samples from each soil horizon (8). Profile characteristics (Table 1), were representative of soils throughout the Atlantic Coastal Plain (20). The effective root zone was estimated to be approximately 1 m when pits were excavated and also by evaluating ten-

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Table 1. Characteristics of a Norfolk loamy sand (Typic Paleudult) near Florence, SC.

Horizon	Depth	Texture	Plant available water	Organic matter	Bulk density	CEC†	Ex-changeable Al	Water pH	Mehlich 1 Extractable					
									P	K	Ca	Mg	Mn	Zn
	cm		$cm\ cm^{-1}$	$g\ kg^{-1}$	$Mg\ m^{-3}$	$cmol\ (p^+)\ kg^{-1}$			$mg\ kg^{-1}$					
Ap	0–23	lfs	0.165	5.2	1.55	1.6	0.0	5.8	52	47	351	56	14	2.8
E	24–28	lfs	0.150	3.0	1.67	1.6	0.0	6.2	30	66	293	58	12	1.3
B21t	29–94	scl	0.196	0.2	1.54	2.4	0.0	4.7	0	82	323	64	1	0.3
B22t	95–136	sc-scl	0.100	0.0	1.68	4.2	1.9	4.6	0	27	68	192	1	0.2
C	137–162	sl-scl	0.110	0.0	1.74	4.1	2.8	4.4	0	23	56	156	1	0.4

† CEC, cation exchange capacity.

siometer data (7). The Al concentration was negligible because of a good liming history. Extractable P and K concentrations were typical for Coastal Plain soils and would be rated as a high P and medium K soil test (9).

Statistical Design

Four replications of each treatment were arranged in a randomized complete block within a split-split-split-plot design. Analysis of variance (ANOVA) was computed and least significant differences (LSD) were calculated using appropriate error terms for each parameter (32).

Water management treatments (whole plots) included a nonirrigated (NI) treatment and two irrigated treatments. Water applications were scheduled using either tensiometers (TENS) to measure soil-water potential or a computer-based water balance (CBWB) as described by Camp et al. (7). Irrigation water was applied through double-wall trickle irrigation tubes spaced 48 cm apart on the soil surface with emitters spaced 30 cm apart along each line. The system was operated at maximum design pressure (125 kPa) to provide a vertical stream of water which promoted uniform wetting of the soil surface. Water was supplied to each group of four plots through PVC pipe, regulated with pressure regulators, and measured with positive displacement meters. Trickle tubing was replaced each year to prevent degraded irrigation uniformity caused by plugging or leaks.

Row spacing treatments (subplots) included single rows spaced 96 cm apart and twin rows spaced 35 cm apart in 1980 or 30 cm apart in 1981 and 1982. Twin and single row configurations were planted with John Deere[3] Flex-71 planters. Twin rows were achieved by mounting two additional planter units on a standard two-row tool bar as close as possible to existing units and centering them 112 cm apart in 1980 or 96 cm apart in 1981 and 1982.

Plant population (sub-subplots) in 1980, 1981, and 1982 averaged 6.7, 7.1, and 7.1 plants m^{-2} for low or 8.9, 11.2, and 10.3 plants m^{-2} for high treatments, respectively. The low population was within current recommendations (35) while the high population was similar to those reported for maximum corn grain production (1,27). Desired plant densities were achieved by planting approximately 10% more seed and thinning each row at growth stage 1.0 (12). Stand density was reconfirmed at harvest by counting the number of plants in each harvested segment.

Total N, P, and K applications in kg ha^{-1} for low and high fertilizer treatments (sub-sub-subplots) were 200, 30, and 167 or 315, 30, and 167 in 1980; 200, 30, and 167 or 336, 30, and 280 in 1981; and 200, 30, and 167 or 336, 43, and 280 in 1982, respectively. The low fertilizer rate was based on current recommendations for corn production in South Carolina (9). The high fertilizer program was based on plant population (26) so that the high population × high fertilizer treatment and the low plant population × low fertilizer treatment combinations both supplied approximately 3 g N $plant^{-1}$.

