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WATER, NITROGEN AND WEED STRESS IN FIELD CORN (*ZEA MAYS* L.): SHOOT GROWTH AND DEVELOPMENT

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EPHRATH J. E., ALM D. M., HESKETH J. D. and HUCK M. G. *Water, nitrogen and weed stress in field corn (Zea mays L.): shoot growth and development.* BIOTRONICS **25**, 55–65, 1996. Nitrogen (N) balances of soil–crop systems must be monitored more closely in the future to minimize ground water pollution. Maize was grown in rain–sheltered plots on a Flanagan silt–loam soil under three moisture regimes: Wet (**W**, weekly irrigations equal to water lost by a standard evaporation pan); Limited irrigation (**L** or 1/2 **W**) and Dryland (**D**, no irrigation). For each soil moisture regime, supplemental nitrogen (NH_4NO_3) was applied at 0, 125 and 250 kg *N* ha^{-1}. Seedlings of common lambsquarter were transplanted 0.15 m apart into the maize rows in sub–plots of each soil moisture regime at the medium *N* level or 125 kg *N* ha^{-1}. Soil moisture profiles were measured twice weekly, leaf water potential (Ψ_{leaf}) was monitored with a leaf pressure bomb and root growth was followed at weekly intervals using minirhizotron tubes. Generally yield correlated well with either Ψ_{leaf} or *N* per plant. Higher *N* or water applications led to less negative Ψ_{leaf} values, one stress substituting for the other in controlling crop stress or yield. Leaf % *N* as an indicator for yield was compromised by small differences among treatments within sampling dates and the $N \times \Psi_{leaf}$ interaction; Ψ_{leaf} as an indictator for when to irrigate was not compromised.

Key Words: *Zea mays* L.; competition; ground water; irrigation; moisture; plant nutrient; leaf area; leaf nitrogen.

INTRODUCTION

Water stress is an important factor controlling crop yields (*5, 13–17, 23 24*), and the degree of its control is partly dependent on the nitrogen (*N*) content of the plant (*4, 11, 12, 18*). Tesha and Eck (*22*) found that reductions in dry matter accumulation due to water stress in sweet corn were alleviated somewhat by applying more *N*, suggesting that some of the some of the drought stress effects were due to decreased *N* availability in the soil.

Low available soil *N* generally leads to a smaller shoot/root ratio (*17*). Enhanced root growth due to low available soil *N* presumably helps to meet the shoot demand for *N*. However, Bennett *et al.* (*3*) demonstrated that although corn plants fertilized with high rates of *N* had similar or slightly lower leaf water potential (Ψ_{leaf}), compared to plants given low rates of *N*, the high *N* plants had lower stomatal resistances at a particular Ψ_{leaf} and extracted more water from deeper soil layers. They concluded that plants grown in soils high in *N* were less affected by water stress than plants grown in soils with low *N*. Thus, knowing the spatial distribution of roots in the soil profile is necessary for understanding interactions between water and *N* stresses on shoot/root growth. Eck (*6*) found that *N* fertilization increased yields slightly under water stress, where large yield increases occurred under *N* fertilization and frequent irrigation. Radin and Parker (*21*) reported greater dry matter production per water used in low *N* plants. In general the leaf area index (*LAI*) and its duration (*LAD*) decreased as water stress increased (*2, 9, 25, 26*) or mineral nutrient stress increased.

Exley and Snaydon (*8*) tested effects of *N* on root and shoot competition between wheat [*Triticum aestivum* (L.) em. Thell] and blackgrass (*Alopeecurus myosuroides* Huds.). They reported that *N*-fertilization partially alleviated effects of root competition but did not affect shoot competition. Others have studied such effects in crops and weeds (*19, 20*). N×water interactions, of course, are difficult to study in legumes (*13–15*).

We set out here to describe effects of a weed and interactions between irrigation and *N* levels on leaf area, *N* content, dry matter, water potentials and grain yield in field corn (*Zea mays* L.). Soil *N* applications need to be more closely tailored to the needs of the plant to minimize *N*-leaching into ground water. A tissue test indicating when more *N* might be added to the crop, taking into account other existing or potential crop stresses, would be helpful for managing *N* in corn production systems.

