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NUTRIENT ACCUMULATION RATES FOR WHEAT IN THE SOUTHEASTERN COASTAL PLAIN

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ABSTRACT: Wheat (*Triticum aestivum* L.) production has increased in the southeastern Coastal Plains to provide many farmers with an increased mid-year cash flow, and because breeding programs have improved disease resistance and increased yield potential for this crop. To determine if current fertilizer application rates were being utilized, nutrient accumulation rates for wheat grown on Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Paleudults) were quantified using mathematical splining. Wheat was sown in mid-November at a rate of 100 kg ha^{-1} (288 seed m^{-2}) in 190-mm rows and fertilized with 84-30-56 kg ha^{-1} N-P-K for a 1986-87 crop, and with 120-16-31 kg ha^{-1} N-P-K for a 1987-88 crop. Aerial plant samples were collected seven or eight times between mid-February (Feekes growth stage 5) and maturity in early June. Plant growth and N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn concentrations were measured. Aerial nutrient accumulation was calculated and described by splining with compound cubic polynomials. The accumulation patterns were similar to those previously identified for corn (*Zea mays* L.), with peak rates often occurring during both vegetative and reproductive growth stages. Total aerial N accumulation was approximately 120 kg ha^{-1} each year, with maximum accumulation rates of about 2.0 and 3.5 kg ha^{-1} day^{-1} in 1987 and 1988. Grain yield in 1987 and 1988 averaged 5,030 and 6,190 kg ha^{-1}, respectively. Mathematical splining was an effective method for quantifying the aerial plant growth and nutrient accumulation rates. The results indicate that by using a split-application technique to apply 80 to 120 kg ha^{-1} of N, the apparent N recovery was at least 65%. This study shows that Coastal Plain farmers can have both good yield and an environmentally sustainable wheat production program with similar management practices.

INTRODUCTION

Wheat in the southeastern Coastal Plain has often been grown as a low-input crop. Annual production, however, has increased substantially because of recent genetic improvements (5), demonstrations of high-yield potential in Europe and other parts of the United States (8,9), and farmer need for greater mid-year cash flow (13).

Wheat and other winter crops, such as rapeseed (*Brassica napus* L.) (16), have two other advantages when grown in the southeastern Coastal Plain. First, a relatively mild winter season, coupled with cultivars that require less time to mature, make double-cropping with soybean [*Glycine max* L. (Merr.)], cotton (*Gossypium hirsutum* L.), or grain sorghum [*Sorghum bicolor* (L.) Moench] feasible. Second, rainfall during the winter averages more than 9.0 cm per month (2). However, this abundant rainfall may reduce wheat root growth if soil oxygen levels become to low (3), and also increase leaching losses of N and other plant nutrients.

Karlen et al., (11,12) documented use of compound cubic polynomials to describe amounts and rates of aerial dry matter and nutrient accumulation for corn. The technique identified when maximum nutrient accumulation occurred and enabled them to recommend more environmentally acceptable nutrient management strategies for corn production. Karlen and Whitney (10) reported aerial dry matter and nutrient accumulation for hard red winter wheat in the Great Plains, but neither total amounts, nor rates of nutrient accumulation were available for soft red winter wheat in the southeastern Coastal Plains. The objective of this study was to use compound cubic polynomials (splining) to describe amounts and rates of dry matter and nutrient accumulation for soft red winter wheat grown in the southeastern Coastal Plain.

MATERIALS AND METHODS

Field studies were conducted on Norfolk loamy sand at the USDA-ARS, Coastal Plains Soil and Water Conservation Research Center near Florence, SC. Wheat followed corn in 1986-87 and soybean in 1987-88. Previous crop residues were incorporated by disking to a depth of approximately 0.1 m. Preplant fertilizer, supplying 34-30-56 kg ha^{-1} N-P-K for the 1986-87 crop, and 37-16-31 kg ha^{-1} N-P-K for the 1987-88 crop, was broadcast in November of each year. Coker[1] (Coker's Pedigreed Seed Co., Hartsville, SC) wheat cultivar No. 983 was sown at a rate of 100 kg ha^{-1} (288 seed m^{-2}) in rows spaced 190 mm apart in mid-November. Urea-ammonium nitrate fertilizer was applied 18 February, 1987, to supply an additional 50 kg ha^{-1} of N, and on 23 February, 1988, to supply 85 kg ha^{-1} of N. Aerial biomass and nutrient accumulation were measured by collecting sixteen 1-m whole plant samples seven or eight times between mid-February [Feekes growth stage (GS) 5] (14) and maturity (GS-11) in early June.

