Influence of Nitrogen Fertilization and Leaf Management on Nitrogen Use Efficiency and Agronomic Performance of Mammoth Cultivars of Flue-cured Tobacco

by

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(ABSTRACT)

Mammoth cultivars of flue-cured tobacco flower under short day photoperiods, thereby increasing the potential number of leaves per plant. Field experiments were conducted in 1991 and 1992 at the Virginia Tech Southern Piedmont Agricultural Experiment Station near Blackstone, Virginia to determine the influence of nitrogen rate on nitrogen use efficiency and its components on two mammoth cultivars and a conventional cultivar. Experiments were also conducted to determine the effects of leaf number, time of topping, and nitrogen rate on yield, quality, and other agronomic characteristics. Nitrogen uptake, utilization, and use efficiencies decreased while nitrogen accumulation increased as nitrogen rates increased from 67 to 112 kg ha^{-1}. Mammoth cultivars were more efficient than the conventional cultivar for nitrogen uptake, utilization, and use. Only NC 27 NF benefits from

increasing nitrogen above the recommended rate. Yield increased by 17 percent as the leaf number increased from 20 to 36. In contrast, both agronomic traits and chemical characteristics decreased accordingly. The ratio of nitrogen to nicotine that was unacceptable at leaf numbers above 28. Yield, value, and quality decreased as topping was delayed by seven to 21 days. Yield was reduced by 30 kg per hectare per day when topping was delayed by 21 days after the conventional cultivar reached the bud stage. Leaf lengths and widths of mammoth cultivars were larger than the conventional cultivar. Mammoth cultivars were higher yielding and had better quality at 112 kg ha^{-1} N when compared to the conventional cultivar, although these differences were not significant.

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Chapter I.

Introduction

Mammoth cultivars of flue-cured tobacco (*Nicotiana tabacum* L.) have homozygous recessive alleles at two loci (45) which induces plants to continue vegetative growth until the shorter days of late summer. This mammoth character increases the potential number of leaves that can be produced in a growing season (27). Increased leaf number per plant usually results in increased yield (3,5,7,24,27,34). However, when mammoth cultivars are allowed to produce more than 20 to 24 leaves per plant, smaller, thinner leaves, reduced nicotine, and inferior quality can be expected (26,30,31). Chaplin (7) reported decreased quality, measured as value per hundred weight, as the number of leaves on 'Hicks Mammoth' increased from 20 to 35. He attributed this reduction in quality to higher leaf numbers rather than the mammoth gene. Wernsman and Matzinger (45) reported that when mammoth cultivars were topped at the same leaf number as their day-neutral parent, the mammoths produced higher yields with equal or superior leaf quality as measured by grade index.

Nitrogen is one of the most expensive fertilizer nutrients used in crop production (1). The proper use of nitrogen has become an important issue in agriculture today because of surface and ground water pollution, due to leaching and soil erosion (42). For tobacco production, nitrogen should be within narrow limits to insure timely maturation and ripeness of leaves (22), with both over and under fertilization having an adverse effect on quality.

Nitrogen is translocated to the meristematic region of the tobacco plant, where it is utilized during the growth process. Much of the competition for nitrogen is eliminated once tops and suckers are removed, thus more nitrogen becomes available for nicotine syntheses (31). The nitrogen accumulated in the additional leaf tissue, seed pods, and seeds is discarded with the tops when topping is delayed. Therefore plants should be topped as soon as they reach the desired leaf number (8).

Nitrogen use efficiency is an estimate of how efficient plants are at removing applied nitrogen from the soil and converting that nitrogen into yield. Sisson et al. (42) reported a 75 percent increase in the nitrogen use efficiency of flue-cured tobacco cultivars over time with no direct selection for that trait, however, no mammoth cultivars were included in this study. Some preliminary results from unpublished work conducted at the Virginia Tech Southern Piedmont Agricultural Experiment Station indicated that increased nitrogen rates result in higher yield and quality of mammoth cultivars. Mammoth cultivars also had less immature and unripe cured leaf at the higher nitrogen rates.

The objectives of this study were:

(1) to compare the nitrogen use efficiency of two mammoth cultivars to that of a conventional cultivar and to determine if the nitrogen use efficiency of the mammoth tobaccos has improved to the point where increased nitrogen rates are needed to recognize the full potential of these cultivars, and

(2) to determine the effect of nitrogen rate, leaf number, and time of topping on the yield, quality, plant height, leaf length and width, and chemical composition of two mammoth cultivars as compared to a conventional cultivar.

Chapter II.

Literature Review

MAMMOTH TOBACCO

The mammoth gene in flue-cured tobacco (*Nicotiana tabacum* L.) induces cultivars to flower under a shortday photoperiod, whereas normal cultivars are day-neutral (27). This simply inherited mammoth character (7) is conditioned by recessive alleles at two loci (46), and allows the plants to continue vegetative growth without the usual terminal inflorescence when grown during the long days of summer (30).

Mammoth selections of flue-cured tobacco produce fewer pre- and post-topping suckers, more leaves, higher yields, greater acre values, and lower values per hundred weight than their day-neutral recurrent parent (30). The quality of leaf produced by mammoth cultivars was initially believed to be inferior to that of genetically comparable day-neutral cultivars because of the lower value per hundred weight. However, Chaplin (7) reported no association between the mammoth gene and inferior quality. He concluded that the lower values per-hundred-weight were probably related to improper leaf number management. Jones and Terrill (27) later reported that the mammoth cultivars 'NC 2326' and

'Speight G-28' produced superior quality leaf as compared to their day-neutral counterpart. In addition to producing high yields of excellent quality tobacco (26), mammoth cultivars provide several other advantages. Premature flowering is essentially eliminated because these cultivars generally do not flower until the shorter days of late summer. Producers can reduce labor costs by synchronizing topping and sucker control since apical dominance is maintained until the plant flowers. Mammoth cultivars may also produce larger and higher quality top leaves than conventional cultivars, if properly managed (30,45).

Yields of mammoth cultivars increase as the number of leaves per plant increases, however, leaf quality decreases in proportion to leaf numbers in excess of the optimum (7,27,30,31,45). Wernsman and Matzinger (45) reported that mammoths topped at the same leaf number as conventional cultivars had higher yields with equal or superior quality leaf and did not differ in total alkaloid and reducing sugar concentrations. In contrast, King (28) observed an improved sugar to nicotine ratio as the leaf number increased in mammoth cultivars.

NITROGEN

Nitrogen is the major limiting factor in crop production (47). Not only does nitrogen have a more critical effect on the growth and development of tobacco than any other nutrient (6), it is also the most expensive fertilizer nutrient in crop production (1). Historically, increased tobacco yield has corresponded with increased rates of applied nitrogen fertilizer (42). The nitrogen supply should be within narrow limits to ensure timely maturation, ripeness of leaves, and high quality flue-cured tobacco (22). Improper nitrogen fertilization is responsible for much of the poor quality tobacco grown each year (46). Ideally, tobacco plants should maintain uninterrupted, rapid growth from transplant to the approach of maturity (43). Under normal conditions, most of the nitrogen is needed two to three weeks after transplanting (25), with 95 percent of the total nitrogen in the plant being absorbed within nine weeks after transplanting (22). Curing difficulty and problems with delayed ripening may occur (25) if the nitrogen supply in the soil is not depleted when the plant flowers or reaches the desired leaf number (31,33).

The definition of quality for flue-cured tobacco is the sum of its physical and chemical attributes that make it most suitable for the manufacture of cigarettes (46). Nitrate reduction and photosynthesis are two physiological processes within the plant that predetermine quality of the cured leaf. Metabolic priority is directed to the uptake and reduction of nitrate nitrogen during growth. Most of the nitrate in the root is translocated to the shoot for reduction and reallocation during exponential growth (41). The reduced nitrogen is utilized in the biosynthesis of amino acids, proteins, and nicotine. The rate of nitrate uptake is dependent upon the amount of applied and residual nitrogen fertilizer (46), moisture (4), and amount of root tissue present (41). Raper et al. (41) reported that varying light and temperature altered the apparent efficiency of absorption in the root system.

The producer must be careful not to overuse nitrogen. Quality of cured leaf is closely related to nitrogen fertilization. Therefore there is a fine line between insufficient and excess nitrogen. Excessive use of nitrogen fertilizers is an unnecessary production cost and may adversely effect tobacco and water quality (26). Increasing nitrogen rates generally increases leaf length, leaf width, and yield (29). These increases are usually accompanied by a decrease in weight per unit area of the cured leaf (43). Total nitrogen within the plant tends to increase at a comparable rate with increasing nitrogen rates (35). Nitrogen concentration in the cured leaf has been directly correlated with strength of the smoke (38). Quality of flue-cured tobacco tends to decrease as total nitrogen in the plant increases, with the best smoke quality associated with lower nitrogen content (42). However, if total nitrogen concentration is too low, the smoke is insipid with little taste (13).

The degree of ripeness is also an important determinate of smoking quality. Ripe tobacco cures easier, responds readily to ageing, and provides a more flavorful and palatable smoke. In contrast, immature tobacco produces poor aroma and smoke taste (39). Plants excessively fertilized with nitrogen produce very large, thin leaves, and ripening is delayed. Over-fertilized tobacco is difficult to cure. The resulting cured leaf, particularly from upstalk positions, are dark in color, dry, chaffy (46), and produce more K, KL, KF and GK color grade factors (25). Excessive use of nitrogen fertilizers will also increase sucker growth and may lead to excessive use of maleic hydrazide (26). Growth is retarded in under-fertilized plants, and the leaves are smaller but thicker. These leaves are smooth, pale in color, and are consequently often harvested before they are fully ripe. In addition, the cured tobacco lacks texture, is low in alkaloids, high in sugars, and the smoke is flat and insipid (46).

NITROGEN USE EFFICIENCY

Nitrogen use efficiency is a function of nitrogen utilization and uptake (36), with nitrogen accumulation being a major component of nitrogen uptake and utilization (42). There are many factors within these three components that may cause variation in nitrogen use efficiency. For example, nitrogen absorption may be the limiting factor in nitrogen accumulation, while nitrogen uptake could be affected by nitrate reduction and assimilation (15). It has been reported that remobilization from storage in vegetative tissues is important in the utilization of nitrogen in corn (20,40). In contrast, there is little evidence to show that nitrogen from senescencing tissues is remobilized to support development of upper leaves in tobacco (21). Sisson et al. (42) reported a 75 percent increase in nitrogen use efficiency of flue-cured tobacco over time without any direct selection for that trait. Since a precisely controlled nitrogen supply is one of the most critical factors in the management of flue-cured tobacco (46), development of cultivars that are more efficient users of nitrogen would be advantageous.

There is much debate and uncertainty as to what causes one species or type of plant to be a more efficient user of nitrogen than another. Nitrogen use efficiency varies within classes of tobacco (11). Flue-cured tobacco has a much higher nitrogen utilization than burley tobacco because it can produce approximately twice the dry weight per unit of leaf nitrogen accumulated. Nitrogen use efficiency is regulated by nitrogen uptake by the root system and the efficient translocation and metabolic utilization of nitrogen within the plant (37). However, Crafts-Brander et al. (11) showed that the root system had little influence on the physiological difference between flue-cured and burley tobacco. They later reported that because of genetic differences at two loci (which when recessive, results in the burley character), and possibly the higher starch content of flue-cured plants, flue-cured cultivars are more efficient at nitrogen utilization (12).

Nitrogen fertilizer rate appears to be the major factor in the nitrogen use efficiency of tobacco. Nitrogen use, uptake, and utilization efficiencies, as well as net returns are decreased as nitrogen rates increase beyond a certain point (11,36,42). In other words, the law of diminishing returns comes into play. Lower yields and poorer quality tobacco can be expected from the application of additional nitrogen. It appears that nitrogen uptake is more variable among nitrogen rates than utilization efficiency (36). Moll et al. (36) reported that even cultivars with comparably high levels of nitrogen use efficiencies may differ markedly in the way that efficiency is achieved. This can be demonstrated in the following example of two cultivars with similar nitrogen use efficiencies. One cultivar takes up all of the external nitrogen applied to produce a certain yield, thus having a high nitrogen uptake efficiency, while the other cultivar takes up only a fraction of the applied fertilizer to produce the same yield, thus, having a high nitrogen utilization efficiency. Dhugga and Waines (15) suggest that selection for uptake should be more effective in improving overall nitrogen use efficiency than selection for utilization. Sisson et al. (42) reported that nitrogen uptake accounted for 55 to 61% of the variability of nitrogen use efficiency while utilization accounted for only 39 to 45 %. The low nitrogen environment, in which flue-cured tobacco has been traditionally grown, may have offered little selection pressure for more efficient utilization. In contrast, Moll et al. (36) has suggested that corn plants grown in a high nitrogen environment may favor the selection of uptake efficient plants.

LEAF NUMBER

The mammoth character causes otherwise day-neutral cultivars to flower only under short day photoperiods, thereby increasing the potential number of leaves produced per plant in a normal growing season (27). Yield and quality are the two most important economic considerations in tobacco production (7) and both of these parameters can be greatly influenced by the number of leaves per plant.