MATERIALS AND METHODS

Corn cv. Pfister 3000 was planted 30 April 1990 in rain sheltered plots of a Flanagan silt loam (fine montmorillonitic, mesic Aquic Arguidoll) at the University of Illinois South Farm. Rows were 0.76 m apart with plants thinned to one every 0.2 m in the row. Each third of the plot area was given a different irrigation treatment: Wet (**W**) with weekly applications of water to replace losses as measured with a standard evaporation (class "A") pan, Limited irrigation (**L**) where 1/2 of the **W** irrigation rate was applied weekly, and Dryland (**D**) with no irrigation.

Subplots, four rows three m long replicated three times in each irrigation treatment, were fertilized with *N* (NH_4NO_3) at zero (***NN***), 125 kg *N* ha^{-1} (***LN***), and 250 kg *N* ha^{-1} (***HN***). Two light irrigations (10 mm each) were applied to all treatments, the first immediately after planting to facilitate germination and a second after applying *N*. The amount of water applied at each weekly irrigation is shown in Table 1.

Soil moisture profiles were measured twice weekly throughout the growing

Table 1. Weather date at site of the experiment, and amount of irrigation.

Dates	Daily Mean Values					Accumulated Values		
		Air		soil				
	Radiation ($MJ^{-2}d^{-1}$)	T_{max} ℃	T_{min} ℃	T_{max} ℃	T_{min} ℃	Rain	Irrig. cm	Evap.
May 1–15	16.9	19.7	8.9	19.8	12.5	10.3	3.2*	5.1
May 16–31	18.1	21.6	11.3	21.0	14.8	9.8	—	6.0
June 1–20	21.2	26.9	15.5	26.7	19.3	13.7	7.6**	9.6
June 21–July 7	24.2	28.3	16.8	29.3	21.4	5.3	3.8	8.2
July 8–23	19.2	26.4	17.0	28.9	21.9	7.0	8.9	7.8
July 24–Aug 6	23.9	27.3	16.2	30.3	22.3	1.2	9.5	7.2
August 7–16	20.2	25.1	14.2	30.0	21.8	1.8	3.3	4.4
Aug 17–Sept 1	19.0	29.1	18.4	—	—	3.5	8.9	7.1
Total:						52.5	45.2	55.4

*All treatments.
1/2 this and subsequent values were applied to the **L or Limited irrigation treatment. The non-irrigated plots received 8 mm water on June 1 to facilitate germination.

season, using a neutron-scattering technique calibrated against gravimetric soil moisture measurements. Leaf water potentials (Ψ_{leaf}) were measured several times during the growing season at approximately 1200 CDT using the Schölander pressure bomb technique. Root growth was monitored using minirhizotron access-tubes and a miniature video camera (*7*).

One plant per treatment plot was destructively sampled for leaf dry matter, area, and N-content five times during the growing season. Three replicates of Leaf N for every leaf on plants sampled were measured using a Kjeldahl digestion technique (*1*). Internode lengths and total plant heights were also recorded. At maturity ears were dried at 80℃ and kernels were weighed for final yield.

RESULTS AND DISCUSSION

Vegetative growth

There were no detectable differences in leaf tip and collar appearance rates among treatments before silking 28 July, with 18.5 leaves per plant at that date (a mean of 19.6 leaves for all plants sampled then and thereafter). Leaf water potential (Ψ_{leaf}) values for all treatments changed according to the irrigation treatment (Table 2), with high Ψ_{leaf} values in the **W** treatment and low Ψ_{leaf} values in the **D** treatment. Large and significant differences in Ψ_{leaf} were found among the different *N* treatments within each irrigation treatment (Table 3). Increasing applied *N* resulted in an increased in Ψ_{leaf}, even under moisture stress conditions.