Samples were weighed after being dried at 65 C to measure biomass, composited to create eight samples, ground to pass a 0.5-mm screen, and analyzed for N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn at the Clemson University Agricultural Service Laboratory. Mean nutrient accumulation data (Tables 1 and 2) for each year and element were described with compound cubic polynomials (4). Dry matter and nutrient accumulation rates were determined by differentiating the equations. SAS (15) graphics were used to plot total accumulation and rate of accumulation data using day of harvest year as the abscissa. Seasonal rainfall and temperature data were collected near the sampling sites each year. Grain was harvested with an Almaco (G.W.C. Inc., Nevada, IA) plot combine. Grain moisture was measured with a Steinlite Model SS250 meter (Fred Stein Laboratories, Inc., Atchison, KS) and yields were adjusted to a constant water content of 130 g kg^{-1} each year.

RESULTS AND DISCUSSION

Seasonal temperature and rainfall patterns during this study (Fig. 1) were typical for the southeastern Coastal Plain and partially explain the similar total amounts (~12 Mg ha^{-1}) of aerial wheat biomass each year (Fig. 2a). Accumulation patterns, however, were slightly different for the two years. In 1987, accumulation during stem elongation (GS 6-9) was more constant than in 1988. Slightly warmer temperature and higher rainfall during March 1987 as compared to March 1988 probably caused this growth response. In comparison with the post-dormancy aerial biomass accumulation for hard red winter wheat (10), patterns were similar, but amounts were much greater. Grain yield in this study averaged 5,030 and 6,190 kg ha^{-1} in 1987 and 1988, respectively, as compared to an overall average of 2,679 kg ha^{-1} for the hard red winter wheat studies.

Table 1. Aerial dry matter, N, P, K, Ca, Mg, S, B, Cu, Mn, and Zn accumulations for wheat 1986-87.

Variable	02/11/87		03/11/87		04/02/87		04/18/87		05/01/87		05/12/87		05/27/87	
	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std
Dry matter Mg/ha	0.3	0.1	1.0	0.2	3.1	1.0	6.0	1.6	9.3	2.1	12.1	1.5	12.4	3.4
N kg/ha	10.2	3.1	36.1	8.2	66.7	19.9	84.2	28.7	96.9	17.9	115.0	19.8	110.9	30.3
P kg/ha	1.5	0.5	5.9	1.5	12.9	3.8	15.3	4.0	19.0	4.5	20.7	3.2	22.7	7.1
K kg/ha	9.6	2.7	34.3	10.2	100.3	31.7	123.2	40.5	143.2	36.8	133.2	23.1	120.6	36.0
Ca kg/ha	0.7	0.2	2.2	0.6	5.5	1.7	8.3	2.7	11.3	3.5	12.4	1.5	15.8	4.7
Mg kg/ha	0.5	0.1	1.6	0.3	4.3	1.2	6.7	1.9	9.6	1.7	12.4	1.4	14.8	3.4
S kg/ha	0.9	0.3	2.5	0.9	6.9	2.1	8.8	2.1	11.8	2.4	13.7	2.2	13.0	3.6
B g/ha	1.7	0.6	6.3	2.0	9.3	4.6	13.2	2.9	29.0	9.3	30.5	.7.9	30.3	17.2
Cu g/ha	3.1	1.1	8.1	2.9	15.0	8.5	25.7	7.8	43.9	10.9	39.3	9.3	53.7	13.8
Mn g/ha	14.8	10.6	62.7	42.1	156.6	102.9	240.2	140.5	362.0	222.5	392.6	184.5	413.8	246.6
Zn g/ha	7.7	3.3	23.1	6.8	50.1	17.8	74.6	24.4	106.1	27.2	142.5	24.4	164.9	22.8

Table 2. Aerial dry matter, N, P, K, Ca, Mg, S, B, Cu, Mn, and Zn accumulations for wheat 1987-88.

