FLUE-CURED TOBACCO: ALTERNATIVE MANAGEMENT SYSTEMS

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(ABSTRACT)

The United States share of the exported flue-cured tobacco market has decreased over the last decade as other countries have increased production of improved quality tobacco. Such tobacco is available at a substantially lower price than U. S. tobacco and thus desirable for the manufacture of less expensive discount cigarettes. Although world consumption of American style cigarettes is increasing, demand is not sufficient to maintain current production levels of premium quality U. S. flue-cured tobacco. Production systems that increase yields of suitable quality tobacco for discount cigarette manufacture without increasing production costs would allow tobacco to be offered competitively on the world market while maintaining current income. A study of ten management systems was conducted evaluating the influence of plant spacing, topping height, and harvest method on yield and quality of flue-cured tobacco. Leaf populations of 538,000/ha harvested once-over resulted in a 6.5%, 11.0%, 6.0%, and 13.5% increase in yield, value, price, and grade index, respectively, compared to the standard treatment. An expert panel showed no preference among systems and judged all systems acceptable in quality. A study conducted as a randomized complete block in a split plot arrangement evaluated the influence of row spacing and plant spacing on the yield and quality of flue-cured tobacco harvested once-over. Yield, value, and grade index increased while price per kg was unchanged as plant population increased. Flue-cured tobacco harvested in a single harvest produced cured leaf of acceptable quality; however, increased leaf populations are required to maintain acceptable yields.

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Chapter I. Introduction

Flue-cured tobacco growers face a number of challenges due to increasing cost of production and competition in a global market. International competitors are increasing production of tobacco that is both cheaper than U.S. leaf and well suited for the manufacture of less expensive discount cigarettes. As a result, the U.S. share of the world flue-cured tobacco market has been seriously eroded over the last decade. Although there is still a strong market for the high quality tobacco characteristic of U.S. leaf, this demand is not enough to sustain current production levels. To remain price competitive, U.S. flue-cured tobacco growers are seeking strategies to lower costs of production. Labor accounts for 36% of operating costs (Peedin et al. 1994) and the majority of labor is required for harvesting (Gwynn, 1974). In a effort to reduce costs, growers have reduced the number of harvests utilized for a crop and are increasingly adopting mechanization.

Flue-cured tobacco (*Nicotiana tabacum L.*) produced in the U.S. traditionally has been grown with plant spacing and topping heights to achieve approximately 296,000 leaves/ha. Classical research determined leaf populations of 296,000 leaves/ha resulted in the best compromise in yield and quality, thus satisfying the demands of the traditional market and acreage-poundage production control system (Wotlz and Mason, 1966). Woltz and Mason (1966), using various plant spacing and topping height treatments, established that yield was positively related to leaf population. However, as leaf populations increased beyond 296,000 leaves/ha detrimental effects on price/kg and grade index were greater than beneficial effects on yield and value per hectare. (Collins et al., 1969; Kittrell et al., 1972). Topping height and plant spacing have been shown to influence yield, quality, and chemical composition of flue-cured tobacco (Chaplin et al., 1968; Coulson, 1959; Elliot, 1970; Tramel, 1967; Weybrew and Woltz, 1975). Chaplin et al. (1968) reported that an increase in topping height decreased total alkaloids and price but increased yield; whereas, greater plant spacing tended to increase total alkaloids with little effect on reducing sugars. Brown and Terrill (1973) observed that as topping height increased from 12 to 20 leaves, total nitrogen and nicotine decreased while reducing sugars increased. Elliot (1970) reported greater topping height increased yield and grade index, but total alkaloids and lamina weight decreased; greater plant spacing resulted in lower yields and total sugars and increased lamina weight and total alkaloids.

Traditionally, flue-cured tobacco has been harvested in 4 to 5 leaf increments in 5 to 6 sequential harvests as leaves progressively ripen ascending the stalk. The sequential harvest of flue-cured tobacco facilitates the removal of leaves as they reach visual maturity. Sequential harvesting maintains the separation of leaves from different stalk positions allowing prediction of chemical and smoking qualities (Miner, 1980). Sequential harvesting by hand is very labor intensive and availability and cost of necessary labor have become more prohibitive. Modified harvest systems that reduce the number of harvests have demonstrated favorable results in terms of yield and leaf quality compared to traditional multi-pass harvesting system (Brown and Terrill, 1972, 1973; Gwynn, 1969, 1974; Miner, 1980) Flue-cured tobacco topped to 18 leaves produced similar yield and quality when harvested in 6 or 3 primings (Gooden et al., 1976a and 1976b). Suggs (1989) reported that harvesting the bottom four to six leaves in the first priming followed by harvest of all remaining leaves in a second harvest did not significantly reduce yield or value compared to a four-priming optimally harvested check. Harvesting flue-cured tobacco in a single priming would further reduce harvest labor and would lend to improved efficiency of mechanical harvesting. Brown and Terrill (1972) reported that once-over harvest of flue-cured tobacco topped to 12 and 16 leaves when the middle leaves of the plant were deemed ripe did not significantly influence yield compared to multi-pass harvesting. Increasing topping height to 20 leaves and harvesting once-over reduced yield due to the increased number of leaves from lower and upper stalk positions that were not optimally ripe. Gwynn (1974) reported that at equivalent leaf populations harvesting once-over reduced yield compared to three harvests. Miner (1980) reported similar reductions (8%) in yield by harvesting once-over compared to multi-pass harvesting equal leaf populations. The chemical composition of flue-cured tobacco harvested once-over compared favorably to the middle leaves from a normal harvest (Brown and Terrill, 1973).

