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Applied Nitrogen and Phosphorus Effects on Yield and Nutrient Uptake by High-Energy Sorghum Produced for Grain and Biomass[1]

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ABSTRACT

Limited information is available concerning nutrient requirements of *high-energy* sorghums (HES) (*Sorghum bicolor* L., Moench). The purpose of this study was to compare a HES, an intermediate grain cultivar (IGC), and a conventional grain cultivar (CGC) for grain and biomass (stover) yield, responses to applied N and P, and effects on nutrient partitioning and removal. Field experiments were conducted in 1983 and 1984 on Ships clay (Udic Chromustert) near College Station, TX. Nitrogen (0, 84, 168 kg N ha^{-1}) and P (0, 15, 30 kg P ha^{-1}) were factorially applied to the three cultivars. Soil nutrient availability decreased after only one year of total dry matter harvesting and was reflected in greater responses to applied N and lower tissue nutrient concentrations and removals the second year. Cultivar and N influenced grain and biomass yields, while applied P had little effect on these parameters. The CGC and IGC produced more grain, but less biomass, than HES. The CGC removed the least nutrients in biomass and the most in grain, while removals by HES components were reversed. Although HES did yield more total dry matter, total crop N and P removals were similiar for all cultivars. HES did remove greater total quantities of all other nutrients. Applied N increased concentrations and uptake of most nutrients in grain and biomass.

Additional index words: **Nutrient concentrations, Plant characteristics, Cultivar responses, *Sorghum bicolor* L. Moench.**

ALTHOUGH fossil fuel prices have decreased, long-term energy problems remain unresolved. Declining fossil fuel reserves will increase emphasis on alternate, especially renewable, energy sources in the future. Fermentable carbohydrates contained in grains and stovers can be used to produce consumer-usable energy such as ethanol and methane (Wiedenfeld, 1984). Estimates indicate that 139 billion m^3 of methane can be produced annually from terrestrial biomass (Lipinsky et al., 1983), or 27% of the 1982 U.S. natural gas consumption (Holtberg et al., 1983). Future production of biomass-derived methane will depend on the cost competitiveness of this gas compared with other gas and energy sources.

High-energy sorghums (HES) (*Sorghum bicolor* L., Moench) are currently being developed for both grain and biomass production (Miller and Creelman, 1980; Creelman et al., 1981). These sorghums are hybrids of grain by sweet sorghum parents that produce slightly lower grain yields than conventional grain sorghums but large amounts of stover with high carbohydrate concentrations. Sorghum is among the most widely adapted of the warm-season cereal grasses potentially useful for biomass and fuel production. Adaptation to

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subhumid and semiarid climates has extended sorghum production into a much larger geographical region than corn (*Zea mays* L.) or other warm-season cereals (Eastin, 1972).

The grain from HES can be harvested and utilized for feeds and foodstuffs, while the biomass component might serve as a renewable energy source. Total plant utilization can provide producers with multiple avenues of income, but can also remove greater amounts of nutrients, especially N and K, from the soil, depleting its fertility in the long-term. The U.S. Department of Agriculture (1978) estimated that the residues from nine leading crops in the United States contain approximately 40, 10, and 80% of the N, P, and K fertilizers currently applied to all crops. Continued biomass removal may adversely affect soil organic matter content and related chemical and physical properties, resulting in decreased soil tilth and crop yields (Barber, 1979). The nutrient requirements of HES harvested for both grain and biomass vs. conventional hybrids harvested for grain alone will directly influence its potential for economical energy generation and other possible uses.

The purpose of this study was to compare a high-energy, an intermediate, and a conventional grain sorghum hybrid for grain and biomass yield, responses to applied N and P, and effects on nutrient partitioning and removal.

Table 1. Soil nutrient availability with time.

Year	pH	N	P	K	Ca	Mg	Fe	Zn
		mg kg^{-1}						
1983	8.0	16	132	625	4000	500	20.0	0.5
1984	8.3	10	78	563	4000	500	19.0	0.4
1985	8.1	7	34	709	3521	426	13.8	0.4

Table 2. Year and genotypic effects on plant characteristics at anthesis.

Effect	Plant height	Leaf area index	Leaf number
	m		
Year			
1983	1.62†	3.54a‡	9.05
1984	1.54	3.77a	8.90
Cultivar			
AT×399 × RT×430 (CGC)§	1.14	3.34	8.20c
AT×623 × RT×430 (IGC)	1.33	3.59	8.89b
AT×623 × Rio (HES)	2.27	4.03	9.83a

ANOVA¶

Source	df	Plant height	Leaf area index	Leaf number
		Mean squares		
Year (Y)	1	0.39*	2.77	1.19
Cultivar (C)	2	26.61***	8.61***	47.91***
Error a	12	0.02	0.77	3.22
Y × C	2	1.07***	0.52***	0.55
N	2	0.14***	18.61***	18.88***
P	2	0.01	0.54	3.79*
Y × N	2	0.01	0.08	5.84*
C × N	4	0.04***	1.34***	1.98
Error b	152	0.003	0.35	0.97
CV, %		3.37	16.25	10.96

*,*** Significant at $\alpha = 0.05$ and 0.001, respectively.

† Means not followed by letters indicate a significant interaction involving this effect and another main effect detected by ANOVA.

‡ Means within an effect in the same column followed by the same letter are not sigificantly different at $\alpha = 0.05$.

§ CGC, IGC, and HES refer to conventional grain cultivar, intermediate grain cultivar, and high-energy sorghum, respectively.

¶ ANOVA = Analysis of variance, df = degrees of freedom, CV = coefficient of variation.

MATERIALS AND METHODS

Three hybrid sorghum cultivars were used in the study: (i) AT×399 × RT×430, a nonsweet, short-statured, conventional grain cultivar (CGC); (ii) AT×623 × RT×430, an intermediate cultivar taller than the first with good grain yield, moderate biomass potential, and high stalk carbohydrate concentrations at maturity (IGC); and (iii) AT×623 × Rio, a sweet, high-energy type with moderate grain and high biomass yield potentials (HES). These cultivars were grown during 1983 and 1984 near College Station, TX, on a Ships clay soil (Udic Chromustert). Soybean [*Glycine max* (L.) Merrill] had been grown on the site in 1982.

Nitrogen as ammonium nitrate (34-0-0) and P as concentrated superphosphate (0-46-0) were factorially applied annually at rates of 0, 84, and 168 kg N ha^{-1} and 0, 15, and 30 kg P ha^{-1}. Half the N and all the P were broadcast preplant and incorporated into beds with a rolling cultivator. The remainder of the N was sidedress applied approximately 40 days postemergence with a belt fertilizer distributor equipped with knife openers.