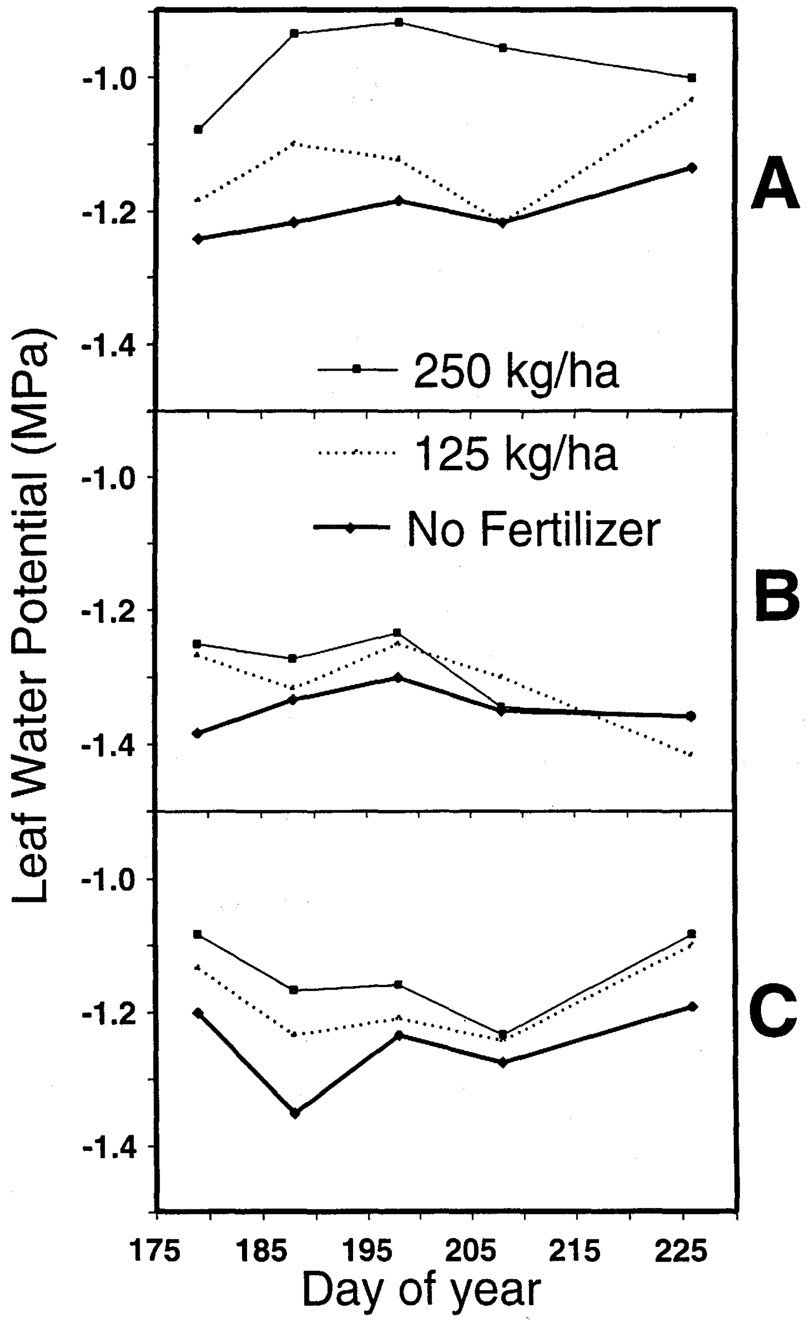

Fig. 1. Leaf water potential (Ψ_{leaf}, Mpa), measured by standard pressure bomb technique in full sunlight at noon on the dates indicated.

A=Full (100%) replacement irrigation.

B=Half (50%) replacement irrigation.

C=No irrigation.

Table 2. Nitrogen and water effects among sampling dates.

Attribute	Sampling Date and Days from January 1					
	20 June 171	7 July 186	23 July 204	6 Aug. 218	16 Aug. 228	(Std. Error.)
Node, highest leaf collar	8.0	15.6	18.5			
Node, highest leaf tip	12.7	17.6	18.5			
Ψ_{leaf}, MPa	−1.20	−1.21	−1.18	−1.24	−1.19	(±0.004)
Area, dm^2/plant	—	64.0	62.9	59.0	56.0	(±0.20)
Dry mass, g/plant	16.0	39.0	41.2	39.7	36.6	(±0.21)
N, g $plant^{-1}$	0.58	1.24	1.15	1.02	0.74	(±0.0023)
Area/mass, dm^2g^{-1}	—	1.64	1.53	1.49	1.53	(±0.017)
Area/N, dm^2g^{-1}	—	51.6	54.5	57.8	75.7	(±0.5)
100* *N*/mass (% *N*)	3.62	3.18	2.80	2.57	2.02	(±0.014)

Leaf areas and weights per plant were lower at the later sampling dates due to shedding of lower leaves (Table 2). Percentage of leaf *N* declined over all sampling dates, with leaves expanding until mid July and silking on 18 July. From early August on, presumably considerable *N* had been redistributed into the ear.