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

Cultural Practices

In March of each year, crop residues and winter weeds were incorporated by disking approximately 10 cm deep. To reduce restrictions to rooting caused by an E horizon, the experimental site was then subsoiled every 96 cm, in two directions (each diagonal to subsequent row direction, but perpendicular to one another) and at a depth of 45 cm. A uniform application of granular preplant fertilizer supplied 65, 30, and 167 kg ha^{-1} of the total N, P, and K applied each year. In 1981, the preplant formulation also contained 53, 2.8, 6.7, and 3.4 kg ha^{-1} S, B, Cu, and Zn; while in 1982, it also contained 22, 53, 2.8, and 3.4 kg ha^{-1} Mg, S, B, and Zn. A disk harrow or field cultivator was used to smooth the soil surface, to incorporate preplant fertilizer, and to incorporate a mixture of butylate (S-ethyl diisobutylthiocarbamate) and atrazine [2-chloro-4(ethylamino)-6-(isopropylamino)-S-triazine].

Pioneer 3382 hybrid corn was planted 10 Apr. 1980, 7 Apr. 1981, and 2 Apr. 1982. Twin-row plots consisted of four pairs spaced 112 or 96 cm apart and 7.62 m long (34 m^2 in 1980, 30 m^2 in 1981 and 1982). Single-row plots were six rows wide by 7.62 m long (44 m^2). High fertilizer plots were sidedressed four times at 10-day intervals beginning when plants were at growth stage 1.5 (12), while low fertilizer plots received two equal applications at growth stages 1.5 and 2.5. Fertilizer nutrients were applied to irrigated treatments by injecting fertilizer solutions into the irrigation water with a Raguse TXT-American pump. Water and fertilizer nutrients were distributed to each plot through one of four PVC manifolds to which the trickle irrigation tubes were connected. For nonirrigated (NI) plots, fertilizer solution was diluted with 1 L of water and applied to the soil surface on both sides of each 7.6 m row using plastic sprinkling cans.

To evaluate plant nutrient status at anthesis (growth stage 5), 20 leaves per plot were collected from opposite and below the primary ear, dried at 70 °C, ground to pass a 0.5 mm stainless steel screen, and analyzed by Clemson University's Agricultural Service Laboratory for N, P, K, Ca, Mg, S, B, Cu, Mn, and Zn. Standard laboratory procedures (15) including Kjeldahl digestion for N and spectroscopy with a Perkin-Elmer ICP/5000 spectrophotometer were used for analyses. Two plants from each plot were also collected at anthesis to estimate maximum leaf area index (LAI), using a LiCor Model 3100 area meter. At physiologic maturity (growth stage 10) a 4 m^2 sample was collected from each plot, dried at 70 °C, ground to pass a 0.5 mm stainless steel screen, digested with sulfuric acid and hydrogen peroxide, and analyzed for N using industrial method 334-74 W/B (33). Ammonium molybdate - ammonium vanadate reagents were used for P and flame emission spectroscopy for K analyses. Total aerial N, P, and K accumulation were calculated by multiplying dry matter and nutrient concentration values.

Table 2. Corn yield components as influenced by total water applied to a Norfolk loamy sand between planting and physiologic maturity.

Management treatment	Water applied	Grain yield	Grain per ear	Kernel wt.	Barren plants	Lodged plants
	mm	Mg ha⁻¹	g	g 100⁻¹	arcsin $x^{-1/2}$	
			1980			
NI†	297‡	5.35	95	19.7	17.1§	23.2§
TENS-50	581	13.34	172	26.6	5.3	4.8
TENS-25	745	13.49	176	26.9	6.7	3.3
$LSD_{0.05}$		1.17	11	1.2	3.6	1.8
CV (%)		17.8	12	8.1	60.5	27.5
			1981			
NI	330‡	4.48	71	24.3	30.5	4.3
CBWB	524	11.46	136	27.1	9.4	11.0
TENS-25	582	11.95	138	27.0	9.7	21.4
$LSD_{0.05}$		0.97	6	0.6	8.3	NS
CV (%)		17.0	8.2	3.7	81.9	179.1
			1981			
NI	485‡	10.27	132	24.4	11.5	20.0
CBWB	598	11.02	136	25.2	10.4	17.9
TENS-25	640	11.03	136	24.8	10.6	19.7
$LSD_{0.05}$		0.32	NS	0.5	NS	NS
CV (%)		4.8	9.0	3.4	35.2	28.7

† NI, nonirrigated; TENS-50, 50 kPa soil-water tension (1980); CBWB, computer-based water balance (1981 and 1982); TENS-25, 25 kPa soil-water tension; NS, not significant; LSD, least significant difference; CV, coefficient of variation.
‡ Seasonal rainfall (1 April to 15 August), irrigated treatments include rainfall plus irrigation water.
§ Transformed values of barren and lodged plant decimalfractions (x).

