INTERACTIONS OF NITROGEN, CHLORINE, AND SULFATE IN THE GROWTH OF BURLEY TOBACCO

by

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INTRODUCTION

Of all the ions introduced in soil for tobacco fertilization, nitrogen, chlorine, and sulfate are probably most important due to their effect on the quality of tobacco produced. In fact, muriate of potash has been removed from all burley tobacco fertilizer recommendations due to the effect chlorine has upon the quality and value of the cured leaf. McCants and Sierra (1965) have suggested that excessive chloride may be one of the major causes of the unusually large amounts of "off grade" tobacco on the market in recent years. Nevertheless, small amounts of chlorine are considered to be beneficial (McCants and Woltz, 1967).

Nitrogen rates have been increasing through the years and increased yields have resulted from the higher rates of nitrogen. However, nitrogen like chlorine has also been associated with the presence of poorer quality tobacco on the market.

Sulfate also had a detrimental effect upon leaf quality. In addition, sulfate failed to produce any beneficial results on yields (Atkinson et al., 1962).

While many experiments have been conducted to study the effect of nitrogen, chlorine, and sulfate on tobacco, research reports indicated that the nitrogen levels applied were below present recommendations. The current recommendations suggested at The Burley Tobacco Workers Conference (1968) are to apply 75 to 150 pounds of nitrogen per acre.

The objectives of this investigation are to study:

(1) The combined effects of nitrogen and varying proportions of muriate and sulfate of potash on chemical composition of burley tobacco.

(2) The degree of anion competition in the uptake of sulfate and chlorine at varying rates of nitrogen.

(3) The influence of nitrogen, chlorine, and sulfate upon the yield, quality, and acre value of the cured tobacco.

LITERATURE REVIEW

Muriate and sulfate of potash have been compared by many researchers using several types of tobacco. They found that chlorine generally produced yield increases. The reduction in leaf grade, due to chlorine accumulation in the leaves, nullified any yield benefits. Nitrogen and sulfates also tended to have similar yield effects but to a lesser degree (McCants and Woltz, 1967).

However, in all of these studies, nitrogen was applied at rates considerably lower than those being used and recommended in the burley tobacco region today. The general recommendations outlined at the 1968 Tobacco Workers Conference, Ashville, North Carolina, suggest application of 75 to 150 pounds of nitrogen per acre, depending upon the amount of legumes in the sod.

Studies by Wedin and Struckmeyer (1958) indicated that the effect of chlorine and sulfate may be different at higher levels of nitrogen. Their research showed that increasing amounts of nitrogen reduced the chlorine content of the leaves. Others (Lundegarth, 1959, and Robertson, 1968) have obtained evidence that anion competition occurs in plants.

Absorption of Nitrogen, Chlorine, and Sulfate

Myhre et al. (1956), Neas (1959), and Reisenauer and Colwell (1950) reported that chlorine was absorbed by tobacco in proportion to the amount applied. Likewise, nitrogen was also absorbed in proportion to the amount applied (Whitty et al., 1966; Salmon, 1967; and Pritchett et al., 1959). However, the mechanisms associated with the actual uptake of these ions are much more complex than initially hypothesized.

The carrier hypothesis, originally formulated to explain cation uptake, is one theory frequently offered to explain anion absorption (Robertson, 1968). Within the realm of the carrier theory, Epstein and Elzam (1965) reported that different ions were absorbed at different rates depending upon their concentrations. In barley roots, they found at least two mechanisms for chlorine absorption. At low external concentrations (0.1 to 0.2 mM), the carrier had a high affinity for chlorine. At concentrations of 0.5 and above, the carrier had a lower affinity for chlorine. Similarly, the dual mechanism theory can be applied to explain the absorption of nitrate ions in barley seedlings.[1]

Robertson (1968) explained that the carriers for chlorine absorption did not require ATP for absorption, but were dependent upon charge separation for energy. He postulated that the chloride ion vacated the site of exchange when replaced by a hydroxyl ion; and then passed to the exterior as the next chloride ion from the outside was absorbed.

Research by Wedin and Struckmeyer (1958) indicated that this energy relationship may also occur in sulfate absorption. They reported that an increase in chloride level from 35 ppm to 280 ppm caused the chlorine content to increase from 0.85 percent to 2.94 percent. A corresponding sevenfold increase of sulfate from 48 ppm to

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[1]R.P. Bosshart. 1969. Evidence for dual mechanisms of nitrate ion absorption in intact barley seedlings. Ph.D. Thesis. Virginia Polytechnic Institute, Blacksburg.

384 ppm only increased the sulfate content from 0.90 percent to 1.60 percent in the tissue. Since the chloride ion is monovalent and the sulfate ion divalent, added energy requirements for sulfate absorption could explain the reduced accumulation.

The absorption of chloride also varied with soil type, soil moisture-holding capacity, and amount of rainfall. Generally, most plants absorbed less chloride during moist growing seasons than during dry seasons (McCants and Woltz, 1967). They explained that the increased absorption during the growing season was due to the influence of rainfall on the distribution of chloride in the root zone. Similar to chlorine, sulfate absorption was dependent upon soil type, pH level, mineral content of the soil, and amount of rainfall.[2]

Competition of Chlorine, Sulfate, and Nitrate Ions During Uptake

Many researchers have indicated that anion competition influenced the accumulation of mineral elements in the plants studied. However, these workers experienced difficulty in conclusively showing this phenomenon due to experimental variation and the complexity of ion absorption. The degree of anion competition also seemed to differ among different species of plants (Robertson, 1968).

Lundegarth (1959) reported that low concentrations of nitrate may actually stimulate absorption of chloride. At higher concentrations, nitrate suppressed chlorine uptake. Also, high concentrations of chlorine had a similar effect upon nitrate. Lundegarth concluded

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[2]K.G. Verghese. 1969. Relationship among sulfate retention and certain soil properties of importance to retention mechanism. Ph.D. Thesis. Virginia Polytechnic Institute, Blacksburg.

that the increased antagonism between nitrate and chloride during the period of continued accumulation pointed to an influence of metabolic competition after which exchange competition occurred between the anions.

In other research, Skogley and McCants (1963) indicated that the chloride anion resulted in decreased NO_3, P, and S accumulation in the leaf. Harward et al. (1956) concluded that nitrate and chloride competed for absorption sites. They reported that increased rates of chlorine decreased the percent total nitrogen in potatoes.

Sequerros et al. (1955) found that the chlorine content of the leaves decreased with increasing amounts of nitrogen because better physiological development occurred. In Tennessee, Nichols et al. (1962) reported that the percent chlorine, using manure as the source of chlorine, decreased in burley tobacco when fertilizer nitrogen was increased.

In wheat seedlings, Stenlid (1957) found no relationship between the accumulation of chloride and nitrate ions. He concluded that the different ions are absorbed by different sites or carriers in the cytoplasm. Stenlid also found different requirements for carbohydrates and other substances necessary for ion accumulation.

Wedin and Struckmeyer (1958) reported that sulfate uptake was decreased by an increase in chlorine level and that chloride uptake was depressed by increasing the sulfate level in the medium. Hoagland (1923) found a similar relationship between chloride and sulfate ions.

On the contrary, Reisenaur and Colwell (1950) reported that high rates of sulfur significantly increased the concentrations of chloride in the leaf. Gauch and Eaton (1942) stated that increasing amounts of sulfate decreased chloride absorption, while increasing amounts of chloride did not affect sulfate content in plants.

In general, chlorine decreased nitrate absorption, especially at higher concentrations (Epstein, 1953). The relationship between chloride and sulfate absorption remains unclear. Eaton (1942) related that the association may be dependent upon the cations present and the tolerance of different plants to chloride and sulfate ions.

Effect of Nitrogen, Chlorine, and Sulfate Accumulation on Chemical Composition

In general, concentrations of nitrogen, chlorine, and sulfate tended to increase as levels of each increased (Neas, 1959; Whitty et al., 1966; Nichols et al., 1959; Hamilton and Bortner, 1966; and Badr, 1968[3]). The sulfur content of the plants increased from bottom to top and chlorine decreased from bottom to top while more nitrogen accumulated in the upper leaves of the plants (Tejwani et al., 1958).

The nitrogen supply also promoted a general increase in the nicotine content of the leaves (Nichols et al., 1958; Whitty et al, 1966; Salmon, 1967; Pritchett et al., 1959; and Badr, 1968[3]). Since nicotine is a nitrogenous compound, nicotine would normally be expected to increase as more nitrogen was available in the system (Garner et al., 1934). As with nitrogen, nicotine also accumulated in the

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[3]A. Badr. 1968. Nitrogen fertilization, nitrogen, and nicotine content of Burley tobacco. M.S. Thesis. Virginia Polytechnic Institute, Blacksburg.

upper leaves of the tobacco plant (Tejwani et al., 1958). Badr (1968)[3] and Takahashi (1964) found that nicotine content increased after topping.

Both chlorine and sulfate are reported to reduce the amount of organic acids in the leaves. This unfavorable characteristic was found to be smaller with sulfates (Sabourin and Bonnet, 1967). However, Gopalachari et al. (1965) explained that the actual number of organic anions did not increase. They found that the total number of anions increased, most of which were chloride ions. Thus, the increase in total anions while the organic anions remained constant would mean an effective decrease in percent organic acids in the plant. They also found that the cation-anion balance remained near one. Sulfate also was found to retard the formation of proteins, a favorable characteristic; whereas, chlorides accelerated protein formation (Sabourin and Bonnet, 1967).

In addition, the form of nitrogen had an influence on the chemical composition of the plant. The percentage of total nitrogen in the tissue may be increased by the presence of ammonium relative to the nitrate form (Evans and Weeks, 1947). However, the total accumulation of nitrogen was less when it was available in the ammonium form. This was reported to be due to the reduced growth of the ammonium supplied plants (McCants and Woltz, 1967).

Effect of Nitrogen, Chlorine, and Sulfate on Growth, Yield, and Quality

Yield increases have been obtained from the application of nitrogen. Nichols et al., (1962) found that maximum yields in burley tobacco were obtained with about 150 pounds of fertilizer nitrogen per acre. Whitty et al. (1966) also reported yield increases with applications up to 160 pounds of nitrogen in 1961 and 180 pounds in 1962. Similar yield increases were obtained by Schipfer (1966) and Wedin (1960).

In flue-cured tobacco, McCants et al. (1967) indicated that chlorine also produced yield increases. He reported that maximum yield occurred at about 30 pounds of chlorine per acre. Above the 30-pound rate, the quality of the cured leaves was reduced. Similar small increases were obtained by Garner et al. (1930), Wedin and Struckmeyer (1958), and Neas (1961). Nichols et al. (1956) showed no yield benefits from chlorine in burley tobacco.

Potassium sulfate has been compared to numerous other potassium sources and no significant yield increases were reported. In burley tobacco, Atkinson et al. (1962) found no differences in yield among the following sources: sulfate of potash-magnesia, nitrate of soda-potash (plus potassium sulfate), potassium carbonate. McCants (1960), using flue-cured tobacco, found no yield differences from potassium nitrate, a mixture of potassium nitrate and potassium chloride, and a mixture of potassium sulfate and potassium chloride.

The effects nitrogen, chlorine, and sulfate had upon quality are quite extensive. Many investigators reported that chlorine decisively impaired the burning quality of cured tobacco (Attoe, 1946; Bowling and Brown, 1947; Clark, 1953; Garner et al., 1930; McMurtrey et al., 1934; Moss et al., 1927; Nichols et al., 1956; and Wedin and Struckmeyer, 1958). High rates of sulfate also decreased the leaf burn (Atkinson et al., 1962 Myrhe et al., 1956; Neas, 1953; Wedin and Struckmeyer, 1958; and Wedin, 1960). Likewise, nitrogen reduced the burning qualities by increasing the leaf thickness (Garner et al., 1934, and Attoe, 1946). A think leaf is found to have better burning qualities than a thick close-textured leaf (McCants and Woltz, 1967). The effects of nitrogen and chlorine was reported to be nearly equal in reducing combustibility, while sulfur reduced the combustion only half that of nitrogen and chlorine (Myrhe et al., 1956).

Chouteau (1966) stated that reduced burning qualities may result from lowering the organic anions bound to the potassium in the leaves. Also, Neas (1959) reported that chlorine increased the moisture content of the leaves. Nitrogen also has the same capability of increasing moisture content in plants (Black, 1968).

In other work, Carr (1933) and Garner et al. (1930) showed that chlorine tended to increase the drought resistance in the plants. Possibly, the work done by Amarell (1958) showing that potassium sulfate increased transpiration in tobacco seedling while potassium chloride decreased transpiration explains the better drought resistance associated with chlorine. This also may account for the higher moisture content of leaves in the presence of chlorine.

Summarily, the early research indicated that muriate of potash should not be used as a source of potash due to the effect chlorine has upon quality. However, the application rates of nitrogen have since increased and in many areas doubled. Also, in light of anion competition occurring at high concentrations of nitrogen and chlorine, recent research has indicated that muriate of potash should be re-evaluated as a practical source of potash.

MATERIALS AND METHODS

This study was conducted on a Dunmore silt loam at the Southwest Virginia Research Station, Glade Spring, Virginia, during 1968. Soil samples were taken and analyzed prior to planting (Table I). Rainfall measurements were made during the growing season (Figure 1).

Fertilizer Treatments

Acre rates of 75, 150, 225, and 300 pounds of nitrogen from ammonium nitrate (33.5% N) were broadcast prior to planting. All plots received a uniform application of 200 pounds of P_2O_5 from 48 percent triple superphosphate. The rate of potassium fertilization was constant at 300 pounds of K_2O per acre and only the form of potash varied. Five ratios, based upon the chemical equivalents of chloride and sulfate ions, were derived from sulphate of potash (50% K_2O) and muriate of potash (60% K_2O) (Table II). In order to maintain the constant rate of K_2O per acre and the proper equivalent ratios, potassium nitrate was used in the fertilizer applications. Also, when potassium nitrate was applied, the amount of ammonium nitrate applied was reduced accordingly.