Plant heights were essentially the same among *N* treatments (Table 3), but were approximately 20 cm less in the non-irrigated plots. Leaf areas per plant were similar within *N* treatments but differed among irrigation treatments (Table 3). Increases in applied *N* at each irrigation level resulted in increases of leaf biomass and percent *N*. The effect of the *N* treatment on leaf percent *N* was somewhat stronger in the **D** compared to the **W** treatments (Tables 3 and 4).

N contamination of runoff water is becoming a major problem in some agricultural areas; it is becoming important to supply only the *N* that the crop can use. Leaf percent *N* might be used to predict when to sidedress. Leaf percent *N* decreased faster as the season progressed under moisture stress conditions than under well-watered conditions (Table 4, Fig. 3). Small differences in leaf percent *N* were detectable by 5 July, which may have been a little late for sidedressing because of plant height. Such differences were maintained over the growing season in the **W** treatment but became much smaller over time in the **L** and **D** treatments. This water stress effect on leaf percent *N* complicates its use as an indicator of when to sidedress.

Results for other treatments similar to those in Fig. 2 and 3 are not shown, but overall results are summarized in Tables 2–4. Details on area and dry or *N* mass per leaf were available for each % *N* value shown in Fig. 3 and plotted up well. Such data are important for developing, calibrating and testing crop models for predicting materials balances and are available upon request, with a software aid for access, statistical analysis and generating figures (*10*).

Table 3. Summary of treatment means (*5 sampling dates*).

(5 dates) Treatment*	Leaf Water Potential MPa	Grain Yield per plant g/pl	Leaf Area (A) dm^2/pl	Leaf Dry Mass (W) g/pl	Leaf N Mass (N) g/pl	Ratios (A/W) dm^2/g	Ratios (A/N) dm^2/g	Ratios (N/W) 100 g/g	Plant Hgt. cm
Means by Irrigation, Fertilizer, and Weed treatment:									
W ***HN***	−0.98	189	65.6	43.8	1.27	1.5	51.7	2.91	204
W ***LN***	−1.13	165	62.9	40.7	1.22	1.55	51.6	3.00	201
W ***LN***+Weeds		148	65.1	38.9	1.15	1.67	56.6	2.96	195
W ***NN***	−1.19	153	63.8	39.1	0.99	1.63	64.8	2.52	197
L ***HN***	−1.15	151	61.8	41.8	1.14	1.48	54.1	2.74	199
L ***LN***	−1.18	146	61.4	41.2	1.18	1.49	52.0	2.86	195
L ***LN***+Weeds		135	61.3	40.9	1.14	1.50	53.9	2.78	203
L ***NN***	−1.25	128	61.9	39.5	1.03	1.57	60.3	2.60	202
D ***HN***	−1.29	124	56.2	37.2	0.89	1.51	63.0	2.40	183
D ***LN***	−1.31	103	54.9	34.8	0.86	1.58	63.6	2.48	178
D ***LN***+Weeds		96	56.1	33.8	0.73	1.67	77.3	2.15	182
D ***NN***	−1.35	95	56.1	34.3	0.78	1.63	71.7	2.28	182
Std. Error (n=12)	−0.013		.62	.65	.007	.052	1.54	.043	0.03
r^2 on yield	.95		.80	.85	.83	.21	.66	.70	.67
r^2 on Ψ_{leaf}		.95	.76	.86	.84	.28	.66	.71	.65
Mean of N treatments:									
HN	−1.14	154	61.2	40.9	1.10	1.5	56.3	2.68	195
LN	−1.21	138	59.7	38.9	1.10	1.53	55.7	2.78	191
LN+Weeds		126	60.8	37.9	1.00	1.60	62.6	2.63	193
NN	−1.26	125	60.6	37.6	0.93	1.61	65.6	2.47	194
Mean of water treatments, excluding weeds:									
W	−1.10	169	64.1	41.2	1.16	1.56	56.0	2.81	201
L	−1.19	142	61.7	40.8	1.12	1.51	54.5	2.73	199
D	−1.32	107	55.7	35.4	0.85	1.57	66.1	2.39	181
Std. Error. (n=36)	−0.004	1.1	0.5	0.5	0.5	0.025	0.019	1.4	0.0005

*See Materials and Methods section for explanation of treatment symbols.