The objectives of this study were to (1) evaluate the reduction in the number of harvests on yield and cured leaf quality, (2) compare yield and quality of high leaf populations harvested once-over to conventionally managed flue-cured tobacco, (3) characterize the effect of increasing leaf population on plant and leaf components, and (4) evaluate the influence of increasing plant population utilizing uniform plant arrangements on yield and cured leaf quality of flue-cured tobacco.

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Chapter II.

Literature Review

Influence of Leaf Population on Yield and Quality

The present flue-cured tobacco supply control and price support system is based on acreage and poundage quotas. As a result, growers' interests have been best served by producing tobacco with the highest price, rather than producing excessive quantities. Manipulations of leaf populations per acre by altering plant population or leaf number per plant has been demonstrated to influence yield, visual quality and chemical composition of flue-cured tobacco (Chaplin et al., 1964, Chaplin et al. 1968, Coulson, 1959, Elliot, 1970, Tramel, 1967, Woltz, 1955, Woltz and Mason, 1966). Leaf populations have greater influence on yield and quality of flue-cured tobacco than plant spacing or topping height alone (Woltz and Mason, 1966). A leaf population of approximately 296,000 leaves per hectare has been identified as optimum to achieve the highest quality and sufficient quantity of cured leaf under the current quota system (Woltz and Mason, 1966). However, yield has been demonstrated to increase at leaf populations greater than 296,000 leaves, but at a compromise to quality and net profit.

Carr and Neas (1957) investigated the effects of three topping heights, three plant spacings and two nitrogen rates on yield and quality of flue-cured tobacco. Altering topping height had a greater influence on yield and value than from a relative change in plant spacing. The influence of topping height was confounded by the resulting delay in time of topping. All plants were allowed to come into early flower before they were topped to the desired number of leaves per plant. Marshall and Seltman (1964) later reported that for every day delay in topping after the desired number of leaves per plant was reached a one percent loss per day in cured leaf yield occurred. Woltz and Mason (1966) reported that yield is closely associated with the number of leaves per hectare and the relationship was not appreciably influenced by fertilizer, variety, topping height or plant spacing. Yield increased with higher topping height and with increasing plant population. Of more significance, was the effect of number of leaves per hectare on yield and the consistency of yield between varying topping height and plant population treatments with equal leaf population per hectare.

In a similar study, Collins et al. (1969) evaluated three leaf populations (296,000, 370,000 and 445,000) per hectare at two topping heights and two nitrogen rates. Yield per hectare increased (7.72%) as leaf population increased from 296,000 to 445,000 leaves per hectare; however, net price decreased (9.47%) more rapidly. An interaction between nitrogen rate and topping was observed. There was no difference in yield or value at the low topping height (17 leaves) between the recommended rate or the recommended rate plus twenty pounds. The recommended rate produced a higher price and net price at the 17 leaf topping height. At the higher topping height (20 leaves) yield, value, and net price were higher at the recommended rate plus twenty pounds. Woltz and Mason (1966) reported that at leaf populations exceeding 316,000 per hectare, a higher than recommended rate (4/3) of nitrogen improved preference of cured leaf. These data suggest that higher than recommended rates of nitrogen should be avoided when tobacco is topped relatively low, but higher rates may be desirable at higher topping heights.

Three flue-cured varieties were grown at 51, 61, or 71 cm plant spacing in rows 107 cm apart and topped at 14, 16, or 18 leaves (Elliot, 1970). Yields increased with increasing topping height, however, grade indexes tended to decrease. Closer plant spacing increased yield in two out of three years and produced no differences in grade index. Area of the top leaf decreased as topping height increased and as plant spacing decreased. Lamina weight decreased with increasing height of topping and closer plant spacing. Lamina weight was negatively correlated with leaf population per acre. Topping height exhibited more influence on lamina weight from leaves of middle stalk positions while closer spacing influenced lower leaves more dramatically. Woltz and Mason (1966) reported that increased topping height and plant population decreased the length and width of the eleventh leaf of three flue-cured tobacco varieties. Topping height and plant density effects on leaf size were similar, suggesting that leaf size, other factors being constant, is a function of leaf population. Woltz and Mason (1966) also observed a change in leaf shape at higher topping heights and closer plant spacing or higher leaf populations. Leaves became more narrow and peaked near the tips.