Variable	02/16/88		03/07/88		03/16/88		03/25/88		04/18/88		05/02/88		05/16/88		06/03/88	
	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std	mean	std
Dry matter Mg/ha	0.5	0.2	0.8	0.2	1.6	0.4	3.3	0.5	6.2	0.8	8.4	1.4	12.1	1.7	11.5	1.3
N kg/ha	16.0	5.8	47.2	13.3	60.3	12.5	90.3	14.2	99.3	15.3	90.8	23.5	119.2	22.8	113.9	18.9
P kg/ha	2.4	0.8	3.3	0.8	6.4	1.4	11.6	1.9	14.5	3.2	13.8	3.5	17.5	3.2	22.0	2.3
K kg/ha	17.2	6.1	26.0	7.9	65.2	17.2	124.4	20.6	154.1	24.4	157.0	28.8	152.4	40.5	100.5	18.5
Ca kg/ha	1.2	0.4	2.0	0.6	4.0	1.1	8.6	1.0	10.8	2.7	14.8	2.2	16.3	5.6	11.3	2.6
Mg kg/ha	1.4	1.3	1.4	0.4	2.8	0.7	5.8	0.9	9.0	1.8	11.5	2.0	16.0	3.4	15.0	1.6
S kg/ha	1.1	0.5	1.9	0.9	3.4	1.6	9.1	1.4	10.2	2.3	9.8	1.5	12.9	2.3	11.9	2.7
B g/ha	2.7	0.7	4.4	1.4	7.6	1.8	15.1	2.8	22.2	3.1	34.0	9.2	43.9	12.5	33.4	9.1
Cu g/ha	2.6	0.8	4.9	1.6	12.8	7.9	19.9	6.8	23.7	14.1	32.1	7.4	48.3	12.2	53.1	8.9
Mn g/ha	13.5	7.6	24.3	12.2	42.9	14.6	103.9	24.8	166.2	38.7	200.7	32.8	294.0	85.4	277.9	83.5
Zn g/ha	11.6	3.6	16.1	4.5	31.7	7.0	65.4	9.7	115.0	13.2	127.7	34.8	198.6	26.5	219.9	39.4

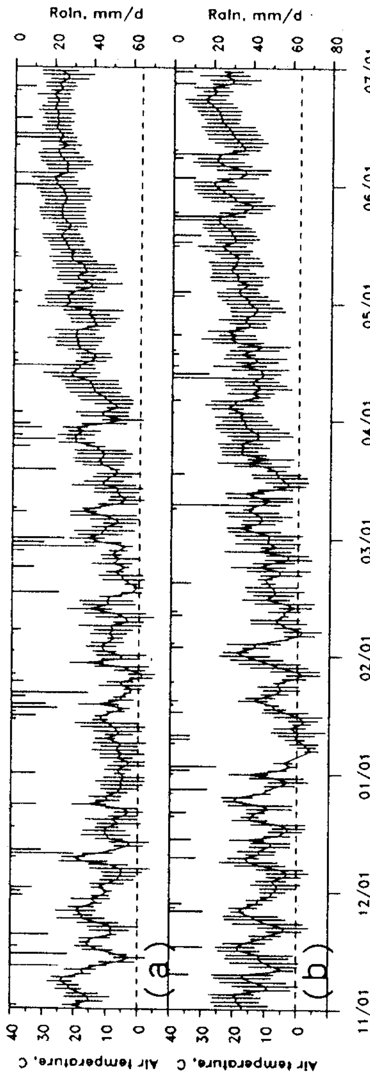

Figure 1. Seasonal rainfall and temperature for 1986–87 (a) and 1987–88 (b).

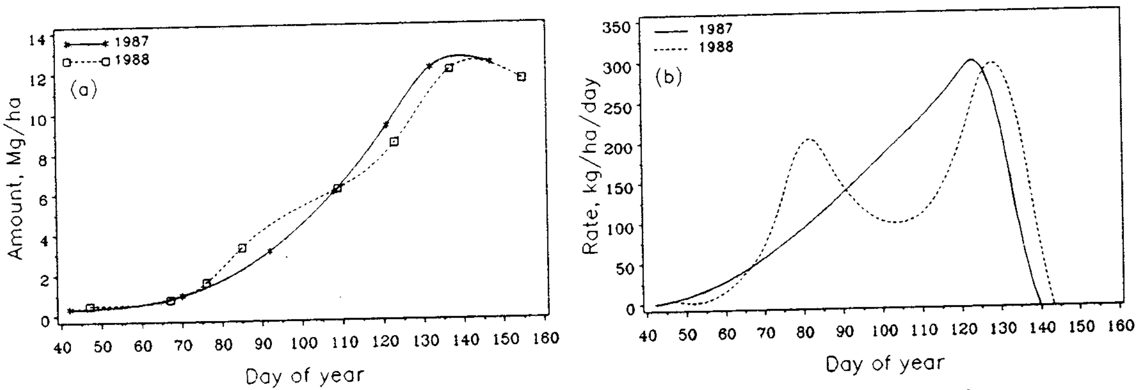

Figure 2. Amount (a) and rate (b) of aerial dry matter accumulation.