Grain yield was measured by hand harvesting the center 12 m² of each 30 m² twin-row plot or the center 16 m² of each 44 m² single-row plot. Yield components were determined by counting the number of ears, plants, and barren stalks in each harvested area. Moisture content of the grain after shelling was measured with a Steinlite Model SS250 meter. Plot yields were adjusted to a constant water content of 155 g kg⁻¹. Subsamples of grain were dried at 70 °C before measuring the weight of 100 kernels. The decimal fraction of barren and lodged plants was determined by division. An arcsin transformation (32) was performed before statistical analysis of the barren and lodged data because the decimal fractions had a binomial distribution. Transformed data are presented for the reader, but actual decimal fractions for barren and lodged plants can be recomputed using $[\sin(x)]^2$ where x is the tabular value presented for any treatment. Statistical calculations were made using appropriate software written for Hewlett-Packard desktop microcomputers.

RESULTS AND DISCUSSION

Water Management Effects

Total rainfall received between planting and physiologic maturity was 297, 330, and 485 mm in 1980, 1981, and 1982, respectively. In 1980, a period of drought occurred during vegetative growth stages, while in 1981, it occurred at anthesis. Rainfall in 1982 was well distributed and very little irrigation water was required. This type of variation in seasonal rainfall is typical and is one factor complicating irrigation management in the Coastal Plain.

Total water application was determined by rainfall plus the amount of irrigation water applied to meet scheduling criteria and ranged from 297 to 745, 330 to 582, and 485 to 640 mm during 1980, 1981, and 1982, respectively. Two common water management treatments, nonirrigated (NI) and maintenance of soil-water tension below 25 kPa (TENS-25), were evaluated each season. Grain yields for these two treatments were significantly different each year (Table 2). The alternative irrigation scheduling technique (TENS-50 in 1980; CBWB in 1981 and 1982) reduced the amount of irrigation water applied by 164, 58, and 42 mm in 1980, 1981, and 1982, respectively. This treatment increased grain yield compared to NI treatments, but did not result in grain yields which were significantly different from those produced using TENS-25 water management (Table 2). When averaged for the two scheduling methods, irrigation increased corn grain yields 150, 161, and 8% compared to NI grain yields in 1980, 1981, and 1982.

Table 3. Total aerial accumulation of N, P, and K as influenced by seasonal water supply.

Management treatment	Water applied	N	P	K
	mm	kg ha⁻¹		
	1980			
NI†	297‡	155	45	189
TENS-50	581	225	63	263
TENS-25	745	227	61	266
$LSD_{0.05}$		24	11	38
CV (%)		20	31	26
	1981			
NI	330‡	224	36	344
CBWB	524	249	39	359
TENS-25	582	259	42	383
$LSD_{0.05}$		NS	5	NS
CV (%)		21	10	28
	1982			
NI	485‡	219	37	312
CBWB	598	230	37	319
TENS-25	640	204	34	300
$LSD_{0.05}$		14	NS	NS
CV (%)		10	19	19

† NI, nonirrigated; TENS-50, 50 kPa soil-water tension (1980); CWBW, computer-based water balance (1981 and 1982); TENS-25, 25 kPa soil-water tension; LSD, least significant difference; CV, coefficient of variation.
‡ Seasonal rainfall (1 April to 15 August), irrigated treatments include rainfall plus irrigation water.

In 1980 and 1981, both irrigated treatments significantly increased the amount of grain ear⁻¹ (ear size) and kernel weight (Table 2). In 1982, kernel weight for the CBWB treatment was significantly greater than for the NI treatment, but all other yield component comparisons were nonsignificant. The number of barren plants was greatest in 1981 because drought occurred at anthesis (growth stage 5). That is the most critical period for corn to suffer water stress (30), because pollination and silk emergence are not synchronized. The NI treatment had fewer barren plants in 1982 than for either 1980 or 1981 (Table 2). There were also no significant differences in plant barrenness among water management treatments that year. In 1980 the number of barren plants differed significantly for the two irrigated water management treatments, but other yield components comparisons were not significant at P(0.05).

