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PLANT DENSITY, DISTRIBUTION, AND FERTILIZER EFFECTS ON YIELD AND QUALITY OF IRRIGATED CORN SILAGE

KEY WORDS: Corn forage production, corn forage quality, *Zea mays* L.

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ABSTRACT

Grain deficits frequently occur in the Southeastern Atlantic Coastal Plain because erratic rainfall patterns and soil properties often limit corn (*Zea mays* L.) yields, however, harvesting corn for silage may enable farmers to produce a second grain crop during the same calendar year. Effects of row spacing, plant population, and fertilizer program on yield, quality, and mineral concentrations of corn silage grown with irrigation on Typic Paleudult soils were therefore investigated. Two plant population treatments which averaged 7.0 and 10.1 plants m^{-2} were evaluated with two fertilizer programs that differed in N, N and K, and N, P, and K in 1980, 1981, and 1982, respectively. Each plant density by fertilizer combination was evalu-

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ated in single rows spaced 96 cm apart and in twin rows which approximately doubled the intrarow plant spacing. Plot size for the 2 X 2 X 2 factorial experiment ranged from 30 to 44 m^2. Yield, quality, and mineral concentrations of corn silage grown in single rows spaced 96 or 75 cm apart and twin rows were also evaluated in large (185 m^2) plots under center pivot irrigation during 1981 and 1982.

Dry matter yields of 22 to 26 Mg ha^{-1} were achieved with plant densities of 6.7 to 13.5 plants m^{-2} at both experimental sites. Highest silage yields were produced with stand densities of 9 m^{-2} or more planted in single 75 cm or twin rows, but yield differences were statistically significant at P(0.05) in only two of five site years. Increasing total N-P-K application beyond 200-30-167 kg ha^{-1} increased crude protein slightly in 1980 and significantly in 1981 and 1982. Concentrations of Mn and Zn in silage were increased by higher fertilization, presumably because nitrification reduced surface soil pH and increased their availability. Dry matter yield, fiber, energy, and other mineral nutrients were not significantly influenced by fertilizer program. These experiments identified management practices for the Atlantic Coastal Plain which resulted in corn silage yields equal to those produced in the cooler mountain region of Georgia and that exceeded current average production in South Carolina by approximately 40% without reducing apparent feed quality.

INTRODUCTION

Grain deficits in the Atlantic Coastal Plain[2] may limit feed supply for dairy and beef animals in this region. These feed deficits occur despite an annual precipitation which exceeds 110 cm because seasonal rainfall events are erratic and major soils can retain only 10-15 cm m^{-1} or less of plant available water[17,20]. Irrigation can be utilized and managed several ways to prevent water shortages[4,8,25], but a more complete approach to compensate for low grain supplies may be to harvest corn (*Zea mays* L.) as silage and to subsequently grow another grain crop during the same calendar year. This type of cropping system would more efficiently utilize the 210-250 "frost-free" growing days[14] each season, but to succeed, basic information about management practices which increase silage yield and quality is needed.

Plant populations for maximum silage production, are usually greater than for maximum grain production[15] because yield by plant population relationships are parabolic for corn grain but asymptotic for dry matter production[11]. High grain content is generally considered an important determinant of silage feeding value because grain increases dry matter content and decreases loss of nutrients, water, soluble carbohydrates, and protein in seepage effluent[23,30]. However, the importance of a high grain component has been questioned by researchers in Great Britain and New Zealand[29,30].

In the Atlantic Coastal Plain, many soils have physical and chemical properties which influence corn production. These properties include: dense E (A_2) horizons where bulk densities frequently exceed 1.7 kg m^{-3}, low water retention, low organic matter contents, and low cation exchange capacities[17]. These soil characteristics often restrict root development and thus reduce nutrient and water use efficiencies. Effects of plant population, row width, fertilization, and water management on corn silage production have been evaluated in several environments[12,16,22,23,24,26,29,30], but none of those studies were conducted on soils where subsoiling is required for optimum corn production with or without irrigation[6,7].

Lutz and Jones[18] found silage yields in Virginia to be greatest when a late-maturing hybrid was planted at approximately 74,000 plants ha^{-1} in 40 cm rows. Plant population significantly influenced P concentrations one year, but, in general, neither row spacing, hybrid, nor population treatments significantly influenced ear leaf N, P, or K concentrations. Doss et al.[10] found in Alabama that high plant populations increased irrigated corn silage (dry matter) yield approximately 6%, but reducing row spacing from 101 to 51 cm increased yield less than 1%. They also reported that the percentage of ears in the dry matter decreased from 39 to 34% as row width decreased and plant population increased.