The experiment had a randomized complete-block, split-plot design, with genotypes serving as main plots and the nine fertility combinations randomly assigned as subplots. Each combination was replicated four times. Each sublot consisted of six rows, 7.6 m long and 0.68 m apart. Planting occurred in late March each year, with plants being thinned after emergence to approximately 132 000 plants ha^{-1}.

Prior to the study, 12 soil samples were taken at random, across the study area to a depth of 0.3 m. Subsequent samples were taken from control plots in January 1984 and 1985 to assess changes in soil nutrient availability with time. Samples were analyzed for pH (1:2, soil/water), NO_3–N (extracted by water and analyzed by specific ion electrode), extractable P, K, Ca, and Mg (1.4 *M* NH_4OAc + 0.025 *M* EDTA), and Fe and Zn (DTPA-TEA) by the Texas A&M University Extension, Soil Testing Laboratory, College Station, TX (Table 1).

Propazine [2-chloro-4,6-bis(isopropylamino)-*s*-triazine] at 1.8 kg a.i. ha^{-1} was applied preemergence for weed control. Greenbug (*Schizaphis graminum*) and sorghum midge (*Contarinia sorghicola*) were controlled with dimethoate [*O,O*-dimethyl *S*-(*N*-methylcarbamoylmethyl)phosphorodithioate] at 0.15 kg a.i. ha^{-1} and fenvalerate [cyano(3-phenoxyphenyl)methyl 4-chloro-alpha-(1-methylethyl)benzeneacetate] at 0.5 kg a.i. ha^{-1}, respectively. Insecticides to control greenbug and midge were applied 2 weeks postemergence and at anthesis, respectively. Plots were furrow irrigated twice in 1983 and three times in 1984 to alleviate any water stress. Each irrigation supplied approximately 80 mm of water.

At approximately 50% of full anthesis each year, four plants from the second and fifth plot rows were randomly selected and measured for height and leaf number. One of these plants was harvested and leaf area was determined with a portable leaf area meter. Leaf area index (LAI) was calculated from the data obtained with single plants and the population density.

The middle 3 m of the two innermost rows of each subplot were hand harvested for grain and biomass (stover) yield at maturity. Panicles were threshed with a stationary plot thresher and grain moisture content was determined by electrical resistance. Grain yields were adjusted to 14% moisture (U.S. Grade 2). Biomass from the areas where panicles were harvested was removed at ground level and weighed to obtain fresh weight yields. Two plants per plot from the stover yield sample were randomly chosen and dried at 70°C for 4 days to determine biomass dry matter production.

Table 3. Regression equations for the relationships between plant characteristics and applied nutrients at anthesis.

Significant effect	Regression equation	SE	R^2
Cultivar × N	Plant height (m)		
AT×399 × RT×430 (CGC)†	$Y = 1.12 + 0.00060\ N^{***} - 0.000003\ N^{2**}$	0.005	0.90
AT×623 × RT× 430 (IGC)	$Y = 1.30 + 0.00081\ N^{**} - 0.000003\ N^{2*}$	0.011	0.84
AT×623 × Rio (HES)	$Y = 2.17 + 0.00230\ N^{**} - 0.00001\ N^{2*}$	0.034	0.88
Cultivar × N	Leaf area index		
AT×399 × RT×430 (CGC)	$Y = 2.96 + 0.0079\ N^{**} - 0.00002\ N^{2*}$	0.14	0.87
AT×623 × RT×430 (IGC)	$Y = 3.08 + 0.0159\ N^{**} - 0.0001\ N^{2*}$	0.26	0.75
AT×623 × Rio (HES)	$Y = 3.16 + 0.0253\ N^{**} - 0.0001\ N^{2***}$	0.28	0.88
Year × N	Leaf number		
1983	$Y = 8.52 + 0.02\ N^{**} - 0.017\ P^{*} - 0.0001\ NP^{*} - 0.001\ N^{2*} + 0.0005\ P^{2*}$	0.37	0.95
1984	$Y = 8.03 + 0.024\ N^{**} - 0.0001\ N^{2*}$	0.32	0.85

*,**,*** Significant at the 0.05, 0.01, and 0.001 levels, respectively.
† CGC, IGC, and HES refer to conventional grain cultivar, intermediate grain cultivar, and high-energy sorghum, respectively.

Biomass and grain subsamples were subsequently ground in a Wiley mill to pass a 1-mm screen and were then passed through a cyclone mill to obtain uniform particle size. Samples were analyzed for total N, P, K, Ca, Mg, Fe, and Zn following a hydrogen peroxide–sulfuric acid digestion (Texas Agricultural Extension Service, 1980).

Determination of amounts of nutrients removed was achieved by multiplying nutrient concentrations of grain and biomass by the dry matter yield of these components. A combined analysis of variance over years for measured parameters was performed as outlined by McIntosh (1983) using the general linear models procedure (SAS Institute, 1982). Differences among treatment means for years and genotypes were delineated using Duncan's Multiple Range Test (Snedecor and Cochran, 1980). Response surface regression was utilized to model effects of significant quantitative factors on dependent variables.

RESULTS AND DISCUSSION

Plant Characteristics at Anthesis

The various hybrids differed in height, leaf number, and LAI (Table 2). These results agree with those of Thomas and Miller (1981) who also reported greater leaf number and leaf area per plant with tropically adapted cultivars. All main effects and first and second order interactions were determined in the analysis of variance for plant characteristics at anthesis, but only significant effects have been reported for brevity.

Applied N was an important determinant of plant parameters at anthesis (Tables 2 and 3). Added N disproportionately increased the height of HES as compared to the other cultivars. A significant cultivar × N interaction also occurred with LAI, with HES again exhibiting the greatest response to added N, while CGC showed the least response. Added P had no significant effect on these traits with the exception of leaf number. The large initial amount of available soil P plus added P negatively influenced leaf number in 1983 but had no effect in 1984, possibly due to lower available P the second year.

Grain and Biomass Yields

Cultivar influenced both grain and biomass yields (Table 4). Both CGC and IGC produced significantly greater grain yields than did HES. Almost the opposite trend occurred with biomass yield. The HES was the highest biomass producer, IGC was intermediate, and CGC produced the least biomass at all N rates.