Increased topping height results in increased yields (3,5,7,9,16,19,23,24,27,28,30,34), primarily due to the production of more harvestable leaves per acre. King (28) reported a 28 percent yield increase when topping height was increased from 14 to 26 leaves. However, at higher leaf numbers, the increased yields were obtained at the expense of lower individual leaf weights (16,28,31) and lower values per hundred weight (7). Mann and Chaplin (30) reported increased yields resulted from harvesting a greater number of low quality leaves.

Higher yields, from increased leaf number, require the handling of more leaves during harvesting and curing, which is not economically desirable. Since tobacco is controlled by a production quota system based on weight allotments, production of flue-cured tobacco with higher leaf numbers per plant would reduce the acreage required. This would reduce cost of production to growers (28), however, this reduction may be offset by increased labor and fertilization costs. Plants should be topped to increase the proportion of large and well developed leaves in order to produce the greatest yield of high quality tobacco (8). Early and low topping tends to increase the body and size of leaves.

Collins et al. (9) concluded that increasing the topping height of conventional cultivars reduced market price more than increasing plant populations. They also observed decreased labor efficiency as the weight per leaf decreased from increased topping height. In contrast, King (28) found no significant change in grade index of the mammoth NC 22 NF topped at 18, 22, and 26 leaves. His results suggest leaf quality can be maintained in mammoth cultivars topped at higher leaf numbers than is currently recommended for flue-cured tobacco.

Chemical concentrations can be increased or decreased by changes in leaf population (18). Although reducing sugars are effected very little by increased topping height (16), nicotine levels are decreased (5). King (28) reported an improved sugar to nicotine ratio in mammoth cultivars as leaf number increased from 18 to 26 leaves. The extent to which topping height influences nicotine content of the lower leaves is probably determined by the number days between topping and harvest (18).

Nitrogen fertilization has the greatest effect of any cultural practice on nicotine accumulation (43). Elliot (16) observed topping height had more influence on total alkaloids than on total nitrogen concentration. It appears that higher than recommended nitrogen rates should not be used when plants are topped relatively low but additional nitrogen may be needed where topping is relatively high (9,34).

TIME OF TOPPING

Delay of topping from the early bud stage to fully open flower progressively decreases leaf yields and nicotine levels in conventional cultivars (6). Marshall and Seltman (32) reported a one percent decrease in cured leaf weight for each day that topping is delayed after the plant reaches the early bud stage. Collins et al. (9) also suggested that conventional cultivars should be topped as soon as possible after the desired leaf number is reached. If topping is delayed to the point where flowers and seed pods have developed, a large decrease in yield and body of the tobacco leaf can be expected because both flowers and seed pods are strong sinks for photosynthate.

The mammoth character causes tobacco plants to continue vegetative growth, without the usual terminal inflorescence, when grown during long days of summer (30). Therefore, mammoth cultivars continue to produce leaves until they are induced to flower at the time of a short photoperiod or until the plant is topped. Although mammoth cultivars may not produce flowers or seed pods before topping, they may produce many more leaves than desired before the apical meristem is removed at topping. This additional upper leaf tissue is also a strong sink for nitrogen and photosynthate (22). These extra leaves which are discarded at topping, rob the plant of vital resources which in turn reduces yield, leaf body, and nicotine concentration (43). Jones et al. (26) reported an estimated 29 kilogram per hectare per day reduction in yield when topping was delayed by seven to fourteen days for two mammoth cultivars, NC 27 NF and NC 37 NF.

Effects of topping on yield and quality are influenced considerably by fertility level. Significant increases in yield and quality were found only at high nitrogen rates when topping heights were increased (29,34). In contrast, Collins (8) reported that flue-cured tobacco should be topped early, regardless of the nitrogen level. Considerable nitrogen is absorbed during late growth (22) and if topping is delayed this absorbed nitrogen is discarded with the upper leaf tissue at topping. Most of the competition for nitrogen is eliminated after topping and more nitrogen will become available for nicotine synthesis (31). The accumulation of nicotine occurs rapidly after topping and continues until the leaves are harvested.

CHEMICAL COMPOSITION

Cigarette manufacturers are concerned with more than the visual and physical properties of the cured leaf when purchasing tobacco. Chemical composition of the leaves, and how different cultural practices affect that chemical composition, also play a vital role in the quality of cured leaves (25). Variables such as nitrogen rates, leaf number, and time of topping may have a profound effect on the chemical composition of the cured leaf.

Nicotine is the principle alkaloid found in tobacco (43). Accumulation of nicotine begins soon after transplanting and continues to accumulate even after growth stops (14). The maximum nicotine content of individual leaves occurs at progressively higher stalk positions as the plant matures i.e., top leaves have the highest nicotine concentration (2,4). The best quality leaf is obtained from a fully developed leaf with a relatively high nicotine content (three to four percent) (28,29). Sugar and nicotine are two constituents of flue-cured tobacco with the greatest contribution to the characteristic and satisfaction of cigarette smoke. Reducing sugar concentration tends to vary by stalk position. Reducing sugars increase from the bottom to the middle of the plant and decrease from the middle to the top of the stalk. Court et al. (10) showed a positive association between reducing sugars and tobacco quality. Sugars and nicotine are inversely related. Thus, the sugar to nicotine ratio is a useful and simple index of chemical quality (46).

Proper nitrogen rates are needed to produce a leaf with acceptable chemical composition. Nitrogen may have the greatest effect of any cultural practice on nicotine accumulation. Soil texture, rainfall during the season, and nitrogen rates account for 81 percent of the variation in total alkaloid production (43). Nicotine is synthesized in the plant using nitrogen absorbed before and after topping (17,43). Most nitrogen is absorbed before topping and ideally, nitrogen should be depleted before topping for proper ripening (28). According to Mahadik (29), increasing the nitrogen rate increased yield, nicotine, and total nitrogen content (35). Increasing total nitrogen in the plant has been associated with decreased quality (42). However, since good quality flue-cured tobacco should be moderately high in nicotine (28,29), an optimum nitrogen fertilization rate should be reached. The concentration of nitrogen is positively correlated with nicotine and negatively related with sugar content of the leaf (5). According to Tso (43), the sooner after transplanting a nitrogen deficiency occurs the higher the sugar to nicotine ratio.

Topping and controlling leaf axillary buds (suckers) in flue-cured tobacco also increases the nicotine content of the cured leaf, with nicotine concentration being the highest at the lower topping levels (43). Wallace et al. (44) demonstrated that floral development at topping did not influence nicotine concentration but the period of time from topping to harvest did. Nicotine levels increased as harvest time was delayed from 10-30 days after topping. Nicotine accumulation decreased as the number of leaves remaining on the plant at topping increased.

The ability of mammoth tobaccos to produce many more leaves than conventional cultivars may cause a wide range of chemical variability. Chaplin (7), working with a mammoth derived from 'Bunn Special', reported the content of total alkaloids decreased as the number of leaves per plant increased while having only a minimal effect on reducing sugars. He also concluded that there may be a genetic association between the mammoth gene and a lower percentage of reducing sugars. In contrast, King (28) reported that the sugar to nicotine ratio improved as leaf number increased up to 26. In another study, decreased nicotine content was observed in mammoth cultivars during the first harvest, with a large increase in nicotine and reducing sugar concentrations after the second harvest (31). This large increase probably resulted from topping between the first and second harvest. This demonstrates the marked influence of proper topping on the chemical composition of the cured leaf, as well as emphasizing the effect of the time between topping and harvest. When compared to conventional cultivars, where both were topped at twenty leaves, the mammoth has equal quality, with the same value per hundred weight, percent alkaloids, and total nitrogen/total alkaloid ratio (7,45).

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Chapter III.

Nitrogen Use Efficiency of Mammoth cultivars of Flue-Cured Tobacco[1]

ABSTRACT

Nitrogen use efficiency in flue-cured tobacco (*Nicotiana tabacum* L.) is an estimate of how well cultivars take up applied nitrogen and convert it into yield. Nitrogen use efficiency of conventional cultivars has improved over time with the development of genetically improved cultivars. Field experiments were conducted in 1991 and 1992 to compare the nitrogen use efficiency of two mammoth cultivars, NC 27 NF and NC 37 NF, with a conventional cultivar, Coker 319. Cultivars were grown at 67, 89, and 112 kg ha^{-1} nitrogen. The objective was to determine if increased nitrogen rates are needed to recognize the full potential of mammoth cultivars. Whole plant dry weight, cured leaf yield, and corresponding total nitrogen concentration were used to determine nitrogen accumulation and nitrogen uptake, utilization, and use efficiencies. Significant differences for nitrogen use efficiency and chemical composition were found among cultivars and nitrogen rates.

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[1] This chapter will be submitted for publication in Agronomy Journal. Style and notation conform to the requirements of the journal and references are cited by number.

Mammoth cultivars tended to have higher yields, values, greater concentrations of total alkaloids and total nitrogen, and lower concentrations of reducing sugars in the cured leaf. Mammoth cultivars were 11 to 19% more efficient at nitrogen use than C 319. Nitrogen uptake, utilization, and use efficiencies decreased as nitrogen rates increased from 67 to 112 kg ha^{-1}. NC 27 NF had the highest yield and use efficiency at the higher nitrogen rates and appeared to benefit from increased N rates.

INTRODUCTION

Nitrogen is the major limiting factor in crop production (19). Not only does nitrogen have a more critical effect on the growth and development of tobacco than any other nutrient (2), it is also the most expensive fertilizer nutrient used in crop production (1). The nitrogen supply should be within narrow limits to ensure timely maturation, ripeness of leaves, and high quality flue-cured tobacco (8). Since a precisely controlled nitrogen supply is one of the most critical factors in the management of flue-cured tobacco (18), development of cultivars that are more efficient users of nitrogen would be advantageous.

Sisson et al. (15), reported a 75 percent increase in nitrogen use efficiency of flue-cured cultivars over time without any direct selection for that trait. However, no mammoth cultivars were included in their study. Nitrogen use efficiency is a function of nitrogen utilization and uptake (14). Nitrogen accumulation is a major component of nitrogen uptake and utilization efficiencies (15). There are many factors within these three components that may cause variation in nitrogen use efficiency. Nitrogen absorption may be the limiting factor in nitrogen accumulation, while nitrogen uptake could be affected by nitrate reduction and assimilation (7). The amount of nitrogen fertilizer applied appears to be the major factor in the nitrogen use efficiency of tobacco. Nitrogen use, uptake, and utilization efficiencies, as well as net returns are decreased with increasing nitrogen rates (4,14,15).

There is much debate and uncertainty as to what causes one species or one type of plant to be a more efficient user of nitrogen than another. Nitrogen use efficiency varies within classes of tobacco (4). Flue-cured tobacco has a much higher utilization efficiency than burley tobacco because it can produce approximately twice the dry weight per unit of leaf nitrogen accumulated. Flue-cured tobacco has been traditionally grown in low nitrogen environments and about four times less nitrogen fertilizer is recommended than for burley production (5). Moll et al. (14) suggested that corn plants grown in a high nitrogen environment may favor the selection of uptake efficient plants. Therefore the environment in which flue-cured tobacco has traditionally been grown may have offered little selection pressure for more efficient utilization. Dhugga and Waines (7) suggested that selection for uptake efficiency should be more effective in improving overall nitrogen use efficiency than selection for utilization efficiency.

Mammoth selections of flue-cured tobacco produce fewer pre- and post-topping suckers, more leaves, higher yields, greater hectare values, and lower values per hundred weight than their day-neutral recurrent parents (12). Chaplin (3) reported no association between the mammoth gene and inferior quality. He concluded lower values per hundred weight were probably related to excessively high leaf numbers. Jones and Terrill (11) later reported that the mammoths 'NC 2326' and 'Speight G-28' produced superior quality leaf as compared to their day-neutral counterpart. Preliminary investigations conducted in Virginia indicated that mammoth cultivars may require higher than recommended nitrogen rates. The objective of this study was to compare the nitrogen use efficiencies of two mammoth cultivars to a conventional cultivar and to determine if the nitrogen use efficiency of the mammoths has improved to the point where increased nitrogen rates are needed to realize the full potential of these cultivars.

MATERIALS AND METHODS

Field experiments were conducted at the Virginia Polytechnic Institute and State University Southern Piedmont Agricultural Experiment Station (SPAES) near Blackstone, VA in 1991 and 1992 on a Durham sandy loam soil (Typic Hapludult, fine-loamy, siliceous, thermic). Experiments were conducted as a split-plot in a randomized complete block design with three replications where cultivars ('NC 27 NF', 'NC 37 NF', and 'Coker 319') were whole plots and nitrogen rates (67, 89, and 112 kg ha^{-1}) were sub-plots. Coker 319 was selected because its maturity rate is similar to the mammoth cultivars. Each plot received an initial base rate of 44.8 kg ha^{-1} nitrogen. Additional nitrogen, to supply 67, 89, and 112 kg ha^{-1}, was applied as a sidedress 14 days after transplanting. Each sub-plot consisted of two rows containing 24 competitive plants spaced 51 cm apart with 122 cm between rows. One row was used to collect agronomic and cured leaf data, while the other was used to collect whole plant green tissue samples.