Water management inconsistently influenced the number of lodged plants (Table 2). In 1980 lodging was most severe for NI management. The exact cause is unknown, but lodging appeared to be related to stalk strength which may have been reduced by low K accumulation (Table 4). Previously, K accumulation by soybean (*Glycine max* L. Merr.) was shown to be reduced during drought, apparently because diffusion pathways were broken when the Norfolk loamy sand became dry (17). In 1980, drought occurred while the corn was growing vegetatively (7), which is also when K accumulation is greatest (12). Those conditions may have caused greater lodging to occur in NI plots than in either irrigated treatment.

In 1981 and 1982, lodging occurred, but it did not appear to be related to stalk strength, and differences among water management treatments were not significant. Total K accumulations those years were much greater than in 1980 (Table 3). This presumably reflected greater rainfall during vegetative growth stages (7) and also may be why lodging occurred by plant roots pulling out of the ground rather than by stalks breaking over.

Leaf-B concentrations were inversely related to the amount of water applied. This occurred because fertilizer B was applied preplant, and on Typic Paleudults, B and other nutrients are very mobile (23,25). Concentrations of B in leaves opposite and below the primary ear at anthesis averaged 23, 18, and 13 mg kg^{-1} in 1981 and 16, 12, and 11 mg kg^{-1} in 1982 for the NI, CBWB, and TENS-25 treatments, respectively.

Total N and P accumulations were increased by irrigation in 1980 (Table 3). This presumably reflected better growth and higher grain yield (Table 2). In 1981, total P accumulation for TENS-25 was significantly greater than for the NI treatment, but all other nutrient accumulation comparisons that year were not significant. Total N accumulation for CBWB was significantly greater than for TENS-25 in 1982 (Table 3). This was the only nutrient accumulation comparison where the two irrigated water management treatments differed significantly. Reduced nutrient accumulation for the NI treatment in 1980 was caused by drought, but no reason is offered to explain total P and N accumulation differences in 1981 or 1982.

Row Configuration Effects

Twin-and single-row configurations were evaluated in subplots each year. When averaged across water management treatments, grain yields for the twin-row configuration were 0.76, 0.52, and 0.63 Mg ha^{-1} greater than for the single rows spaced 96 cm apart in 1980, 1981, and 1982, respectively. In 1981 and 1982, neither ears $plant^{-1}$, grain ear^{-1}, nor kernel weight were significantly different for the two row spacings. In 1980, the number of ears $plant^{-1}$ averaged 0.93 for twin rows and 0.92 for single rows, but this significant difference was partially offset by a significantly lower amount of grain ear^{-1} (142 vs. 154 g ear^{-1} for twin and single rows, respectively). Row spacing caused no significant difference in the number of barren or lodged plants, nor in concentrations of N, P, K, Ca, Mg, S, B, Cu, Mn, or Zn in leaves at anthesis (data not presented).

Total N, P, and K accumulations in 1982 averaged 225, 38, and 323 kg ha^{-1} for twin rows and 210, 34, and 297 kg ha^{-1} for single rows in 1982. The difference in N, P, and K accumulations was significant at P(0.05) in 1982, but the only other nutrient accumulation difference, significant because of row spacing, was for P in 1981 when twin-row plants accumulated 41 kg ha^{-1}, compared to 35 kg ha^{-1} for single row plants.

Grain-yield-to-nutrient-uptake ratios have been suggested (28) as a method to compare nutrient utilization efficiencies for different production systems. In 1980, 1981, and 1982, N ratios averaged 53, 38, and 50; P ratios averaged 192, 245, and 302; and K ratios averaged 45, 26, and 35, respectively. There were no significant differences in those ratios because of row spacing, indicating nutrient-use efficiency was not changed.