Cummins and Dobson[9] reported that silage yield response to management practices varied with physiographic region. In the Georgia Piedmont, hybrid maturity did not significantly influence yield, but row spacing and plant population did. In the Mountain Region, plant population significantly influenced yield, but row spacing did not. Ear content was inversely proportional to plant population at both locations, but the change was sufficient to decrease in vitro dry matter digestability only in the Piedmont. Differences in response between locations were attributed to rainfall distribution and temperature.

Effects of alternate agronomic management practices on quantity and quality of corn silage produced with irrigation on Coastal Plain soils were not known, but to achieve maximum water and nutrient use efficiency, changes in traditional cultural practices may be required. This study was initiated to determine the influence of row configuration, plant population, and fertilizer program on production of corn silage on a Typic Paleudult. The objective was to identify practices that would produce high silage yields without decreasing feed quality.

MATERIALS AND METHODS

In 1980, 1981, and 1982, two plant populations, two row configurations, and two fertilizer programs were evaluated on a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudult) at Site A near Florence, S.C. Plot size was dependent upon row configuration and varied from 30 to 44 m^2. Treatments were repeated on the same land surface each year. Water was supplied through trickle irrgation tubes spaced 45 cm apart whenever soil water tension at 30 cm exceeded 25 kPa. Plant populations and fertilization treatments, which were replicated four times in a split-plot experimental design, are listed in Table 1.

In 1981 and 1982, twin rows and single rows spaced 96 or 75 cm apart were also replicated four times and evaluated in a randomized complete block design on the same soil series at Clemson University's Research and Education Center (Site B) near Darlington, S.C. Water was applied at that site through a center pivot irrigation system whenever soil-water tensions at 30 cm exceeded 25 kPa.

Prior to planting at Site A, the entire field (0.5 ha) was subsoiled in two directions (each diagonal to row direction, but perpendicular to one another) at a depth of 45 cm. Fertilizer containing 67-30-167 kg ha^{-1} N-P-K and the "low" levels of secondary and micronutrients (Table 1) was broadcast. Recommended herbicides[31] were broadcast and incorporated by disking. Preplant fertilizer and herb-

Row configuration, plant population, and fertilization treatments evaluated for corn silage production in the U.S. Southeastern Coastal Plain.

Year	Row Spacing	Population		Dolomitic Lime	Total Fertilizer nutrients							
		Low	High		N	P	K	Mg	S	B	Cu	Zn
	Site A	plants m^{-2}		kg ha^{-1}								
80	Twin[1/]	6.7	8.9	-	200	30	167	-	-	-	-	-
80	Twin	6.7	8.9	-	315	30	167	-	-	-	-	-
80	Traditional[2/]	6.7	8.9	-	200	30	167	-	-	-	-	-
80	Traditional	6.7	8.9	-	315	30	167	-	-	-	-	-
81	Twin	7.1	11.2	-	200	30	167	-	53	2.8	6.7	3.4
81	Twin	7.1	11.2	-	336	30	280	-	66	2.8	6.7	3.4
81	Traditional	7.1	11.2	-	200	30	167	-	53	2.8	6.7	3.4
81	Traditional	7.1	11.2	-	336	30	280	-	66	2.8	6.7	3.4
82	Twin	7.1	10.3	1900	200	30	167	22	46	2.8	-	3.4
82	Twin	7.1	10.3	1900	336	43	280	22	59	2.8	-	3.4
82	Traditional	7.1	10.3	1900	200	30	167	22	46	2.8	-	3.4
82	Traditional	7.1	10.3	1900	336	43	280	22	59	2.8	-	3.4
	Site B										(Mn)	
81	Twin	9.5	13.7	1200	295	30	180	27	56	1.4	-	9.0
81	Narrow[3/]	9.5	-	1200	295	30	180	27	56	1.4	-	9.0
81	Traditional	9.2	-	1200	295	30	180	27	56	1.4	-	9.0
82	Twin	7.0	9.7	560	260	40	225	27	25	1.4	0.7	6.7
82	Narrow	9.3	-	560	260	40	225	27	25	1.4	0.7	6.7
82	Traditional	8.4	-	560	260	40	225	27	25	1.4	0.7	6.7

1/ Twin rows spaced 30 or 36 cm apart with each pair 96 or 112 cm apart
2/ Single rows spaced 96 cm apart
3/ Single rows spaced 76 cm apart

icide programs were the same at Site B, but larger plot size permitted in-row subsoiling directly ahead of planting. Pioneer Brand Hybrid 3382[1/] was planted and hand thinned at both sites to final populations listed in Table 1. Post-emergence N, P, K, S, and B applications were made by injecting fertilizer solutions or suspensions into irrigation water in two to four equal applications.