By differentiating aerial accumulation data (Fig. 2a), it is possible to quantify rates of biomass accumulation. The 1987 rate curve (Fig. 2b) showed a steady increase until about May 1, when plants began to flower (GS 10.5). In 1988, there were two periods of accelerated aerial accumulation. Slower accumulation between these periods presumably occurred because of the four consecutive days in mid-March when daily minimum temperatures were below freezing (Fig. 1b). A maximum aerial biomass accumulation rate of about 300 kg ha^{-1} day^{-1} occurred just before flowering.

Total aerial N accumulation was approximately 120 kg ha^{-1} each year (Fig. 3). Grain N concentration in 1988 averaged 1.68% (±0.02%). If this value is also used for 1987, then from 84 to 104 kg ha^{-1} N was removed in grain. Soil N was not measured for this study, but both Stanford and Smith (17) and Talpaz et al., (18) reported potential N mineralization (N_o) as 5 kg ha^{-1} cm^{-1} depth of topsoil for Norfolk fine sandy loam. Our studies were conducted on a Norfolk loamy fine sand that has a low total N concentration (7). Assuming mineralization did not provide more than 40 kg N ha^{-1}, apparent N recovery in the grain was at least 65%. This recovery is similar to that reported by Harper et al., (6), suggesting that management practices used for these studies were environmentally sound. However, research with N^{15} fertilizer is needed to quantify N cycling for this Coastal Plain soil.

The N rate curves generally show two periods of rapid aerial accumulation (Fig. 3b). The first occurred when plants were growing vegetatively (GS 5-9) while the second occurred during grainfill (GS 10.5-11). This is similar to patterns for corn (11,12). In 1987, N accumulated during vegetative growth at about 1.4 kg ha^{-1} day^{-1}. In 1988, there were both early and late vegetative peaks that averaged approximately 1.75 and 3.75 kg ha^{-1} day^{-1}, respectively. Differences in

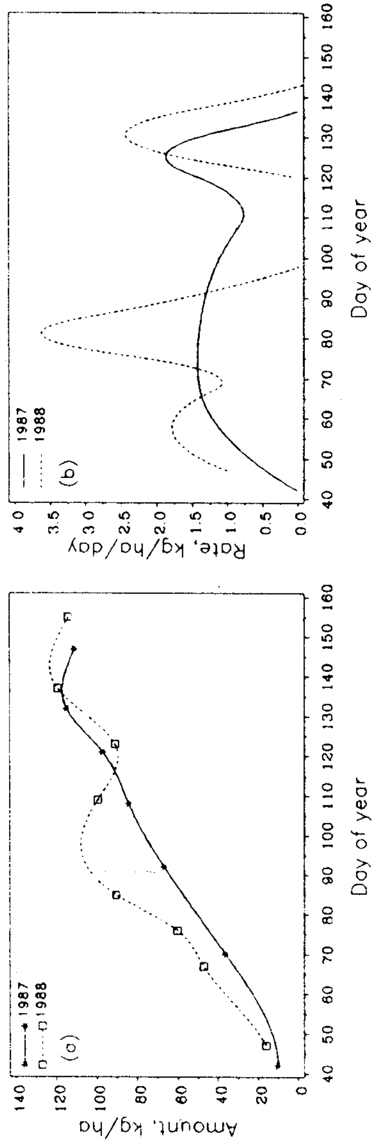

Figure 3. Amount (a) and rate (b) of aerial nitrogen accumulation.

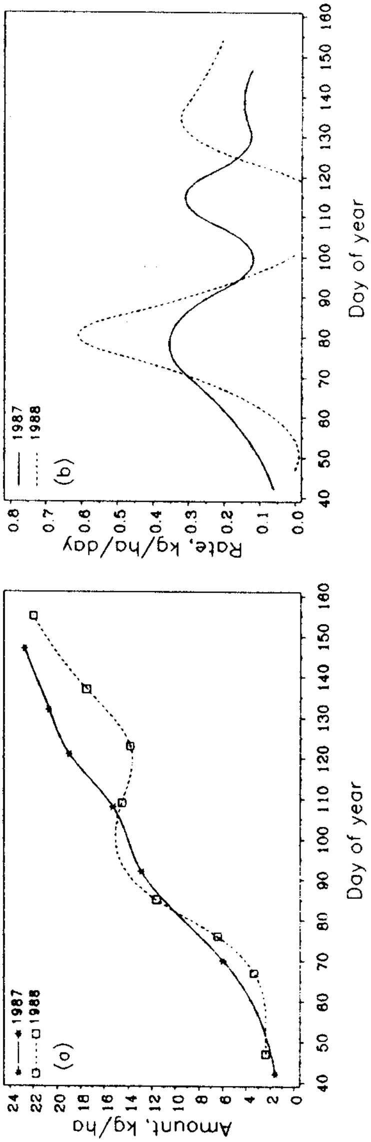

Figure 4. Amount (a) and rate (b) of aerial phosphorus accumulation.