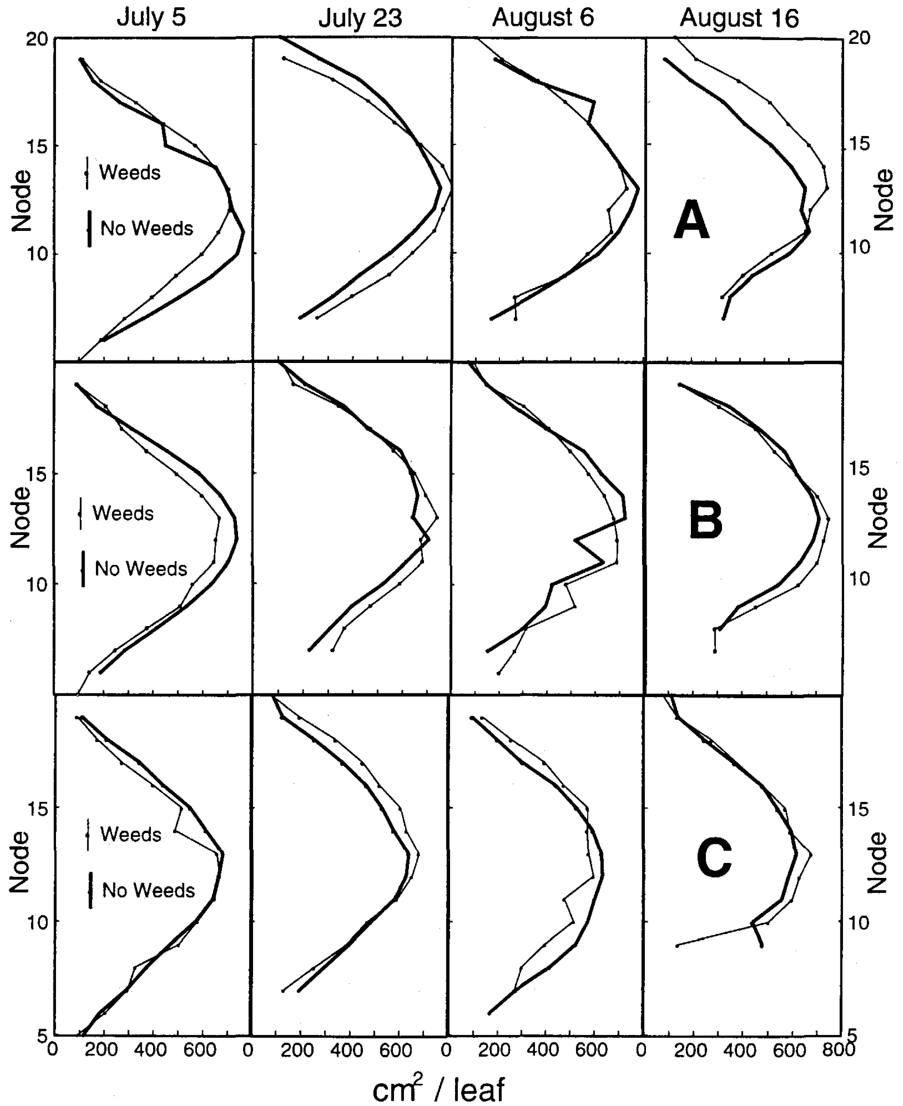

Fig. 2. Distribution of corn leaf area, by node at four sampling dates. A, B and C represent full, half and no replacement irrigation, as in Fig. 1.