Grain yield was consistently increased by planting twin rows. We hypothesized that this would occur because improved plant distribution would reduce intrarow competition for water. Extensive tensiometer data from 30-, 60-, 90-, 120-, and 150-cm depths within the profile and at several position relative to the row were collected each year (7), but analysis failed to confirm or dispel our hypothesis. However, our results agree with current recommendations for reducing row width from 100 to 75 cm, provided water management and production practices, such as plant population, fertilization, and weed control, are adequate (35).

Plant Population Effects

Current plant population recommendations range from four to five plants m^{-2} for nonirrigated production and from six to seven plants m^{-2} for irrigated production (35). In this experiment, plant populations averaging 7.0 and 10.1 plants m^{-2} were evaluated in sub-subplots to determine whether in conjunction with twin row spacing grain yield could be significantly increased by further increasing plant population. The interaction for plant population and row spacing was not significant, therefore, main effects of plant population on grain yield components have been summarized in Table 4.

In 1980, average grain yield with 8.9 plant m^{-2} was significantly greater than with 6.7 plants m^{-2}, but when the high population treatment averaged 11.2 plants

Table 4. Influence of plant population on yield and yield components of corn grown on a Norfolk loamy sand near Florence, SC.

Population	Grain yield	Grain per ear	Kernel wt.	Barren plants	Lodged plants
plants m^{-2}	Mg ha^{-1}	g	g 100^{-1}	arcsin $x^{-1/2}$	
		1980			
6.7	10.42	160	24.7	8.4†	8.9†
8.9	11.04	135	24.0	11.0	12.0
$LSD_{0.05}$‡	0.39	4	0.3	1.7	3.0
CV (%)	8.4	6	2.7	40.8	68.2
		1981			
7.1	9.55	138	26.9	9.7	5.3
11.2	9.04	92	25.4	23.4	19.2
$LSD_{0.05}$	0.40	4	0.3	3.1	5.5
CV (%)	10.2	8	2.3	43.8	105.1
		1982			
7.1	10.80	154	25.4	6.0	14.6
10.3	10.89	114	24.2	15.7	23.7
$LSD_{0.05}$	NS	4	0.5	1.4	3.2
CV (%)	7.1	7	4.6	30.9	39.1

† Transformed values of barren and lodged plant decimal fractions (x).
‡ LSD, least significant difference; CV, coefficient of variation; NS, not significant.

m^{-2} in 1981, average grain yield was significantly lower than with 7.1 plants m^{-2}. Average ear size for the high population treatment was 92 g in 1981, indicating plant population had been increased too much (Table 4). In 1982, the high population treatment averaged 10.3 plants m^{-2} and numerically increased grain yield compared to the low population treatment which averaged 7.1 plants m^{-2}. Duncan (11) stated that reduced kernel weight and ear size were the first steps toward plant barrenness. Both parameters were reduced significantly as plant population was increased from 7 to 11 plants m^{-2} in this experiment. The number of barren and lodged plants was also significantly greater at the high population than at the low population each year.

Plant population significantly influenced leaf area index (LAI). In 1980, 1981, and 1982, maximum LAI values averaged 4.1, 4.2, and 4.6 for low plant population treatments and 4.9, 6.4, and 6.4 for high plant populations treatments. Increased LAI values imply greater light interception by the canopy, but this parameter was not measured. However, Duncan (11) concluded from an experiment with plant densities of 1.5, 3.0, 5.9, and 11.9 plants m^{-2} that when LAI exceeded 3.5 to 4.5, photosynthesis per hectare was maximized. Those results suggest photosynthesis was probably at a maximum for both plant populations in this experiment.

Fertilization Effects

Two fertilizer treatments (low and high) evaluated in sub-sub-subplots did not cause significant differences in grain yield or yield components (data not presented). Analysis of leaf tissue collected at anthesis showed that N, K, Mn, and Zn concentrations were higher in plants fertilized at the high rate than in plants fertilized at the low rate (Table 5). Nitrogen and K concentrations reflected higher fertilizer application rates, while higher Mn and Zn concentrations reflected greater acidification associated with nitrification of additional UAN fertilizer (2). The high fertilization treatment also reduced leaf-Mg concentrations, presumably in response to higher K concentrations in the soil and plant. Concentrations of Ca, B, and Cu were not significantly influenced by fertilization treatment. All measured nutrient concentrations were within currently recommended sufficiency ranges (16,24).