rainfall (Fig. 1) after top-dressing with N fertilizer in mid-February presumably caused the two patterns to differ. The maximum accumulation rates during grainfill were approximately 2.0 to 2.5 kg ha^{-1} day^{-1} in 1987 and 1988, respectively.

Similar amounts of P (~22 kg ha^{-1}) were accumulated each year, although in 1988, maximum accumulation occurred about one week later (Fig. 4). The P rate curves also showed peaks of accumulation during vegetative and reproductive growth stages (Fig. 4b). The 1987 vegetative peak averaged about 0.35 kg ha^{-1} day^{-1} for a longer period than the 1988 vegetative peak which averaged about 0.63 kg ha^{-1} day^{-1}. The accumulation rate during grainfill averaged approximately 0.3 kg ha^{-1} day^{-1} both years.

Total K accumulation averaged 140 to 160 kg ha^{-1} in 1987 and 1988, with peak rates of about 3.5 and 7.0 kg ha^{-1} day^{-1}, respectively (Fig. 5). Most K accumulation occurred during the stem elongation or vegetative growth stages. Very little K was accumulated during grainfill and only a small amount (~26 kg ha^{-1} in 1988) was removed in the grain.

Aerial accumulation amounts and rates for S, Ca, and Mg by soft red winter wheat are presented in Figs. 6, 7, and 8, respectively. Aerial S accumulation averaged 14 kg ha^{-1} each year. Maximum accumulation during vegetative growth stages was about 0.2 kg ha^{-1} day^{-1} in 1987 and 0.7 kg ha^{-1} day^{-1} in 1988. During grainfill, the maximum S accumulation rate was about 0.25 kg ha^{-1} day^{-1} both years.

Maximum aerial Ca accumulation averaged 16 kg ha^{-1} (Fig. 7). In 1987, accumulation during stem elongation averaged 0.15 kg ha^{-1} day^{-1}, while in 1988, Ca accumulated at a rate of more than 0.5 kg ha^{-1} day^{-1} during vegetative growth. During grainfill Ca accumulated at rates of 0.27 to 0.33 kg ha^{-1} day^{-1} for both years.

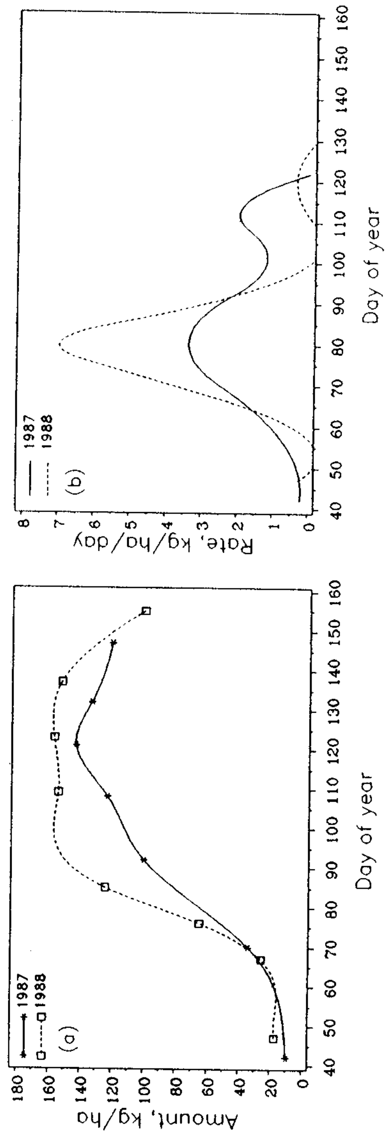

Figure 5. Amount (a) and rate (b) of aerial potassium accumulation.