Weed×water effects

Effects of weeds on maize leaf area, biomass, leaf ercent N and plant height are shown in Tables 3 and 4. Maize plots with weeds were all given the low N treatment (LN, 125 kg N ha^{-1}). Leaf N mass and percent were affected by lack of irrigation (Tables 3 and 4), presumably because of root competition in the upper part of the soil profile where most of the applied N must have stayed. The effects of weeds on leaf area and dry mass were time dependent: at the beginning of the season, when weeds were small, there was no effect of weeds on maize leaf area and dry mass. Later in the season, when weeds were larger with more roots, maize plants were affected by weed presence. Weed effects were more significant on leaf area than on dry matter.

Leaf percent N was lower in weedy compared to weed-free plots (LN

Table 4. Leaf N-content (means of entire plant, by sampling date)

Treatment*	Sampling Dates and Days from January 1					
	June 20 171	July 5 186	July 23 204	Aug. 6 218	Aug. 16 228	Mean
W *HN*	3.72	3.17	3.03	2.75	2.69	3.02
W *LN*	3.72	3.39	3.17	2.73	2.70	3.14
W *LN*+weeds	3.57	3.36	3.25	2.72	2.52	3.08
W *NN*	3.58	2.92	2.65	2.34	2.18	2.73
L *HN*	3.71	3.48	2.92	2.97	1.57	2.93
L *LN*	3.71	3.42	2.98	2.91	2.13	3.03
L *LN*+weeds	3.67	3.49	2.88	2.80	1.97	2.96
L *NN*	3.60	3.15	2.69	2.90	1.66	2.80
D *HN*	3.53	3.14	2.62	2.26	1.58	2.63
D *LN*	3.52	3.08	2.64	2.23	1.92	2.68
D LN+weeds	3.45	2.80	2.48	1.74	1.57	2.41
D *NN*	3.52	2.83	2.55	2.04	1.71	2.53
Std. Error (N=x, overall)	0.113					
r^2 (yield vs. N)	.68	.32	.59	.50	.55	.71
r^2 (Ψ_{leaf} vs. N)	.73	.24	.31	.41	.53	.72

*See Materials and Methods section for explanation of treatment symbols.

treatments, Table 4), the difference being greatest in the **D** treatment.

Kernel yields

Yields were affected by N, water and weed treatments (Table 3). Among the nine weed-free treatments, yield regressed well against Ψ_{leaf} (r^2=.95), compared to N mass (0.8) or N percent (0.71). Among all treatments, yield and Ψ_{leaf} correlated well with leaf area, dry mass and N (Table 3, .76 to .85) but not as well as the correlation of yield with leaf water stress or with water×N (both 0.95). The correlation of yield with the seasonal mean of leaf percent N at different dates or among dates varied from 0.5 to 0.71, Table 4. The seasonal mean of Ψ_{leaf} then seemed to be a good indicator of the water×N interaction effect on yield, but such an indicator doesn't help to determine how much N to apply at the beginning of the season or when it would be beneficial to sidedress during the same season. Such information is useful for making management decisions in subsequent years.