Plants were topped at 20 harvestable leaves. Fertilization, harvesting, curing, and other production practices, other than those mentioned above, were consistent with recommendations for the production of flue-cured tobacco by the Virginia Cooperative Extension Service

(10). Irrigation was applied as needed to ensure adequate moisture. Leaching was not considered to be a problem either year. Cured leaf of each plot was weighed by harvest, assigned an official U.S. Government grade, and plot yields were measured. Value per acre (value), average price (AP) and grade index (GI) were determined from the cured leaf. Composite samples consisting of approximately 30 g cured leaf were collected from each harvest for total nitrogen, total alkaloid, and reducing sugar determinations (6,9).

Green tissue samples for the whole plant analysis were taken at the last normal cultivation (layby), 10 days after layby, topping, and at first harvest. Three consecutive plants, that were representative of the row, were selected at random for each sample date. Plants were removed from the plot, roots washed, and plants divided into lamina, midribs, roots (lateral and fibrous), and stalk (the stump was included in the stalk fraction). Green weight, dry weight, and leaf number were recorded for each plot. Plant sections were dried at 52° to 65°C for five to seven days, ground to pass through a 40 mesh screen, and analyzed for total alkaloids (6) and total nitrogen (9).

Nitrogen use efficiency and its component traits were determined as described by Sisson et al. (15). Data was analyzed as a split-plot design using SAS (16). Four additional experiments were also conducted both years but with nitrogen rates as whole plots and cultivars as subplots. Since the same trends were observed for yield, value, nitrogen use efficiency, and its component traits, results from these additional tests are reported fro cured leaf.

RESULTS AND DISCUSSION

Data from each experiment was analyzed for each year and over years. Interaction effects were non-significant and error variances between years were homogeneous. Therefore, data was combined over years.

WHOLE PLANT ANALYSIS

Graphs representing total alkaloid and total nitrogen concentrations through the season (layby to first harvest) are presented in Fig. 1 through 6. Significant differences for total alkaloids were observed among cultivars for midrib, root, and stalk at all sample dates. Significant differences among N rates, when averaged across cultivars, were observed for the root at topping; and for leaf lamina at first harvest.

Both mammoth cultivars had consistently higher total alkaloid concentrations than C 319 in the midrib, root, and stalk (Fig. 1-3). Between mammoth cultivars, NC 37 NF had the highest alkaloid concentration, and was significantly higher than C 319. The 112 kg ha^{-1} N treatment had significantly lower concentrations of total alkaloids in the root than either the 67 or 89 kg ha^{-1} rates at topping and significantly higher concentrations in the lamina at first harvest.

Fig. 1. Mean of percent total alkaloids of lamina (A), midrib (B), root (C), and stalk (D) of three cultivars at 67 kg ha^{-1} N from 1991 and 1992.

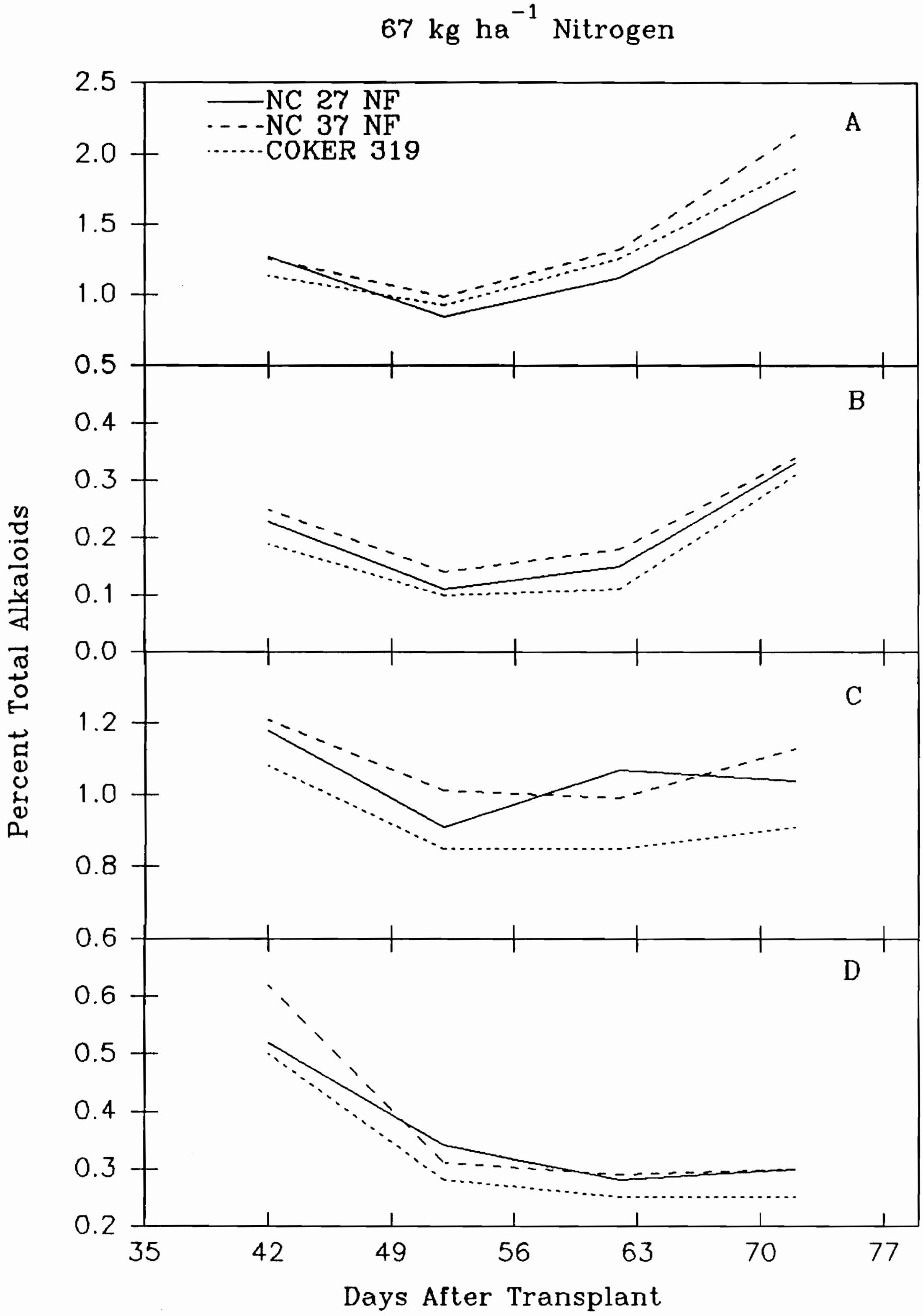

67 kg ha^{-1} Nitrogen
NC 27 NF
NC 37 NF
COKER 319
A
B
C
D
Percent Total Alkaloids
2.5
2.0
1.5
1.0
0.5
0.4
0.3
0.2
0.1
0.0
1.2
1.0
0.8
0.6
0.6
0.5
0.4
0.3
0.2
35
42
49
56
63
70
77
Days After Transplant

Fig. 2. Mean of percent total alkaloids of lamina (A), midrib (B), root (C), and stalk (D) of three cultivars at 89 kg ha^{-1} N from 1991 and 1992.

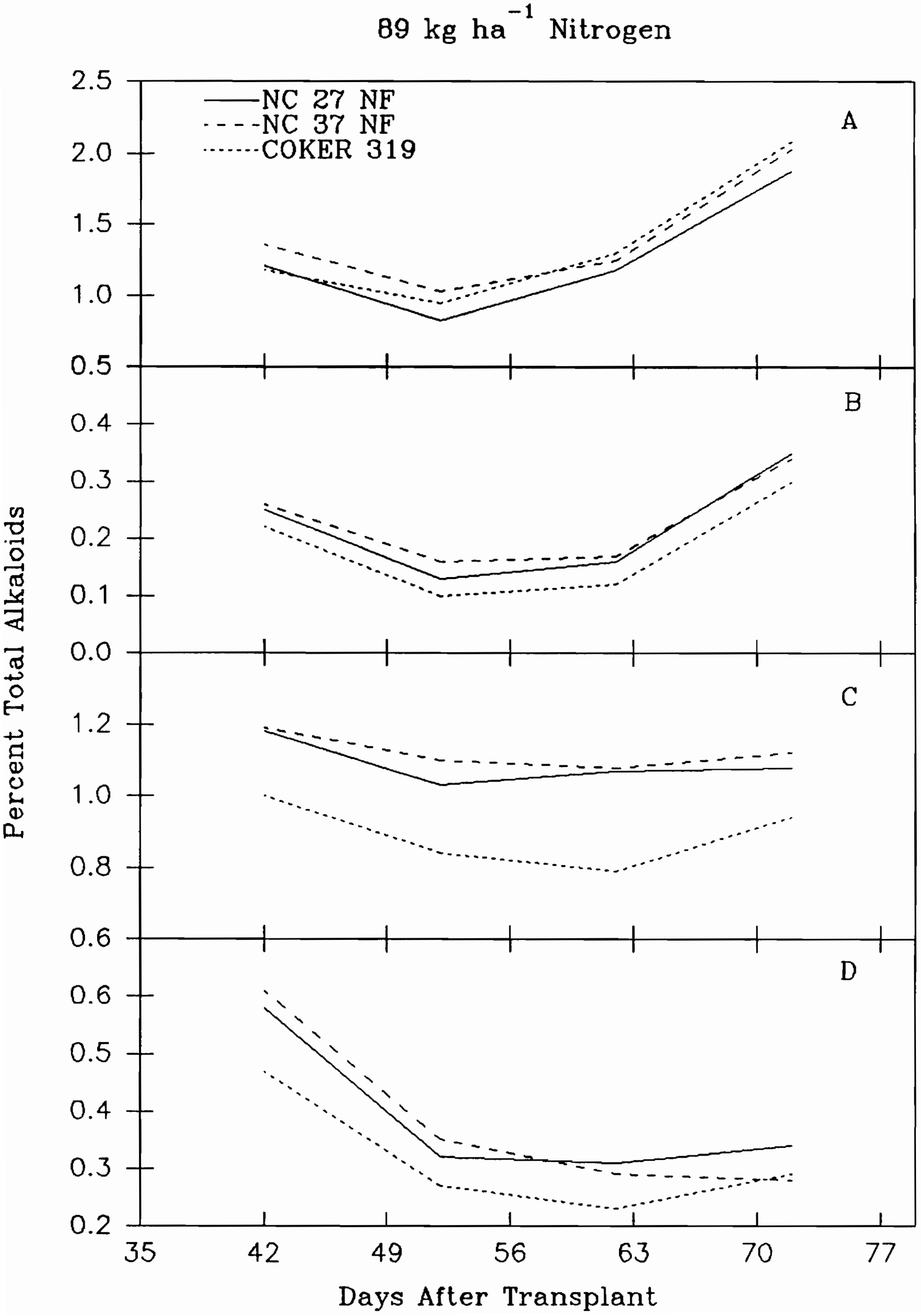

89 kg ha^{-1} Nitrogen
NC 27 NF
NC 37 NF
COKER 319
A
B
C
D
2.5
2.0
1.5
1.0
0.5
0.4
0.3
0.2
0.1
0.0
1.2
1.0
0.8
0.6
0.6
0.5
0.4
0.3
0.2
Percent Total Alkaloids
35
42
49
56
63
70
77
Days After Transplant

Fig. 3. Mean of percent total alkaloids of lamina (A), midrib (B), root (C), and stalk (D) of three cultivars at 112 kg ha^{-1} N from 1991 and 1992.