Table 5. Influence of fertilizer regime on nutrient concentrations in leaves opposite and below the primary ear at silking.

N-P-K	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn	N/S
kg ha^{-1}	g kg^{-1}						mg kg^{-1}				
				1981							
200-30-167	26.4	2.8	21.8	3.5	2.0	1.7	17	11	50	26	16
336-30-280	28.3	3.0	22.9	3.4	1.7	2.0	18	11	64	30	15
LSD$_{0.05}$†	0.8	0.1	0.7	NS	0.1	0.2	NS	NS	4	2	NS
CV (%)	6.6	5.8	7.5	13	11	24	29	12	18	15	28
				1982							
200-30-167	29.7	2.9	27.9	3.6	2.2	--	13	10	30	26	--
336-43-280	30.5	3.0	28.5	3.5	2.0	--	13	11	40	33	--
LSD$_{0.05}$	0.6	NS	0.5	NS	0.1	--	NS	NS	3	2	--
CV (%)	4.6	4.6	4.0	7.2	8.5	--	24	17	19	16	--

† LSD, least significant difference; CV, coefficient of variation; NS, not significant.

In 1981, total N and K accumulation by plants receiving the high fertilization treatment was 41 and 47 kg ha^{-1} greater than that of plants receiving the low fertilizer treatment. This presumably reflected higher rates of N and K fertilizer, but N accumulation in 1980 and N, P, and K accumulation in 1982 were not significantly increased by higher fertilization rates (data not presented).

Treatment Interactions

Interactions among water management, row spacing, plant population, and fertilizer program were generally not statistically significant at P(0.05). The exception was for water management and plant population, but even for those factors only 5 of 15 interactions for various parameters were statistically significant (Table 6). In 1980 and 1981, grain yield decreased as plant population increased without irrigation, but with irrigation grain yield increased as plant population increased. In 1982, however, rainfall was well distributed throughout the growing season and the plant population × water interaction was not significant. Kernel weight and ear size (grain ear^{-1}) decreased as plant population increased for all water management treatments. The parabolic relationship between plant population and grain yield (10) can also

Table 6. Water management and plant population interaction effects on yield components of corn grown on a Norfolk loamy sand.

Water applied	Population	Grain yield	Grain per ear	Kernel wt.	Barren plants	Lodged plants
mm	plants m^{-2}	Mg ha^{-1}	g	g 100^{-1}	arcsin x$^{-1/2}$	
			1980			
297†	6.7	5.54	105	20.0	16.4‡	21.1‡
581	6.7	12.84	186	26.9	4.0	3.1
745	6.7	12.87	188	27.2	4.9	2.5
297	8.9	5.16	85	19.4	17.8	25.2
581	8.9	13.85	157	26.2	6.7	6.5
745	8.9	14.10	163	26.5	8.4	4.2
LSD$_{0.05}$		0.67	6	0.6	2.9	5.3
CV (%)		8.4	6	2.7	40.8	68.2
SIG§		*	NS	NS	NS	NS
			1981			
330†	7.1	5.80	94	25.5	19.6	3.1
524	7.1	11.30	161	27.5	3.7	4.1
582	7.1	11.55	161	27.6	5.7	8.8
330	11.2	3.16	48	23.1	41.3	5.6
524	11.2	11.62	111	26.7	15.2	18.0
582	11.2	12.35	116	26.4	13.7	34.0
LSD$_{0.05}$		0.70	7	0.4	5.4	9.6
CV (%)		10.2	8	2.3	43.8	105.1
SIG		**	NS	**	**	**
			1982			
485†	7.1	10.27	149	24.9	6.8	16.0
598	7.1	10.84	154	25.4	5.4	13.4
640	7.1	11.26	157	25.8	5.7	14.5
485	10.3	10.27	110	23.8	16.2	23.9
598	10.3	11.20	117	24.6	15.3	22.3
640	10.3	11.20	119	24.3	15.6	24.9
LSD$_{0.05}$		0.57	7	0.9	2.5	5.6
CV (%)		7.1	7	4.6	30.9	39.1
SIG		NS	NS	NS	NS	NS

*,** Significance of water x plant population interaction at 0.05 and 0.01, respectively.
† Seasonal rainfall, (1 April to 15 August), irrigated treatments include rainfall plus irrigation water.
‡ Transformed values of barren and lodged plant decimal fractions (x).
§ NS, not significant, LSD, least significant difference, CV, coefficient of variation.

be observed from data in Table 6 which show that lower grain yields can occur because of low plant population or because of increased plant barrenness. The number of barren or lodged stalks was also increased by stress caused by higher plant population or a lack of plant available water.