Influence of Leaf Population on Chemical Constituents

Nicotine provides the physiological strength in tobacco smoke and is the most characteristic chemical constituent of tobacco (Garner, 1950). Woltz et al. (1948) established a direct relationship between nicotine and total nitrogen in the cured leaf. The flavor and pleasing qualities of the taste of tobacco smoke are directly correlated with the nitrogenous constitutes of tobacco (Bates, 1958). A rather close association between the total nitrogen content and the apparent sensory strength or impact of tobacco smoke has been demonstrated. Tobacco with a higher total nitrogen content produces a stronger tasting, more pungent smoke compared to lower total nitrogen content. Working with six flue-cured varieties, Collins et al. (1965) associated cured tobacco with nitrogen:nicotine ratios above 1.0 with harsh, pungent smoke characteristics and ratios below 0.5 with smoke lacking flavor and impact.

Nicotine concentrations of tobacco leaves are influenced markedly by cultural practices and weather conditions (Campbell et al., 1982). Variations in plant population, topping height and soil fertility have significant effects. Total alkaloids are inversely associated with number of leaves per plant (topping height) and plant density (Elliot, 1970, Weybrew and Woltz, 1975). Topping height is a more effective diluter of total alkaloids than plant spacing (Campbell et al., 1982). Total alkaloids decreased as topping height was increased from 12 to 15 to 18 leaves per plant (Elliot, 1970). Total alkaloids were higher when tobacco was topped to 12 leaves even at a constant leaf population of 296,000 leaves per hectare and in the absence of a fertility gradient than higher topped plants (Weybrew and Woltz, 1975). Elliot (1970) reported differences in the nicotine content due to topping height or plant spacing were apparent at all individual harvests but were more pronounced in the harvest of the upper leaves. However, the relative rank of harvests varied for total N. The 14 leaf topping height resulted in the highest total N content for the third and fourth harvest while total N was highest in the fifth harvest of plants topped to 18 leaves. Total Nitrogen concentrations at a constant leaf population of 296,000 leaves per hectare were not influenced by topping height or row width (Weybrew and Woltz, 1975). Total nitrogen increased with fewer leaves, whether by lower topping or wider spacing, and the increase was associated with an effective per leaf fertility gradient (all treatments fertilized the same) (Weybrew and Woltz, 1975; Elliot, 1970).

Reducing sugar content of cured tobacco can be associated with quality within the range of 12 to 25 percent; however , there is no clear optimum (Collins, 1965). According to Harlan and Moseley (1955), very high levels of sugars impart tobacco with a smooth texture, dense structure, poor fire-holding ability and a smoke with poor aroma and flavor. Reducing sugar content of flue-cured tobacco tends to be highest in leaves of middle stalk positions and decrease toward the upper and lower regions of the stalk (Tso, 1990). Reducing sugar content of cured tobacco is inversely related to available nitrogen (Elliot, 1975). There is a clear association of high alkaloids and low sugars with droughty tobacco and conversely, of low alkaloids and high sugars with wet-weather tobacco (Weybrew et al., 1983). Cultural management has a profound effect on the quality of flue-cured tobacco and the associated chemical constituents (Weybrew and Woltz, 1975). Collins et al. (1961) reported a sugar to nicotine ratio of 10:1 as most appropriate for desirable smoking qualities. Tobacco with sugar to nicotine ratio over 15 are considered to be lacking in flavor and a ratio of less than 5 considered harsh (Tso, 1990). Elliot (1970) demonstrated that reducing sugars and the sugar to nicotine ratio decreased with increasing plant spacing. Reducing sugars and the sugar/nicotine ratio were shown to be positively correlated with leaf population. At extremely high plant population, Campbell et al. (1980) observed no significant effect of population on sugar content. Reducing sugar content of cured tobacco increased with higher topping (12 to 20 leaves) and closer plant spacings; however, no differences were observed at equal leaf populations (Weybrew and Woltz, 1975).

Influence of Harvest Method on Yield and Quality

Flue-cured tobacco is characteristically harvested by removing three to four leaves per harvest in approximately six weekly harvests (Tso, 1990). This multi-pass procedure is done to facilitate the sequential removal of leaves as they reach visual maturity thought to optimize leaf quality. Sequential harvesting is compatible with the government leaf grading system since the integrity of leaves from different stalk positions is maintained, thus allowing prediction of chemical and smoking qualities (Miner, 1980). The multi-pass procedure requires considerable expenditure of resources, primarily labor.