Corn silage yields were determined by hand harvesting two 1-m row segments at Site A or four 1-m row segments at Site B. After weighing each sample, six representative plants from each plot were chopped, weighed, and dried to determine dry matter percentages. Dried subsamples were ground in a Wiley mill to pass a 2 mm stainless steel screen, subsampled again, and ground to pass a 0.5 mm stainless steel screen. Crude protein was estimated by measuring total Kjeldahl N and crude fiber was calculated using acid detergent fiber (ADF) measurements. Total digestable nutrients (TDN) were subsequently calculated using crude protein and fiber. Minerals (P, K, Ca, Mg, Cu, Mn, and Zn) were measured with a Perkin-Elmer ICP/5000 spectrophotometer. Data were analyzed statistically and interpreted using analysis of variance and least significant difference (LSD) at P(0.05).

RESULTS AND DISCUSSION

Low plant populations at Site A averaged 7.0 plants m^{-2} and represented current recommendations for irrigated corn silage production in this area[31]. High populations ranged from 8.8 to 11.2 plants m^{-2}, and were similar to those which had maximized corn silage production in other physiographic regions[9,26]. Although irrigated grain production was increased at higher populations[13], measurements of dry matter yield, silage quality, and mineral composition (Table 2) showed few significant differences at P(0.05).

Silage yields in these experiments were similar to those produced in the Mountain Region of Georgia[9], but they were approximately 40% greater than current average production in South Carolina. The grain content, which averaged 53% in 1980, 50% in 1981, and 48% in 1982, was not influenced by plant population.

Two fertilizer regimes evaluated at Site A differed in N in 1980, N and K in 1981, and N, P, and K in 1982 (Table 1). Dry matter yield,

Table 2

nfluence of plant population on yield and quality of irrigated corn silage grown at Site A.

Year	Stand Density	Dry Matter	Grain Yield	Crude Protein	Crude Fiber	Energy (TDN)	Minerals P	K	Ca	Mg	Cu	Mn	Zn	Ca/P Ratio
	plants m^{-2}	--Mg ha^{-1}--		------------------------------%------------------------------							---mg kg^{-1}---			
80	6.7	24.5	12.9	6.1	17.7	72.3	.20	1.04	.14	.15	1.5	20	18	0.7
80	8.9	26.2	13.9	5.8	18.5	71.3	.20	1.08	.14	.15	1.9	22	16	0.7
LSD(.05)		NS	.8	.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
81	7.1	23.8	11.4	6.3	22.7	65.0	.18	1.58	.18	.13	4.1	37	21	1.1
81	11.2	23.3	12.0	5.9	23.8	65.6	.16	1.62	.18	.13	3.9	34	18	1.2
LSD(.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
82	7.1	22.4	10.8	6.3	20.9	68.9	.16	1.39	.15	.15	6.6	22	20	0.9
82	10.3	23.5	11.2	6.2	21.3	68.4	.16	1.40	.15	.15	7.1	17	18	1.0
LSD(.05)		1.1	NS	NS	NS	NS	NS	NS	NS	NS	NS	5	NS	NS

fiber, and TDN percentages were not significantly different between fertilizer treatments in any of the 3 years (Table 3). The higher fertilization rate increased crude protein slightly in 1980 and significantly in 1981 and 1982. Concentrations of Mn and Zn in the silage were also increased by higher fertilization. This probably occurred because nitrification of the additional N fertilizer reduced surface soil pH[3] and increased availability of those micronutrients. Concentrations of other mineral nutrients were not significantly different for the two fertilizer regimes.

Plant population by fertilization interactions were not significant at P(0.05) except for crude protein in 1980 and for K in 1981. Average crude protein concentration for the high population by low fertilization treatment was 5.4%. This was significantly lower than all other treatment combinations which averaged 6.2% (±0.1). In 1981, average K concentration in silage from the high population by high fertilizer treatment was 1.8%. This was significantly greater than other treatment combinations which averaged 1.5%(±0.1).