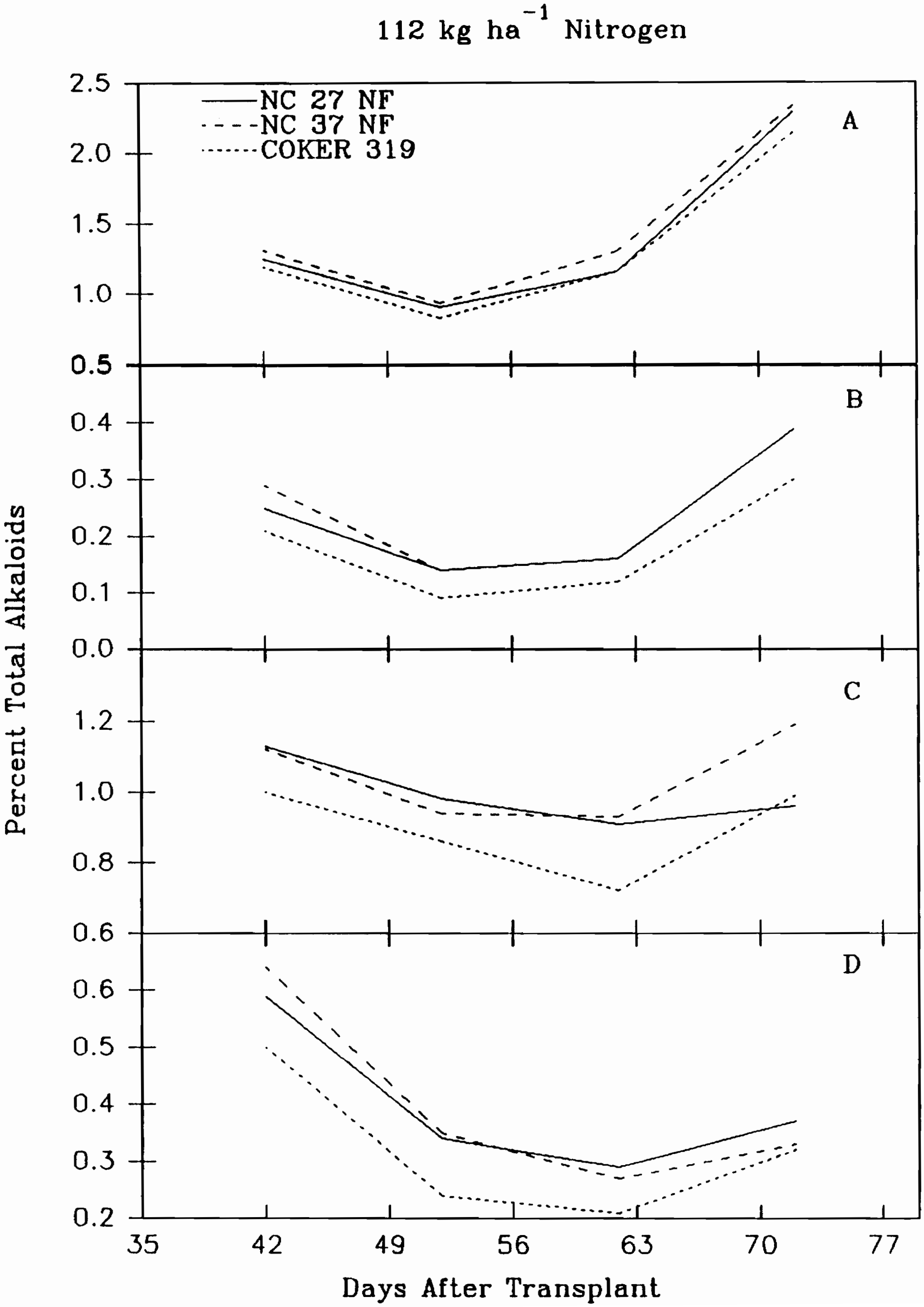

112 kg ha^{-1} Nitrogen
NC 27 NF
NC 37 NF
COKER 319
A
B
C
D
2.5
2.0
1.5
1.0
0.5
0.4
0.3
0.2
0.1
0.0
1.2
1.0
0.8
0.6
0.6
0.5
0.4
0.3
0.2
Percent Total Alkaloids
35
42
49
56
63
70
77
Days After Transplant

Fig. 4. Mean of percent total nitrogen of lamina (A), midrib (B), root (C), and stalk (D) of three cultivars at 67 kg ha^{-1} N from 1991 and 1992.

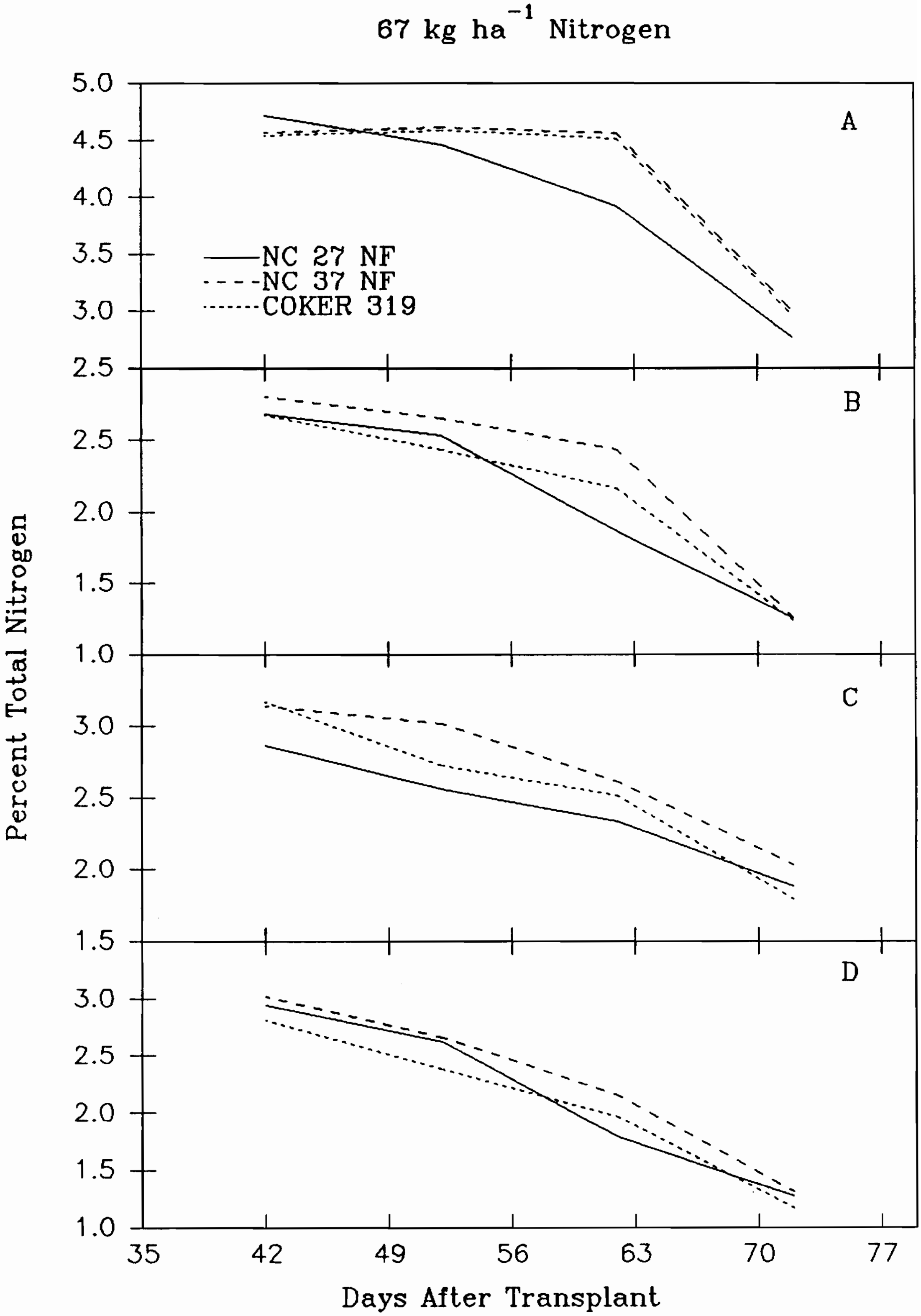

67 kg ha^{-1} Nitrogen
A
B
C
D
NC 27 NF
NC 37 NF
COKER 319
Percent Total Nitrogen
Days After Transplant
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
35
42
49
56
63
70
77

Fig. 5. Mean of percent total nitrogen of lamina (A), midrib (B), root (C), and stalk (D) of three cultivars at 89 kg ha^{-1} N from 1991 and 1992.

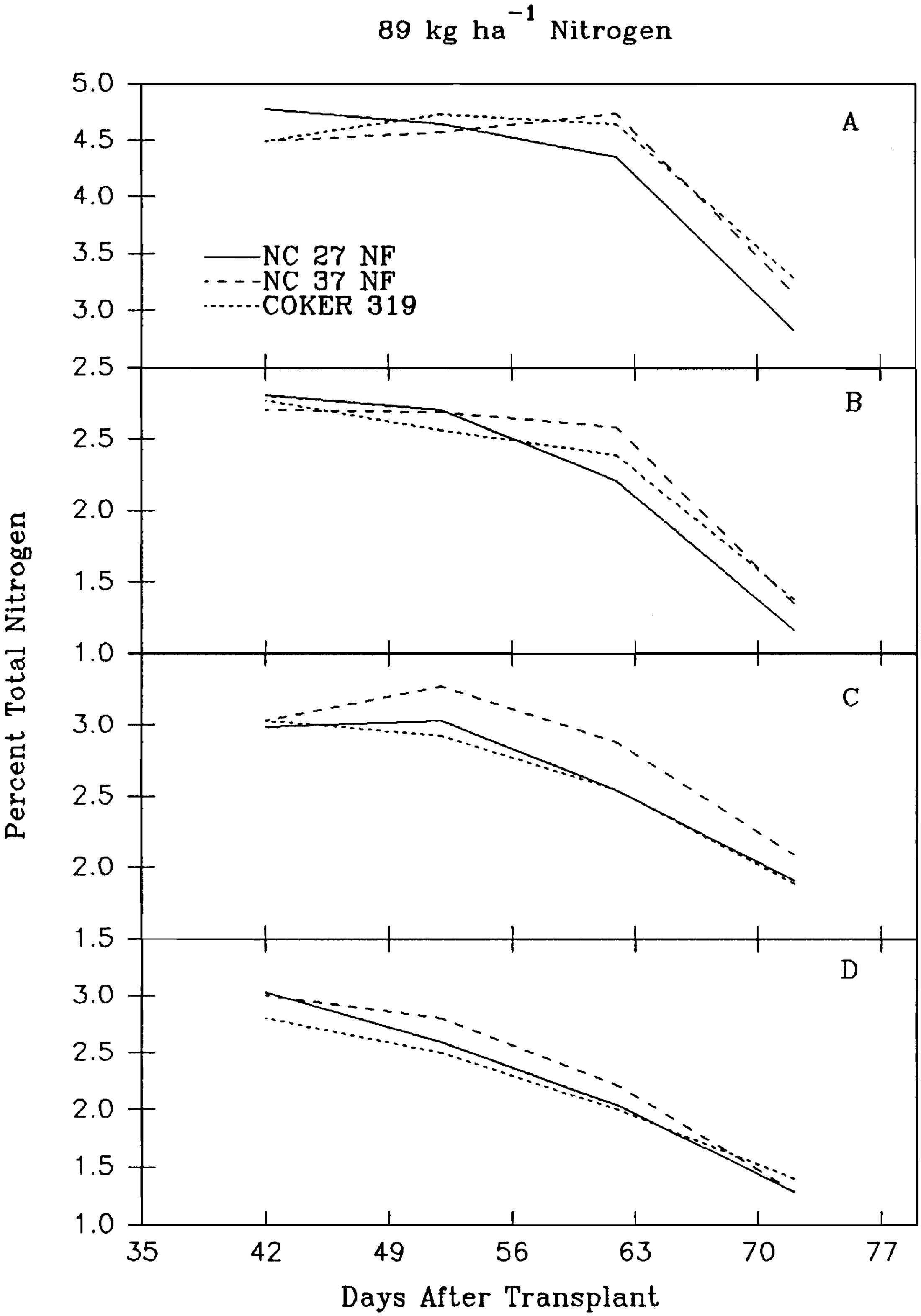
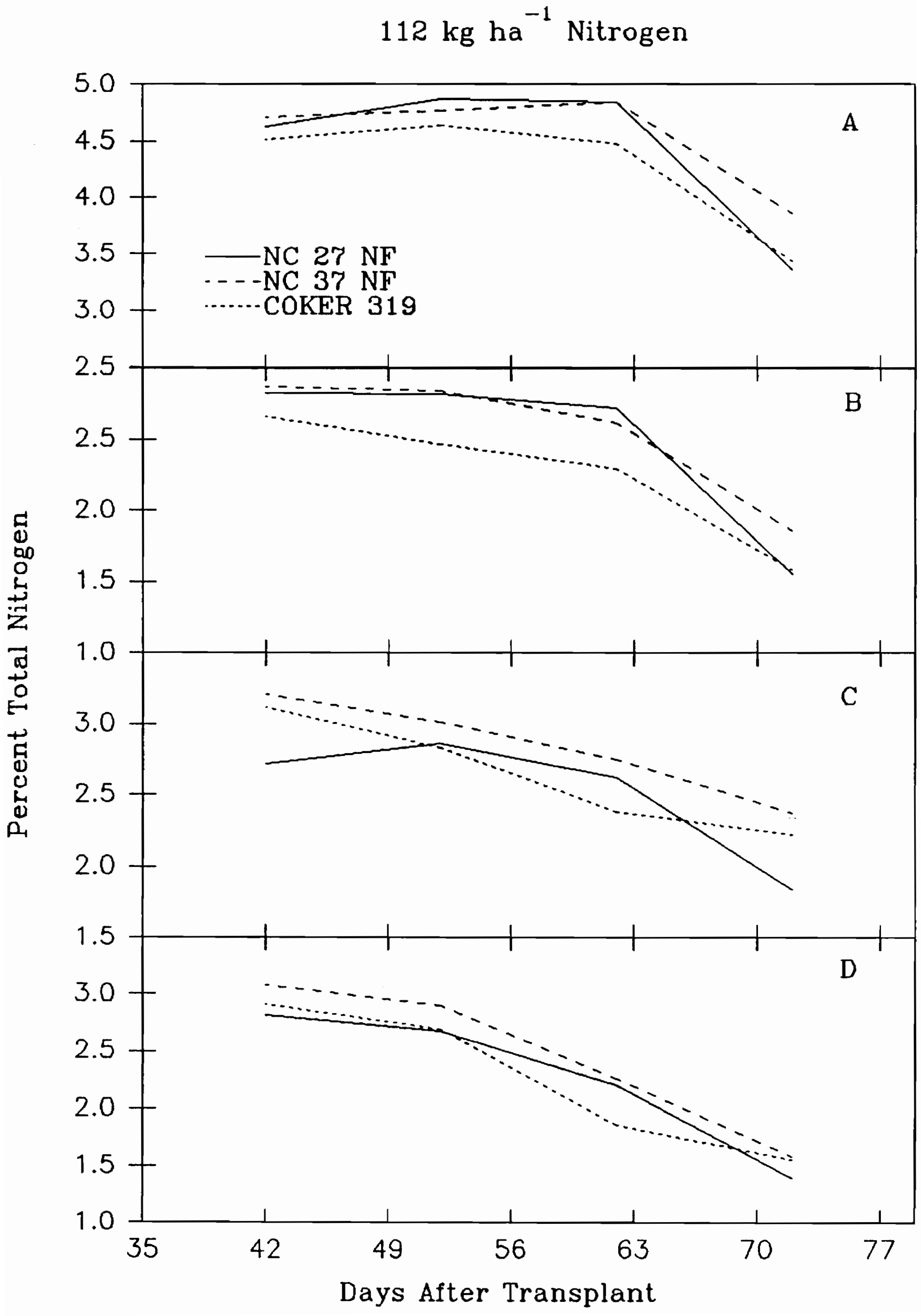

89 kg ha^{-1} Nitrogen
Percent Total Nitrogen
Days After Transplant
A
B
C
D
NC 27 NF
NC 37 NF
COKER 319
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
35
42
49
56
63
70
77

Fig. 6. Mean of percent total nitrogen of lamina (A), midrib (B), root (C), and stalk (D) of three cultivars at 112 kg ha^{-1} N from 1991 and 1992.