Experimental Design

A split block design with three replications was used. The plants were grown in six row plots (17.5 x 33 feet) with the outer rows serving as common borders for the adjoining plots. Spacing between the rows was 3.5 feet and 1.5 feet within the row. Samples during the growing season were taken from the second row. Two separate

Table I. Chemical analyses of soil samples of a Dunmore silt loam, Southwest Virginia Research Station, Glade Spring, Virginia.

Depth	Description	pH	% O.M.	Nutrients in lb./acre and levels*			
				CaO	MgO	P_2O_5	K_2O
0-6 in.	Mean of 60 plots	5.48	2.58	1953 M	364 VH	250 VH	145 M
6-12 in.	Mean of 60 plots	5.48	1.61	1771 M	379 VH	174 H	107 M
12-18 in.	Mean of 16 plots	5.45	0.54	1820 M	396 VH	85 H	86 L
18-24 in.	Mean of 16 plots	5.23	0.32	1623 M	364 VH	53 M	64 L

*VH = very high, H = high, M = medium, L = low.

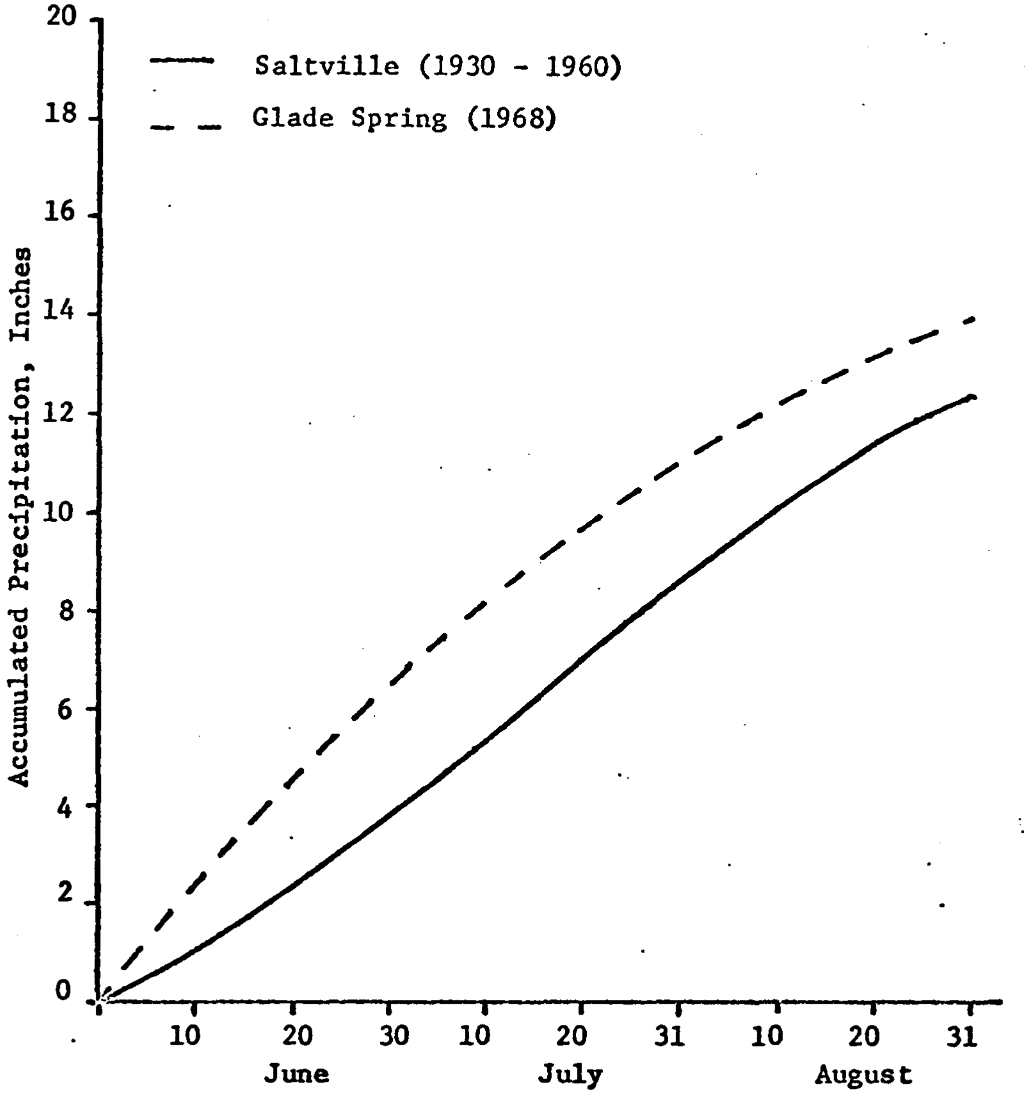

Figure 1. Accumulation curves of precipitation at the Southwest Virginia Research Station, Glade Spring and Saltville, Virginia. (Saltville is located 9 miles from the station.)

Table II. The amount of chlorine and sulfate applied from muriate and sulfate sources of potash in 1968.

Anion Proportions*		Anions, lb/acre	
Sulfate	Chlorine	Sulfate	Chlorine
100	0	322	0
75	25	242	59
50	50	161	119
25	75	81	178
0	100	0	238

*The proportions are based upon the chemical equivalents of chlorine and sulfate.

rows were harvested for barn curing. A border row was located between the sample row and the harvest rows to remove the effect of missing plants in the sample row.

Management Practices During the Growing Season

The plants were selected for uniformity from the plant beds and transplanted to the field on June 5, 1968. The plants were topped after 75 days to the leaf that would develop into the best commercial leaf. Suckers were removed by hand as needed.

Sampling Procedures

During Growing Season

Plants were harvested for chemical analysis at intervals throughout the growing season (Table III). At each sampling time, two plants were harvested, one from each end of the row. After the first sampling, alternate plants were harvested in order to reduce missing plant effects.

In several plots, the above procedure for selection of plants was deviated from due to the irregularity of stand. The plants were visually selected according to their size in relationship to the average size of all plants in the plot.

Leaves were separated from the stalks. The leaves and stalks were placed in a forced-draft oven at 140°F and their dry weight determined. Samples were ground and sub-samples taken for chemical analysis.

Final Harvest

Forty plants were harvested from each plot on September 18, 1968, 100 days after transplanting. After cutting, the plants were left in

Table III. Time of sampling, topping, and final harvest during the 1968 growing season.

Description	Sampling Date	Days After Transplanting
Transplanting	June 10	0
Sample No. 2	July 10	30
Sample No. 3	July 30	50
Sample No. 4 (Topping)	Aug. 24	75
Sample No. 5	Sept. 4	86
Sample No. 6	Sept. 18	100
Final Harvest*	Sept. 18	100

*Forty plants were harvested for curing. At all the other sampling dates, only two plants were harvested.

the field for a few hours to wilt, and subsequently, taken to the barn for curing.

After curing, the leaves were separated from the stalks and divided into farm grades, weighed, and sub-samples taken. The midrib was removed from each leaf; and the lamina, midribs, and stalks were dried at 140°F. All grades were ground separately and the midrib and lamina were composited on the basis of their percentage of the total weight of the cured leaf. These composited samples from each plot were used for chemical analysis.

The remainder of the whole leaf samples was used to determine U.S. grades. The average season price for each grade was used to calculate the acre value.

Chemical Analyses

Chloride

The Aminco-Cotlove Automatic chloride titration procedure was used to analyze the samples (American Instrument Company, Inc. Cat. Nos. 4-4419B and 4-4420B).

Sulfate

The extraction method outlined by Sandford and Lancaster (1962) was utilized. The sulfate content was subsequently determined turbidmetrically according to the procedure of Massoumi and Cornfield (1963).

Total Alkaloids

According to the method by Cundiff and Markunas (1955), the alkaloid content was determined as percent nicotine.

Total Nitrogen

The standard macro-Kjedahl procedure was used with the following modification:

> Digestion Mixture: 200 parts of anhydrous Na_2SO_4, 4 parts of anhydrous $CuSO_4$, and 1 part of Se metal (Peterson and Chesters, 1964).

Statistical Analyses

The data were analyzed using the BMD 02V program for analysis of variance of a factorial design (Dixon, 1965). The program was adapted for use on the IBM 360 computer.

The yield, acre value, and 1945 adjusted acre value data were fitted to a quadratic regression model. A regression analysis program, BMD 03R (Dixon, 1965), was employed for evaluating the effect of the selected parameters. With this program, a sequence of multiple regression equations are developed in a stepwise manner with a new variable added at each step. The variable added was the one that makes the greatest reduction in the error sum of squares.

For the 1945 adjusted acre value, the average seasonal prices in 1945 were used. Mean prices were found for both the 1945 and 1968 prices using the 1968 grades. The difference between the two means was added to each 1945 price used. The 1945 prices were selected because the price spread between the poor and high quality grades was at a maximum then. Consequently, reduction in quality due to any treatment effects would be more apparent.

RESULTS AND DISCUSSION

Yield During Growing Season

Growth rates for leaves, stalks, and shoots are presented in Figure 2. The growth rates refer to the rate of dry matter accumulated on an acre basis per day. Shoot growth rate sharply increased until topping time (75 days). After topping, shoot growth rate rapidly declined to a minimum during the 86 to 100 day period.

During the first 30-day period (Figure 2), both leaf and stalk growth rates were small. The leaf rate increased while the stalk rate remained low during the following 20 days. The growth rates were slow early due to the shock associated with transplanting and the time necessary for root establishment. Prior to harvest, the rate of stalk growth became higher than leaf growth. Thus, the maximum rate of leaf growth occurred early while the maximum rate of stalk growth occurred near maturity.

Effect of Nitrogen Applications

Fertilizer nitrogen applied at 75, 150, 225, and 300 pounds per acre had no significant effect upon the accumulation of dry matter in the leaves, stalks, and shoots (Table XVII). Since the samples consisted of only two plants, the experimental error may have overshadowed treatment differences. Also, a large percentage of plant resets after transplanting increased the sample variation.

Effect of Sulfate and Chlorine

The anion proportions, varying from 100 percent sulfate to

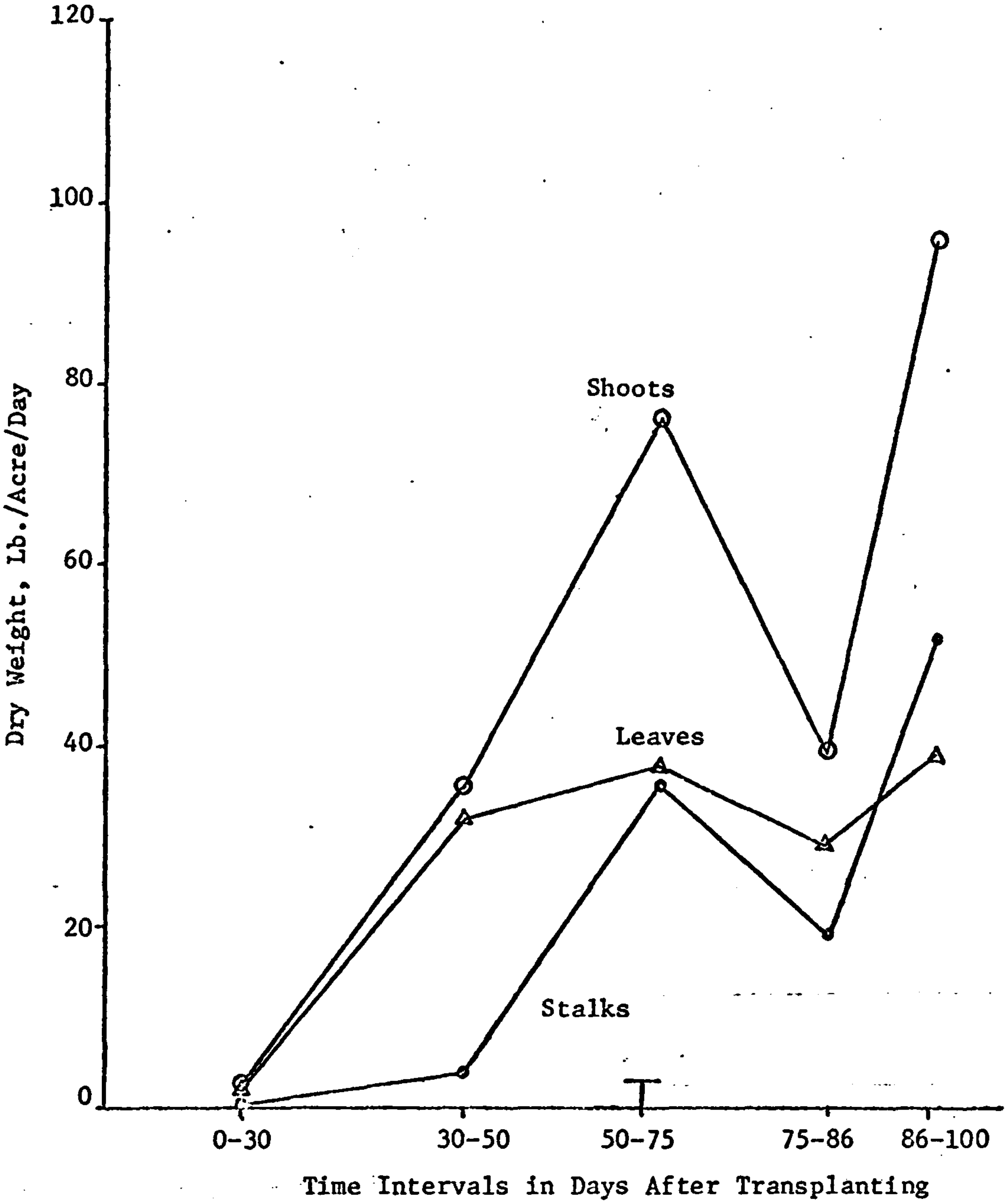

Figure 2. Rate of growth for stalks, leaves, and shoots.

100 percent chlorine, had no effect upon plant growth (Table XVII). Again, sample variation may have precluded detection of treatment differences.

Nitrogen Uptake

Absorption Rate

Nitrogen absorption was slow until the plant was established; after which, the rate of uptake steadily increased in the leaves (Figure 3). After topping, the rate decreased to a level comparable to that found soon after transplanting and then sharply increased to a maximum level. At these same points, the rate of dry matter accumulation follows the same pattern (Figure 2). This seems to indicate that the rate of nitrogen uptake and dry weight accumulation are quite closely related. Nitrogen has been repo-ted to increase the growth of plant tissue (Black, 1968).