Surface regression analyses modeling grain yield as a function of applied N and P were performed by year (Fig. 1). The equation in 1983 was a saddle point with grain yield reduced by added P. The estimated average yield increase in 1983 was only 15% with the addition of either intermediate or high rates of both N and P. No significant response to P was detected in 1984 and variations in grain yield were explained by N alone. Estimated average grain yield enhancements in 1984 were 48 and 56% with the addition of 84 and 168 kg N ha^{-1}, respectively.

CGC and IGC showed similar quadratic relationships between biomass produced and added N, but the latter produced approximately 1 000 kg ha^{-1} more dry residue at all N rates than the former (Fig. 2). The HES exhibited a greater biomass response to applied N than did the other cultivars, as is indicated by the increased slope of the regression equation. Biomass dry matter production by HES was increased by 3 100 (40%) and 4 700 (60%) kg ha^{-1} with 84 and 168 kg applied N ha^{-1}, respectively. No effect of added P on sorghum biomass yield was detected.

Table 4. Year and genotypic effects on sorghum grain and biomass yields.

Effect		Grain	Biomass		
		kg ha^{-1}			
Year					
1983		5 390†	7 400a‡		
1984		5 350	6 800b		
Cultivar			0 N	84 N	168 N
AT×399 × RT×430 (CGC)§		5 670a	3 900c	5 100c	5 700c
AT×623 × RT×430 (IGC)		5 830a	4 800b	6 300b	6 800b
AT×623 × Rio (HES)		4 600b	7 800a	10 900a	12 500a
ANOVA¶					
		Mean squares			
Year (Y)	1	58 181	19 217 440*		
Cultivar (C)	2	32 175 562***	614 964 354***		
Error a	12	570 751	1 007 776		
N	2	6 449 064***	151 968 503***		
N × P	4	787 279*	1 508 414		
Y × N	2	5 096 135***	1 069 460		
C × N	4	596 199	16 189 386***		
Error b	152	305 100	70 006		
CV, %		10.28	11.77		

*,**,*** Significant at $\alpha = 0.05$, 0.01, and 0.001, respectively.
† Means not followed by letters indicate a significant interaction involving this effect and another main effect detected by ANOVA.
‡ Means within an effect in the same column followed by the same letter are not significantly different at $\alpha = 0.05$.
§ CGC, IGC, HES refer to conventional grain cultivar, intermediate grain cultivar, and high-energy sorghum, respectively.
¶ ANOVA = Analysis of variance, df = degrees of freedom, CV = coefficient of variation.

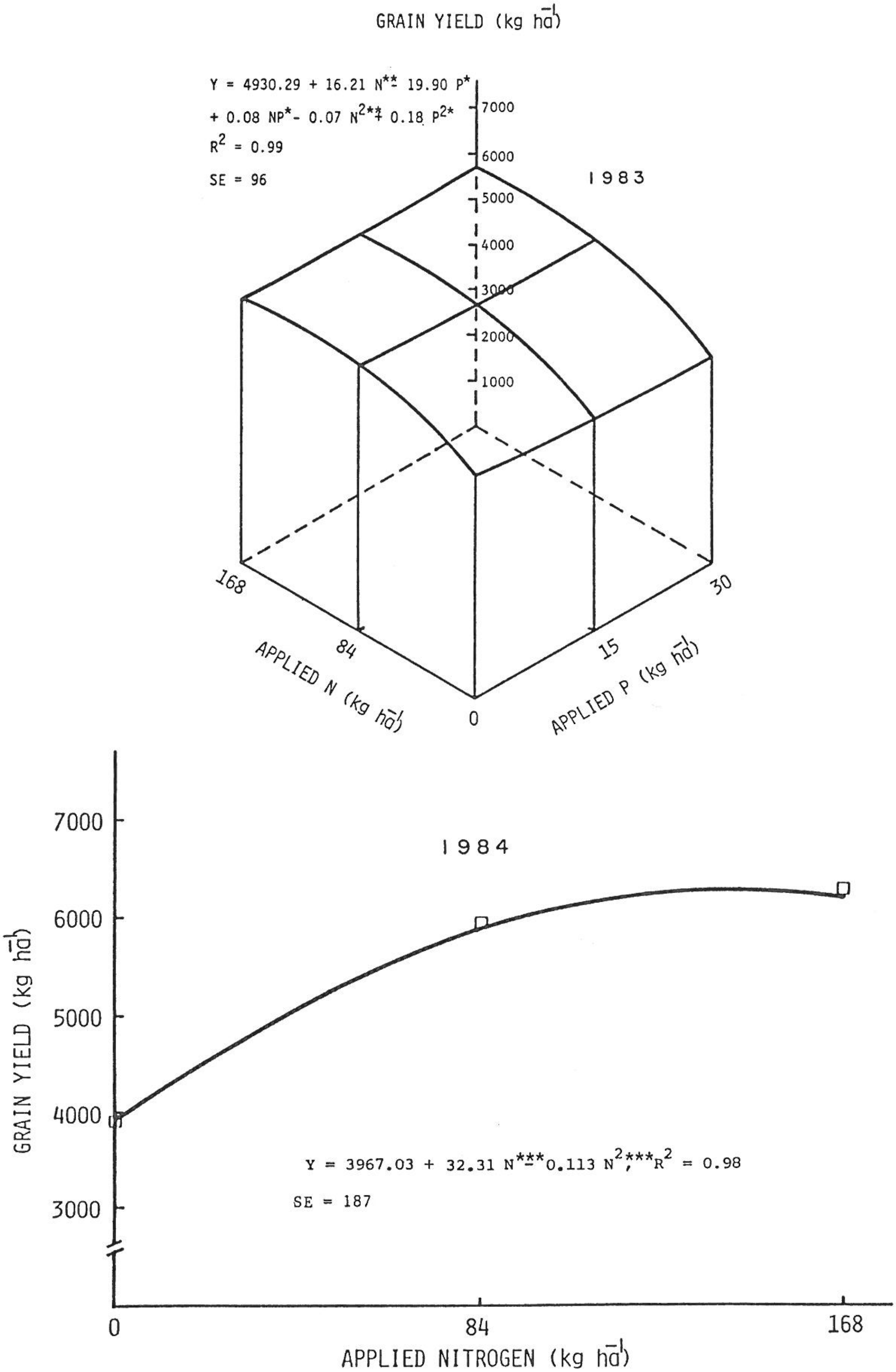

Fig. 1. Effects of applied N and P in 1983 and applied N in 1984 on grain yield of sorghum. *, **, and * indicate significance at the 0.05, 0.01, and 0.001 levels, respectively.**