SUMMARY AND CONCLUSIONS

Planting in twin rows increased grain yield an average of 0.64 Mg ha^{-1} (10 bu/A), indicating this is an alternative method for gaining advantages of narrow row spacing for corn without requiring major equipment replacement. A plant density of approximately seven to nine plants m^{-2} appears sufficient for irrigated production using either soil-water potential or a water balance to schedule water applications. For nonirrigated production, plant density should not exceed seven plants m^{-2}. Irrigation increased grain yield 150, 161, and 8% in 1980, 1981, and 1982, respectively, by increasing kernel weight and number of kernels per ear. This study did not quantify fertilizer rates for corn production in the Atlantic Coastal Plain, but application rates of more than 200, 30, and 167 kg ha^{-1} of N, P, and K did not significantly increase grain yield.

REFERENCES

1. Armstrong, D., B. Agerton, and S. Martin (ed.) 1982. Better crops with plant food. Vol. LXVII. Potash & Institute. Atlanta, GA. p. 4-5.
2. Berti, W.R., D.L. Karlen, and C.R. Camp. 1983. Seasonal variations in soil pH and extractable nutrient concentrations in an intensively-managed corn program. Agron. Abstr. American Society of Agronomy, Madison, WI. p. 164.
3. Brown, R.H., E.R. Beaty, W.J. Ethredge, and D.D. Hayes. 1970. Influence of row width and plant population on yield of two varieties of corn (*Zea mays* L.). Agron. J. 62:767–770.
4. Bruce, R.R., J.L. Chesness, T.C. Keisling, J.E. Pallas, Jr., D.A. Smittle, J.R. Stansell, and A.W. Thomas. 1980. Irrigation of crops in the Southeastern United States: Principles and practice. USDA-ARS, New Orleans, LA ARM-S-9.
5. Camp, C.R., G.D. Christenbury, and C.W. Doty. 1984. Tillage effects on crop yield in Coastal Plain soils. Trans. ASAE 27:1729–1733.
6. Campbell, R.B., D.C. Reicosky, and C.W. Doty. 1974. Physical properties and tillage of paleudults in the Southeastern Coastal Plain. J. Soil Water Conserv. 29(5):220–224.
7. ———, D.L. Karlen, and J.R. Lambert. 1985. Irrigation scheduling and row configuration for corn in the southeastern Coastal Plain. Trans. ASAE (in press).
8. Council on Soil Testing and Plant Analysis. 1980. Reference methods for soil testing. Council on Soil Testing and Plant Analysis. Athens, GA.
9. Department of Agronomy and Soils, Department of Horticulture, Department of Forestry, and Department of Agricultural Chemical Services. 1982. Lime and fertilizer recommendations based on soil-test results. Cir. 476. Coop. Ext. Serv., Clemson University, Clemson, SC.
10. Downey, L.A. 1971. Plant density-yield relations in maize. J. Aust. Inst. Agric. Sci. 37:138–146.
11. Duncan, W.G. 1972. Plant spacing, density, orientation, and light relationships as related to different corn genotypes. Reprinted from Proc. 27th Annual Corn and Sorghum Research Conf. Am. Seed Trade Assoc., Washington, DC.
12. Hanway, J.J. 1971. How a corn plant develops. Spec. Rep. no. 48. Iowa State University, Ames, IA.
13. Hook, J.E., E.D. Threadgill, and J.R. Lambert. 1984. Corn irrigation scheduled by tensiometers and the Lambert model in the humid Southeast. Agron. J. 76:695–700.
14. Horn, D.P., M.M. Alley, and P.R. Bertsch. 1982. Cation exchange capacity measurements. Comm. Soil Sci. Plant Anal. 13(10):851–862.