Traditional, 96 cm row spacing was compared to a twin-row configuration which was similar to that used by Stanley and Rhoads[28]. It was selected as a method to increase plant density because it accommodated conventional subsoiling, planting, and harvesting equipment, but improved spatial distribution of plants. The twin-row configuration significantly increased corn grain yields at P(0.10) in 1980 and at P(0.05) in 1982 (Table 4), but silage yields were increased significantly only in 1982. Silage P and Zn concentrations were decreased significantly by planting in twin rows in 1980 (Table 4), but all other quality and mineral concentration measurements at Site A showed no significant difference because of row spacing.

The three row configuration treatments evaluated at Site B showed few significant differences. In 1981, dry matter yield (Table 5) was significantly higher in twin rows at a population of 13.7 plants m^{-2}. This was similar to previous work[5,23] in Great Britain, which concluded optimum population densities for dry matter production were between 10 and 15 plants m^{-2}. Silage quality and mineral concentrations were not significantly different at the 13.7 plant m^{-2} population. This suggests that for maximum irrigated corn silage production in this physiographic region, further research should be conducted using a twin-row planting concept at very high plant populations.

Table

Influence of fertilizer regime on yield and quality of irrigated corn silage grown at Site A.

Year	Applied N-P-K	Dry Matter	Grain Yield	Crude Protein	Crude Fiber	Energy (TDN)	Minerals P	K	Ca	Mg	Cu	Mn	Zn	Ca/P Ratio
	kg ha^{-1}	--Mg ha^{-1}--		----------------	----------------	------%	------	------	------	------	---mg kg^{-1}			
80	200-30-167	25.9	13.2	5.8	17.9	72.0	.20	1.00	.13	.14	1.7	18	17	0.6
80	310-30-167	24.8	13.5	5.8	18.5	71.3	.20	1.08	.14	.15	1.8	24	17	0.7
LSD(.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	5	NS	NS
81	200-30-167	22.7	11.5	5.6	23.2	66.2	.16	1.52	.18	.14	3.7	28	16	1.1
81	336-30-280	24.2	11.9	6.6	23.3	64.4	.17	1.68	.18	.12	4.2	42	23	1.1
LSD(.05)		NS	NS	0.4	NS	NS	NS	.10	NS	.01	0.5			NS
82	200-30-167	22.4	10.9	6.1	21.1	68.5	.16	1.36	.15	.15	7.1	15	16	1.0
82	336-43-280	23.5	11.1	6.5	21.0	68.8	.16	1.43	.15	.15	7.0	24	22	0.9
LSD(.05)		NS	NS	0.2	NS	NS	NS	NS	NS	NS	NS	5	3	NS

Table 4

Influence of row configuration on yield and quality of irrigated corn silage grown at Site A.

Year	Row Spacing	Dry Matter	Grain Yield	Crude Protein	Crude Fiber	Energy (TDN)	Minerals P	K	Ca	Mg	Cu	Mn	Zn	Ca/P Ratio
		--Mg ha^{-1}--		----------%----------							---mg kg^{-1}---			
80	Twin[1/]	25.7	13.9	5.9	18.4	71.4	.20	1.00	.13	.15	1.8	20	15	0.7
80	Trad.[2/]	25.0	12.8	6.1	17.8	72.2	.21	1.12	.14	.14	1.7	22	18	0.7
LSD(.05)		NS	NS	NS	NS	NS	0.1	NS	NS	NS	NS	NS	3	NS
81	Twin	24.3	11.9	6.2	23.2	64.4	.18	1.56	.18	.13	3.9	35	20	1.0
81	Trad.	22.8	11.5	6.0	23.2	66.2	.16	1.64	.19	.13	4.1	35	20	1.2
LSD(.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
82	Twin	24.4	11.5	6.2	21.4	68.3	.16	1.34	.14	.15	6.5	20	18	0.9
82	Trad.	21.4	10.6	6.3	20.8	69.0	.16	1.45	.16	.15	7.2	20	20	1.0
LSD(.05)		2.8	0.4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

1/ Twin rows spaced 30 or 36 cm apart with each pair 96 or 112 cm apart.
2/ Single rows spaced 96 cm apart.

Table 5

Yield, quality and mineral composition of corn silage produced under center pivot irrigation at Site B.