112 kg ha^{-1} Nitrogen
Percent Total Nitrogen
Days After Transplant
NC 27 NF
NC 37 NF
COKER 319
A
B
C
D
5.0
4.5
4.0
3.5
3.0
2.5
2.5
2.0
1.5
1.0
3.0
2.5
2.0
1.5
3.0
2.5
2.0
1.5
1.0
35
42
49
56
63
70
77

Significant differences were observed among N rates for total nitrogen concentration of the leaf, midrib, root, and stalk, at ten days after layby, at topping, and at first harvest. Significant differences were observed among cultivars for total nitrogen concentration, in the midrib at ten days after layby; for lamina, midrib, and, stalk at topping; and for lamina at first harvest.

Total nitrogen concentration within the lamina significantly increased with increasing N rates at all sample dates except layby. Ten days after layby, higher total nitrogen concentrations were detected in the root and stalk at 112 kg ha^{-1} (fig. 6), and in the root at 89 kg ha^{-1} (Fig. 5). Midrib, root, and stalk had significantly higher nitrogen concentrations at 89 and 112 kg ha^{-1} than at 67 kg ha^{-1} when sampled at topping. Higher concentrations were detected at 112 kg ha^{-1} than at 67 or 89 kg ha^{-1} in the root and midrib, while the stalk increased in total nitrogen concentration with increasing nitrogen rates at first harvest. Both mammoth cultivars had significantly higher total nitrogen concentrations than C 319 in the midrib at ten days after layby and at topping. NC 37 NF was higher in total nitrogen concentration than NC 27 NF or C 319 in the stalk at topping; and higher in the lamina than NC 27 NF at topping and at first harvest.

All cultivars continued taking up nitrogen further into the season at higher nitrogen rates, thereby increasing their total nitrogen concentration which inturn led to higher total alkaloid concentrations (Fig.s 1-6). The higher nitrogen concentration in NC 37 NF was also reflected in higher total alkaloid concentrations in all plant sections. Total nitrogen and total alkaloid concentrations were higher in lamina than in root, midrib, or stalk for each cultivar. Our data supports previous work (13) that nitrogen stored in the plant is rapidly converted to nicotine shortly after topping. At the higher N rates the mammoth cultivars, especially NC 27 NF, appear to be more efficient at the reduction of nitrate and its subsequent synthesis into nicotine. The data also supports the logical sequence that nitrogen is taken up in the root, translocated through the stalk to the midribs, where it is then distributed throughout the lamina.

CURED LEAF YIELD AND QUALITY

Significant differences were observed among cultivars for yield and value when averaged over nitrogen rates (Table 1). NC 27 NF had significantly higher yields than NC 37 NF and C 319, and was a significantly in value than C 319. Mammoth cultivars consistently produced higher yields than C 319 each year of the study. No significant differences were observed among nitrogen rates for yield and value when averaged across cultivars. The lack of significant yield increases due to nitrogen rates may be a result of residual nitrogen in the soil, however, measurements for residual soil nitrogen were not taken. Price and grade index were significantly higher at 67 kg ha^{-1} than at 112 kg ha^{-1} N. (Table 1). Grade index provides a means of uniform visual evaluation of quality, average price represents the average price paid for the representative grades of the sample, and value per hectare reflects the average auction price per kg cured leaf produced on a hectare. Our results suggest that the application of additional nitrogen above that currently recommended, to the soils at SPAES, is a costly production practice with no benefit in yield.

Significant differences were observed among N rates for percentage of total alkaloids, reducing sugars, and total nitrogen. Total nitrogen and total alkaloid concentrations significantly increased, while percent reducing sugars decreased as nitrogen rates increased from 67 to 112 kg ha^{-1}. Significant differences were observed among cultivars for percent total alkaloids when averaged across N rates. NC 37 NF was significantly higher in total alkaloid concentration than either NC 27 NF or C 319 (Table 1).

Table 1. Mean agronomic characteristics and nitrogen use efficiency estimates of three cultivars grown at three nitrogen rates near Blackstone, VA, in 1991 and 1992.

	Yield	Value	Price	GI[2]	NAAC[1]	NUPT	NUTL	NUSE	Total alkal.	Red. sug.	Total N
	kg ha^{-1}	\$ ha^{-1}	\$ kg^{-1}		kg ha^{-1}		----------kg kg^{-1}--------			--------%---------	
Cultivar											
NC 27NF	3691	13998	3.80	62	94.7	1.08	39.6	42.9	3.26	12.09	2.56
NC 37NF	3502	13422	3.83	64	90.7	1.04	39.3	40.8	3.51	11.79	2.59
Coker 319	3366	12913	3.84	64	83.9	0.97	40.2	39.2	3.25	12.70	2.51
LSD P=0.05)	145	662	NS	NS	6.0	0.07	NS	2.4	0.16	NS	NS
Nitrogen (kg ha^{-1})											
67	3528	13573	3.85	67	82.1	1.22	43.0	52.3	3.14	14.61	2.34
89	3554	13540	3.81	63	90.7	1.01	39.7	39.7	3.36	12.04	2.55
112	3479	13221	3.80	60	96.5	0.86	36.5	31.1	3.51	9.93	2.77
LSD(P=0.05)	NS	NS	0.04	4	4.1	0.05	1.5	1.6	0.25	1.87	0.15

[1] NACC=nitrogen accumulation; NUPT=nitrogen uptake efficiency; NUTL=nitrogen utilization efficiency; and NUSE=nitrogen use efficiency.

[2] GI = Grade Index.

Agronomic measurements as well as chemical characteristics indicate a decline in quality as nitrogen rates increased. In general, increased N rates decreased GI, AP, and percent reducing sugars while increasing total nitrogen and total alkaloids. Smoke from tobacco that is high in total alkaloids and low in reducing sugars is more harsh with a stronger, more bitter flavor (17). With the exception of the increased total alkaloid concentration of NC 37 NF, there was little variation in the chemical composition among cultivars.

NITROGEN USE EFFICIENCY

Nitrogen use efficiency (NUSE) and its components (nitrogen accumulation (NACC), nitrogen uptake efficiency (NUPT), and nitrogen utilization efficiency (NUTL)) were determined from the cured leaf data (Table 1; Fig. 7) and whole plant green tissue samples taken at first harvest (Table 2). Nitrogen may be continually taken up and the plants may continue to increase biomass as tobacco plants continue growth throughout the season. Thus, values for green tissue data are likely to continue changing until maturity.

NITROGEN ACCUMULATION

Nitrogen accumulation is a basic component of NUPT and NUTL and is a measure of the amount of nitrogen accumulated in the leaves or in the entire plant in the case of the green tissue samples. In the cured leaf data, significant differences were observed among cultivars and among N rates (Table 1). Nitrogen rates were responsible for most variation in this trait, with significantly more nitrogen accumulated at 112 kg ha^{-1} than at 89 kg ha^{-1} which accumulated significantly more nitrogen than 67 kg ha^{-1}. Although both mammoth cultivars accumulated more nitrogen than C 319, all cultivars reacted similarly to increasing nitrogen rates, which is reflected by the lack of significant interactions. Nitrogen accumulation was the factor that contributed most to the increased uptake efficiency of mammoth cultivars, which inturn led to the greatest increase in N use efficiency of mammoth cultivars. Significance was found only among N rates in the whole plant analysis, with NACC increasing as N rates increased.

Fig. 7. Mean of cured leaf N-accumulation (NACC) (A), N-uptake efficiency (NUPT) (B), N-utilization efficiency (NUTL) (C), and N-use efficiency (NUSE) (D) of three cultivars at three N rates from 1991 and 1992.

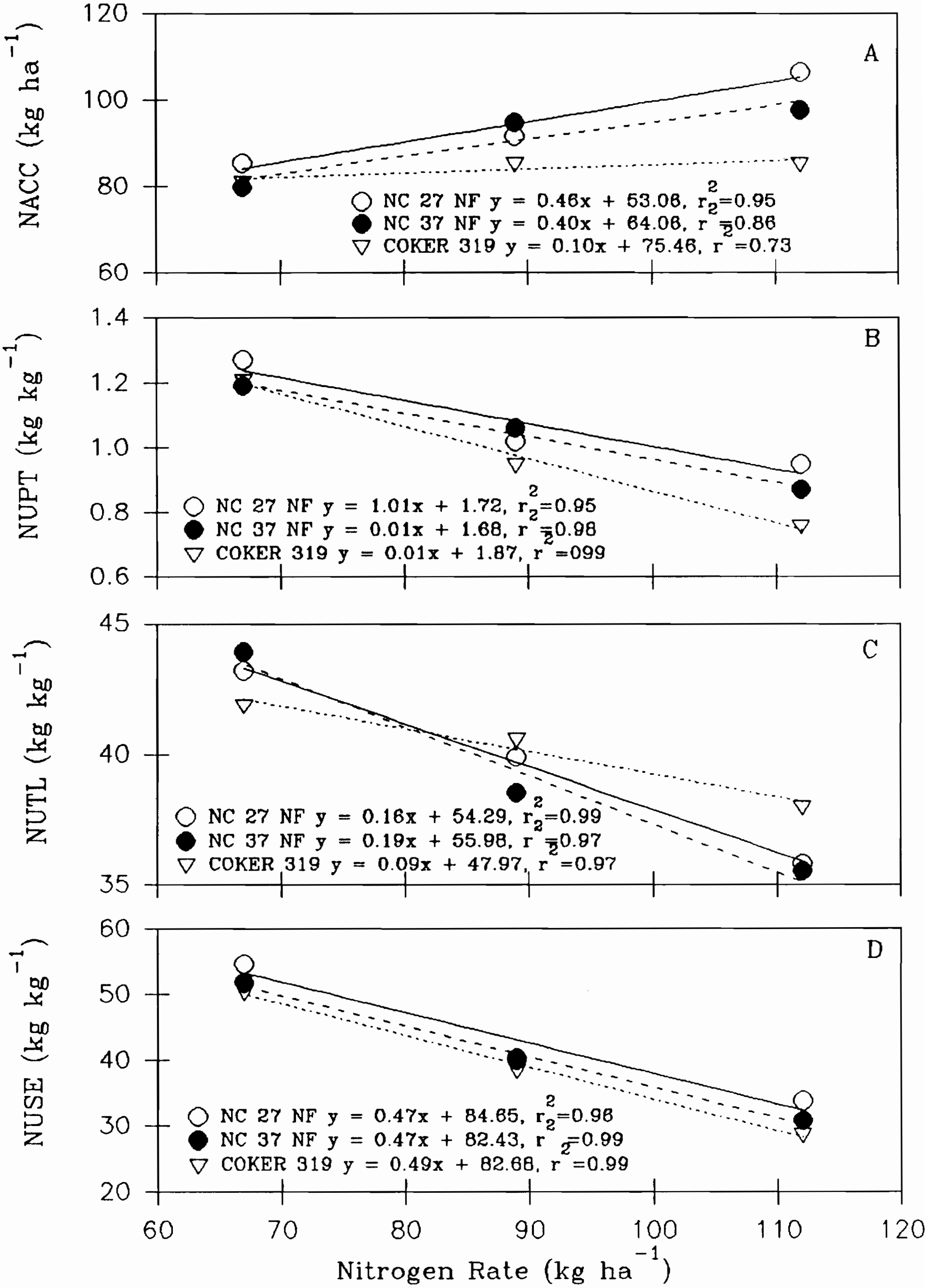

A
NACC (kg ha^{-1})
120
100
80
60
○ NC 27 NF y = 0.46x + 53.06, r^2=0.95
● NC 37 NF y = 0.40x + 64.06, r^2=0.86
▽ COKER 319 y = 0.10x + 75.46, r^2=0.73
B
NUPT (kg kg^{-1})
1.4
1.2
1.0
0.8
0.6
○ NC 27 NF y = 1.01x + 1.72, r^2=0.95
● NC 37 NF y = 0.01x + 1.68, r^2=0.98
▽ COKER 319 y = 0.01x + 1.87, r^2=099
C
NUTL (kg kg^{-1})
45
40
35
○ NC 27 NF y = 0.16x + 54.29, r^2=0.99
● NC 37 NF y = 0.19x + 55.98, r^2=0.97
▽ COKER 319 y = 0.09x + 47.97, r^2=0.97
D
NUSE (kg kg^{-1})
60
50
40
30
20
○ NC 27 NF y = 0.47x + 84.65, r^2=0.96
● NC 37 NF y = 0.47x + 82.43, r^2=0.99
▽ COKER 319 y = 0.49x + 82.66, r^2=0.99
60
70
80
90
100
110
120
Nitrogen Rate (kg ha^{-1})

Table 2. Mean green tissue samples taken at first harvest for three cultivars at three nitrogen rates grown over two years near Blackstone, VA.