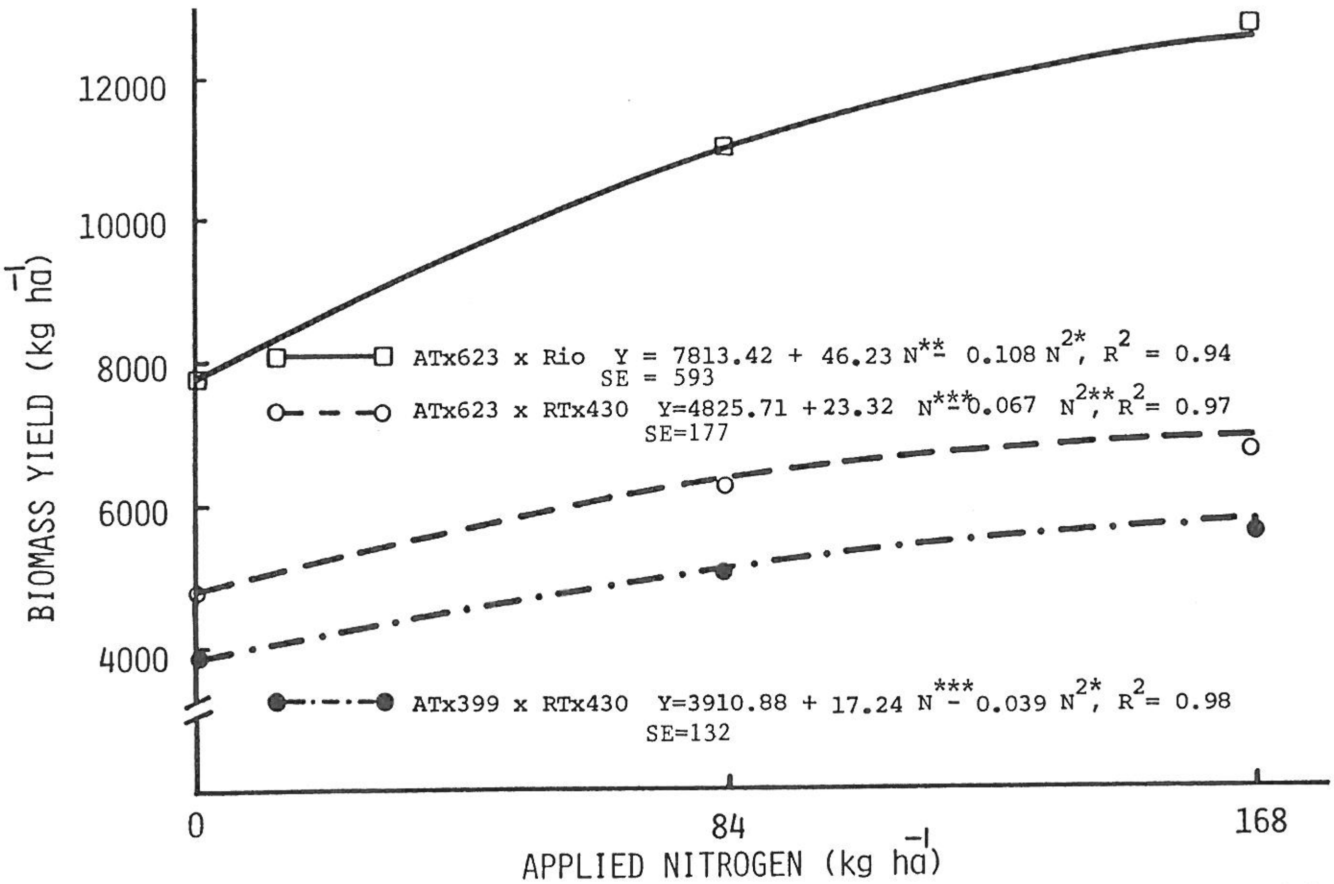

Fig. 2. Applied N effects on biomass yield within genotype. *, **, and * indicate significance at the 0.05, 0.01, and 0.001 levels, respectively.**

Nutrient Concentrations

Concentrations of all nutrients, except Mg, in grain and biomass were greater in 1983 than in 1984 (Table 5). Nutrient concentration differences between years were more noticeable in biomass than in grain, reflecting the ability of the plant to translocate nutrients to grain at the expense of the remaining vegetative parts of the plant. Average N, K, and Fe biomass concentrations in 1984 decreased 36, 20, and 30%, respectively, when compared to 1983 levels.

Genotypic differences in nutrient concentrations of grain and residue also occurred (Table 5). Grain N, P, and Mg concentrations were lower for the high grain yielding cultivars (CGC and IGC) than for the lowest grain yielder (HES). Potassium did not follow this trend and was lower in concentration in the grain of HES than for the other cultivars. The reason for this result is unknown, although the large K demand by the bio-

Table 5. Year and genotypic effects on nutrient concentrations of grain and biomass.

Effect	N	P	K	Ca	Mg	Fe	Zn
				g kg^{-1}			
				Grain			
Year							
1983	14.17†	3.37	3.24	0.14a‡	1.28b	0.073a	0.032a
1984	13.10	2.94	2.59	0.12b	1.39a	0.044b	0.027a
Cultivar							
AT×399 × RT×430 (CGC)§	13.29	3.18	2.99	0.13a	1.31	0.058a	0.031a
AT×623 × RT×430 (IGC)	12.88	3.06	3.24	0.128ab	1.24	0.060a	0.027b
AT×623 × Rio (HES)	14.73	3.23	2.51	0.121b	1.45	0.057a	0.030a
				Biomass			
Year							
1983	7.04	1.39a	17.73	4.56a	1.25	0.150a	0.033a
1984	4.51	1.14a	14.24	4.61a	1.28	0.101b	0.027b
Cultivar							
AT×399 × RT×430 (CGC)	7.05	1.49a	17.36a	5.53a	1.28	0.151	0.036a
AT×623 × RT×430 (IGC)	6.32	1.29b	15.22b	5.06b	1.23	0.129	0.031b
AT×623 × Rio (HES)	3.94	1.02c	15.38b	3.16c	1.08	0.097	0.022c

† Means not followed by letters indicate a significant interaction involving this effect and another main effect detected by ANOVA.
‡ Means within an effect and plant component in the same column followed by the same letter are not significantly different at α = 0.05.
§ CGC, IGC, and HES refer to conventional grain cultivar, intermediate grain cultivar, and high-energy sorghum, respectively.