In the stalks, the rate of nitrogen accumulation followed nearly the same pattern as found in the leaves. However, the rate did not begin to increase until the 30 to 50 day period. Whereas, the rate of accumulation in the leaves increased soon after transplanting.

Accumulation and Content

The percentage nitrogen in the tobacco plants reached a maximum 30 days after transplanting (Figure 4). Beyond the 30-day growing period, the nitrogen content decreased in the plant. After topping, the rate of decrease diminished (Table IV). Since a tobacco plant absorbs most of its required nitrogen early in the growth period (Raper and McCants, 1967), the younger plants could be expected to have higher nitrogen concentrations. Thus, the nitrogen content

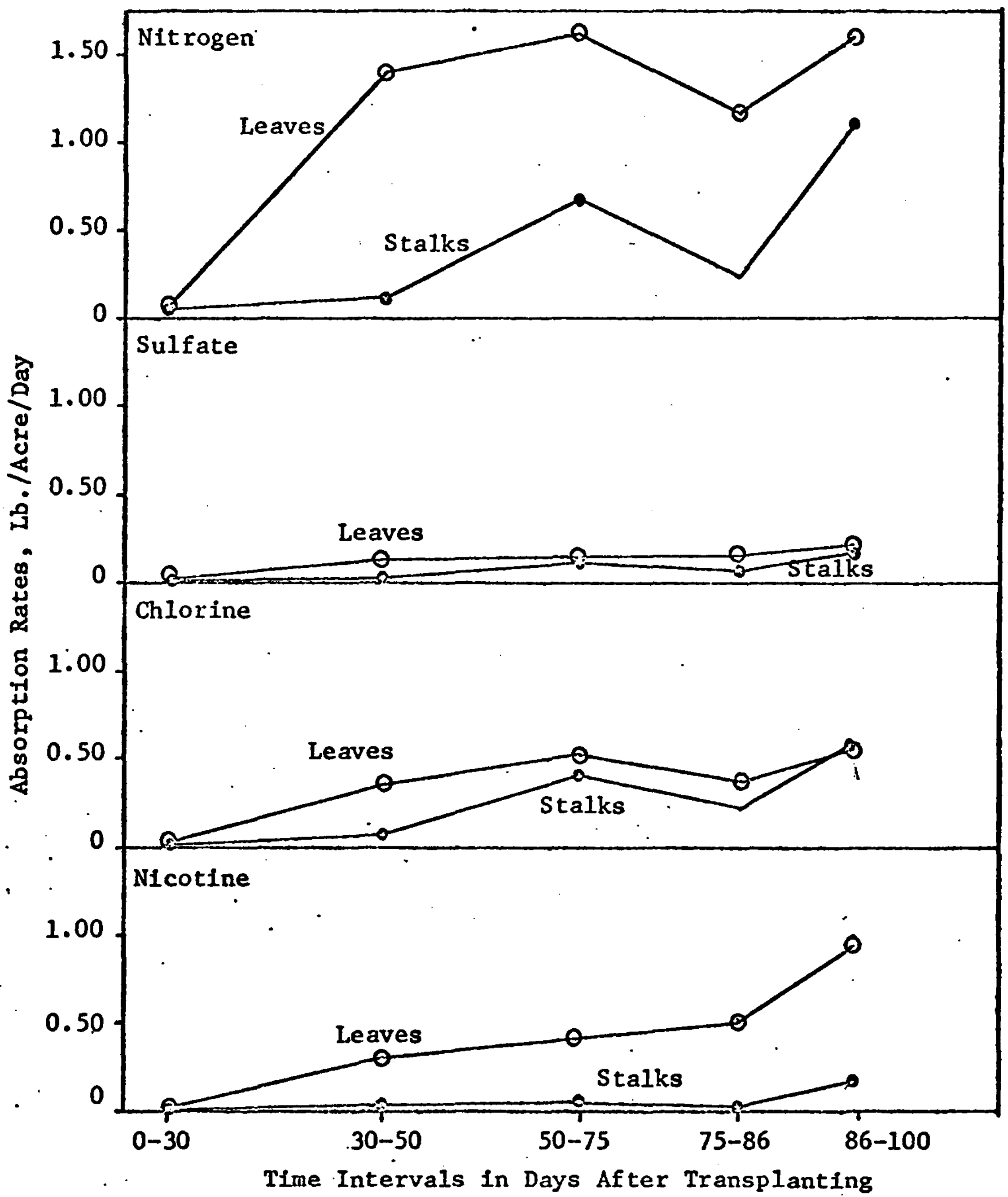

Figure 3. Nitrogen, sulfate, chlorine, and nicotine absorption rates in the leaf and stalk portions of the tobacco plant.

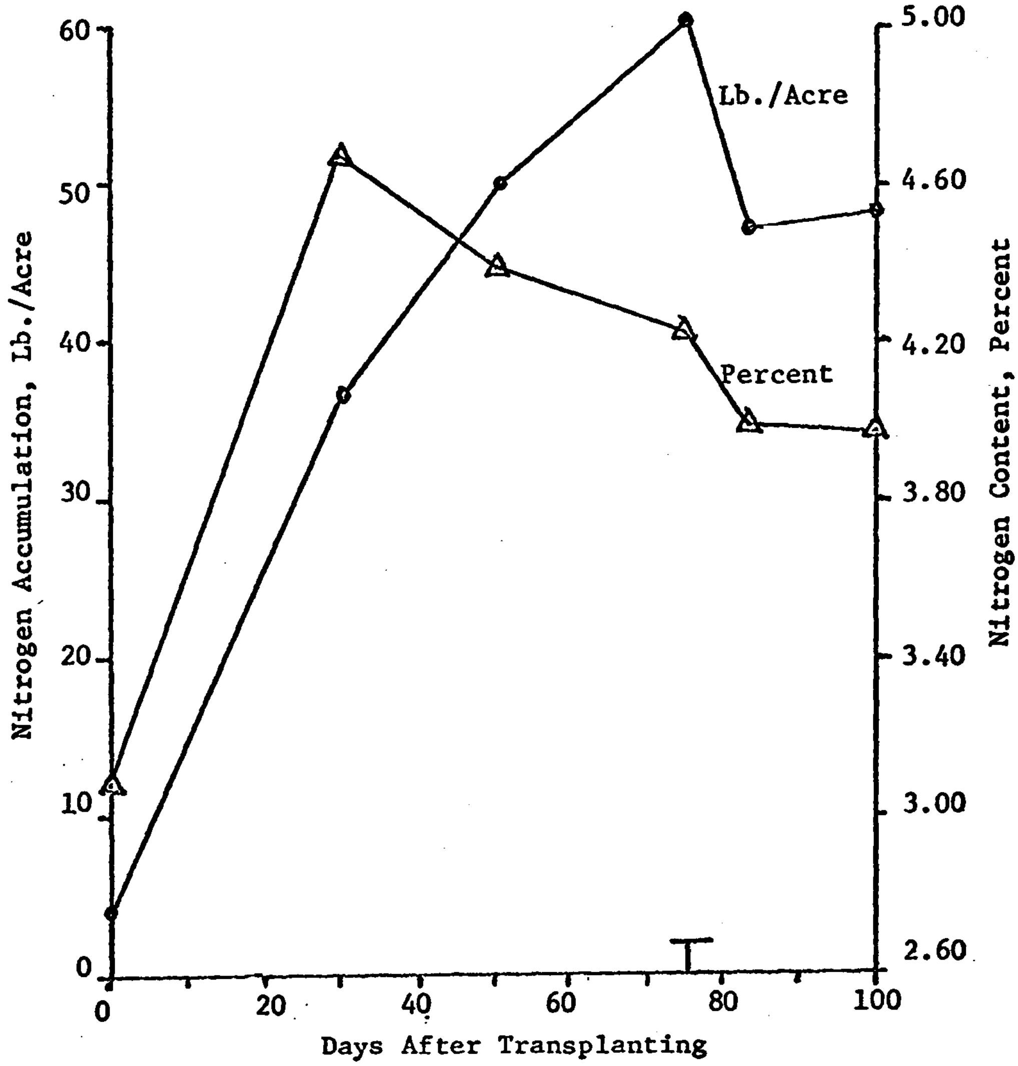

Figure 4. Nitrogen accumulation and content in the tobacco plant at the various stages of growth. (T indicates time of topping.)

Table IV. Effect of nitrogen rates and sampling dates upon total nitrogen content of tobacco leaves.

Days After Transplanting	Nitrogen, lb/acre 75	150	300	Mean
		- % N -		
30	4.57	4.68	4.84	4.69 c*
50	4.33	4.22	4.61	4.38 b
75	4.19	4.07	4.46	4.24 b
86	4.01	3.74	4.16	3.97 a
100	3.94	3.61	4.25	3.93 a
Mean	4.21 a**	4.06 a	4.46 b	

*Means in column not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

decreased as the plant accumulated dry matter.

Nitrogen uptake (a function of yield and content) peaked at topping time (Figure 4). After topping, nitrogen accumulation decreased slightly. Badr (1968)[3] also found that nitrogen accumulation decreased after topping.

Effect of Nitrogen Applications

The effect of applied nitrogen is presented in Table IV. As the nitrogen rates were increased from 75 to 150 pounds, the percentage of nitrogen in the leaves decreased slightly, although not significantly. When the application was increased to 300 pounds per acre, nitrogen content sharply increased.

Effect of Sulfate and Chlorine

The effect of sulfate and chlorine on nitrogen content and uptake was not significant (Table XVII). Kretschmer et al. (1953) found high amounts of chlorine decreased the total nitrogen content in the plant. Sample variation possibly made the treatment differences nonsignificant.

Sulfate Uptake

Absorption Rate

The rate of sulfate absorption in the leaves was extremely low throughout the growing season (Figure 3) when compared to the rates of nitrogen and chlorine uptake (Figure 3). Hoagland (1923) also found the rate of sulfate absorption to be lower than that of nitrate and chlorine.

Accumulation and Content

At transplanting, the sulfate content of the plants was 0.75 percent (Figure 5). By the time the 30-day sample was taken, the content had decreased to 0.35 percent. After this period, the sulfate percentage increased steadily except for a sharp decrease at topping time.

After the 30-day sample, the accumulation of sulfate increased lineally up to topping time. After topping, the sulfate accumulation remained nearly the same until harvest.

Effect of Nitrogen Rates

The application of fertilizer nitrogen did not affect the content nor the uptake of sulfate in the plant during the growing season (Table XVII). Hoagland (1923) also found that nitrogen had little effect upon sulfate uptake.

Effect of Sulfate and Chlorine

The application of sulfate and chlorine affected the sulfate content of the growing tobacco plant (Tables V and XVII). As the amount of sulfate decreased, the sulfate in the plants tended to decrease (Table V). However, there was no statistical ($p = 0.05$) difference between 100 percent sulfate and 50 percent sulfate. With 300 pounds of nitrogen, the amount of sulfate in the ratio had no effect upon the sulfate content.

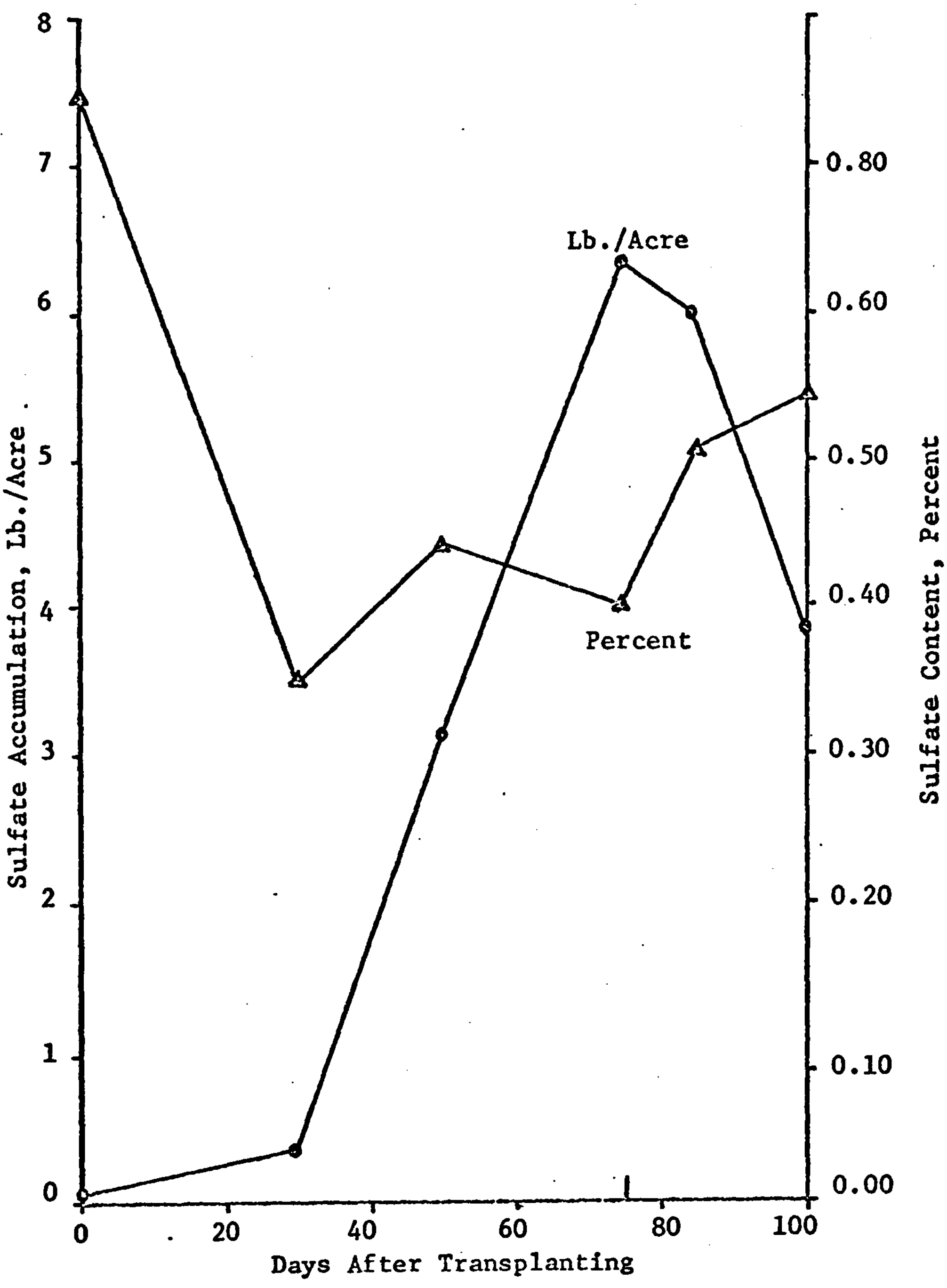

Figure 5. Sulfate accumulation and content in the tobacco plant at the various stages of growth. (T indicates time of topping.)