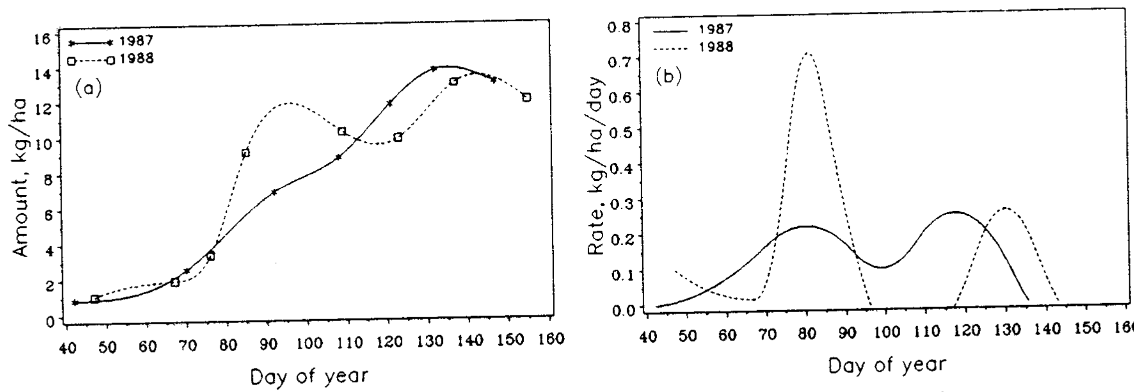

Figure 6. Amount (a) and rate (b) of aerial sulfur accumulation.

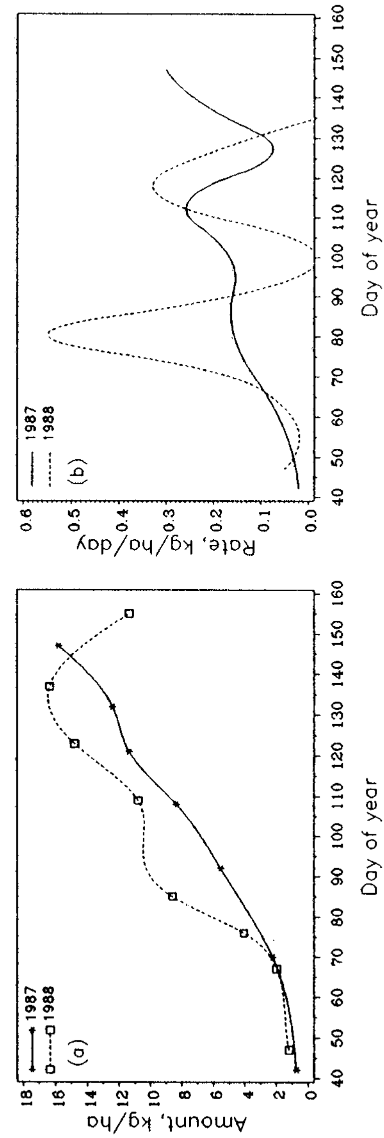

Figure 7. Amount (a) and rate (b) of aerial calcium accumulation.

Magnesium accumulation totaled approximately 16 kg ha^{-1} each year (Fig. 8). During vegetative growth stages in 1987, the Mg accumulation rate was fairly constant, averaging about 0.125 kg ha^{-1} day^{-1}. During grainfill Mg accumulated in aerial plant parts at a rate of approximately 0.25 kg ha^{-1} day^{-1}. In 1988, Mg accumulated during both vegetative growth stages and grainfill at rates of more than 0.35 kg ha^{-1} day^{-1}.

Accumulation amounts and rates for B, Cu, Mn, and Zn are shown in Figs. 9, 10, 11, and 12, respectively. The authors are unaware of any similar data for soft red winter wheat. Aerial B accumulation (Fig. 9) plateaued at approximately 30 and 45 g ha^{-1} in 1987 and 1988, respectively. In 1987, the most rapid B accumulation occurred during grainfill at a rate of approximately 1.4 g ha^{-1} day^{-1}. Accumulation of B in 1988 averaged approximately 1.0 g ha^{-1} day^{-1} during both vegetative and grainfill growth stages.

Total Cu accumulation averaged nearly 55 g ha^{-1} in both 1987 and 1988. In 1988, there appeared to be two periods of Cu accumulation for which maximum rates averaged approximately 1.0 and 1.3 g ha^{-1} day^{-1} (Fig. 10). Those periods coincided with stem elongation and grainfill, respectively. The splining technique also indicated two maximum accumulation periods for Cu in 1987. However, we speculate that this is an artifact due to differentiation of fluctuating data, since both peaks occurred after flowering and because average total Cu accumulation decreased at the sixth sampling date.

Maximum Mn accumulation in 1987 and 1988 was about 400 and 300 g ha^{-1}, respectively. As shown for corn (12) maximum Mn accumulation peaks occurred during both vegetative and reproductive growth stages. In contrast, more rapid Mn accumulation (8 to 11 g ha^{-1} day^{-1}) occurred for wheat during grainfill rather than during stem elongation (Fig. 11b).