Cultivar	N Rate	NACC[1]	NUPT	NUTL	NUSE
	kg ha^{-1}	kg ha^{-1}	--------kg kg^{-1}-------		
NC 27NF	67	86.26	1.28	55.12	68.89
NC 27NF	89	85.13	0.95	52.35	49.19
NC 27NF	112	117.11	1.05	45.77	47.83
NC 37NF	67	87.29	1.30	49.54	63.89
NC 37NF	89	84.26	1.29	50.56	47.58
NC 37NF	112	101.38	0.94	39.40	35.80
C 319	67	86.47	1.29	54.94	69.05
C 319	89	91.08	1.01	47.81	47.57
C 319	112	103.59	0.92	43.95	39.47
LSD (P=0.05)		NS	NS	NS	NS

[1] NACC = nitrogen accumulation; NUPT = nitrogen uptake efficiency; NUTL = nitrogen utilization efficiency; and NUSE = nitrogen use efficiency.

NITROGEN UPTAKE EFFICIENCY

NUPT is an estimate of how efficient plants are at removing applied N from the soil. Efficiencies greater than 1.0 indicate the plants were probably removing residual nitrogen. In the cured leaf data, significant differences were observed among cultivars and N rates. NUPT decreased as nitrogen rates increased (Fig. 7B). Both mammoth cultivars were more efficient at uptake than C 319, however, significant differences were observed only between NC 27 NF and C 319. The higher NUPT of mammoth cultivars at higher N rates contributed the most to increased NUSE of mammoth cultivars. NUPT was responsible for 77, 71 and 69 percent of NUSE at 67, 89, and 112 kg ha $^{-1}$ N, respectively. In the whole plant analysis, as in cured leaf data, nitrogen rates had the greatest influence on the variance of NUPT (Table 2). Significant differences were observed only among N rates. All cultivars were more efficient at 67 kg ha $^{-1}$ than at 89 or 112 kg ha^{-1} N.

NITROGEN UTILIZATION EFFICIENCY

NUTL is an estimate of how efficient plants are at converting nitrogen taken up into cured leaf yield or plant biomass, whichever the case may be. In the cured leaf, as N rates increased the utilization efficiency decreased (Fig. 7C). Plants were most efficient at 67 kg ha$^-$

^{1} followed by 89 and then 112 kg ha^{-1} N. In contrast to Sisson et al. (15) NUTL did not account for a large proportion of the increased NUSE (23, 29, and 31 percent at 67, 89, and 112 kg ha^{-1} N, respectively). Mammoth cultivars tended to be more efficient than C 319, however, these differences were not significant. In the whole plant analysis, significant differences were observed only among N rates, with NUTL decreasing as nitrogen rates increased.

NITROGEN USE EFFICIENCY

NUSE is a function of nitrogen uptake and utilization. It is a combined measure of how well the plants can remove applied nitrogen from the soil and convert it into yield. In both cured leaf and whole plant analyses, NUSE decreases as nitrogen rates increase when averaged over cultivars. Only in the cured leaf data was significance found between cultivars. NC 27 NF was most efficient followed by NC 37 NF and C 319, however, significant differences were observed only between NC 27 NF and C 319.

In both the cured leaf and green tissue samples, all cultivars showed an expected decrease in nitrogen uptake, utilization, and use efficiencies as N rates increased. The plants are unable to produce as much yield with each additional unit of nitrogen, i.e., the law of diminishing returns. The optimum efficiency is reached when the value of the resulting increased yield, from the additional nitrogen, equals the cost of the additional unit of nitrogen.

In the cured leaf, both mammoth cultivars were able to accumulate more nitrogen than was applied at the two lower rates. However, at 112 kg ha^{-1} only NC 27 NF was able to accumulate nearly all of the nitrogen applied. This was reflected by greater than 100 % uptake efficiencies of mammoths cultivars at 67 and 89 kg ha^{-1} N. NC 27 NF and NC 37 NF were 19 and 11%, respectively, more efficient at uptake than C 319 at 112 kg ha^{-1}. The increases in nitrogen use efficiencies of mammoth cultivars can be attributed to their higher uptake efficiencies rather than nitrogen utilization. These trends are consistent with results observed in corn (14) and wheat (7).

NC 27 NF tended to be a most efficient user of nitrogen in the whole plant green tissue analysis, although these trends were consistent between years the differences were not significant. Nitrogen, as well as biomass, continues to accumulate after the first harvest. Our cured leaf data supports the conclusion that whole plant differences between cultivars may become evident as the season progresses.

CONCLUSIONS

Results from the cured leaf data indicate that the mammoth cultivars do appear to be more efficient users of nitrogen. However, only NC 27 NF would seem to benefit from increasing recommended nitrogen rates. Results indicate that increasing N rates for NC 37 NF and Coker 319 would only increase production costs and decrease quality while showing no benefit in yield. The increase in nitrogen use efficiency of the mammoths was due to better uptake efficiencies rather than utilization efficiencies, which is consistent with other agronomic crops (7,14). There appears to be little difference in the nitrogen use efficiency of the cultivars at the first harvest date. Since differences were observed among cultivars for cured leaf it is possible that whole plant differences between cultivars become evident later in the season. Thus, further research is needed to determine whole plant efficiencies at the end of the season.

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Chapter IV.

Influence of Nitrogen rate, Leaf Number, and Time of Topping on Yield and Quality of Mammoth Tobacco Cultivars[1]

ABSTRACT

Flue-cured tobacco (*Nicotiana tabacum* L.) yields can be increased by increasing the number of leaves per plant although cured leaf quality is generally reduced. Delayed topping reduces yield and quality because the additional upper leaf tissue, seed pods, and seeds that are produced are strong sinks for photosynthate. Field experiments were conducted in 1991 and 1992 to determine the effect of increased leaf number and delayed topping on the yield and quality of two mammoth cultivars, NC 27 NF and NC 37 NF, as compared to a conventional cultivar, Coker 319. All three cultivars were grown at 60, 80, and 100 lbs/acre nitrogen. Yield, quality, chemical components, and plant characteristics were evaluated. Significant differences were observed among cultivars, nitrogen rates, leaf number and time of topping. A 27 lb/acre/day reduction in yield and a 50 dollar/acre/day reduction in value was observed when topping

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[1] This chapter will be submitted for publication in Journal of Production Agriculture. Style and notation conform to the requirements of the journal and references are cited by number.

was delayed from seven to 21 days. A 17% increase in yield was observed when leaf number was increased from 20 to 36. Increased yields were associated with lower weights per leaf and poor chemical characteristics.

INTRODUCTION

The mammoth character in flue-cured tobacco (*Nicotiana tabacum* L.) induces cultivars to continue vegetative growth, without the usual terminal inflorescence, during long days of summer (19). Consequently, mammoth cultivars will continue to produce leaves until the short photoperiods of late summer or until the plant is topped. Both yield and quality, the two most important economic considerations in tobacco production (4), can be influenced by the number of leaves per plant and time of topping.

Increasing topping height tends to increase yields (1,2,4,6,8,10,12,13,16,17,19,22) primarily as a result of production of more harvestable leaves per acre. King (17) reported a 28 percent yield increase when leaf number was increased from 14 to 26 on the mammoth cultivar 'NC 22 NF'. However, at the higher leaf numbers, increased yields were obtained at the expense of lower individual leaf weights (8,17,20) and lower values per hundred weight (4). Mann and Chaplin (19) reported that increased yields were a result of a greater number of low quality leaves harvested. Collins et al. (6) observed increased in leaf number due to increased topping heights of conventional cultivars reduced price more than increased plant population. They also observed decreased labor efficiency as the weight per leaf decreased as a result of increasing topping height. In contrast, King (17), reported no significant change in grade index at 18, 22, and 26 leaves when working with the mammoth 'NC 22 NF'. Contrary to general beliefs, his results suggest that non-flowering plants can be topped at higher leaf numbers than is currently recommended for flue-cured tobacco while maintaining a high level of quality.

Delaying topping in conventional cultivars from the early bud stage until the fully open flower progressively decreases leaf yields and nicotine concentration (3). Marshall and Seltman (21) reported a one percent decrease in cured leaf weight for each day that topping was delayed after the plant reached the desired leaf number. A further decrease in yield can be expected if topping is delayed to the point where flowers and seed pods are developed. Both flowers and seed pods are strong sinks for photosynthate which tends to decrease the weight and body of the tobacco leaf (5). Although mammoth cultivars may not produce flowers or seed pods before topping, they may produce many more leaves than desired before the apical meristem is removed at topping. This additional upper leaf tissue is also a strong sink for nitrogen and photosynthate (11). These extra leaves, which are discarded at topping, rob the plant of vital resources which in turn reduces yield, leaf body, and nicotine content (23). Jones et al. (15), reported an estimated 26 pound per acre per day reduction in yield when the topping of the mammoth cultivars, 'NC 27 NF' and 'NC 37 NF', was delayed by seven to fourteen days.

Effects of topping on yield and quality are influenced considerably by fertility level, with significant increases detected only when topping height as well as N rates are high (18,22). Although Collins (5) reported that flue-cured tobacco should be topped early, regardless of the nitrogen level. Considerable nitrogen is absorbed during late growth (11), and if topping is delayed, this absorbed nitrogen is simply discarded with the upper leaf tissue at topping. Most of the competition for nitrogen is eliminated after topping and more nitrogen will become available for nicotine synthesis (20). The accumulation of nicotine occurs rapidly after topping and continues until the leaves are harvested.

Topping and controlling suckers in flue-cured tobacco will also increase total alkaloid concentration of the cured leaf, with nicotine concentration being highest at lower topping levels (23). Wallace et al. (24) demonstrated that floral development at topping did not influence nicotine concentration but the period of time between topping to harvest did. Nicotine levels increased as harvest time was delayed from 10-30 days after topping. Nicotine accumulation decreased as the number of leaves remaining on the plant at topping increased.

The ability of mammoth tobaccos to produce many more leaves than conventional cultivars may cause a wide range of chemical variability. Chaplin (4), working with a mammoth derived from 'Bunn Special', observed a decrease in total alkaloid concentration as the number of leaves per plant increased while having only a minimal effect on the reducing sugars. He also concluded that there may be a genetic association between the mammoth gene and a lower percentage of reducing sugars. In contrast, King (17) found that the sugar to nicotine ratio improved as leaf number increased. In another study with mammoth tobacco decreased nicotine concentration was observed after the first harvest, with a large increase in nicotine and reducing sugar concentrations after second harvest (20). This large increase was probably due to topping between the first and second harvest. This demonstrates the marked influence of proper topping on the chemical quality of the cured leaf, as well as emphasizing the effect of the time between topping and harvest. When compared to conventional cultivars, where both were topped at twenty leaves, the mammoth has equal quality, with the same value per hundred weight, percent alkaloids, and total nitrogen to total alkaloid ratio (4,25). The objective of this experiment was to determine the effects of nitrogen (N) rate, leaf number, and time of topping on two mammoth cultivars as compared to a conventional cultivar.

MATERIALS AND METHODS

Field experiments were conducted at the Virginia Polytechnic Institute and State University Southern Piedmont Agricultural Experiment Station (SPAES) near Blackstone, VA in 1991 and 1992 on a Durham sandy loam soil (Typic Hapludult, fine-loamy, siliceous, thermic). Experiments were conducted as a split-split plot in a randomized complete block design with three replications where N rates were whole plots and cultivars were sub-plots. The three nitrogen rates were 60, 80, and 100 lbs/acre. Two mammoth cultivars, NC 27 NF and NC 37 NF, and one conventional cultivar, Coker 319 (C 319) were evaluated. Coker 319 was selected because its maturity rate is similar to the mammoth cultivars. In experiment one, time of topping was the sub-sub plot, while in experiment two, leaf number was the sub-sub plot. In the time of topping experiment the first treatment was topped when plants reached 20 leaves with the top leaf having a length of six inches (the equivalent of the button stage of conventional cultivars, for simplicity this stage will be designated as the button stage). Plots were then topped seven, 14, and 21 days after the first topping date. All plants were topped at 20 harvestable leaves. In experiment two, plants were topped at 20, 24, 28, 32, and 36 leaves. Since conventional cultivars are unable to produce as many leaves per plant as the mammoth cultivars, only the mammoth cultivars were evaluated at leaf numbers greater than 24. Each plot received an initial base rate of 40 lbs N/acre. Additional nitrogen was applied to supply 60, 80, and 100 lbs N/acre as a sidedress 14 days after transplanting. Each sub-sub-plot consisted of single a row containing 24 competitive plants spaced 20 inches apart with 48 inches between rows. Fertilization, harvesting, curing procedures, and other production practices, other than those mentioned above, were consistent with recommendations for the production of flue-cured tobacco by the Virginia Cooperative Extension Service (15). Irrigation was used as needed to ensure adequate moisture. Leaching was not considered to be a problem either year. Cured leaf from each plot was weighed by harvest, assigned an official U.S. Government grade, plot yields, value per acre, average price, and grade indices were computed. Measurements for middle and top leaf lengths and widths, as well as final plant heights were taken after the second harvest. Composite samples consisting of approximately 30 g cured leaf were collected from each plot for total nitrogen (7), total alkaloid, and reducing sugar (15) determinations.