Restraints involving the availability and cost of necessary labor needed to harvest a crop have risen considerably over time. Harvest mechanization of flue-cured tobacco has increased as labor restraints have heightened. Multi-pass mechanical harvesters have the ability to harvest variable leaf numbers as leaves ripen. However, the efficiency of the machine is increased by fewer harvests of increased leaves per harvest (Gwynn, 1969). Consequently, the extreme reduction in number of harvests would be removal of all leaves in a single pass (once-over). Once-over harvest is controversial because leaves are mixed across stalk positions and tend to grade in the USDA leaf (B) grade group (Miner, 1980). Also, once-over harvest poses a concern to manufacturers who blend tobacco of specific leaf characteristics to produce characteristic American blend cigarettes.

Modified harvest systems that reduce the number of harvests including the once-over method have demonstrated favorable results in terms of leaf yield and leaf quality compared to normal harvesting (Brown and Terrill, 1972, Brown and Terrill, 1973, Gwynn, 1969, Gwynn, 1974, Miner, 1980). Tobacco topped at 12 and 16 leaves and harvested once-over, when middle leaves were judged ripe, produced yields similar to that of normal harvest (Brown and Terrill, 1972). However, normal harvest produced greater yields when plants were topped at 20 leaves. The top leaves of once-over harvested plants were still undergoing leaf expansion while lower leaves had become overly ripe. This resulted in lower yield. Generally, at similar leaf populations, yields are reduced by once-over harvest compared to normal harvest (Gwynn, 1974). Evaluating three plant populations, two topping heights and two transplanting dates, Miner (1980) reported a yield decrease (8.7%) associated with once-over harvest compared to normal multi-pass harvest at equal leaf populations. Once-over harvest of leaf populations 50 percent greater than recommended reduced the amount of land required to produce a specified quota by 12 percent, however 32 percent more transplants are required. Miner estimated gross and net returns of mechanically once-over harvesting, recommended, and 50 percent greater than recommended leaf populations. Gross and net returns increased by 13.5 and 17 percent, respectively, for the two leaf populations if the quota system was based solely on an acreage basis. Although, the land required to produce a specified quota at the higher population is reduced by 12 percent, net returns based on a poundage allotment would only be increased by 0.5 percent over normally recommended leaf populations based on results of this experiment.

Terrill (1975) reported that once-over harvest reduces yield and alters the chemical composition of the resulting cured leaves, especially with regard to stalk position differences. Once-over harvest resulted in lower percentage of soluble nitrogen in the lower leaves, but only slightly lower nicotine content. Reducing sugars increased as harvest intensity increased. Nicotine levels were reduced in the upper leaves of once-over harvested tobacco. Most of these chemical changes were associated with the degree of maturity. Brown and Terrill (1973) reported striking differences in the chemical composition of relative stalk positions of tobacco harvested normally and once-over. Once-over harvesting, initiated when middle leaves were deemed ripe, produced cured tobacco chemically comparable to that typical of middle stalk positions of tobacco harvested conventionally. The most dramatic alterations of chemical constituents by once-over harvest occurred in the nitrogen faction. Lower nicotine levels were indicative of the lower and upper stalk positions of once-over harvested treatments compared to normal harvest. Once-over treatments were harvested 2 to 3 weeks before the completion of harvest of normal multi-pass treatments. Moseley et al. (1963) reported a progressive increase in nicotine content with increasing maturity of normally harvested tobacco.

However, nicotine content of once-over harvested treatments was relatively constant over the range of stalk positions and did not follow the normal progression with increasing position that is typical of sequentially harvested tobacco (Moseley et al., 1963). When once-over treatments were harvested when the total plant was judged to be at optimum ripeness, Miner (1980) reported little effect by harvest method on total nitrogen, total alkaloids, or reducing sugars. Brown and Terrill (1973) observed that reducing sugar content of the lowest stalk position of normally harvested tobacco was significantly higher than that of once-over harvested tobacco. They stated that the over-maturity of lower stalk position of the once-over treatments resulted in increased respiration and thus depletion of accumulated starch. However, there were only small differences in reducing sugar content between the two harvest methods at other stalk positions.

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Chapter III.
The Effect of Plant Spacing, Topping Height, and Harvest Method on the Agronomic Characteristics of Flue-cured Tobacco

Abstract

The U.S. share of the world flue-cured tobacco market has steadily declined while international competitors have increased production of lower cost tobacco demanded for the manufacture of less expensive discount cigarettes. Although there is still a strong demand for high quality tobacco characteristic of U.S. leaf, this demand is not enough to sustain current production levels. Higher yielding production methods may allow growers to economically produce and market the style of tobacco demanded by the low-cost segment of the industry.