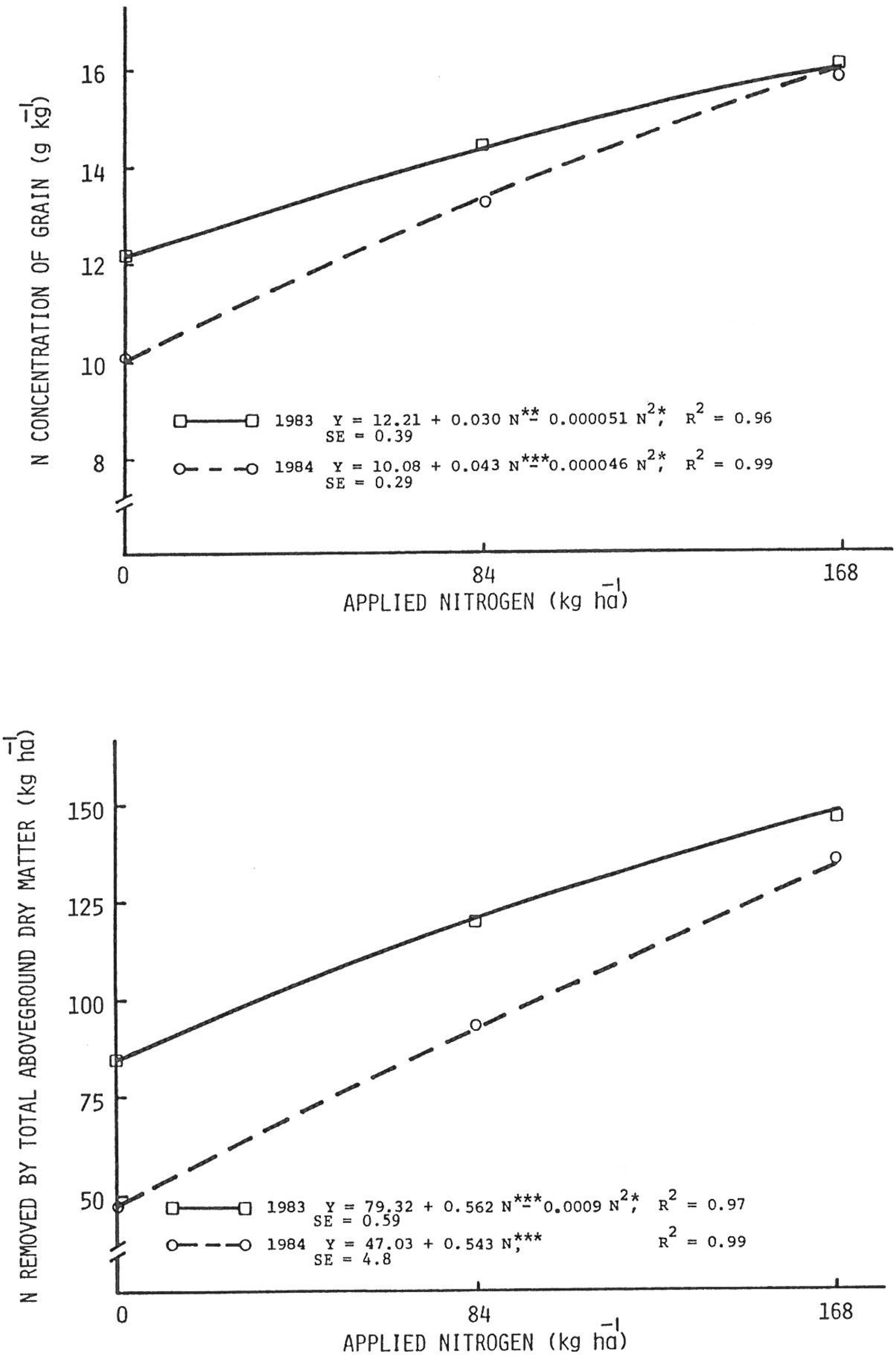

Fig. 3. Applied N effects on grain N concentration and total crop N removal within year. *, **, and * indicate significance at the 0.05, 0.01, and 0.001 levels, respectively.**

mass component of this cultivar may have resulted in lower K translocation to the grain.

Nutrient concentrations in the biomass followed a trend similar to that observed for grain, in that the cultivar producing the least biomass (CGC) had the greatest concentrations and the cultivar yielding the most biomass (HES) had the lowest concentrations (Table 5). A dry matter dilution effect apparently was important, with the exception of the K concentration of IGC which was not significantly different from that of HES.

Other than cultivar, applied N most affected the nutrient concentrations of both grain and residue, while applied P had little effect in altering these concentrations. The N content of sorghum grain was significantly increased by each additional increment of applied N (Fig. 3). The N concentration of grain produced in 1984 equaled that of 1983 only when 168 kg N ha^{-1} was applied. Increases in N concentrations of the grain with N fertilization ranged from 18% when 84 kg N ha^{-1} was applied to 30% when 168 kg N ha^{-1} was added. Biomass N enhancements were even more dramatic than those of grain, increasing 24 and 75% when 84 and 168 kg N ha^{-1} were applied, respectively.

Although applied N had significant quadratic effects on Ca, Fe, and Zn concentrations in the grain, predicted concentrations of these nutrients increased only slightly with the addition of increasing rates of N. Percentage increases were 8 and 13 for Ca, 6 and 9 for Fe, and 7 and 3% for Zn when 84 and 168 kg N ha^{-1}, respectively, were added. The N effect on grain K concentration was only slightly significant (0.05) and significant year × N (0.0001) and cultivar × N (0.0001) interactions were also present.

Applied N quadratically increased the K concentration of biomass in 1983 but did not alter it in 1984. The N concentration of biomass in 1983 was much higher than in 1984 (7.0 vs. 4.5 g kg^{-1}), with a correspondingly increased K concentration during the first year (17.7 vs. 14.2 g kg^{-1}). Biomass K concentration was increased by 13% in 1983 when N was applied compared to treatments receiving no N. Applied N also quadratically increased the Mg concentration of the residue averaged across all cultivars and years. Zinc concentration of biomass, on the other hand, was reduced by N and P addition with the lowest concentration (0.018 g kg^{-1}) obtained at maximum N and P rates.