Table V. Effect of nitrogen rates and sulfate-chlorine ratios upon sulfate content of tobacco leaves.

Anion Ratios	Nitrogen, lb/acre 75	150	300	Mean
		- % SO_4 -		
$\frac{100\ SO_4}{0\ Cl}$	0.50 a*	0.50 a	0.47 a	0.49 b
$\frac{50\ SO_4}{50\ Cl}$	0.43 ab	0.46 ab	0.45 a	0.45 b
$\frac{0\ SO_4}{100\ Cl}$	0.38 b	0.39 b	0.40 a	0.39 a
Mean	0.44 a**	0.45 a	0.44 a	

*Means in columns not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

Chlorine Uptake

Absorption Rate

As with nitrogen and dry matter accumulation, the rate of chlorine absorption in the leaves was quite low during the first 30 days of the growing season (Figure 3). In the next 20-day period, the leaf rate increased while the stalk rate remained low. After topping, the chlorine rate dipped.

The rate of chlorine uptake seems to follow the same pattern as the rate of dry matter accumulation. This relationship may be due to the favorable influence chlorine has upon leaf development (Garner et al., 1930).

Accumulation and Content

Percent chlorine in the plant increased over the growing season (Figure 6). Topping caused a temporary decrease in chlorine content. The dip was probably due to a decrease in the rate of dry matter production at this time (Figure 2).

The accumulation of chlorine also increased over the growing season except for a short lag during the first 30 days. Reisenauer and Colwell (1950) also found that uptake of chlorine by plants increased linearly over a wide range of concentrations.

Effect of Nitrogen Rates

Percent chlorine in the leaves and stalks are presented in Tables VI and VII. With 75 pounds of nitrogen per acre, the chlorine content in the leaves was 1.32 percent. The chlorine content increased to 1.58 percent with 150 pounds. By increasing the nitrogen

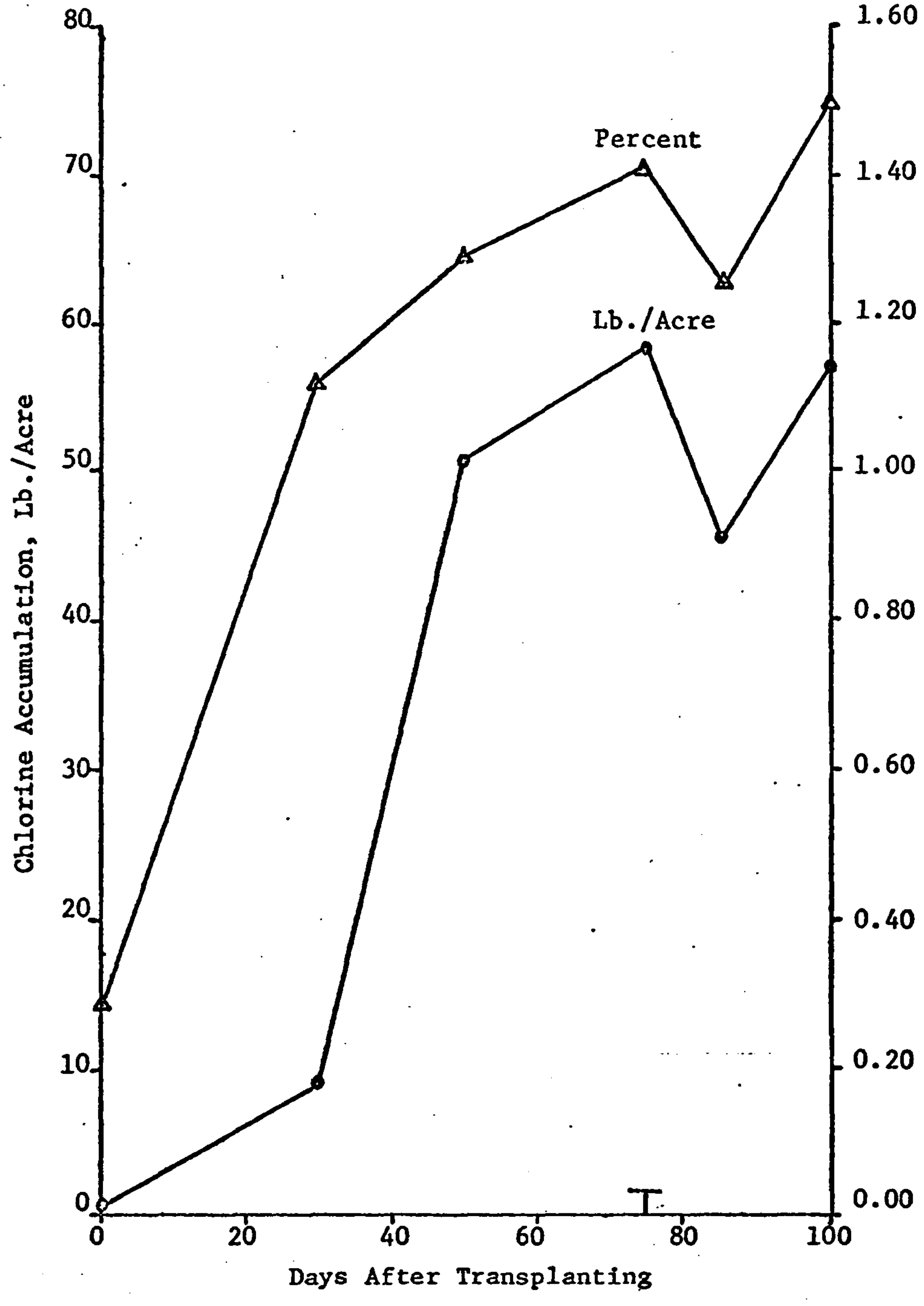

Figure 6. Chlorine accumulation and content in the tobacco plant at the various stages of growth. (T indicates time of topping.)

Table VI. Effect of nitrogen rates and sulfate-chlorine ratios upon chlorine content of tobacco stalks.

Anion Ratios	Nitrogen, lb./acre			Mean
	75	150	300	
		- % Cl -		
$\frac{100\ SO_4}{0\ Cl}$	0.69 a*	0.58 a	0.49 a	0.59 a
$\frac{50\ SO_4}{50\ Cl}$	1.55 b	1.42 b	1.31 b	1.43 b
$\frac{0\ SO_4}{100\ Cl}$	1.95 c	1.70 c	1.40 b	1.68 c
Mean	1.23 b**	1.40 c	1.07 a	

*Means in columns not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

Table VII. Effect of nitrogen rates and sulfate-chlorine ratios upon chlorine content of the tobacco leaves.

Anion Ratios	Nitrogen, lb./acre			Mean
	75	150	300	
		- % Cl -		
$\frac{100\ SO_4}{0\ Cl}$	0.43 a*	0.54 a	0.34 a	0.43 a
$\frac{50\ SO_4}{50\ Cl}$	1.44 b	1.60 b	1.26 b	1.43 b
$\frac{0\ SO_4}{100\ Cl}$	2.09 c	2.59 c	1.56 b	2.09 c
Mean	1.32 b**	1.58 c	1.06 a	

*Means in columns not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

rate to 300 pounds, the chlorine content sharply decreased to 1.06 percent. High rates of nitrogen suppressed the chlorine content in the leaves. The data indicated that anion competition occurred between the nitrate and chlorine ions, especially between the 150 and 300 pound rates. Lundegarth (1959) also found these ions competitive.

In the tobacco stalks, nitrogen had a similar effect upon the chlorine content (Table VII). In general, the amount of chlorine was about the same in stalks as leaves.

Effect of Sulfate : Chlorine

The percent chlorine in both the leaves and stalks increased as the proportion of chlorine in the ratios increased (Table VI and VII). In other words, the chlorine content increased with increasing amounts of applied chlorine. This finding is in agreement with Neas (1959). However, the increase in chlorine content was much smaller with 300 pounds of nitrogen per acre, possibly due to anion competition.

Nicotine Accumulation

Accumulation Rate

The rate of nicotine accumulation gradually increased in the leaves as the growing season progressed (Figure 3). After topping, the rate sharply increased. Badr (1968)[3] also found that nicotine increased after topping.

In the stalks, the accumulation rate remained low during the growing season. During the final period, a slight increase was noted.

Nicotine Content

Percent nicotine in the leaves increased very slowly until topping time (Figure 7). After topping, the nicotine content sharply increased. Badr (1968)[3] also reported that nicotine accumulation was associated with the rate of growth.

Thus, due to a lower growth rate immediately after topping (Figure 2), more nitrogen was available for movement to the roots. It appeared that since nicotine synthesis is located in the root system (Wolf and Bates, 1964), the nitrogen that moved to the roots was synthesized into nicotine and translocated to the leaves and stalks instead of being incorporated into amino acids to be utilized in protein synthesis.

Effect of Nitrogen Rates

Nitrogen applications did not affect the nicotine content of either the leaves or stalks during the growing season (Table XVII). Schipfer (1966) also found that the rate of nitrogen did not influence the nicotine content. Takahashi (1964) and Pritchett et al. (1959) found that nitrogen influenced the nicotine content. The differences are possibly due to the effect nitrogen would have upon the size and activity of the root system.

Effect of Sulfate : Chlorine

Effects of the various proportions of sulfate and chlorine on nicotine content were not significant (Table XVII). Woltz et al. (1948) and Neas (1961) also found no effect from chlorine on nicotine content. Kamprath et al. (1957) found that the application of sulfate on tobacco had no influence upon nicotine.

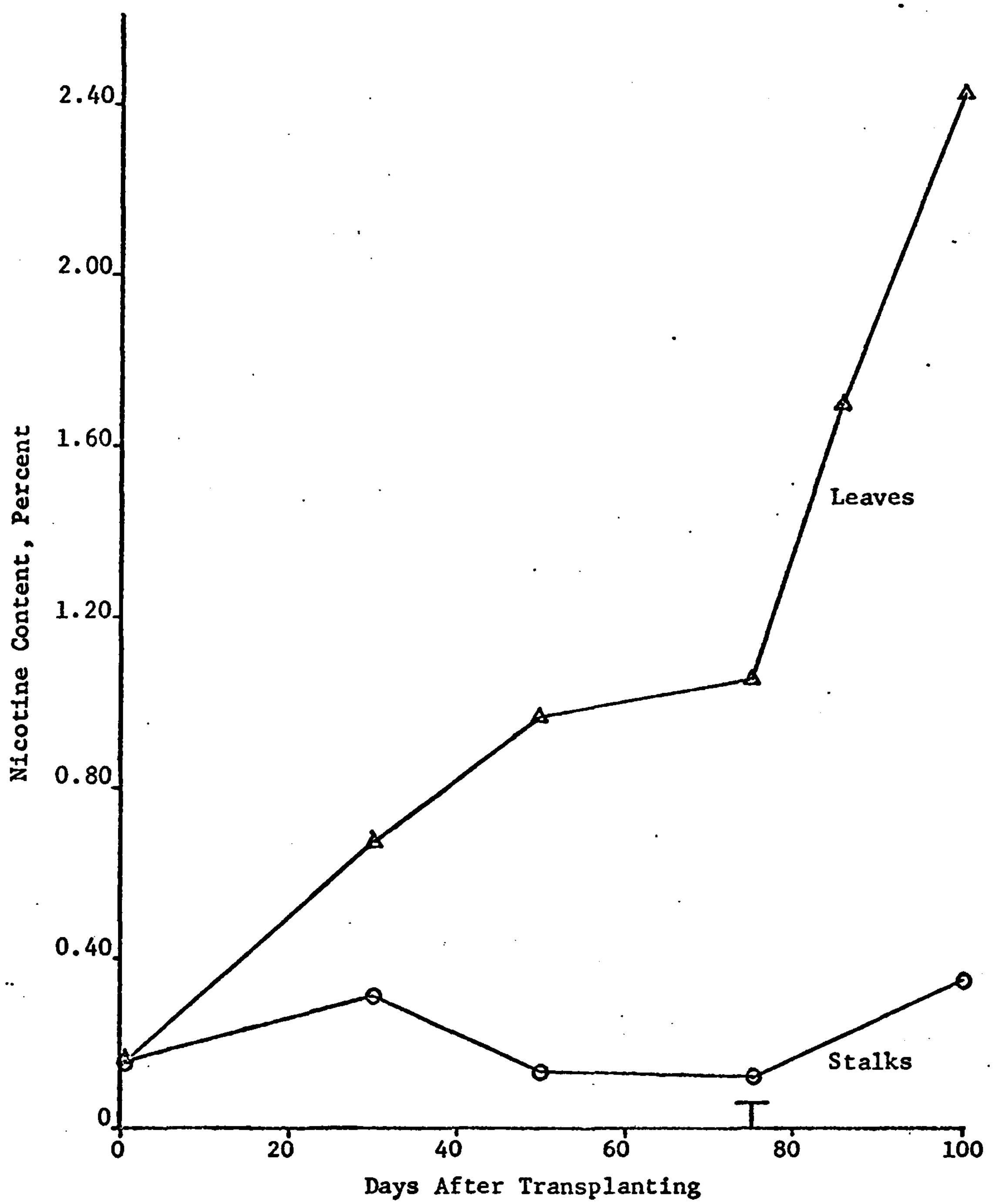

Figure 7. Concentration of nicotine in the leaf and stalk portions of the tobacco plant. (T indicates time of topping)

Yield of Cured Leaves

Effect of Nitrogen Rates

Nitrogen applications did not significantly affect acre yields (Table XVII). Atkinson (1966) reported that nitrogen only increased acre yield with irrigation. Nichols et al. (1962) found that maximum yield could be obtained with 150 pounds per acre. Wallace and Rock (1966) applied 240 pounds for maximum yields; they reported that nitrogen responses were quite variable during different years and on different soils.