15. Issac, R.A., and W.C. Johnson. 1977. Laboratory procedures for the soil and plant analysis laboratory. Univ. Ga. Soil and Plant Analysis Laboratory, Athens, GA.
16. Jones, J.B., Jr., and H.V. Eck. 1973. Plant analysis as an aid in fertilizing corn and grain sorghum. p. 349–364. *In* L.M. Walsh and J.D. Beaton (ed.) Soil testing and plant analysis. Soil Science Society of America, Madison, WI.
17. Karlen, D.L., P.G. Hunt, and T.A. Matheny. 1982. Accumulation and distribution of K, Ca, and Mg by selected determinate soybean cultivars grown with and without irrigation. Agron. J. 74:347–354.
18. Lambert, J.R. 1980. Irrigation management - humid areas. Proc. Am. Soc. of Agric. Engr. 2nd Natl. Irrigation Symposium. Irrigation Challenge of the 80's, Oct. 20-23, Lincoln, NE. p. 175–184.
19. Larson, W.E., and J.J. Hanway. 1977. Corn production. *In* G.F. Sprague (ed.) Corn and corn improvement. Agronomy 18:625–669.
20. Long, F.L., H.F. Perkins, J.R. Carreker, and J.M. Daniels. 1969. Morphological, chemical, and physical characteristics of eighteen representative soils of the Atlantic Coast Flatwoods. Res. Bull. no. 59. Soil and Water Conserv. Res. Div., Agric. Res. Serv., USDA, Washington, DC.
21. Lutz, J.A., Jr., H.M. Camper, and G.D. Jones. 1971. Row spacing and population effects on corn yield. Agron. J. 63:12–14.
22. Nunez, R., and E.J. Kamprath. 1969. Relationships between N response, plant population, and row width on growth and yield of corn. Agron. J. 61:279–282.
23. Page, N.R., and H.P. Cooper. 1955. Less soluble boron compounds for correcting boron nutritional deficiencies. J. Agric. Food Chem. 3:222–225.
24. Plank, C.O. 1979. Plant analysis handbook for Georgia. Bull. No. 735. Coop. Ext. Serv., Univ. Ga, Athens, GA.
25. Rhoads, F.M. 1970. Redistribution of fertilizer salts in soil columns after leaching with water. Fla. Soil Crop Sci. Soc. Proc. 30:298–304.
26. ———. 1981. Plow layer soil water management and program fertilization on Florida Ultisols. Soil Crop Sci. Soc. Fla. 40:12–16.
27. ———, and R.L. Stanley, Jr. 1978. Effect of population and fertility on nutrient uptake and yield components of irrigated corn. Fla. Soil Crop Sci. Soc. Proc. 38:78–81.
28. ———, and ———. 1981. Fertilizer scheduling, yield, and nutrient uptake of irrigated corn. Agron. J. 73:971–974.
29. Richards, L.A. 1965. Physical condition of water in soil. *In* C.A. Black (ed.) Methods of soil analysis. Agronomy 9:128–152.
30. Shaw, R.H. 1977. Climatic requirement. p. 591–624. *In* G.F. Sprague (ed.) Corn and corn improvement. Agronomy no. 18, American Society of Agronomy, Madison, WI
31. Stanley, R.L., and F.M. Rhoads. 1974. Response of corn (*Zea mays* L.) to population and spacing with plow-layer soil water management. Fla. Soil Crop Sci. Soc. Proc. 34:127–130.
32. Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. 2nd ed. McGraw-Hill. NY, NY.
33. Technicon Industrial Systems. 1977. Industrial Method no. 334-74 W/B⁺. Individual/simultaneous determination of N and/or P in BD acid digests. p. 1–17. Technicon Industrial Systems, Tarrytown, NY.
34. Trouse, A.C., Jr. 1983. Observations on under-the-row subsoiling after conventional tillage. Soil Tillage Res. 3:67–81.
35. Zublena, J.P. C.L. Parks, E.C. Murdock, J.P. Krausz, R.P. Griffin, G.D. Christenbury, R.A. Spray, L.A. Stanton, and F.J. Wolak. 1983. Corn production guide for South Carolina. Cir. no. 587. Coop. Ext. Serv., Clemson University, Clemson, SC.