Nutrient Removals

The combined analysis of variance over years for nutrients removed by grain, biomass, and the total crop is summarized in Tables 6 and 7. Differences in total nutrient removal between years was better explained by differences in nutrient concentrations of grain and residue rather than by differences in dry matter production. Nutrient removal in grain, biomass, and the total crop were generally lower in 1984 than in 1983 (Table 8). Total crop removals of N, P, K, Ca, Mg, Fe, and Zn decreased by 21, 18, 26, 10, 2, 37, and 24%, respectively, in 1984 when compared to

Table 6. Mean squares from combined analysis of variance over years for N, P, and K removed by grain, biomass, and total aboveground dry matter.

		N			P			K		
Source	df†	G‡	B	T	G	B	T	G	B	T
Year (Y)	1	875	23 476***	33 418***	245	350*	1 180**	537***	65 199***	77 573***
Cultivar (C)	2	985*	1 108***	203	167***	233***	8	796***	120 647***	103 009***
Y × C	2	536	903**	48	14	3	4	3	2 103	1 959
Error a	12	150	75	302	7	5	11	6	680	706
N	2	31 892***	24 754***	109 957***	663***	243***	1 643***	330***	48 917***	57 225***
P	2	51	168	388	14*	27**	73***	5	252	198
N × P	4	161*	201	709**	14**	9	30**	8*	265	252
Y × N	2	1 651***	243	1 708***	6	15*	3	1	2 580**	2 532**
Y × P	2	261**	49	122	8	7	5	4	431	500
C × N	4	20	286*	376	3	7	19	5	3 275***	3 286***
Error b	152	51	91	160	3	4	8	3	483	518
CV, %		11.2	24.1	12.2	12.1	24.5	12.4	12.3	19.6	18.1

*,**,*** Significant at the 0.05, 0.01, and 0.001 levels, respectively.
† df = Degrees of freedom; CV = coefficient of variation.
‡ G = Grain; B = biomass; T = total aboveground dry matter.

Table 7. Summary of significant effects from combined analysis of variance over years for Ca, Mg, Fe, and Zn removed by grain, biomass, and total aboveground dry matter.

		Ca			Mg			Fe			Zn		
Source	df	G†	B	T	G	B	T	G	B	T	G	B	T
Year (Y)	1	**	*	*	**	NS‡	NS	***	***	***	NS	**	***
Cutlivar (C)		***	***	***	**	***	***	***	***	**	**	***	*
Y × C		NS	**	**	NS	NS	NS	**	NS	NS	NS	***	**
N		***	***	***	***	***	***	***	***	***	***	***	***
N × P		**	NS	NS	**	NS	*	NS	NS	NS	NS	NS	NS
Y × N		***	**	**	***	**	***	NS	NS	NS	NS	*	NS
C × N		NS	***	***	NS	***	***	NS	**	**	NS	NS	*
C × P		NS	NS	NS	NS	**	*	NS	NS	NS	NS	NS	NS
CV, %		12.8	12.5	12.3	10.8	16.3	11.4	17.3	23.4	19.2	16.4	23.1	15.8

*,**,*** Significant at the 0.05, 0.01, and 0.001 levels, respectively.
† G = Grain; B = biomass; T = total aboveground dry matter; df = degrees of freedom; CV = coefficient of variation.
‡ NS = Nonsignificant.

Table 8. Year effects on nutrient quantities removed by grain, biomass, and total aboveground dry matter.

Effect	N	P	K	Ca	Mg	Fe	Zn
	kg ha^{-1}						
Year				Grain			
1983	65.8†	15.7a‡	15.1a	0.6	6.4	0.3a	0.15a
1984	61.8	13.6a	11.9b	0.5	5.9	0.2b	0.13a
				Biomass			
1983	50.1	9.8	129.7	31.5	9.1	1.0a	0.23a
1984	29.2	7.3	95.0	28.5	8.4	0.7b	0.16b
				Total aboveground dry matter			
1983	115.9	25.5a	144.8	32.2	15.1	1.4a	0.38a
1984	91.0	20.9b	106.9	29.0	14.8	0.9b	0.29b

† Means not followed by letters indicate a significant interaction involving this effect and another main effect detected by ANOVA.
‡ Means within a component in the same column followed by the same letter are not significantly different at $\alpha = 0.05$.

1983, even though mean grain and biomass yields declined by only 0.6 and 8% and the total crop dry matter yield decreased only 5%.

Cultivar differences in amounts of nutrients removed in grain and biomass were also observed (Table 9). As anticipated, cultivars with higher grain yields removed the greatest quantities of nutrients in the grain component. These differences resulted from significantly higher grain production rather than higher concentrations in grain since most nutrient compositions were lower in the higher than in the lower grain yielders. The HES removed significantly greater amounts of nutrients in biomass than did IGC or CGC, with the latter cultivar tending to remove the least nutrients in biomass. Biomass nutrient removals of N, P, K, Ca, Mg, Fe, and Zn by HES were 22, 45, 87, 23, 81, 43, and 33% greater, respectively, than amounts removed by CGC.

When nutrient removal in the total crop was considered, no genotypic differences in N and P uptake were detected (Table 9). Grain cultivars removed more N and P in grain and less in biomass, while the HES behaved in a reverse manner. The net effect, however, was similar total crop N and P removal for all cultivars. Quantities of K, Ca, Mg, Fe, and Zn removed by the total aboveground crop were consistently greater for HES, intermediate for IGC, the lowest for CGC.

Total K uptake was especially influenced by cultivar. The HES removed an average of 61 and 69 kg ha^{-1} more K than did IGC and CGC, respectively, with 94% of the total being removed by biomass. The other two cultivars had 85% of their total K removed in the biomass component. Previous research on K in grain sorghum both supports (Lane and Walker, 1961) and contrasts with (Roy and Wright, 1974) this result. The large quantity of K removed by HES grown for total dry matter harvesting may be important when compared with conventional grain hybrids produced for grain only.

Increased dry matter production and slightly greater nutrient concentrations promoted by N addition resulted in N also being a strong determinant of total crop nutrient uptake. When total crop N uptake was regressed against applied N, the 1983 intercept was greater and the slope was smaller than in 1984 (Fig. 3). Even at the highest rate of applied N, the amount of N removed by the total crop dry matter in 1984 was 10% less than that in 1983, implying that 168 kg N ha^{-1} was not sufficient for maximum dry matter production or N uptake, or both, in 1984.