Looking at the yields of the individual grades, nitrogen significantly affected the yield of the "Green" grade (Table XVIII). The leaves for the "Green" grade are located at the top of the plant. Tejwani et al. (1958) found that nitrogen accumulated in the upper leaves of the plant. The yield increase was possibly due to a larger supply of nitrogen in the top leaves. Nitrogen applications had no effect upon the other grades of cured tobacco.

Effect of Sulfate : Chlorine

The sulfate-chlorine treatments had no significant effect upon the acre yield (Table XVIII). The response to chlorine and sulfate has been quite sporadic. The effects of both chlorine and sulfate are quite dependent upon soil type and amount of rainfall. McCants and Woltz (1967) working with flue-cured tobacco reported that small amounts of chlorine increased yields. Nichols et al. (1956) showed no yield response from chlorine. Likewise, Atkinson et al. (1962) found no yield differences from sulfate.

For the grade yields, sulfate and chlorine affected the yield of the "Flyings" grade (Table XVIII). None of the other grades were affected. Since chlorine accumulates in the lower leaves and sulfate accumulates in the upper leaves (Tejwani et al., 1958), chlorine may have influenced the yield of the lower leaves.

Acre Value of Cured Leaves

Effect of Nitrogen Rates

Applications of nitrogen did not affect the acre value of the cured leaves (Table XVIII), which was probably due to the absence of yield response and a narrow price spread between grades. When the 1945 prices were used to produce a wider price spread, the nitrogen treatments were responsible for significant value difference (Table XVIII). Also, average 1968 prices were significantly affected by the nitrogen treatments.

Effect of Sulfate : Chlorine

Sulfate and chlorine treatments did not significantly affect the acre value, average price, nor the 1945 adjusted acre value (Table XVIII). Nichols et al. (1956) found that only three consecutive yearly additions of 555 pounds of sulfur reduced yield and value of burley tobacco.

Increased average prices could be obtained with only about 20 pounds of chlorine. Above this level, chlorine normally reduced the acre value of the leaves. However, the reduction was very dependent upon the factors affecting chlorine absorption and the amount of chlorine absorbed (McCants and Woltz, 1967).

Since nitrogen reduced chlorine uptake (Sequerros et al., 1955 and Nichols et al., 1962), the amount of chlorine in the cured leaves was possibly not determined to the quality of the leaves. Thus, the acre value was not affected.

Chemical Properties of Cured Leaves

Total Nitrogen

Effect of Nitrogen Rates. The amounts of total nitrogen in the cured lamina, midribs, and stalks are presented in Figure 8. Nitrogen accumulation in the lamina of the plants with 150 pounds of nitrogen were lower than the 75, 225, and 300 pound levels of nitrogen.

In the midribs, the 150 pound rate also decreased nitrogen content. The 300 pound level of nitrogen increased the accumulation of nitrogen over the 75 pound rate.

The application of nitrogen did not affect the level of nitrogen in the stalks (Figure 8). However, the total accumulation was near that found in the lamina portion. The accumulation of nitrogen was considerably lower in the midribs.

Effect of Sulfate : Chlorine. The effects of the sulfate-chlorine treatments upon total nitrogen in the plant were nonsignificant (Table XIX). Skogley and McCants (1963) found that chlorine decreased nitrate accumulation. The nitrogen content was not fractionated in this study. Consequently, the nitrate content of the leaves cannot be reported. Competition between the chlorine and nitrate ions may have favored ammonium uptake in the plant. Thus, the total nitrogen accumulation would be unchanged.

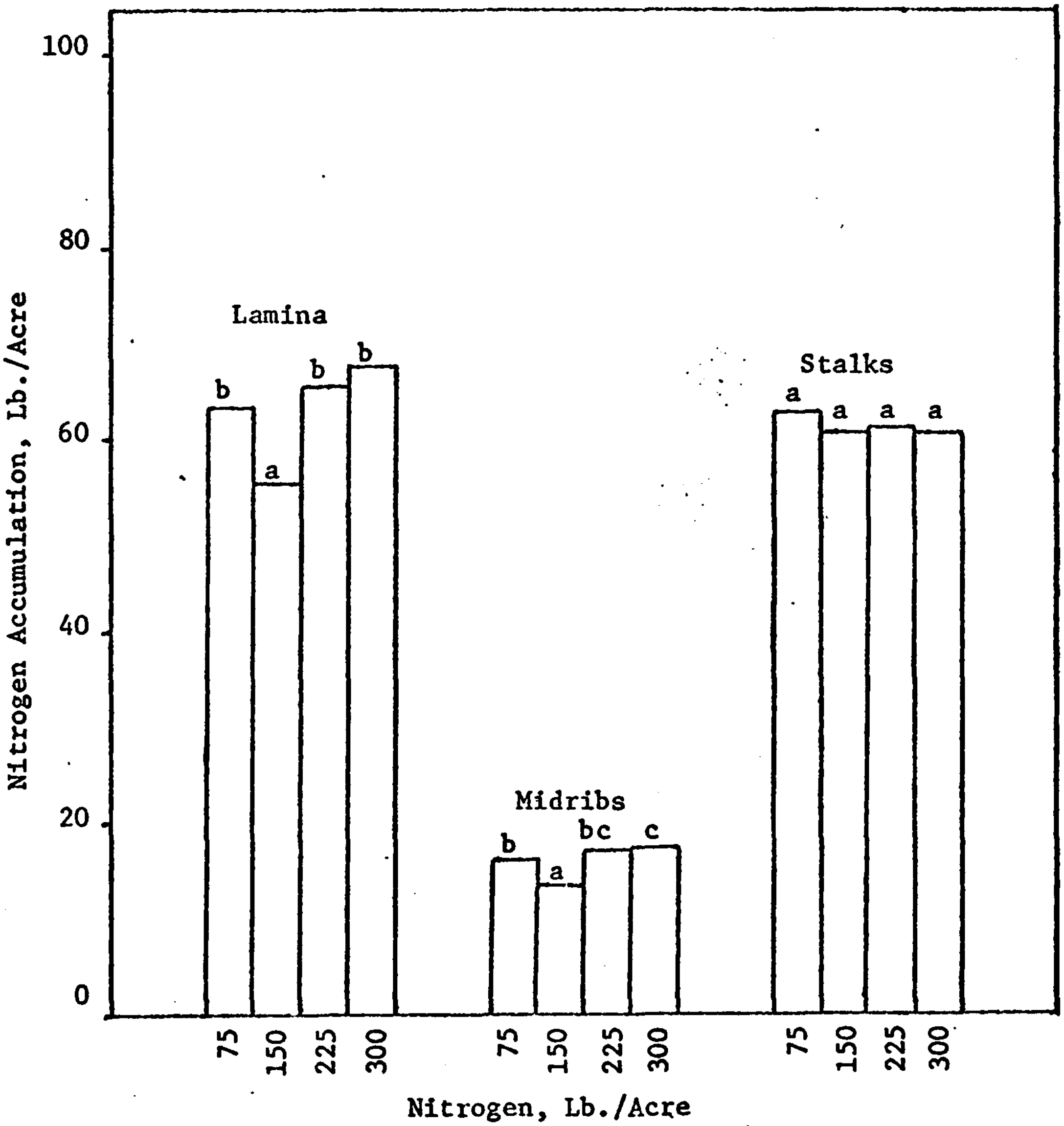

Figure 8. Effect of nitrogen rates upon total nitrogen accumulation in the lamina, midrib, and stalk portions of the cured tobacco plant. Means are significantly different at the 5% level when labeled with unlike letters within each plant part.

Sulfate

Effect of Nitrogen Rates. Nitrogen applications did not affect the content nor uptake of sulfate in the lamina (Table XIX). The nitrogen treatments did influence the sulfate content in the midribs (Table VIII). Maximum sulfate content was found in the 150 pound nitrogen treatment. Nitrogen rates of 75, 225, and 300 produced equal sulfate content in the midribs. In the stalks, nitrogen had no effect upon sulfate uptake (Table XIX).

Due to the differences in chemical charges on the nitrate and sulfate ions, applications of nitrogen should not enhance or retard the uptake of sulfate. Nitrogen could possibly influence sulfate accumulation indirectly through improved growth. In this study, the absence of yield responses removed the growth and dilution effects.

Effect of Sulfate : Chlorine. The sulfate-chlorine treatment produced significant effects upon the sulfate content of the lamina, midrib, and stalk portions of the plant (Table XIX).

The data for the sulfate content of the plant parts are presented in Table IX. In the lamina portion, the sulfate concentration increased as the proportion of sulfate increased. Wedin and Struckmeyer (1958) found the same occurrences in the presence of chlorine. Sulfate content in the midribs and stalks followed nearly the same pattern as the lamina portion.

Chlorine

Effect of Nitrogen Rates. The effect of nitrogen on the uptake of chlorine in the lamina is presented in Figure 9. When no chlorine was applied, nitrogen did not influence the chlorine uptake. As the

Table VIII. Effect of nitrogen rates and sulfate-chlorine ratios upon sulfate content of cured midribs.

Anion Ratios	Nitrogen, lb./acre				Mean
	75	150	225	300	
		- % SO_4 -			
100 SO_4 / 0 Cl	0.52	0.62	0.48	0.51	0.53 c*
75 SO_4 / 25 Cl	0.47	0.55	0.42	0.44	0.47 b
50 SO_4 / 50 Cl	0.42	0.49	0.45	0.42	0.44 b
25 SO_4 / 75 Cl	0.33	0.41	0.39	0.40	0.38 a
0 SO_4 / 100 Cl	0.33	0.39	0.38	0.35	0.36 a
Mean	0.41 a**	0.49 b	0.42 a	0.42 a	

*Means in columns not followed by common letters differ significantly ($p = 0.05$, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly ($p = 0.05$, Duncans Multiple Range Test).

Table IX. Effect of sulfate-chlorine ratios upon the sulfate content in plant parts of the cured tobacco plant.

Anion Ratios	Plant Parts: Lamina	Midribs	Stalks
		- % SO_4 -	
$\frac{100\ SO_4}{0\ Cl}$	0.58 d*	0.53 c	0.47 c
$\frac{75\ SO_4}{25\ Cl}$	0.50 c	0.47 b	0.41 b
$\frac{50\ SO_4}{50\ Cl}$	0.47 bc	0.44 b	0.38 ab
$\frac{25\ SO_4}{75\ Cl}$	0.45 ab	0.38 a	0.37 a
$\frac{0\ SO_4}{100\ Cl}$	0.42 a	0.36 a	0.35 a
Mean	0.48	0.44	0.40

*Means in columns not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

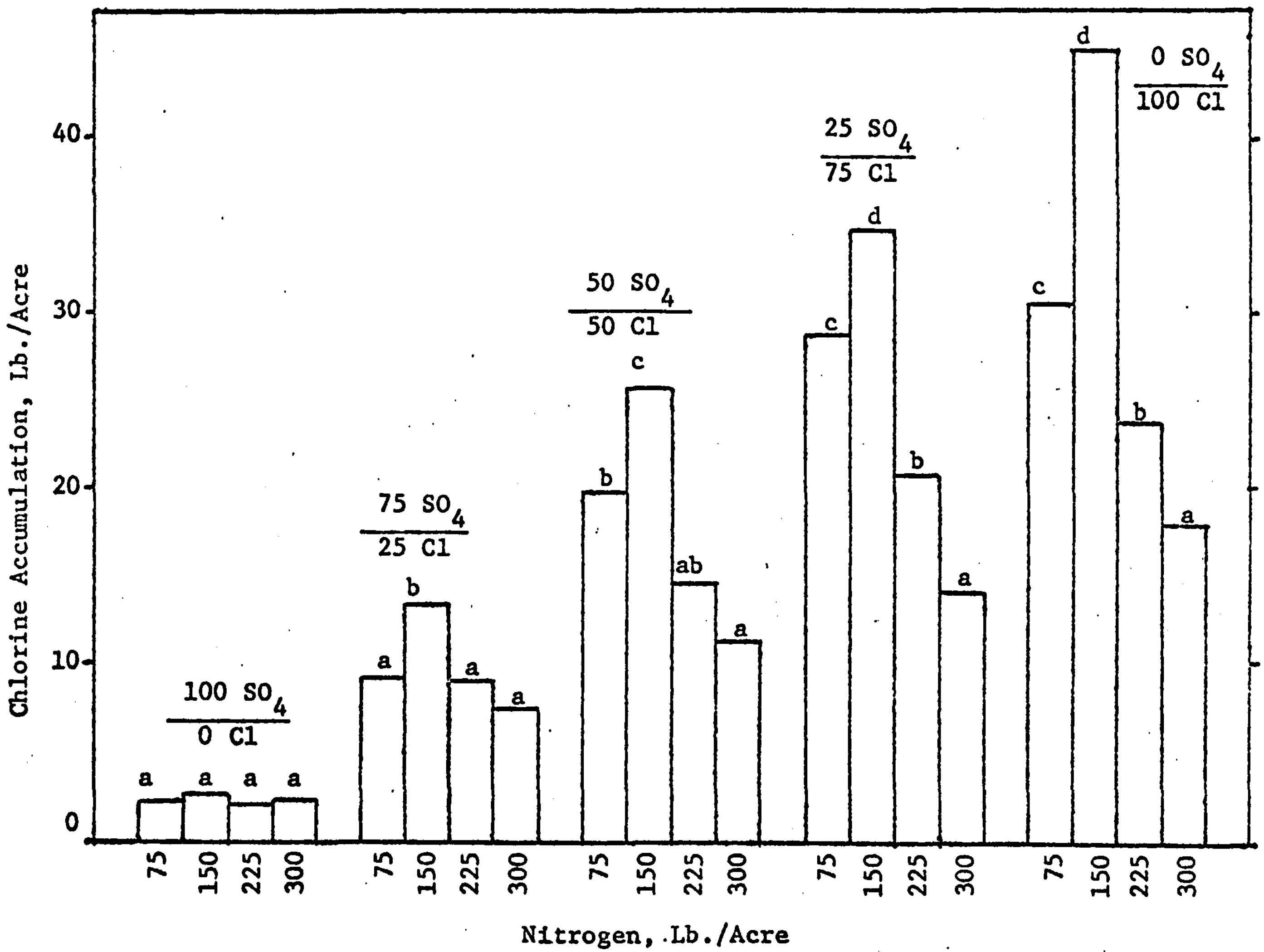

Figure 9. The effect of applied nitrogen and sulfate-chlorine ratios on chlorine accumulation in the cured lamina. Means are significantly different at the 5% level when labeled with unlike letters within each sulfate-chlorine ratio.

amount of applied chlorine increased, nitrogen had a larger effect upon chlorine accumulation. At each level of chlorine, the 150 pound rate of nitrogen showed maximum chlorine accumulation. As the rate of nitrogen increased to 225 and 300 pounds, chlorine accumulation sharply decreased to level below the 75 pound application. The minimum amount of chlorine was found in the lamina receiving 300 pounds of nitrogen. Lundegarth (1959) found that the high levels of nitrate nitrogen suppressed chlorine uptake. Lundegarth explained that the suppression of chlorine may be due to the influence of metabolic competition after which exchange competition occurs between the anions. Sequerros et al. (1955) also showed that chlorine decreased with increasing amounts of nitrogen.