A two-year study was conducted to evaluate the influence of three plant spacings (30, 46, and 61 cm), two topping heights (15 and 20 leaves), and three harvest management variables on the agronomic characteristics of flue-cured tobacco. Harvest management treatments consisting of the conventional multi-pass (4-5 harvests, as-ripe), last-over (2 harvests), and once-over (single harvest) were evaluated on flue-cured tobacco spaced 61 cm within the row and topped to 15 and 20 leaves. All combinations of plant spacing and topping height treatments were utilized to evaluate the effects of leaf population on tobacco harvested once-over. Leaf populations twice the standard harvested once-over increased yield and value 6 and 11%, respectively, while grade index was not influenced significantly. Total alkaloids were unchanged and reducing sugars were reduced compared to the standard. Specific leaf weight, lamina weight, and midrib weight decreased with closer spacing, however, all once-over systems yielded 100% USDA leaf (B). Reducing harvest intensity and topping height of equal plant populations reduced yield but resulted in no effect on grade index and chemical constituents. Average

price was improved with fewer harvests due to the increasing proportion of yield grading USDA leaf (B). An expert smoking panel had no preference between systems regardless of leaf population or harvest method and determined all systems acceptable in quality.

The results of this study suggest that harvesting flue-cured tobacco in a single harvest without a reduction in yield will require higher than conventional leaf populations. Although increased inter-plant competition lowered reducing sugars content of the close spaced tobacco, the cured leaf was determined as usable as the standard treatment with a more desirable bulk density. The later maturity of the close-spaced treatments has the potential to improve efficiency of curing barn use and permit the production of additional tobacco with existing curing facilities.

Introduction

U.S. tobacco possesses unique chemical characteristics and superior flavor and aroma due to almost optimum growing conditions and two centuries of experience growing flue-cured tobacco. However, U.S. tobacco is available to the world market at a much higher price than that of its primary international competitors due to higher costs of production and the traditional market system that controls production and supports price. Brazilian flue-cured tobacco is available to world trade on a redried, free-on-broad basis, at prices ranging from 4 to 6.20 $U.S./kg compared to U.S. prices of 6 to 8 $U.S./kg (Glass, 1995). In recent years, the price differential between U.S. tobacco and other international sources, as well as a world tobacco surplus, has led to a softening demand for U.S. tobacco abroad. Exports of unmanufactured flue-cured tobacco decreased 15% between 1992 to 1993 (Tobacco S&O, 1994). During the same period, importation of flue-cured tobacco into the U.S. increased 58% (Tobacco S&O, 1993). The increase in tobacco imports coincided with an increase in sales of economy priced cigarettes which demanded a cheaper substitute for U.S. tobacco. The discount segment of the domestic market claimed 30.2% of industry sales in 1992 with projections for 1993 reaching 40% after being nonexistent a decade before (Maxwell, 1993). The influx of imported tobacco and the apparent willingness of consumers to accept lower priced substitutes for the premium brands that traditionally utilized domestically grown leaf triggered much debate within the industry on the potential ability of U.S. growers to competitively produce the lower-cost filler-type tobacco demanded by the market. A close grown tobacco production system was identified to potentially allow U.S. growers to produce the style of tobacco demanded by the market at a competitive price.

Traditionally, flue-cured tobacco has been grown managing plant spacing and topping heights to achieve leaf populations of 300,000 leaves per hectare. Classical research determined leaf populations of approximately 300,000 leaves per hectare produced the best compromise in yield and quality and thus satisfied the demands of the traditional market and marketing system (Woltz and Mason, 1966). Yield has been reported to increase with increasing leaf population above 300,000 leaves per hectare although at a detriment to quality. Collins et al. (1969) reported yield to increase 7.72% as leaf population increased from 300,000 to 445,000 leaves per hectare, while net price decreased more rapidly. Woltz and Mason (1966) reported that yield was closely associated with leaf population per hectare. Yield increased with increasing topping height and closer plant spacing. Increasing leaf populations per hectare may be a means of producing sufficient yield of acceptable quality filler-type tobacco that can be offered at a competitive price and remain profitable to produce.

Flue-cured tobacco, traditionally, has been harvested in 4 to 5 leaf increments from the bottom of the plant at approximately weekly intervals. This multi-pass procedure facilitates the sequential removal of leaves as they reach visual maturity thought to optimize leaf quality. Sequential harvesting is compatible with the USDA leaf grading system since the integrity of leaves from different stalk positions is maintained, thus allowing prediction of chemical and smoking qualities (Miner, 1980). The multi-pass procedure requires considerable expenditure of resources, primarily labor. Restraints involving the availability and cost of necessary labor needed to harvest a crop have risen considerably over time. Harvest mechanization of flue-cured tobacco has increased as labor restraints have heightened.