Year	Row Spacing	Stand Density	Dry Matter	Crude Protein	Crude Fiber	Energy (TDN)	Minerals P	K	Ca	Mg	Cu	Mn	Zn	Ca/P Ratio
		plants m^{-2}	Mg ha^{-}	------------------------------%-----							---mg kg^{-1}.--			
1981	Narrow[1/]	9.5	22.7	7.42	23.0	67.0	.19	1.45	.21	.16	4	28	22	1.08
	Trad.[2/]	9.2	23.1	6.65	23.6	66.1	.20	1.32	.23	.17	5	32	20	1.20
	Twin[3/]	9.5	23.9	6.95	24.5	65.2	.18	1.38	.25	.19	4	32	23	1.44
	Twin	13.7	25.3	7.22	24.9	64.8	.17	1.70	.28	.22	4	36	22	1.66
LSD(.05)		0.5	1.7	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1982	Narrow	9.3	21.6	5.40	22.1	67.2	.19	1.01	.14	.17	5	15	19	0.73
	Trad.	8.4	21.6	5.30	22.3	67.0	.18	1.19	.14	.15	4	14	17	0.82
	Twin	9.7	22.8	5.45	22.4	66.9	.18	1.28	.16	.15	6	13	17	0.89
	Twin	7.0	22.0	5.38	22.2	67.1	.20	1.09	.15	.16	4	13	19	0.76
LSD(.05)		0.8	NS	NS	NS	NS	NS	.17	NS	NS	NS	NS	NS	NS

1/ Single rows spaced 76 cm apart
2/ Single rows spaced 96 cm apart
3/ Twin rows spaced 30 or 36 cm apart with each pair 96 or 112 cm apart

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Average seasonal yield, quality, and mineral composition of irrigated corn silage at Site A.

Year	Dry Matter	Crude Protein	Crude Fiber	Energy (TDN)	P	K	Ca	Mg	Cu	Mn	Zn	Ca/P Ratio
	$Mg\ ha^{-1}$	-----	-----	-----	%	-----	-----	-----	---	$mg\ kg^{-1}$		
1980	25.4	5.97	18.1	71.8	.20	1.06	.14	.15	1.7	21	17	0.7
1981	23.5	6.13	23.2	65.3	.17	1.60	.18	.13	4.0	35	20	1.1
1982	22.9	6.26	21.1	68.6	.16	1.40	.15	.15	6.9	20	19	0.9
LSD(.05)	1.8	NS	0.7	1.9	.01	.11	NS	.01	0.3	6	NS	0.2

Dry matter yield, crude protein, and crude fiber percentages were all lower at Site B in 1982 than in 1981, but the only significant difference was in K concentration. Lower yield and crude protein concentrations suggest that N was insufficient in 1982 because of higher seasonal rainfall[8].

There were few significant differences or interactions among treatments at either location. Therefore, to estimate feeding value of the silage, an average seasonal composition at Site A was computed (Table 6) and compared to average composition of corn silage used for dairy or beef cattle rations[19,21]. These comparisons showed that crude protein percentages were approximately 75% of that commonly found in corn silage used for those cattle rations. Low crude protein reflects whole plant N concentrations which were much lower than the 1.2 to 1.3% suggested as being required for high quality corn silage[27]. This suggests that with irrigation and high plant populations, more N may be required to produce high yielding, high protein corn silage.

Calcium and P concentrations were generally lower than those reported by Perry[21] and Oltjen[19], but of more importance was the Ca/P ratio which was generally at or below the 1:1 ratio considered essential for optimum animal performance. Potassium concentrations were within the normal range in 1980. In 1981 and 1982, K concentration was slightly higher, but probably not high enough to interfere with Mg metabolism and induce hypomagnesaemia. Concentrations of Mg and Cu in silage were slightly low while Mn and Zn concentrations were within the normal range. These general comparisions suggest that quality and mineral composition of the corn silage produced using these management practices would be satisfactory, but to determine true feeding value of silage, livestock feeding trials must ultimately be carried out.

CONCLUSIONS

This research has shown that with irrigation, 22 to 26 Mg ha^{-1} of corn silage dry matter can be produced on Typic Paleudult soils in the Southeastern U.S. These yields, which exceed current average production in South Carolina by approximately 40%, were achieved with plant densities ranging from 6.7 to 13.7 plants m^{-2}. Row spacing was statistically significant in only two of five site years, but numerically higher dry matter yields were obtained by planting high populations in narrow rows. Increasing total N-P-K application beyond 200-30-167 kg ha^{-1} is probably not required for high yield and quality corn silage production, provided N applications are well managed with regard to seasonal rainfall patterns.

Finally, crude protein, crude fiber, TDN, and mineral concentrations showed few significant differences because of the management practices evaluated. Comparisons of these parameters with "commonly used" feeds for beef and dairy cattle indicated the quality would be adequate, but to confirm this, animal feeding trials would ultimately be required.

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