Percent chlorine also showed the same general relationships as chlorine uptake (Table X). This indicated that dilution from increased yields were not producing these treatment differences, since uptake is a function of yield and content.

In the midribs, chlorine accumulation and content also increased to a maximum with 150 pounds of nitrogen and decreased to a minimum with 300 pounds per acre (Figure 10 and Table XI). The overall chlorine content was nearly double that in the lamina portion.

The chlorine content of the stalks is presented in table XII. As with the other plant parts, maximum chlorine was found in the stalks receiving 150 pounds of nitrogen and minimum content with 300 pounds of nitrogen. Chlorine uptake followed the same relationships (Table XIII).

Thus, between 150 and 300 pounds of nitrogen, the reduced chlorine uptake indicated that anion competition occurred between the nitrate and chlorine ions. The reduction occurred similarly in the lamina, midribs, and stalks.

In the plants receiving 75 pounds of nitrogen per acre, chlorine uptake could not be simply explained in terms of anion competition. Possibly, at low levels of nitrogen, the plants did not develop the same size root system. This would mean reduced uptake. However, the yield differences for nitrogen were not significant (Table XIX).

The Effect of Chlorine. In general, chlorine accumulation increased in the lamina, midribs, and stalks as more chlorine was applied (Figures 9, 10, and Table XIII). Pal et al. (1966) and Myhre et al. (1956) also reported that chloride was absorbed in proportion to the amount applied.

Correlation of Nitrogen, Chlorine, and Sulfate Content

Correlation values for the individual plant parts are presented in Tables XIV and XV. Nitrogen and sulfate content were negatively correlated with chlorine content in the lamina and midribs (Table XIV). In the stalks, only sulfate content was significantly correlated with chlorine content. The significant negative relationships between nitrogen, chlorine, and sulfate further indicated that the anions may compete for absorption sites.

The equations for these relationships are as follows (values in parenthesis below regression coefficients are their standard error):

$$\text{Lamina } Y = 8.46 - \underset{(0.17)}{1.08}\ \%N - \underset{(0.73)}{6.10}\ \%\ SO_4$$

Table X. Effect of nitrogen rates and sulfate-chlorine ratios upon chlorine content in the lamina portion of the cured tobacco leaves.

Anion Ratios	Nitrogen, lb./acre 75	150	225	300	Means
		-% Cl-			
$\frac{100\ SO_4}{0\ Cl}$	0.14 a*	0.18 a	0.14 a	0.16 a	0.16 a
$\frac{75\ SO_4}{25\ Cl}$	0.63 ab	0.90 b	0.58 ab	0.48 a	0.65 b
$\frac{50\ SO_4}{50\ Cl}$	1.19 bc	1.83 c	0.93 bc	0.87 a	1.20 c
$\frac{25\ SO_4}{75\ Cl}$	1.53 c	2.16 c	1.27 bc	0.94 b	1.47 c
$\frac{0\ SO_4}{100\ Cl}$	1.85 c	2.86 d	1.48 c	1.15 b	1.83 d
Means	1.07 c**	1.59 d	0.88 b	0.72 a	

*Means in columns not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

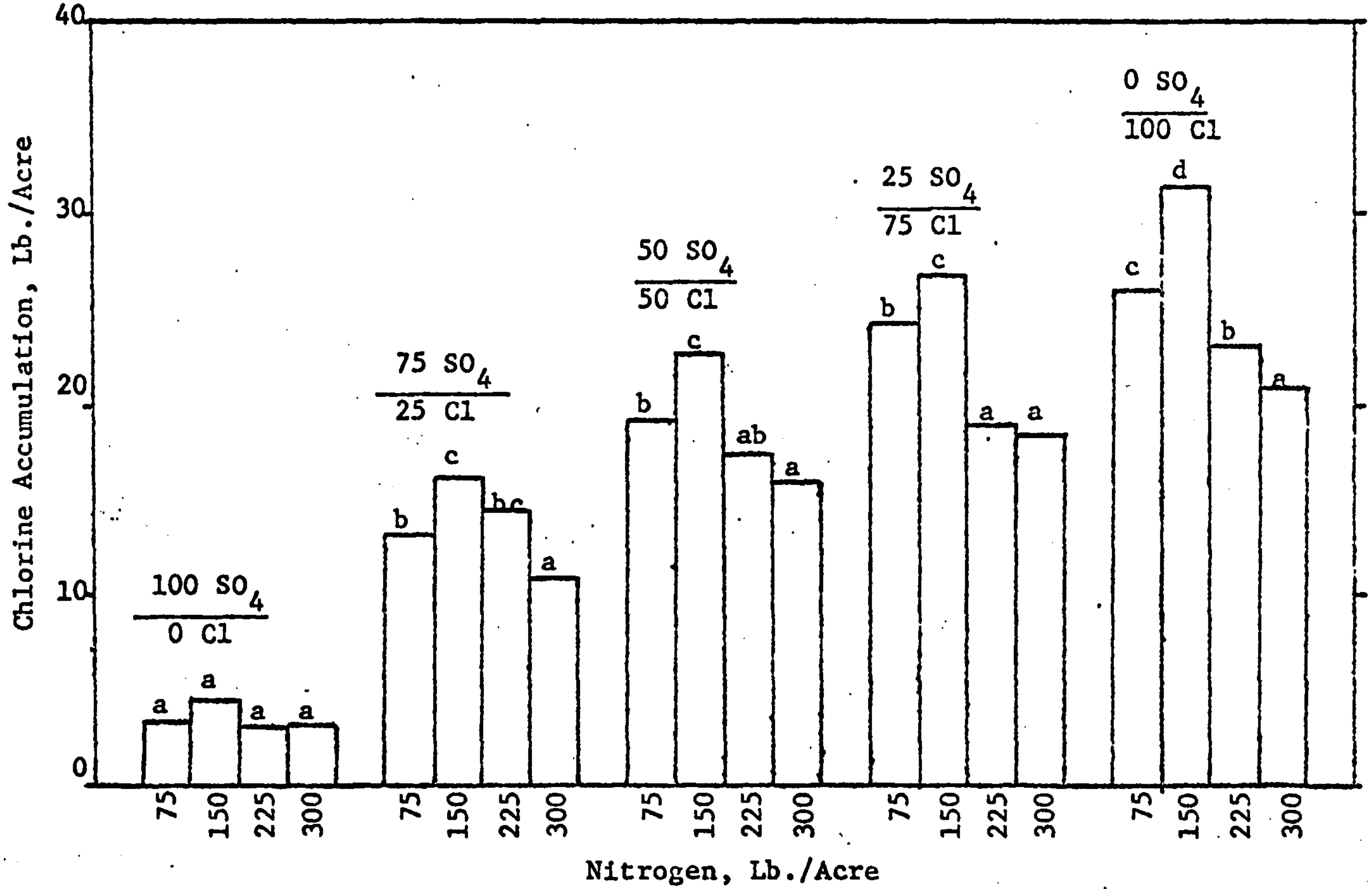

Figure 10. The effect of applied nitrogen and sulfate-chlorine ratios on chlorine accumulation in the midribs. Means are significantly different at the 5% level when labeled with unlike letters within each sulfate-chlorine ratio.

Table XI. Effect of nitrogen rates and sulfate-chlorine ratios upon chlorine content in the midrib portion of the cured tobacco leaves.

Anion Ratios	Nitrogen, lb./acre 75	150	225	300	Mean
		- % Cl -			
$\frac{100\ SO_4}{0\ Cl}$	0.53 a*	0.76 a	0.51 a	0.51 a	0.58 a
$\frac{75\ SO_4}{25\ Cl}$	2.27 b	2.72 b	2.18 b	1.73 b	2.23 b
$\frac{50\ SO_4}{50\ Cl}$	3.27 c	4.09 c	2.93 c	2.79 c	3.27 c
$\frac{25\ SO_4}{75\ Cl}$	3.92 d	4.76 d	3.32 d	3.02 d	3.75 d
$\frac{0\ SO_4}{100\ Cl}$	4.36 e	5.47 c	3.81 e	3.43 3	4.27 e
Mean	2.87 c**	3.56 d	2.55 b	2.30 a	

*Means in columns not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

Table XII. Effect of nitrogen rates and sulfate-chlorine ratios upon chlorine content in the stalk portion of the cured tobacco plant.

Anion Ratios	Nitrogen, lb./acre 75	150	225	300	Mean
		- % Cl -			
$\frac{100\ SO_4}{0\ Cl}$	0.43 a*	0.57 a	0.44 a	0.40 a	0.46 a
$\frac{75\ SO_4}{25\ Cl}$	1.11 b	1.22 b	1.14 b	0.93 b	1.10 b
$\frac{50\ SO_4}{50\ Cl}$	1.47 c	1.49 c	1.28 b	1.33 c	1.39 c
$\frac{25\ SO_4}{75\ Cl}$	1.70 d	1.92 d	1.59 c	1.43 c	1.66 a
$\frac{0\ SO_4}{100\ Cl}$	1.84 d	2.10 e	1.59 c	1.44 c	1.74 e
Mean	1.31 c**	1.46 d	1.21 b	1.11 a	

*Means in columns not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly (p = 0.05, Duncans Multiple Range Test).

Table XIII. Effect of nitrogen rates and sulfate-chlorine ratios upon chlorine accumulation in the stalk portion of the cured tobacco plant.

Anion Ratios	Nitrogen, lb./acre				Mean
	75	150	225	300	
		- lb./acre Cl -			
100 SO_4 / 0 Cl	9.80	13.76	9.24	9.26	10.52 a*
75 SO_4 / 25 Cl	25.68	28.80	25.05	21.96	25.37 b
50 SO_4 / 50 Cl	31.19	35.25	25.77	25.67	29.47 b
25 SO_4 / 75 Cl	39.60	43.39	34.80	29.51	36.83 c
0 SO_4 / 100 Cl	46.99	53.63	43.10	35.04	44.69 d
Mean	30.65 b**	34.97 c	27.59 ab	24.29 a	

*Means in column not followed by common letters differ significantly ($p = 0.05$, Duncans Multiple Range Test).

**Means in row not followed by common letters differ significantly ($p = 0.05$, Duncans Multiple Range Test).

Table XIV. Correlation data measuring relationships among % nitrogen, % sulfate, and % chlorine content of tobacco plant parts.

Independent Variable	% Chlorine	
	Partial r	Multiple R
	- Lamina -	
% Nitrogen	-0.642**	0.800**
% Sulfate	-0.740**	
	- Midribs -	
% Nitrogen	-0.590**	0.749**
% Sulfate	-0.699**	
	- Stalks -	
% Nitrogen	-0.241	0.746**
% Sulfate	-0.740**	

**Significant at the 0.01 level.

Table XV. Simple correlation coefficients between chlorine and nitrogen content and the content of sulfate, nitrogen, and chlorine of tobacco plant parts.

Content	Plant Parts		
	Lamina	Midrib	Stalk
		% Chlorine	
% Sulfate	-0.622**	-0.571**	-0.727**
% Nitrogen	-0.453**	-0.373*	-0.133
		% Nitrogen	
% Sulfate	-0.077	-0.181	-0.044

*Significant at the 0.05 level

**Significant at the 0.01 level

$$\text{Midrib } Y = 14.99 - \underset{(0.50)}{2.75}\ \%N - \underset{(1.51)}{11.15}\ \%\ SO_4$$

$$\text{Stalks } Y = 5.01 - \underset{(0.18)}{0.46}\ \%N - \underset{(0.76)}{6.33}\ \%\ SO_4$$

Y = estimate of chlorine content

The regression equations indicate that sulfate had a much larger negative effect upon chlorine than nitrogen. In each plant part, the coefficients for sulfate were nearly five times larger than nitrogen.

Simple correlation data are presented in Table XV. The data showed that chlorine content was negatively influenced by sulfate content in the entire plant. The negative relationship between the chlorine and sulfate content was possibly due to the dependence introduced by the sulfate-chlorine treatments. Likewise, chlorine content was also negatively affected by nitrogen content in the lamina and midrib portions but not in the stalks.

Nitrogen content was negatively influenced by chlorine and vice versa. Sulfate and nitrogen had no effect upon each other.

Nicotine Content

Effect of Nitrogen Rates. Nitrogen applications significantly affected nicotine accumulation in the lamina portion (Figure 11). Nicotine content increased lineally up to 225 pounds of nitrogen and then decreased slightly. McCants and Woltz (1967) reported that the nicotine content increased up to point where excesses resulted in physiological breakdown of leaves.

The application of nitrogen had no effect upon the nicotine content of the midribs and stalks (Table XIX).