Modified harvest systems that reduce the number of harvests including the once-over method have demonstrated favorable results in terms of yield and leaf quality compared to traditional multi-pass harvesting (Brown and Terrill, 1972 and 1973, Gwynn, 1969, Gwynn, 1974, Miner, 1980). Tobacco topped to 12 and 16 leaves and harvested once-over when the middle leaves were judged ripe produced yields similar to that of multi-pass harvesting. Gwynn reported that at similar leaf populations per hectare that once-over harvesting reduced yield. Miner reported similar reductions (8.7%) in yield by harvesting once-over compared to multi-pass harvesting equal leaf populations. However, harvesting leaf populations 50 percent greater than recommended reduced the amount of land required to produce a specified quota by 12%. The increase in yield at a 50% greater leaf population than recommended compensated for the loss of yield incurred from once-over harvesting.

The objectives of this study were to: (1) evaluate the reduction in the number of harvests on yield and cured leaf quality, (2) compare yield and quality of high leaf populations harvested once-over to conventionally managed flue-cured tobacco, and (3) characterize the effect of increasing leaf population on plant and leaf components.

Materials and Methods

Field experiments were conducted at the Virginia Polytechnic Institute and State University, Southern Piedmont Agricultural Research and Extension Center near Blackstone, Virginia in 1993 and 1994 on a Chesterfield (like) - Mayodan (like) - Bourne (like) complex sandy loam soil (Typic Haplaudult, fine loamy, siliceous, thermic). Experiments were conducted in a randomized complete block design with four replications. Treatments evaluated included three plant spacings, two topping heights and three harvest methods in plots with rows 122 cm wide and 12.2 m long consisted of 20 plants of the flue-cured variety K 326 (Table 3.1). Plant spacings of 61, 46, and 30 cm and topping heights of 15 and 20 leaves in all combinations resulted in leaf populations ranging from 201,819 to 538,205 leaves per hectare. The 61 cm plant spacing treatments were repeated three times to evaluate the effects of three harvest procedures. The three harvest procedures evaluated were:

1. 4 to 5 sequential harvests of 4 to 5 leaves as leaves progressively ripen ascending the plant (as-ripe);
2. 2 harvests (last-over), leaves of the lower third of the plant are harvested followed by harvest of all remaining leaves when a compromise in maturity is reached within the group;
3. 1 harvest (once-over), lower ground leaves are allowed to over-mature and burn-off while upper leaves mature.

The 30 and 46 cm spaced treatments were only harvested by the once-over procedure. Nitrogen was supplied on a 1,000 leaf basis at a rate of 0.33 kg per 1,000 leaves (Table 3.1). A standard application of 785 kg/ha of 6-12-18 was applied in two bands 25 cm apart at bedding and additional nitrogen was supplied by sidedress application of 15-0-14 at appropriate rates for each treatment. Topping was performed at the elongated button stage when the desired number of leaves per plant was reached. Sucker control and other production practices not mentioned were consistent with Virginia Cooperative Extension recommendations for flue-cured tobacco production (Jones *et al.*, 1992). Irrigation was applied as needed to maintain adequate soil moisture.

Treatments harvested as last-over and once-over were separated at the time of harvest into stalk positions (Fig. 3.1) to allow sampling and grading of cured tobacco by position. Tobacco was then recombined as dictated by harvest treatment to facilitate sampling and grading by corresponding harvest method. Plot weights and official USDA grades were recorded and plot yield (kg/ha), average price (US$/kg), value per hectare and grade indexes were calculated. Grade index, a quantitative description of grade, (Bowman *et al.*, 1988) provides a means of uniform evaluation of the visual quality of the cured leaf, average price represents the average auction price of the representative grades of the cured leaf for the respective season, and value per acre reflects the average gross revenue of cured leaf produced on a hectare. Total alkaloids and reducing sugars were analyzed from a core sample from cured tobacco separated by stalk position and by harvest treatment grouping (Davis 1976; Horwirtz, 1980). In 1994, chemical analysis of the cured leaf of the once-over harvested treatments was performed on the uppermost leaf and every 5th leaf descending the stalk separately, in addition to stalk position analysis.

The American Tobacco Company evaluated chemical and smoking characteristics of the cured tobacco from the 1993 experiment. Treatments evaluated included T2, T4, T6, T9, and T10. Treatments were combined across reps and stalk positions to provide enough tobacco for the manufacture of cigarettes, thus statistical analysis of the data was not possible.

Chemical analyses were conducted on the cut and blended tobacco used for the manufacture of the experimental cigarettes using standard procedures of the American Tobacco Company Laboratory. Tobacco was formulated as an all flue-cured cigarette with no flavorings added. Cigarettes were manufactured to a uniform firmness to provide unbiased smoking characteristics (Table 3.2). Standard cigarette specifications were used to manufacture the cigarettes. Cigarette length was 99 mm with a filter length of 31 mm and an overwrap length of 35 mm. Ecusta 12409 cigarette paper was used to manufacture the cigarettes with non-perforated tipping and a model 5.0Y/28,000 w/2,700 PW @ 26 PD filter.