Apparent uptake of applied N, estimated by subtracting the average amount of N removed by the total aboveground crop where no N was applied from the N removed by the crop at a given level of N application, was higher in 1984 than in 1983. When 84 kg N ha^{-1} was added in 1983, 41 kg N, or 49% of the applied N was taken up, resulting in a net dry matter increase of 2 800 kg ha^{-1}. Corresponding values in 1984 were 45 kg N, or 53% of the applied N, and a dry matter increase of 3 600 kg ha^{-1}. Increased N application to 168 kg N ha^{-1} caused a further increase in N uptake of 69 kg N, or 41% of the applied N in 1983, and 87 kg N, or 52% of the applied N in 1984. Respective increases in total dry matter production above the control were 3 700 and 5 000 kg ha^{-1}.

Applied N increased both P and K removals (Table 6), with P uptake increased 6 (34%) and 9 (52%) kg ha^{-1} with N rates of 84 and 164 kg N ha^{-1}. Increased P uptake was primarily attributed to increased production with applied N since tissue P concentrations were not greatly affected. Applied N also significantly enhanced total crop K removal, with the magnitude

Table 9. Genotypic effects on nutrient quantities removed by grain, biomass, and total aboveground dry matter.

Effect	N	P	K	Ca	Mg	Fe	Zn
	kg ha^{-1}						
Cultivar				Grain			
AT×399 × RT×430 (CGC)§	66.1a†	15.5a	14.5b	0.6a	6.5a	0.3a	0.15a
AT×623 × RT×430 (IGC)	65.7a	15.4a	16.3a	0.6a	6.3a	0.3a	0.13b
AT×623 × Rio (HES)	59.5b	12.9b	9.8c	0.5b	5.8b	0.2b	0.12b
				Biomass			
AT×399 × RT×430 (CGC)	35.8c	7.3b	85.4‡	26.8	6.3	0.7	0.18
AT×623 × RT×430 (IGC)	39.5b	7.8b	92.2	30.3	8.6	0.8	0.19
AT×623 × Rio (HES)	43.6a	10.6a	159.4	33.0	11.4	1.0	0.24
				Total aboveground dry matter			
AT×399 × RT×430 (CGC)	101.9a	22.8a	99.9	27.4	12.8	1.0	0.33
AT×623 × RT×430 (IGC)	105.2a	23.2a	108.5	30.9	14.9	1.1	0.32
AT×623 × Rio (HES)	103.1a	23.5a	169.2	33.5	17.2	1.3	0.36

† Means within a component in the same column followed by the same letter are not significantly different at $\alpha = 0.05$.
‡ Means not followed by letters indicate a significant interaction involving this effect and another main effect detected by ANOVA.
§ CGC, IGC, and HES refer to conventional grain cultivar, intermediate grain cultivar, and high-energy sorghum, respectively.

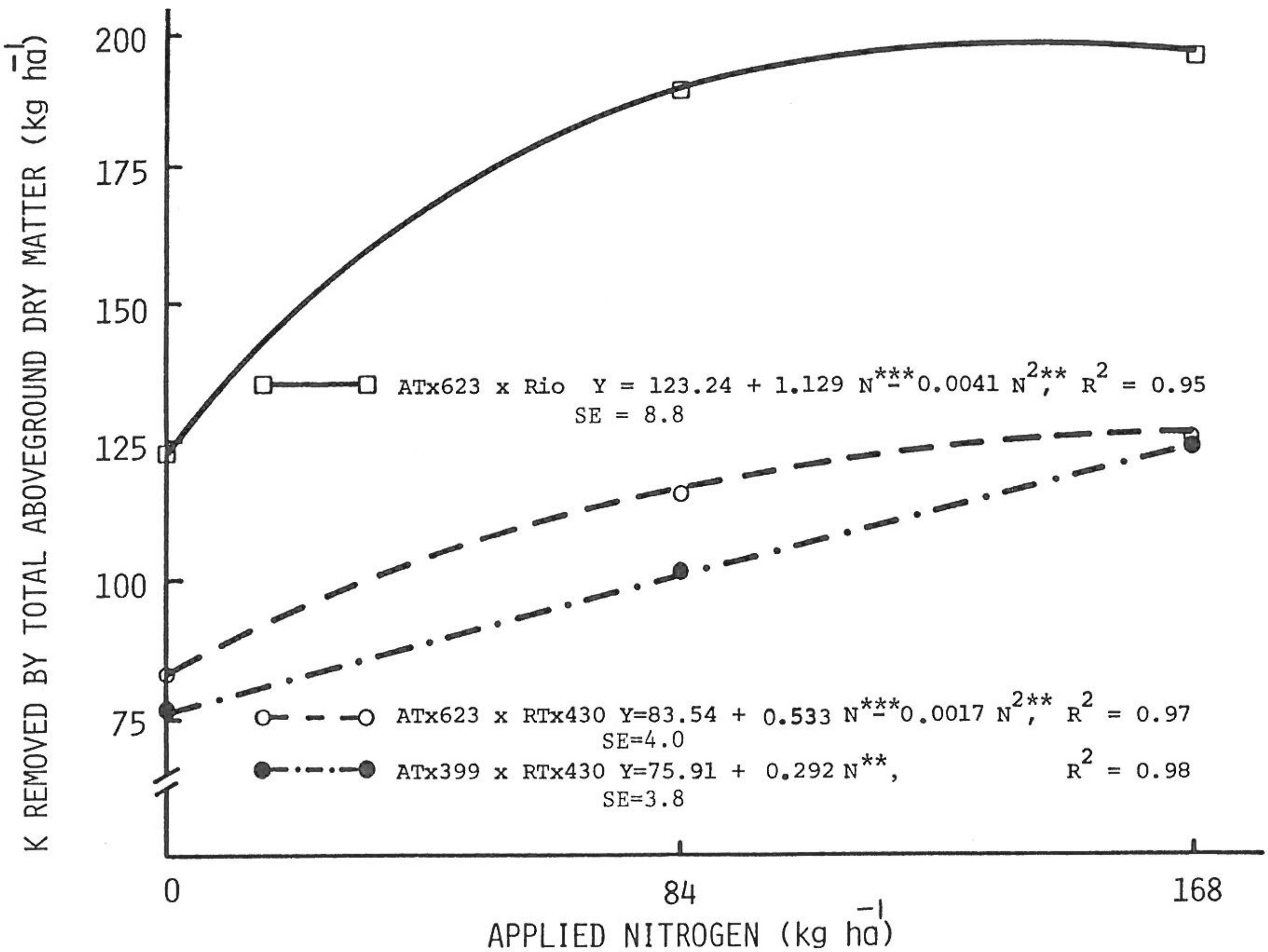

Fig. 4. Applied N effects on total K uptake within genotype. *, **, and * indicate significance the at 0.05, 0.01, and 0.001 levels, respectively.**

of the response being different for each cultivar (Fig. 4). The regressions for CGC and IGC were similar, with a maximum total K removal of about 123 kg ha^{-1} when 168 kg N ha^{-1} were applied, representing an increase of approximately 20% over treatments that received no N. Potassium removal by HES was increased 53 and 59%, respectively, as compared to controls, with the addition of 84 and 168 kg N ha^{-1}. Applied N also quadratically increased total crop uptake of Ca, Mg, Fe, and Zn (data not shown). These increases were generally caused by increases in total dry matter production with applied N and also slight increases in the concentrations of these nutrients. Cultivar responses were also somewhat different, with HES generally removing the greatest amounts of these elements.