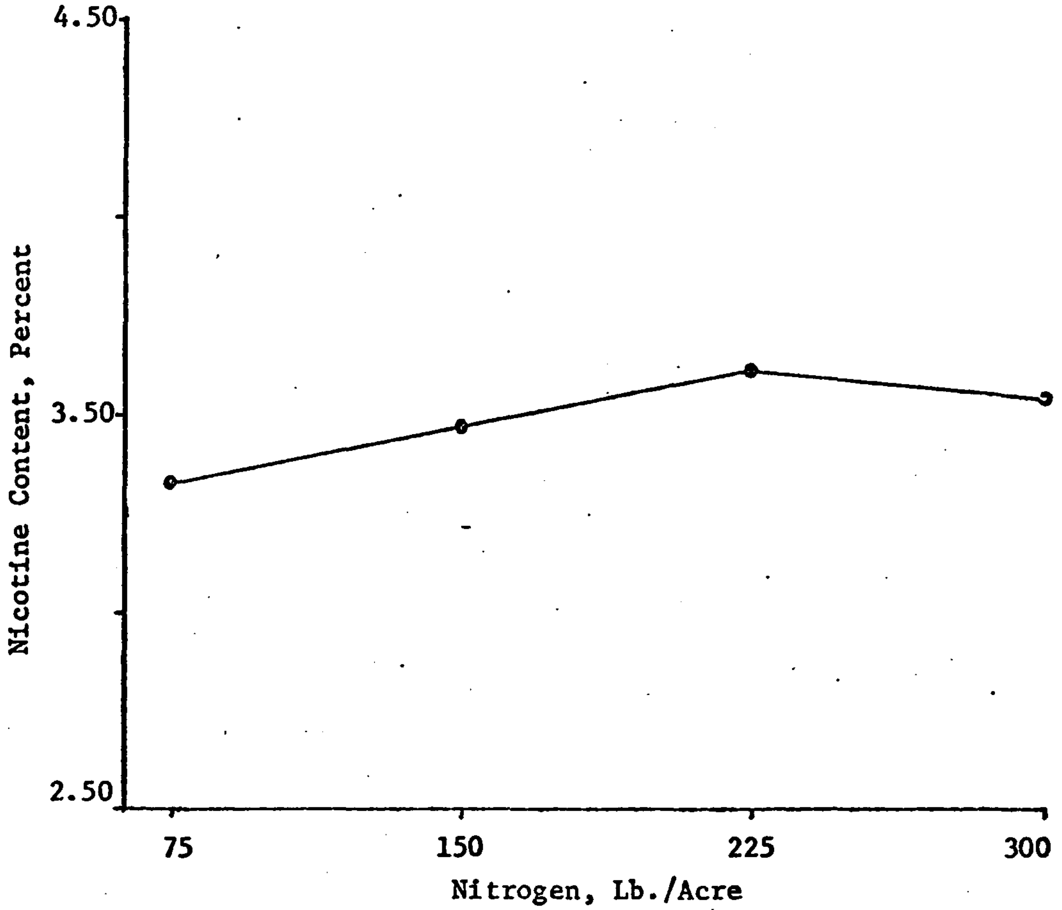

Figure 11. The effect of applied nitrogen upon nicotine content of the lamina portion of the cured leaf.

Effect of Sulfate : Chlorine. The anion ratios did not affect the nicotine content in the cured plant (Table XIX). Woltz et al. (1948) and Neas (1961) showed that chlorine did not affect nicotine content.

Economic Analyses

Optimum Acre Yield

The model with yield as the dependent variable and nitrogen and sulfate-chlorine ratios as the independent variable is of the form:

$$Y = b_0 + b_1 N + b_2 N^2 + b_3 S + b_4 S^2 + b_5 NS \qquad (1.1)$$

Where: Y = acre yield

b_0 = mean of acre yield

b_1 = i-th regression coefficient

N = rate of nitrogen application

S = sulfate-chlorine ratios

The coefficients for the above equation are presented in Table XVI. The R^2 values indicated that the fit of the equation was extremely poor. A plot of all the sample observations (Figure 12) indicated that the sample variation was quite large. However, the coefficients of variation calculated from observations within nitrogen treatments were 6.9 percent, 7.0 percent, 6.7 percent, and 6.9 percent for the 75, 150, 225, and 300 pound rates of nitrogen, respectively. Thus, the lack of fit seemed to be due to the lack of yield response to nitrogen.

Since the variation explained by the model was extremely small, further economic analysis of the acre yield was of no significance.

Table XVI. Coefficients of yield and acre-value equations for individual nitrogen and chlorine-sulfate treatments.

Dependent Variable	Coefficients b_0	b_1	b_2	b_3	b_4	b_5	R^2
Acre yield	2523.46	112.07	-11.23	-24.75	12.15	-13.45	0.07
		(114.68)	(84.22)	(21.15)	(12.64)	(13.78)	
Acre value	2020.46	89.04	-16.91	-104.03	18.14	-2.80	0.08
		(87.91)	(64.56)	(16.21)	(9.69)	(10.26)	
1945 adj. Acre value	1785.66	344.29	-60.86	-35.37	15.47	-23.88	0.25
		(108.56)	(79.72)	(20.02)	(11.96)	(12.66)	

( ) values below the regression coefficients are their standard errors.

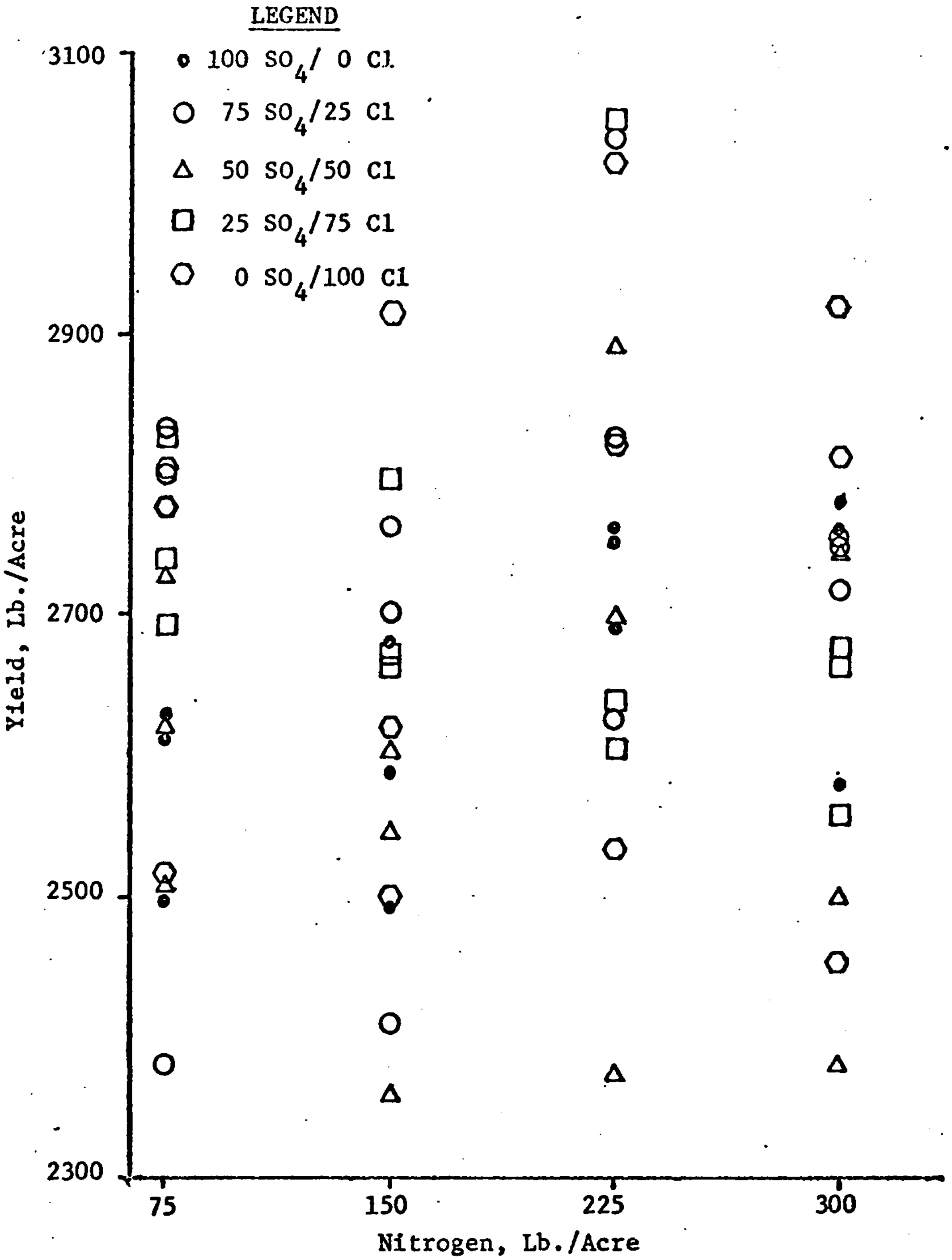

Figure 12. Plot of the observed yield values for nitrogen rates and sulfate-chlorine ratios.

Optimum Acre Value

The 1968 average seasonal prices were introduced into equation (1.1). The new equation was as follows:

(1.2) Y_2 = (Ave. seasonal price x $Y_{1.1}$)

Y_2 = 1968 acre value

The coefficients for Equation (1.2) are presented in Table XVI. As with acre yield, the R^2 value was extremely low (0.08). Thus, the regression equation could not be used for economic interpretation of any practical value.

The 1945 average seasonal prices were adjusted to the 1968 mean in order to introduce prices with a larger spread between the low and high quality leaves. The coefficients for these prices are in Table XVI. Although the R^2 value increased considerably, the unexplainable variation in the equation was still too large for further economic interpretation.

SUMMARY AND CONCLUSIONS

A field experiment with Burley 21 tobacco was conducted on a Dunmore silt loam soil at the Southwest Virginia Research Station, Glade Spring, Virginia. The effect of nitrogen rates and chemical equivalent ratios of muriate and sulfate of potash on the rate of growth, yield, and value were determined. The leaves and stalks were analyzed for total nitrogen, chlorine, sulfate, and nicotine during the growing season. The cured plants were separated into lamina, midribs, and stalks and analyzed for the same chemical properties.

Nitrogen was applied at 75, 150, 225, and 300 pounds per acre. In association with the nitrogen treatments, muriate and sulfate of potash were combined in five chemical proportions varying from 100 percent sulfate of potash to 100 percent muriate of potash.

Effect of Nitrogen Rates

During the growing season, nitrogen treatments did not affect the growth of leaves and stalks. N content was lowest for the 150 pound N treatment but further increases in nitrogen applied produced sharp increases in nitrogen content. The rate of nitrogen did not influence the uptake of sulfate.

During the growing season and in the cured plants, chlorine uptake was negatively influenced by the rate of nitrogen applied. As the nitrogen rates were increased from 150 to 225 and from 225 to 300 pounds per acre the chlorine accumulation sharply decreased. Maximum chlorine was found at the 150 pound rate. Also, total nitrogen accumulation reached a minimum with the same treatment. Correlation data from the cured plant also showed that nitrogen and chlorine contents were negatively related. The negative effect of chlorine and nitrogen seemed to be due to anion competition.

Total nitrogen content was lowest for the 150 pound per acre rate in both the lamina and midrib portions. In the lamina, the 75, 225, and 300 pound rates resulted in equivalent nitrogen contents. Sulfate accumulation was influenced by nitrogen in the midribs but not in the lamina. The 150 pound rate increased the sulfate content in the midribs.

During the growing season, nicotine accumulation was not influenced by nitrogen level. However, after curing, the nicotine content increased with rates of nitrogen up to 225 pounds.

Nitrogen had no effect upon the yield and acre value of the crop. However, as the average seasonal prices were changed to include a wider price spread between grades, nitrogen applications significantly influenced the acre value.

Effect of Sulfate-Chlorine Ratios

The sulfate-chlorine treatments did not affect the growth rate, nitrogen content, or the nicotine content during the growing season. Increasing amounts of sulfate increased the sulfate content and increasing amounts of chlorine increased the chlorine content.

In the cured plants, the sulfate-chlorine ratios did not significantly affect total nitrogen uptake, nicotine content, acre yield, or acre value. Chlorine accumulation increased in all the plant parts as the amount of applied chlorine increased. Likewise, increasing amounts of sulfate in the mixture produced increased sulfate accumulation.

Further studies are necessary to understand the reduced chlorine uptake at lower rates of applied nitrogen. Also, the nitrogen content should be fractionated in order to clearly establish the degree of anion competition.

LITERATURE CITED

Amarell, H. 1958. Einfluss Von Diingung, Boden und Sorte auf die "relative transpiration" jungu TabaRpflanzen. (Effect of fertilization, soil, and variety on the "relative transpiration" of young tobacco plants.) Dresden Insts. TabaRforsch Bev. 5(2): 217-219. (Bib. of Ag. 408. Feb. 1959).

Atkinson, W.O. 1966. Effect of irrigation, plant population, and nitrogen fertilization on yield and value of burley tobacco. Kentucky Agr. Expt. Sta. 78th Ann. Rep. 23.

Atkinson, W.O., L.A. Link, and C.E. Bortner. 1962. Effects of potassium fertilizers on yield, value, and chemical composition of burley tobacco. Tob. Sci. 6: 112-115.

Attoe, O.J. 1946. Leaf burn of tobacco as influenced by content of potassium, nitrogen, and chlorine. J. Amer. Soc. Agron. 38: 186-196.

Black, C.A. 1968. Soil-plant relationships. John Wiley & Sons, Inc. New York. 792 p.

Bowling, J.D., and D.E. Brown. 1947. Rates of potash in growth and nutrition of Maryland tobacco. U.S.Dept.Agr. Tech, Bull. No. 933: 13-14.

Carr, J.M. 1933. Bright tobacco culture in the coastal plain of Georgia. Georgia Coastal Plain Exp. Sta. Bull. 22: 23-26.

Chouteau, J. 1966. Acid-base balance of the chemical composition of tobacco leaves with reference to chlorides. The relationship with combustibility. Serv. Exploit. Ind. Tob. Allumettes Ann. Sect. 2(3): 115-122.

Clark, F. 1953. Fertilizer test with flue-cured tobacco. Univ. Fla. Agr. Exp. Sta. Bull. S-12: 19.