The experimental cigarettes for each treatment were smoked for determination of smoke chemistry by a Filtrona smoking machine (SM350). Cigarettes were smoked to a length of 61 mm with 35 cc puffs, a 2-second duration at 1 puff per minute. Values were averaged over 8 ports smoking 5 cigarettes each. Since tobacco was combined across reps, estimates of error were unavailable and means could not be separated.

Smoke flavor evaluations were conducted by a panel of 10 American Tobacco Company expert panelists. The panel evaluated the treatments by preference in pair comparisons (Fig. 3.1). The close spaced treatments, T9 and T10 were compared to evaluate the effect of topping height on the 30 cm treatments.

Leaf length and width were measured in 1994 for plants from the once-over harvest treatments. All leaves from three plants per plot were measured 5, 17, and 41 days after topping and a day prior to harvest. Leaf area (Suggs *et al.*, 1964) and leaf area index (Gardner *et al.*, 1985) were calculated.

$$\text{Leaf Area} = \text{length} \times \text{width} \times 0.6534$$

$$\text{Leaf Area Index} = \frac{\text{total leaf area per plant}}{(\text{row width} \times \text{plant spacing})}$$

Leaf positions 5, 10, 15, and 20 were removed from 2 or 3 (last sample date) plants per plot for destructive sampling. The uppermost leaf of the plant was considered the 15th or 20th leaf depending on topping height. Sampling was performed 10, 21, and 33 days after topping and a day prior to harvest. On the sampling date prior to harvest all leaves of the plant were sampled. Sampling involved measuring leaf length and width, separating and weighing lamina and midrib, and removing three disks (32.5 cm^2) per leaf for determination of specific leaf weight. Leaf disks were removed from three positions: one each from the tip of the leaf, from above the fourth lateral vein adjacent the midrib, and above the fourth lateral vein near the margin of the leaf. Fresh weights of the three leaf disks were recorded and leaf disks were then dried in an oven at 90 C and dry weights were determined. Specific leaf weight (mg/cm^2) was calculated on a dry basis (Gardner *et al.*, 1985).

$$\text{Specific Leaf Weight (SLW)} = \frac{\text{weight of 3 disks}}{\text{area of 3 disks } (97.42 \text{ cm}^2)}$$

Fresh lamina and midrib weights were recorded for each sample date. For the sampling immediately prior to harvest, lamina and midrib samples were dried in a forage dryer (90° C) and dry weights recorded. Lamina and midrib weights are presented on a dry basis. At harvest of the once-over treatments in 1994, leaves from stalk positions 5, 10, 15, and 20 were separated for curing. After curing, five intact leaves were chosen at random from each stalk position. Leaf and width measurements were made, leaf disks removed, and lamina and midrib separated for determinations described previously.

Analysis of variance was performed using the PROC ANOVA in SAS (SAS Institute, 1989). Treatment means were separated with the Waller-Duncan K-ratio test. Comparison of the control (T2, 61cm-20lvs as ripe) to the once-over harvested treatments

(T5-T10) was made using the Dunnett's test (Zar, 1984). Linear regression analysis (PROC REG in SAS) was used to quantify the effect of leaf population on variables measured for the treatments harvested once-over. Linear regression models of the effect of plant spacing of treatments harvested once-over were compared to evaluate the effects of topping height by means of *t*-tests for common slope and y-intercept (Kleinbaum et al., 1988).

Results and Discussion

Yield

Yield of the management systems studied ranged from 2,631 to 4,208 kg/ha in 1993 and from 2,782 to 3,647 in 1994 (Table 3.3). The 30 cm & 20 lvs once-over treatment (T10) produced the greatest yield in both years while the 61 cm & 15 lvs once-over treatment (T5) produced the lowest yield. The yield of 4 of 6 once-over harvested treatments in each year (T6, T8, T9, and T10 in 1993 and T7, T8, T9, and T10 in 1994) did not differ significantly from the standard 61 cm & 20 lvs as-ripe treatment (T2). The 30 cm & 20 lvs once-over treatment (T10) produced 328 (8%) and 163 (5%) kg/ha more cured leaf yield in 1993 and 1994 respectively, than the standard 61 cm & 20 lvs as-ripe treatment (T2). Treatments of equal leaf populations harvested once-over (T5 and 6) resulted in reduced cured leaf yield compared to the treatments harvested in 5 sequential harvests (T1 and 2). The last-over harvest procedure (T3 and T4) resulted in smaller decreases in yield due to less over-ripening occurring at the bottom of the stalk before harvest compared to the once-over harvest of similar leaf populations. These data suggest that harvesting recommended plant and leaf populations last-over would be a better compromise for reducing the number harvests compared to harvesting once-over.