RESULTS AND DISCUSSION

Data from each experiment was analyzed for each year and over years. Interaction effects were non-significant and error variances between years were homogeneous. Therefore, data was combined over years.

Experiment 1. (Time of Topping)

CURED LEAF YIELD AND QUALITY

Significant differences were observed among cultivars and topping time for yield (Table 1). No significant differences were observed among N rates. NC 27 NF was significantly higher yielding than NC 37 NF which yielded significantly higher than C 319. Plants topped in the button stage were similar in yield to those topped seven days later. This lack of significance was probably due to many plants still being in the button stage seven days after the first topping date. Yield significantly decreased at each delay in topping beyond seven days after the button stage. A 27 pound per acre per day reduction in yield was observed when topping was delayed from seven to 21 days after the button stage. There was a 35 pound per acre per day reduction when topping was delayed from 14 to 21 days. NC 27 NF appeared to perform better at the

Table 1. Mean chemical and agronomic traits of three cultivars as affected by three nitrogen rates and four topping times over a two year period.

								Middle Leaf		Top Leaf		
	Yield	Value	Price	GI[1]	Total alkaloids	Red. sug.	Total N	L	W	L	W	Plant height
	lbs/A	$/A	$/lb		-----------%-----------			--------------in--------------				
Cultivar												
NC 27NF	3264	5514	1.69	58	3.31	11.56	2.56	27.0	10.9	27.0	11.5	31.3
NC 37NF	3045	5179	1.70	60	3.58	11.03	2.62	26.3	10.7	26.5	11.2	33.0
Coker 319	2898	4922	1.70	60	3.21	12.82	2.50	26.1	11.2	24.0	10.0	35.9
LSD(P=0.05)	190	378	NS	NS	0.14	0.76	0.09	0.5	0.4	0.6	0.3	1.1
N Rate lbs/A												
60	3082	5288	1.72	64	3.18	14.09	2.35	25.8	10.6	25.0	10.4	33.1
80	3081	5218	1.69	60	3.34	11.60	2.57	26.4	11.0	25.8	11.0	33.5
100	3043	5108	1.68	55	3.58	9.73	2.77	27.2	11.2	27.7	11.3	33.5
LSD(P=0.05)	NS	NS	NS	8	0.33	2.28	0.23	NS	0.5	1.3	0.8	NS
Top Time												
Button	3197	5443	1.70	60	3.55	11.40	2.64	27.7	11.5	27.0	12.0	31.1
7	3196	5428	1.70	59	3.64	11.75	2.63	27.0	11.1	27.7	11.4	32.7
14	3065	5215	1.70	61	3.26	12.14	2.51	25.9	10.7	25.6	10.6	34.7
21	2818	4733	1.68	59	3.01	11.93	2.47	25.1	10.4	24.1	9.8	35.0
LSD(P=0.05)	87	164	0.02	NS	0.10	0.63	0.06	0.6	0.3	0.6	0.3	0.8

[1] GI = Grade Index.

higher nitrogen rates than either NC 37 NF or Coker 319 and may indicate NC 27 NF could benefit from increased nitrogen rates.

Grade index (GI), average price (AP), and value per acre (value) estimates were calculated from cured leaf data. Grade index provides a means of uniform visual evaluation of quality, average price represents the average price paid for the representative grades of the sample, and value per acre reflects the average auction price per pound of cured leaf produced on an acre. Significant differences for value were observed among cultivars and among topping times (Table 1). NC 27 NF had the highest value followed by NC 37 NF which was higher in value than C 319. Value decreased as topping time was delayed, except between the button and seven day treatments. A 50 and 69 dollar per acre per day reduction in value was observed when time of topping was delayed from 7 to 21 days and 14 to 21 days, respectively. This demonstrates the importance of proper topping.

Significant differences were observed for price among topping times and for GI among N rates (Table 1). Plants topped 21 days after the button stage had a significantly lower price than all other treatments. Grade index decreased as N rates increased, with a significantly lower GI observed at 100 than at the 60 lb/acre N. The lower GI, due to N rates, indicates that plants are accumulating too much nitrogen, which usually results in large, rank leaves. This additional nitrogen, taken up by the plants in the 14 and 21 treatments, may have been discarded with the tops. Thus decreases in quality, as a result of delayed topping, may have been compensated for by the increased nitrogen rates. This may be the reason no significant decreases in GI were observed between topping times.

Significant differences among cultivars, N rate, and time of topping were observed for total alkaloids, reducing sugars, and total nitrogen (Table 1). Total nitrogen and total alkaloid concentrations increased and reducing sugar content decreased as N rates increased from 60 to 100 lbs/acre. A leaf that is high in total alkaloids and low in reducing sugars generally produces smoke that is more harsh with a stronger and more bitter flavor (8). Mammoth cultivars were higher in total nitrogen and lower in reducing sugars than C 319, however significant differences were observed only between NC 37 NF and C 319 for total nitrogen. The tendency of mammoth cultivars to be lower in reducing sugar concentration was consistent with Chaplin's observations (4). The higher nitrogen concentration of NC 37 NF contributed to its significantly higher total alkaloid concentration than NC 27 NF or C 319. Total nitrogen and alkaloid concentrations decreased while reducing sugars increased as topping time was delayed. Our data supports Elliots work (9) that the number of days between topping and harvest is probably the determining factor in the amount of nicotine accumulated. No significant differences were observed between the button stage and the seven day treatment.

PLANT MEASUREMENTS

Significant differences were observed among cultivars, N rates, and time of topping for top leaf length and middle and top leaf width (Table 1). Both middle and top leaf width, and top leaf length increased as N rates increased, with significant differences detected between 60 and 100 lbs N/acre. There were no significant differences among N rates for plant height or middle leaf length. Coker 319 had the highest plant measurement followed by NC 37 NF which was significantly taller than NC 27 NF. With the exception of middle leaf width the leaves of the mammoth cultivars were generally larger in all measurements than C 319. Mammoth cultivars had longer top leaves than C 319, and NC 27 NF had longer middle leaf than NC 37 NF or C 319. C 319 had a wider middle leaf than NC 37 NF, and NC 27 NF had wider top leaf than NC 37 NF which was wider than C 319. Leaf size was significantly decreased as topping time was delayed, with the exception of top leaf length, where there was no difference between the button stage and the seven day treatment.

These results support previous work that showed mammoth cultivars can produce larger top leaves than conventional cultivars. Therefore the increased yield of the mammoths may, at least in part, be a result of a larger leaf area.

Experiment 2. (Leaf Number)

CURED LEAF YIELD AND QUALITY

Significant differences in yield were observed among cultivars, N rate, and leaf numbers (Tables 2 and 3). Yield increased with increasing nitrogen rates, however significant differences were observed only between 60 and 80 lbs N/acre when averaged over mammoth cultivars. NC 27 NF had a significantly higher yield than NC 37 NF or C 319. Yield increased with increasing leaf numbers. A 17 percent increase in yield was observed when leaf number increased from 20 to 36 leaves per plant when averaged over mammoth cultivars and N rates, and a five percent

Table 2. Mean chemical and agronomic traits of two mammoth cultivars topped at five leaf numbers and grown under three nitrogen rates in 1991 and 1992.

	Yield	Value	Price	GI[1]	Total alkaloids	Red. sug.	Total N	Middle Leaf		Top Leaf		Plant height
								L	W	L	W	
	lbs/A	$/A	$/lb		-----------%-----------			--------------in--------------				
Cultivar												
NC 27NF	3407	5784	1.70	60	2.66	11.61	2.38	25.4	10.2	22.8	9.8	44.1
NC 37NF	3197	5467	1.71	61	2.86	11.24	2.38	24.6	9.7	22.4	9.4	46.2
LSD(P=0.05)	116	206	NS	NS	0.14	NS	NS	0.6	0.2	NS	0.4	0.9
N Rate lbs/A												
60	3314	5645	1.70	60	2.36	11.97	2.36	24.6	10.0	22.4	9.6	44.8
80	3234	5544	1.72	63	2.29	11.95	2.29	24.8	9.8	22.3	9.4	45.2
100	3358	5688	1.69	58	2.48	10.36	2.48	25.4	10.0	23.1	9.9	45.3
LSD(P=0.05)	123	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Leaf No.												
20	3072	5269	1.71	61	3.34	11.81	2.47	27.6	11.2	27.5	11.7	30.8
24	3195	5460	1.71	61	2.99	11.65	2.39	25.6	10.3	24.8	10.7	38.1
28	3330	5664	1.70	60	2.76	11.21	2.39	24.5	9.6	22.6	9.8	45.6
32	3417	5803	1.70	60	2.42	11.20	2.33	23.7	9.3	19.9	8.3	52.8
36	3596	5932	1.70	60	2.28	11.25	2.31	23.3	9.2	18.4	7.5	58.3
LSD(P=0.05)	120	234	NS	NS	0.12	NS	0.07	0.6	0.3	0.7	0.4	0.9

[1] GI = Grade Index.

Table 3. Mean chemical and agronomic traits of three cultivars topped at 20 and 24 leaves per plant and grown under three nitrogen rates in 1991 and 1992.

	Yield	Value	Price	GI[1]	Total alkaloids	Red. sug.	Total N	Middle Leaf L	Middle Leaf W	Top Leaf L	Top Leaf W	Plant height
	lbs/A	$/A	$/lb		-----------%	-----------		-------------	-------------	in-------------	-------------	-------------
Cultivar												
NC 27NF	3288	5639	1.72	62	3.02	12.38	2.40	27.3	11.1	26.5	11.5	34.0
NC 37NF	2978	5089	1.71	60	3.31	11.09	2.45	25.9	10.4	25.4	10.9	35.0
Coker 319	2902	5009	1.73	65	3.18	12.72	2.39	26.3	11.2	22.8	9.7	39.0
LSD(P=0.05)	178	403	NS	4	0.21	1.5	NS	0.8	0.4	0.9	0.5	1.3
N Rate lbs/A												
60	3018	5157	1.71	61	3.18	12.22	2.43	25.9	10.7	24.4	10.5	35.5
80	3054	5272	1.73	65	3.10	12.65	2.34	26.5	10.8	25.0	10.7	36.5
100	3097	5309	1.71	61	3.23	11.32	2.47	26.9	11.2	25.6	10.9	36.0
LSD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	1.0	NS	NS	NS	NS
Leaf No.												
20	2986	5135	1.72	62	3.32	11.78	2.46	27.4	11.3	26.6	11.4	32.2
24	3126	5357	1.71	62	3.02	12.34	2.37	25.6	10.5	23.4	10.0	39.8
LSD(P=0.05)	102	185	NS	NS	.12	NS	.06	0.5	0.3	0.6	0.3	1.1

[1] GI = Grade Index.

increase in yield when leaf number was increased from 20 to 24 leaves over all cultivars. Although there were no significant interactions, the higher leaf numbers consistently appeared to have higher yields at higher N rates. Yield of mammoth cultivars as well as the conventional cultivar were increased by increasing leaf number, which is consistent with previous observations (1,2,4,6,16,22).

Significant differences were observed among cultivars and leaf number for value. Grade index was significantly different only when compared over all three cultivars at 20 and 24 leaves. There were no significant difference in average price or among N rates. NC 27 NF had a higher value than NC 37 NF or C 319 when averaged across N rates and cultivars. Value appeared to increase, while grade index and average price appeared to decrease as a result of increasing leaf number. These trends were consistent across years, however the differences were not significant. The lack of significant decreases in grade index and average price may be due to the apparent increase in grade index of higher leaf numbers at high N rates.

Significant differences were observed among cultivars for reducing sugars and total alkaloid concentrations; and among leaf numbers for total nitrogen and total alkaloid concentrations. NC 37 NF had higher total alkaloid and lower reducing sugar concentrations than C 319. Total alkaloids and total nitrogen concentration decreased with increasing leaf number. Our results agree with previous work (8) in that leaf number had a greater effect on total alkaloid than on total nitrogen concentrations. As leaf number increased total alkaloid concentration decreased more rapidly than did total nitrogen concentration. In excessively high leaf numbers total nitrogen values equaled or exceeded total alkaloid values. A ratio of nitrogen to nicotine above 1.0 is not acceptable (23). These results indicate chemical characteristics of tobacco markedly decrease as leaf numbers increase much over the recommended topping heights.