Cundiff, R.H., and P.C. Markunas. 1955. Determination of nicotine, nornicotine, and total alkaloids in tobacco. Anal. Chem. 27(10): 1650-53.

Dixon, W.J. 1965. Biomedical computer programs. Univ. Calif. Los Angeles, California. 620 p.

Eaton, F.M. 1942. Toxicity and accumulation of chloride and sulfate salts in plants. J. Agr. Res. 64: 357-399.

Epstein, E. 1953. Mechanism of ion absorption by roots. Nature 171: 83-84.

Epstein, E., and O.F. Elzam. 1965. Absorption of chloride by barley roots: kinetics and selectivity. Plant Physiol. 40: 620-624.

Evans, H.J., and M.E. Weeks. 1947. The influence of nitrogen, potassium, and magnesium salts on the composition of burley tobacco. Soil Sci. Soc. Am. Proc. 30: 577-582.

Garner, W.W., C.W. Bacon, J.D. Bowling, and D.E. Brown. 1934. The nitrogen nutrition of tobacco. U.S.D.A. Tech. Bul. No. 414.

Garner, W.W., J.E. McMurtrey, Jr., J.D. Bowling, and E.G. Moss. 1930. Role of chlorine in nutrition and growth of the tobacco plant and its effect on the quality of the cured leaf. J. Agr. Sci. 40(7): 627-648.

Gauch, H.G., and F.M. Eaton. 1942. Effect of saline substrate on hourly levels of carbohydrates and inorganic constituents of barley plants. Plant Physiol. 17: 347-365.

"General Recommencations on Fertilizing Burley Tobacco in the Burley Belt," by the Burley Section of the 22nd Tobacco Workers Conference. Asheville, North Carolina. July, 1968. (mimeo)

Gopalachari, N.C., B.V. Kamakrishmayya, and K.S. Murty. 1965. Cation-anion balance in flue-cured tobacco. Soil Sci. 99: 157-160.

Hamilton, J.L., and C.E. Bortner. 1966. Effect of rate of nitrogen on the yield, value, and concentration of total alkaloids, NH_3-N. Total N, P, K, Ca, and Mn in the leaf of burley tobacco produced in 1964 at Campbellsville. Kentucky Agr. Exp. Sta. 78th Ann. Rep. 12.

Harward, M.E., W.A. Jackson, J.R. Piland, and D.D. Mason. 1956. The relationship of chloride and sulfate ions to form of nitrogen in the nutrition of Irish potatoes. Soil Sci. Soc. Am. Proc. 20: 231-236.

Hoagland, D.R. 1923. The absorption of ions by plants. Soil Sci. 16: 225-246.

Kamprath, E.J., W.L. Nelson, and J.W. Fitts. 1957. Sulfur removal by field crops. Agron. J. 49: 289-293.

Kretschmer, A.E., S.S. Toth, and F.E. Bear. 1953. Effect of chloride versus sulfate ions on nutrient-ion absorption by plants. Soil Sci. 76: 193-199.

Lundegarth, H. 1959. Investigations on the mechanism of absorption and accumulation of salts. IV. Synergistic and antagonistic effects of anions. Physiol. Plant. 12: 336-341.

McCants, C.B. 1960. Response of flue-cured tobacco to potassium nitrate and other sources of potassium and nitrogen. Tob. Sci. 4: 223-228.

McCants, C.B., and F.A. Sierra. 1965. Chlorine affects leaf quality. North Carolina Agr. Exp. Sta. Res. Farming 23(3/4): 9.

McCants, C.B., and W.G. Woltz. 1967. Growth and mineral nutrition of tobacco. p. 211-265. In A.G. Norman (ed.) Advances in Agronomy. Academic Press, New York and London. Vol. 19.

McMurtrey, Jr., J.E., W.M. Lunn, and D.E. Brown. 1934. Fertilizer tests with tobacco. Univ. Maryland Agr. Exp. Sta. Bull. 538: 284-285.

Massoumi, A., and A.H. Cornfield. 1963. A rapid method for determining sulphate in water extracts of soils. Analyst. 88: 321-322.

Moss, E.G., J.E. McMurtrey, Jr., and W.M. Lunn. 1927. Fertilizer experiments with flue-cured tobacco. Bull. North Carolina Dept. Agr. June, 1927.

Mhyre, P.L., O.J. Attoe, and W.B. Ogden. 1956. Chlorine and other constituents in relation to leaf burn. Soil Sci. Soc. Am. Proc. 20: 547-551.

Neas, I. 1953. Sulphur nutrition in flue-cured tobacco. Agron. J. 45: 472-477.

Neas, I. 1959. Factors relating to off-type tobacco. Rhodesia Tob. 19: 6-8.

Neas, I. 1961. Fertilizer chlorine and soil fumigation for flue-cured tobacco. Tob. Sci. 5: 76-79.

Nichols, B.C., D.R. Bowman, and J.E. McMurtrey, Jr. 1956. Fertilizer tests with burley tobacco with special reference to potash. Tennessee Agr. Exp. Sta. Bull. 252.

Nichols, B.C., D.R. Bowman, and J.E. McMurtrey, Jr. 1958. Response of burley tobacco to fertilization in the Central Basin. Tennessee Agr. Exp. Sta. Bull. 280.

Nichols, B.C., R.L. Davis, D.R. Bowman, and J.E. McMurtrey, Jr. 1959. Sources of nitrogen for burley tobacco. Tennessee Agric. Exp. Sta. Bull. 302.

Nichols, B.C., R.L. Davis, D.R. Bowman, and J.E. McMurtrey, Jr. 1962. Further studies on fertilizing burley tobacco in the Tennessee Central Basin. Tennessee Agr. Exp. Sta. Bull. 341.

Pal, N.L., M. Bangarayya, and Y.CH. Narasimhamurthy. 1966. Interrelation of potassium and chlorine supply on the burn of flue-cured tobacco. Soil Sci. 102: 346-352.

Peterson, H.C., and G. Chesters. 1964. A reliable total nitrogen determination on plant tissue accumulating nitrate nitrogen. Agron. J. 56: 89-90.

Pritchett, W.L., H.L. Breland, and H.W. Lundy. 1959. Effects of nitrogen fertilizer on the yield and composition of flue-cured tobacco. Soil and Crop Sci. Soc. of Fla. Proc. 19: 418-427.

Raper, C.D., and C.B. McCants. 1967. Nutrient accumulation in flue-cured tobacco. Tob. Sci. 11: 190.

Reisenauer, H.M., and W.E. Colwell. 1950. Some factors affecting the absorption of chlorine by tobacco. Soil Sci. Soc. Am. Proc. 15: 222-229.

Robertson, R.N. 1968. Protrons, electrons, phosphorylation, and active transport. Cambridge University Press, London, 96 p.

Sabourin, L., and R. Bonnett. 1967. Comparison of the effects of chlorine and potassium sulfate on tobacco. Rev. Potasse 12: 1-5.

Salmon, R.E. 1967. Nitrogen and flue-cured tobacco. Tob. Forum of Rhodesia (24): 8-14, May.

Sanford, J.O., and J.D. Lancaster. 1962. Biological and chemical evaluation of the readily available sulfur status of Mississippi soils. Soil Sci. Soc. Am. Proc. 26: 63-65.

Schipfer, L. 1966. Influence of increasing N-fertilization on the content of nitrogen and nicotine of burley tobacco. Coresta Inform. Bull. Spec. (3) No. 3016. (Tob. Abs. 10: 3439).

Sequerros, J.M., J.A. Galbis, and J. Oliver. 1955. Etudes d 'engrais en sols tabacicoles espagnols. II. L 'influence de l 'azote, nitrique et ammonical, et du potassium sur la teneur en chlore de la plante, d 'eduite d 'experience en pots et en champs. International Scientific Tobacco Congress 2: 763-772.

Skogley, E.O., and C.B. McCants. 1963. Ammonium and chloride influences on growth characteristics of flue-cured tobacco. Soil Sci. Soc. Am. Proc. 27: 391-394.

Stenlid, G. 1957. Some differences between the accumulation of chloride and nitrate ions in excised wheat roots. Physiol. Plant. 10: 922-936.

Takahashi, T. 1964. Studies on the control of nicotine content in tobacco. World Tobacco Sci. Congr. Proc. 3rd Cong: 349-356.

Tejwani, K.G., C.K.R. Kurup, and K.V. Venkataraman. 1958. Chemical composition of cigar leaf as influenced by its position on the stalk. Indian J. Agric. Sci. 28(4): 519:29.

Wallace, A., and T. Rock. 1966. Effect of nitrogen rates on yield and quality of burley tobacco. Kentucky Agr. Exp. Sta. 78th Ann. Rep. 24.

Wedin, W.F. 1960. Yield and quality of cigar-type tobacco in relation to potash and nitrogen fertilization. Tob. Sci. 4: 182-185.

Wedin, W.F., and B.E. Struckmeyer. 1958. Effects of chloride and sulfate ions on the growth, leaf burn, composition, and anatomical structure of tobacco (Nicotiana tobaccum L.). Plant Phys. 33: 133-139.

Whitty, E.B., C.B. McCants, and L. Shaw. 1966. Influence of width of fertilizer band of soil on response of burley tobacco to nitrogen and phosphorous. Tob. Sci. 10: 17-22.

Wolf, F.A., and W.W. Bates. 1964. Extent of tobacco root development as related to nicotine content of plant parts. Tob. Sci. 8: 67-69.

Woltz, W.G., W.A. Reid, and W.E. Colwell. 1948. Sugar and nicotine in cured bright tobacco as related to mineral element composition. Soil Sci. Soc. Am. Proc. 13: 385-387.

APPENDIX

Table XVII. Levels of significance of characteristics used to evaluate the interactions of nitrogen, sulfate, and chlorine treatments on the leaves and stalks during the 1968 growing season.

Source	Yield	Sulfate		Nitrogen		Chlorine		Nicotine	
		%	lb/acre	%	lb/acre	%	lb/acre	%	lb/acre
Leaves									
Sampling Dates (D)	**	**	**	**	NS	**	**	**	**
Sulfate-Chlorine Ratios (S)	NS	**	NS	NS	NS	**	NS	NS	NS
Nitrogen Rates (N)	NS	NS	NS	**	NS	**	NS	NS	NS
D x S	NS	**	NS	NS	NS	NS	NS	NS	NS
D x N	NS	NS	NS	**	NS	*	NS	NS	NS
S x N	NS	*	NS	NS	NS	*	NS	NS	NS
D x S x N	NS	NS	NS	NS	NS	**	NS	NS	NS
Stalks									
Sampling Dates (D)	**	**	**	**	**	**	**	**	**
Sulfate-Chlorine Ratios (S)	NS	*	**	NS	NS	**	NS	NS	NS
Nitrogen Rates (N)	*	NS	**	NS	NS	**	NS	NS	NS
D x S	NS	NS	NS	NS	NS	NS	NS	NS	NS
D x N	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x N	NS	NS	NS	NS	NS	*	NS	NS	NS
D x S x N	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at the 0.05 level.

**Significant at the 0.01 level.

Table XVIII. Levels of significance of characteristics used to evaluate the interactions of nitrogen, chlorine, and sulfate treatments.

Source	Acre		Ave.	1945 Adj.	Grade Yields				
	Yield	Value	Price	Acre Value	Flyings	Lugs	Leaf	Tips	Green
Nitrogen Rates (N)	NS	NS	**	**	NS	NS	NS	NS	*
Sulfate-Chlorine Ratios (S)	NS	NS	NS	NS	*	NS	NS	NS	NS
N x S	NS	NS	NS	**	NS	NS	NS	NS	NS

*Significant at the 0.05 level.

**Significant at the 0.01 level.

Table XIX. Levels of significance of characteristics used to evaluate the interactions of nitrogen, sulfate, and chlorine treatments in the various parts of the cured tobacco plant.

Source	Sulfate			Nitrogen		Chlorine		Nicotine	
	Yield	%	lb/acre	%	lb/acre	%	lb/acre	%	lb/acre
					Lamina				
Nitrogen Rates (N)	NS	NS	NS	**	**	**	**	*	NS
Sulfate-Chlorine Ratios (S)	NS	*	NS	NS	NS	**	**	NS	NS
S x N	NS	*	NS	NS	NS	**	**	NS	NS
					Midribs				
Nitrogen Rates (N)	NS	**	NS	**	**	**	**	NS	NS
Sulfate-Chlorine Ratios (S)	NS	**	**	NS	NS	**	**	NS	NS
S x N	NS	NS	NS	NS	NS	**	**	NS	NS
					Stalks				
Nitrogen Rates (N)	NS	NS	NS	NS	NS	**	**	NS	NS
Sulfate-Chlorine Ratios (S)	NS	**	**	NS	NS	**	**	NS	NS
S x N	NS	NS	NS	NS	NS	**	NS	NS	NS

*Significant at the 0.05 level.

**Significant at the 0.01 level.

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Interactions of Nitrogen, Chlorine, and Sulfate in the Growth of Burley Tobacco

by

John Lee Malcolm

ABSTRACT

A field experiment was conducted to study the effect of rates of nitrogen and muriate and sulfate of potash upon the growth, chemical composition, and quality of the Burley 21 variety of tobacco. Rates of nitrogen applied were 75, 150, 225, and 300 pounds per acre. The muriate and sulfate sources of potash were combined on a equivalent basis in the following proportions: 100 SO_4/0 Cl, 75 SO_4/25 Cl, 50 SO_4/50 Cl, 25 SO_4/75 Cl, and 0 SO_4/100 Cl.

The application of nitrogen increased the nitrogen content in the plant during the growing season and of cured leaves, except for the 150 pound rate which decreased the content. Applied nitrogen rates had no effect upon growth or yield above soil derived nitrogen. Chlorine content of growing plants and cured leaves was increased by the addition of 150 pounds of nitrogen. Above 150 pounds, the chlorine content sharply decreased, indicating that anion competition occurred between nitrogen and chlorine ions.

The sulfate-chlorine treatments increased the sulfate content as the proportion of sulfate increased and increased chlorine content as the proportion of chlorine increased. The treatments did not significantly alter yield or acre value of cured leaves.