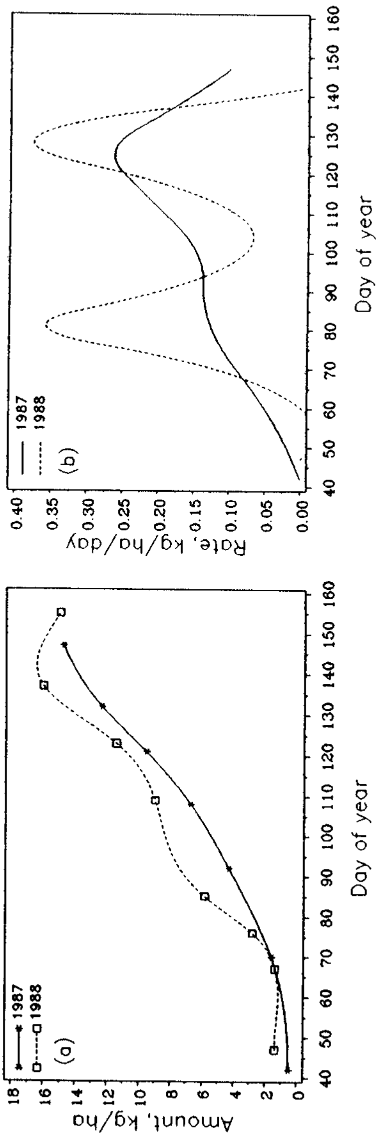

Figure 8. Amount (a) and rate (b) of aerial magnesium accumulation.

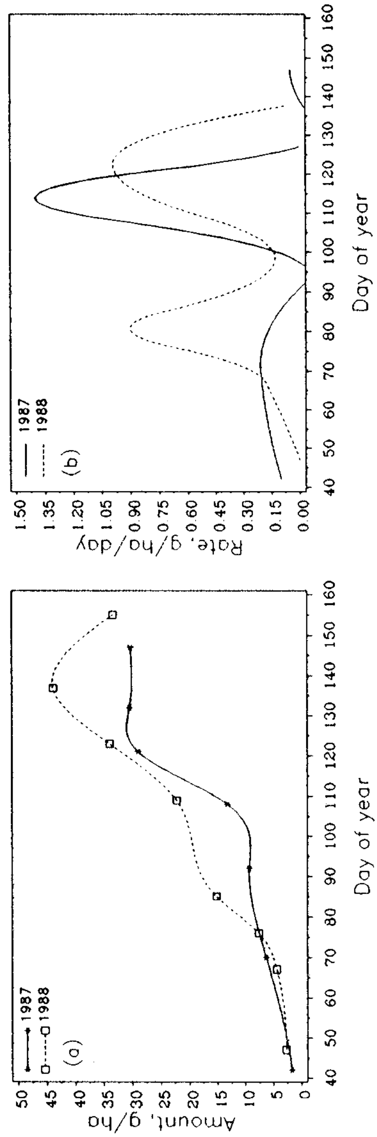

Figure 9. Amount (a) and rate (b) of aerial boron accumulation.

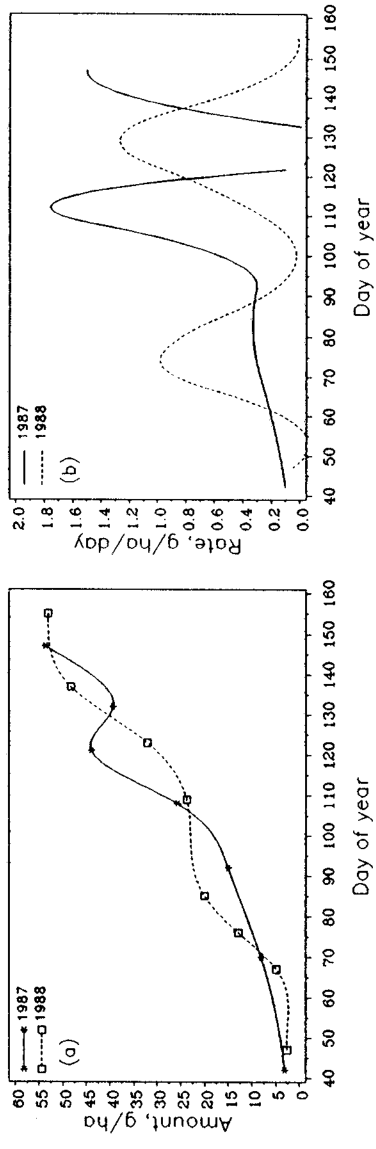

Figure 10. Amount (a) and rate (b) of aerial copper accumulation.