CONCLUSIONS

Since contamination of runoff water with N from fertilizer application may

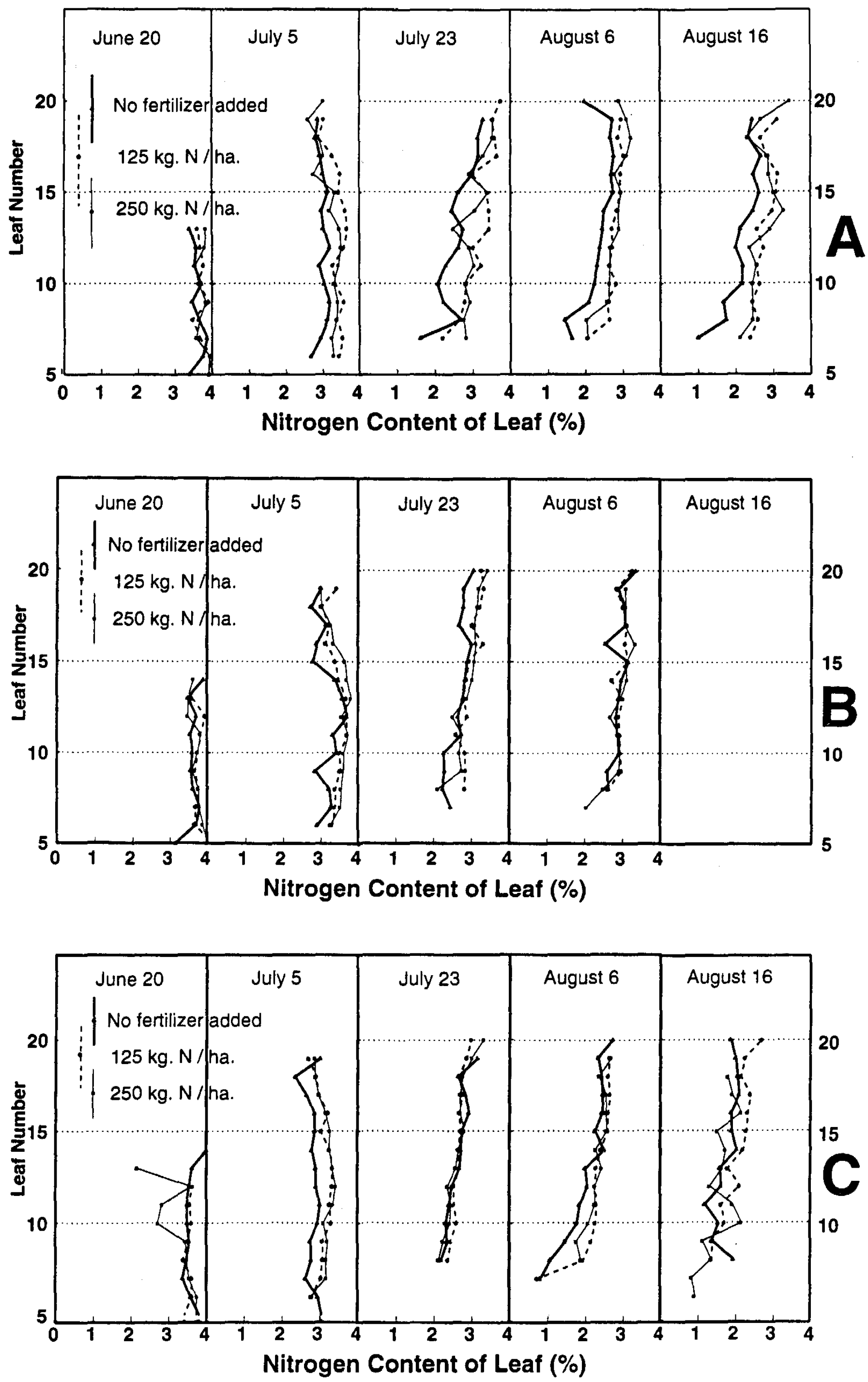

Fig. 3. Seasonal leaf nitrogen content ($N/W \times 100$, or %). Values given are means of duplicate analyses from 3 different plants (from 3 replicated plots) by Kjeldahl analyses.

A, B and C represent full, half and no replacement irrigation, as in Fig. 1.

be a major problem in some agricultural areas, it is becoming important to supply only the N that a crop can use. Leaf percent N might be used as an indicator of need for applying additional fertilizer to the growing crop. Small differences in leaf percent N were detectable by 5 July, and the differences became greater during subsequent ear-filling stages of growth. Although additional fertilizer could be mixed with irrigation water at any time during the growing season, conventional fertilizer application methods might injure corn plants whenever the crop height exceeds the ground clearance of available fertilizer application equipment. There is the possibility of fertilizer application from an airplane but this method may be cost-prohibitive for corn, although it is a common practice on flooded rice fields in Arkansas and East Texas, U.S.A.

It is not clear from these research results and our analysis of the data that leaf % N could be used as a good indicator of yield or a management tool for determining when to sidedress with additional N. The use of Ψ_{leaf} as an indicator of when to irrigate apparently was not compromised by N stress effects. A crop simulation based upon these data might provide a better insight as to which leaves at what time should be tested to give an indication of N or water stress in the crop and how much N or water to apply; clearly both stresses need to be accounted for. Our results do provide further evidence for stress substitutions among soil, environmental and pest factors, with one stress being translated into another.

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