CONCLUSIONS

Cultivar influenced grain, biomass, total crop dry matter yields and crop removal of K, Ca, Mg, Fe, and Zn, but did not affect total N and P uptake. Applied N increased the crop removal of all nutrients, while added P had little or no effect. Although grain yields were similar in both years and biomass yields decreased only slightly in the second year of the study, tissue concentrations of N, P, K, Ca, Fe, and Zn decreased the second year, resulting in decreased total uptake of these nutrients. Decreased soil nutrient availability after harvesting all aboveground dry matter the first season may have been responsible for the decline. Nutrients removed in a total dry matter utilization system would constitute a loss which does not occur with sorghum produced only for grain. Based on this study, HES produced for both grain and biomass removed an additional 140 kg K, 45 kg N, 30 kg Ca, and 10 kg P ha^{-1} when compared to grain cultivars harvested only for grain. The potential need for additional nutrients will affect the grower's cost of production and ultimately the feasibility of biomass-derived energy.

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Effect of Particulates (Dust) on Cotton Growth, Photosynthesis, and Respiration[1]

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ABSTRACT

Wind erosion suspends large quantities of dust in the atmosphere that settle back to the earth's surface and are deposited on plant leaves when wind velocities decrease. The object of this research was to determine the effect of wind-erodible size dust particles on upland cotton [*Gossypium hirsutum* (L.) 'Dunn 120'] growth and physiology. Dust (< 0.106 mm) at concentrations of 0, 10.8, 15.2, 16.5, 22.1, 28.6, 38.5, and 51.1 $\mu g\ m^{-2}$ was settled onto leaves of 22-day-old growth-chamber-grown cotton plants in a dust chamber. Net photosynthesis, dark respiration, dust concentration, leaf area, and dry weight were measured 1, 3, 7, and 14 days after dust was applied. Applied dust (> 15.2 $\mu g\ m^{-2}$) resulted in reduced dry weight at 3, 7, and 14 days after application, but dry weight accumulation was not reduced by increasing dust concentration after day 3. The dry weight reduction was due to reduced photosynthesis, 1 and 3 days after dust application, and increased dark respiration, 1, 3, and 7 days after application when dust application rates exceeded 28.6 $\mu g\ m^{-2}$. This study indicates that particulate deposits can alter cotton growth without physical damage to the plant and without toxic materials present in the dust. However, rapid removal of particulates by wind and rain and low natural deposition rates (1.5 $\mu g\ m^{-2}\ day^{-1}$) indicate that dust deposits on leaves should not be a major problem in cotton production.

Additional index words: **Wind erosion, Dust storms, Air pollution, *Gossypium hirsutum* L., Dust concentration.**

WIND erosion events in western Kansas and eastern Colorado injected approximately 5455 Mg of dust per vertical kilometer into the atmosphere during 1954 and 1955 (3). The average storm lasted 6.6 h and had a median dust concentration of 4.85 mg m^{-3} (9). An estimated 224 × 10^6 Mg of dust was suspended annually in the 1950's (10). Any dust injected into the atmosphere by dust storms, man's activities, or natural disasters will be deposited elsewhere. Dust deposition measured from 1964 to 1966 in the Great Plains averaged 17 to 459 kg ha^{-1} $month^{-1}$ (16). Cement-kiln dust deposits have been reported as high as 3.8 g m^{-2} day^{-1} (6), and the volcanic explosion of Mt. St. Helens deposited a maximum of 300 Mg ha^{-1} on agricultural crops (4).

The effect of gaseous air pollutants such as ozone, SO_2, nitrogen oxides, and fluorides on plant metabolism has received much attention, but the effect of particulates has not been examined extensively, except in those cases where plant damage has been noted.

Hand dusting cement-kiln dust at rates of 0.5 to 3.0 g m^{-2} on green bean [*Phaseolus vulgaris* (L.)] leaves reduced photosynthesis up to 73% (6). Coal dust inhibited photosynthesis at low and medium light levels with Scotch pine [*Pinus sylvestris* (L.)] and poplar (*Populus euramericana*) leaves but not at high levels of illumination because of absorption of light by the coal dust (1). A 1-mm ash coating reduced apple [*Pyrus malus* (L.)] leaf photosynthesis 90%, whereas lighter coatings temporarily reduced photosynthesis 25 to 33% and increased photorespiration by 25 to 50% (4).

Dust coatings increased leaf temperatures 2 to 4°C (7), increased the number of bacteria and fungi on the leaves (14), and increased transpiration (8). Water loss increased with increased concentration and decreased particle size of applied dust.

The objective of this study was to determine the effect of particulate coatings of wind erodible dust on the growth, photosynthesis, and respiration of cotton [*Gossypium hirsutum* (L.)].

MATERIALS AND METHODS

'Dunn 120' cotton was planted in plastic pots with 0.18-m diam and filled with 4 kg of masonry sand sieved to remove all particles larger than 3.35 mm. Plants were grown in a growth chamber at 30°C during a 16-h day and at 25°C during the night. Photon flux was 1400 μmol photon m^{-2} sec^{-1} (400–700 ηm) at the top of canopy. Plants were watered daily with 0.2-strength Hoagland nutrient solution.

Twenty-two days after emergence, plant leaves were coated with dust by sedimentation of known amounts of a mixture of particles < 0.106 mm in diam from Richfield silt loam (fine, montmorillonitic, mesic Aridic Argiustolls), Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustolls), and fluorescent dust (Pigment 2266, United States Radium Corp., Hackettstown, NJ)[3] (49.5:49.5:1 by weight) using a dust

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[3] Product name is given for information only and does not constitute an endorsement by the USDA.