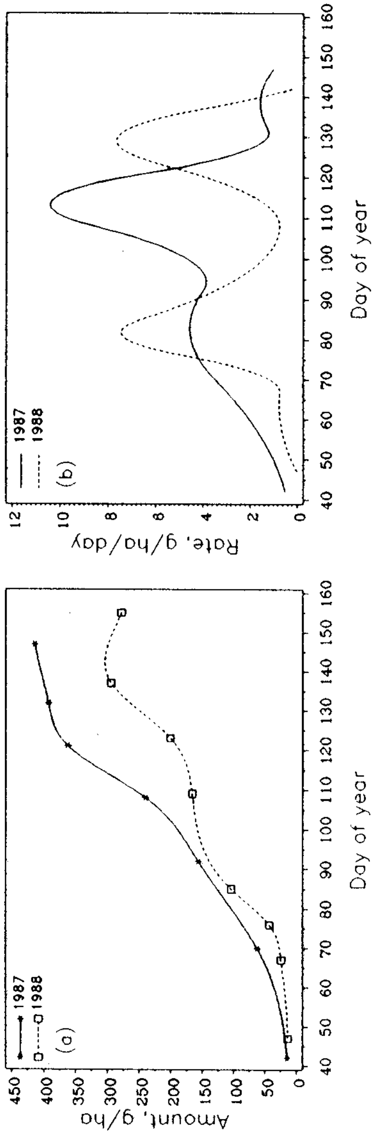

Figure 11. Amount (a) and rate (b) of aerial manganese accumulation.

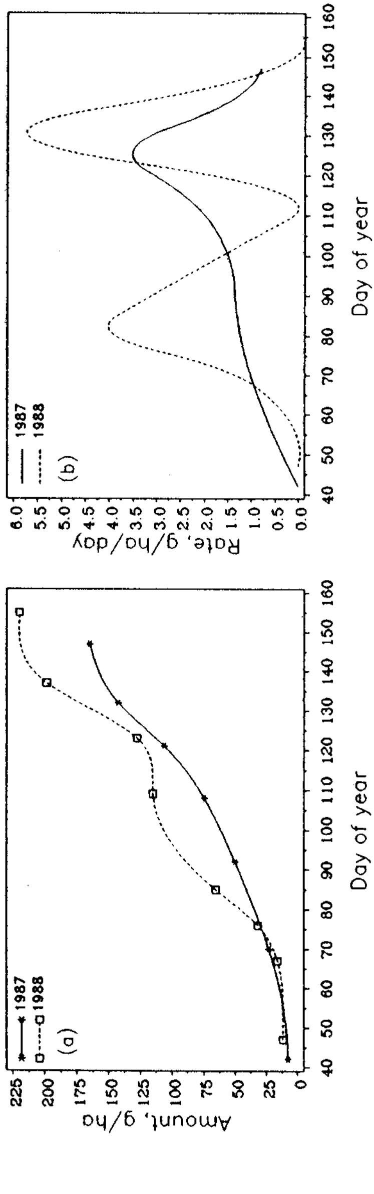

Figure 12. Amount (a) and rate (b) of aerial zinc accumulation.

Total aerial Zn accumulation averaged about 160 and 220 g ha^{-1}, in 1987 and 1988, respectively. In 1988, there were distinct maximum accumulation peaks that averaged about 4.0 and 5.8 g ha^{-1} day^{-1}, for vegetative and grainfill periods, respectively. In 1987, only the grainfill peak which averaged about 3.5 g ha^{-1} day^{-1} was distinct (Fig. 12b).

SUMMARY AND CONCLUSIONS

Use of mathematical splining was an effective method for quantifying aerial plant growth and nutrient accumulation rates for soft red winter wheat. Accumulation patterns were similar to those previously identified for corn, with maximum rates often occurring during both vegetative and reproductive growth stages. Total aerial biomass averaged about 12 Mg ha^{-1} with an aerial N accumulation of almost 120 kg ha^{-1} each year. Grain yield averaged 5,030 and 6,190 kg ha^{-1} in 1987 and 1988. Grain N concentration in 1988 averaged 1.68%, indicating an apparent fertilizer N recovery of at least 65%. Results of this study indicate that by using a split-application of 80 to 120 kg ha^{-1} of N, Coastal Plain farmers can have both good yield and an environmentally sustainable wheat production program.

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