A greater occurrence of target leaf spot and brown spot was observed in the higher leaf number plots in moist conditions. This may be the result of decreased air flow between the rows, which creates an ideal environment for the spread of both pathogens. Another possible explanation is that the thinner leaves of the plants at high leaf numbers were more susceptible to the pathogens than heavier bodied leaves.

PLANT MEASUREMENTS

Significant differences were observed among cultivars and leaf numbers for middle and top leaf measurements and for plant height (Tables 4 and 5). NC 37 NF had shorter and more narrow middle leaf than NC 27 NF or C 319. However, both mammoths had significantly larger top leaves than the conventional cultivar. Every leaf measurement significantly decreased as leaf number increased, except for the middle leaf length when leaf number was increased from 32 to 36. Plant height increased at each increase in leaf number. Coker 319 was significantly taller than the mammoth cultivars when averaged over 20 and 24 leaves, NC 37 NF was significantly taller than NC 27 NF when averaged across all leaf numbers. Thus the average size of all leaves decreases as the number of leaves on the plant increase. Results indicate that the mammoth cultivars tend to have larger leaves than C 319, which may in part, be responsible for their higher yield at equal leaf numbers. Although there were no significant interactions, our results were consistent with previous work (18,22) in that higher leaf number plots tended produced larger leaves and taller plants at the higher nitrogen rates when averaged across cultivars. These trends were consistent between years.

INTERPRETIVE SUMMARY

Delayed topping adversely affects yield, value, physical, and chemical characteristics of the cured leaf in both conventional and mammoth cultivars of flue-cured tobacco. The smaller, thinner, and lower value leaves, that result from delayed topping, indicate that upper leaf tissue as well as seed pods and seeds are strong sinks for the vital resources of the plant.

Yield can be increased by increasing the number of leaves per plant, however this increase in yield is at the expense of leaf size and quality. Although this reduction in quality was not clearly defined with respect to grade index and average price, the chemical composition of the leaf from plants with excessively high leaf numbers was unacceptable. Our results indicate that, for the best quality leaf, mammoth cultivars should not be topped higher than 24 leaves per plant and that both mammoth and conventional cultivars should be topped as soon as they reach the desired leaf number.

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APPENDIX

Appendix Table 1. Mean percentage of total alkaloids of green plant tissue from three cultivars grown at three nitrogen rates in 1991 and 1992.

Cultivar Plant	Sample Date 1[1]			Sample Date 2			Sample Date 3			Sample Date 4		
Sections	67[2]	89	112	67	89	112	67	89	112	67	89	112
	---						%					---
NC 27NF												
A[3]	1.76	1.77	1.73	1.45	1.32	1.57	1.35	1.45	1.36	1.77	1.88	2.10
B	1.47	1.50	1.49	0.98	0.93	0.92	1.21	1.24	1.31	1.89	1.95	2.31
C	1.15	1.02	1.09	0.64	0.66	0.73	1.15	1.15	1.15	1.53	1.90	2.32
D	0.84	0.75	0.76	0.49	0.52	0.54	0.84	0.87	0.85	1.86	1.97	2.44
E	0.60	0.57	0.51	0.28	0.35	0.36	0.56	0.52	0.54	1.73	1.77	2.28
Lamina	1.27	1.21	1.25	0.84	0.83	0.90	1.12	1.18	1.16	1.74	1.88	2.29
Midrib	0.23	0.25	0.25	0.11	0.13	0.14	0.15	0.16	0.16	0.33	0.35	0.39
Root	1.18	1.15	1.13	0.91	1.03	0.98	1.07	1.07	0.91	1.04	1.08	0.96
Stalk	0.52	0.58	0.59	0.34	0.32	0.34	0.28	0.31	0.29	0.30	0.34	0.37
NC 37NF												
A	1.86	2.01	1.81	1.65	1.47	1.51	1.62	1.59	1.59	2.25	2.40	2.31
B	1.46	1.62	1.57	1.16	1.10	1.05	1.27	1.47	1.51	2.13	2.38	2.42
C	1.03	1.13	1.14	0.83	0.82	0.80	1.34	1.11	1.25	2.09	2.21	2.33
D	0.72	0.81	0.84	0.61	0.60	0.58	1.00	0.92	0.91	1.87	2.02	2.29
E	0.57	0.60	0.57	0.39	0.41	0.39	0.59	0.51	0.52	1.66	1.88	2.33
Lamina	1.25	1.36	1.31	0.98	1.03	0.93	1.32	1.25	1.30	2.14	2.03	2.33
Midrib	0.25	0.26	0.29	0.14	0.15	0.14	0.17	0.17	0.16	0.34	0.38	0.39
Root	1.21	1.19	1.12	1.01	1.10	0.94	0.99	1.03	0.93	1.09	1.16	1.19
Stalk	0.62	0.61	0.64	0.31	0.35	0.35	0.29	0.29	0.27	0.28	0.30	0.33

- continued -

Appendix Table 1. Mean percentage of total alkaloids of green plant tissue from three cultivars grown at three nitrogen rates in 1991 and 1992.

Cultivar Plant	Sample Date 1[1]			Sample Date 2			Sample Date 3			Sample Date 4		
Sections	67[2]	89	112	67	89	112	67	89	112	67	89	112
	----------	----------	----------	----------	----------	----------	%	----------	----------	----------	----------	----------
Coker 319												
A[3]	1.61	1.58	1.79	1.50	1.56	1.27	1.53	1.58	1.41	1.94	2.08	2.18
B	1.30	1.34	1.40	1.06	1.09	0.93	1.33	1.46	1.32	2.02	2.16	2.16
C	0.98	1.02	1.06	0.76	0.80	0.69	1.22	1.25	1.06	1.82	2.13	2.18
D	0.66	0.86	0.74	0.56	0.56	0.55	0.87	0.91	0.81	1.95	2.06	2.12
E	0.63	0.90	0.53	0.34	0.34	0.43	0.64	0.57	0.46	1.83	2.03	2.08
Lamina	-1.13	-1.18	-1.19	-0.92	-0.95	-0.83	-1.25	-1.30	-1.16	-1.90	-2.08	-2.14
Midrib	0.19	0.22	0.21	0.10	0.10	0.09	0.11	0.12	0.12	0.31	0.30	0.30
Root	1.08	1.00	1.00	0.85	0.84	0.86	0.85	0.79	0.72	0.91	0.94	0.99
Stalk	0.50	0.47	0.50	0.28	0.27	0.24	0.25	0.23	0.20	0.25	0.29	0.32

[1] Sample date 1 = layby, 2 = 10 days after layby, 3 = topping, and 4 = first harvest.

[2] Nitrogen rates in kg ha^{-1}.

[3] Leaf positions, A = lower leaves and E = top leaves.

Appendix Table 2. Mean percentage of total nitrogen of green plant tissue from three cultivars grown at three nitrogen rates in 1991 and 1992.

Cultivar Plant	Sample Date 1[1]			Sample Date 2			Sample Date 3			Sample Date 4		
Sections	67[2]	89	112	67	89	112	67	89	112	67	89	112
						%						
NC 27NF												
A[3]	3.79	3.68	3.51	3.61	3.69	3.82	2.85	3.18	3.57	2.03	2.06	2.38
B	4.52	4.60	4.64	4.32	4.54	4.95	3.57	3.90	4.54	2.38	2.35	2.91
C	5.18	5.21	4.91	4.70	4.76	5.16	4.41	5.03	5.41	2.76	2.93	3.29
D	5.21	5.29	5.04	5.01	5.45	5.48	4.87	5.61	6.09	3.31	3.26	3.93
E	5.23	5.19	5.12	5.47	5.74	5.81	5.21	5.98	6.18	3.45	3.53	4.09
Lamina	4.72	4.77	4.63	4.46	4.64	4.87	3.92	4.35	4.85	2.76	2.83	3.36
Midrib	2.68	2.81	2.83	2.53	2.70	2.82	1.86	2.21	2.72	1.25	1.16	1.55
Root	2.87	2.99	2.72	2.56	3.03	2.86	2.33	2.54	2.62	1.88	1.91	1.84
Stalk	2.94	3.03	2.82	2.62	2.59	2.67	1.79	2.04	2.20	1.27	1.29	1.41
NC 37NF												
A	3.50	3.53	3.74	3.55	3.51	3.85	3.25	3.49	3.47	2.29	2.19	2.68
B	4.39	4.35	4.51	4.43	4.53	4.72	4.11	4.53	4.41	2.66	2.55	3.13
C	5.04	4.86	5.20	4.89	5.03	5.01	5.07	5.63	5.39	3.26	2.96	3.78
D	5.21	5.10	5.32	5.24	5.20	5.36	5.83	6.04	6.20	3.72	3.38	4.50
E	5.25	4.97	5.14	5.79	5.82	5.67	5.93	6.10	6.25	4.16	3.89	4.97
Lamina	4.57	4.49	4.71	4.61	4.57	4.77	4.56	4.74	4.85	3.00	3.16	3.86
Midrib	2.80	2.70	2.87	2.65	2.69	2.84	2.43	2.56	2.62	1.26	1.35	1.86
Root	3.14	3.03	3.21	3.02	3.27	3.01	2.61	2.88	2.75	2.03	2.09	2.37
Stalk	3.02	3.00	3.08	2.66	2.80	2.90	2.15	2.22	2.26	1.31	1.29	1.58

- continued -

Appendix Table 2. Mean percentage of total nitrogen of green plant tissue from three cultivars grown at three nitrogen rates in 1991 and 1992.

Cultivar Plant Sections	Sample Date 1[1]			Sample Date 2			Sample Date 3			Sample Date 4		
	67[2]	89	112	67	89	112	67	89	112	67	89	112
	%											
Coker 319												
A[3]	3.56	3.65	3.47	3.52	3.55	3.76	3.30	3.28	3.29	2.29	2.36	2.52
B	4.32	4.31	4.25	4.52	4.47	4.61	4.19	4.28	4.16	2.63	2.92	2.89
C	5.08	4.79	4.89	5.00	5.16	4.83	5.20	5.36	5.30	2.88	3.38	3.50
D	5.00	4.96	5.06	5.15	5.39	5.09	5.66	5.89	5.59	3.40	3.73	4.04
E	4.95	4.73	5.30	5.55	5.76	5.76	5.98	6.15	5.90	3.69	4.18	4.06
Lamina	4.54	4.49	4.52	4.59	4.73	4.64	4.51	4.64	4.48	2.96	3.29	3.43
Midrib	2.67	2.77	2.66	2.43	2.56	2.47	2.16	2.39	2.29	1.24	1.38	1.58
Root	3.17	3.03	3.12	2.72	2.93	2.83	2.51	2.54	2.38	1.79	1.89	2.22
Stalk	2.81	2.80	2.91	2.38	2.50	2.69	1.97	2.00	1.86	1.17	1.40	1.56

[1] Sample date 1 = layby, 2 = 10 days after layby, 3 = topping, and 4 = first harvest.

[2] Nitrogen rates in kg ha^{-1}.

[3] Leaf positions, A = lower leaves and E = top leaves.

Appendix Table 3. Mean agronomic and chemical characteristics of three cultivars grown at three nitrogen rates from field tests conducted at the Southern Piedmont Agricultural Experiment Station in 1991 and 1992.

Cultivar	Nitrogen	Yield	Value	Price	Grade Index	Total alkaloids	Reducing Sugar	Total Nitrogen
	kg ha^{-1}	kg ha^{-1}	\$ ha^{-1}	\$ kg^{-1}		--------	%	--------
NC 27NF	67	3677	14143	3.85	68	3.12	14.69	2.33
NC 27NF	89	3614	13524	3.74	59	3.26	11.84	2.54
NC 27NF	112	3782	14328	3.80	59	3.41	9.74	2.81
NC 37NF	67	3470	13360	3.85	67	3.13	14.59	2.29
NC 37NF	89	3593	13798	3.84	65	3.58	11.25	2.64
NC 37NF	112	3443	13108	3.80	61	3.81	9.52	2.85
Coker 319	67	3435	13214	3.85	67	3.18	14.55	2.39
Coker 319	89	3454	13299	3.85	65	3.23	13.02	2.48
Coker 319	112	3211	12228	3.82	60	3.33	10.53	2.66
LSD (P=0.05)		NS	NS	NS	NS	NS	NS	NS

Appendix Table 4. Mean values for nitrogen accumulation and uptake, utilization, and use efficiencies of three cultivars grown at three nitrogen rates from field tests in 1991 and 1992.

Cultivar	Nitrogen	NACC[1]	NUPT	NUTL	NUSE
		kg ha^{-1}	----------kg kg^{-1}----------		
NC 27NF	67	85.6	1.27	43.2	54.7
NC 27NF	89	91.8	1.02	39.9	40.3
NC 27NF	112	106.5	0.95	35.8	33.8
NC 37NF	67	79.7	1.19	43.9	51.7
NC 37NF	89	94.8	1.06	38.5	40.1
NC 37NF	112	97.6	0.87	35.5	30.8
Coker 319	67	81.1	1.21	41.9	50.5
Coker 319	89	85.5	0.95	40.6	38.6
Coker 319	112	85.4	0.76	38.0	28.7
LSD (P=0.05)		NS	NS	NS	NS

[1] NACC=nitrogen accumulation; NUPT=nitrogen uptake efficiency; NUTL=nitrogen utilization efficiency; and NUSE=nitrogen use efficiency.

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