Topping to fewer leaves per plant consistently reduced yield regardless of plant spacing or harvest method.

Yield losses observed with once-over harvesting most likely resulted from over-maturation and senescence of lower leaves as compared to the as-ripe harvested tobacco at equal plant densities. Harvesting flue-cured tobacco in a single harvest was demonstrated by Miner (1980) to decrease yield by 8.7% at equal leaf populations. Increasing leaf population compensated for this loss of lower stalk leaves and resulted in once-over harvest treatments of high leaf populations (T9 and 10) producing yields comparable to the standard as-ripe treatment (T2). Upper leaf positions produced the majority of the yield of the close spaced once-over treatments. Thus, mixing of stalk positions was minimized. These data also suggest that utilization of a once-over harvesting system in flue-cured tobacco without sacrificing significant yield, would require increasing plant population to produce a greater number of harvestable leaves.

Value

Value of the cured leaf produced by the ten management systems studied ranged from 10,796 to 17,067 US$/ha in 1993 and 11,024 to 14,455 US$/ha in 1994 (Table 3.3). The 61 cm & 15 lvs once-over treatment (T5) produced the lowest value in both years and was significantly less than the standard as-ripe treatment (T2). Value of 30 cm & 20 lvs once-over treatment (T10) was 1,920 (11%) and 1,760 (11%) US$/ha greater in 1993 and 1994, respectively, than the 61 cm & 20 lvs as-ripe standard treatment (T2) with the difference in 1994 being significant ($P<0.05$). The greater difference in value between the 30 cm & 20 lvs once-over treatment (T10) and the standard as-ripe treatment (T2) than with yield may be contributed to the once-over harvest procedure that tends to result in the majority of yield grading in the higher valued leaf (B) grade. Reducing the number of harvestable leaves per plant consistently decreased value for each plant spacing and harvest method.

Grade Index and Price

Harvest method had a greater influence on grade index and price than plant spacing and topping height. As the number of harvests was reduced, grade index and price increased regardless of plant spacing or topping height (Table 3.3). In 1993, no significant differences were observed in grade index for the 10 systems evaluated. As-ripe harvested treatments (T1 and T2) resulted in the lowest grade index; while grade index of the last-over harvested treatments (T3 and T4) were intermediate, and the once-over treatments (T5-T10) were the highest. Grade index in 1994 of treatments harvested last-over (T3 and 4) and once-over (T5-10) were significantly greater than the as-ripe harvested treatments (T1 and T2). No consistent difference in grade index was observed between the 15 and 20 leaf topping height treatments regardless of harvest method or plant spacing.

Average price of the management systems evaluated ranged from 3.90 to 4.10 US$/kg in 1993 and from 3.68 to 4.04 US$/kg in 1994 (Table 3.3). Average price of the as-ripe harvested treatments were the lowest in both years while the last-over harvested treatments were intermediate in price and the once-over harvest system resulted in the highest price/kg. Price increased with reduced harvest number due to higher proportion of tobacco grading as leaf (B). Reducing the number of harvests from the 5 sequential harvests (T1 and 2) to 2 harvests (T3 and 4) eliminated low priced priming (P) grade tobacco, reduced the proportion of cutter (C) tobacco, and consequently increased yield of the higher price leaf (B) tobacco (Fig. 3.3a and b). The once-over harvest procedure resulted in 100% leaf (B) tobacco, regardless of plant spacing or topping height. Lower priced leaves from the bottom of the stalk (priming) were lost to over-maturation and senescence under once-over harvest management. The increase in average price as the number of harvests was reduced can be attributed to the increase in total yield grading as higher priced leaf (B) grade and the elimination of the lower-priced priming (P) grade tobacco.

Price and grade index were observed to decline with increasing leaf population among once-over harvested systems in both years. However, the reduction was not as severe as that reported by Collins et al. (1969) under conventional sequential harvesting. The increased competition for light under conditions of closer plant spacing and increased topping height intensified the loss of lower leaves of the stalk and thus increased the proportion of the total yield of upper stalk tobacco under once-over harvest management. Although greater leaf populations increased yield of upstalk tobacco, the price and grade index of this tobacco declined due to loss of body that occurred from over crowding. The leaf (B) tobacco produced by the close spaced once-over treatments should possess desirable bulk density characteristics due to thinner body, thus making a suitable substitute for filler-type tobacco.

Chemical Constituents

Total alkaloids of the cured tobacco in 1993 were greatest for the 61 cm & 20 lvs as-ripe system (T2) and lowest from the 30 cm & 20 lvs once-over treatment (T10) (Table 3.4). Treatments T3, T5, T6, and T10 resulted in significantly lower total alkaloids than the standard 61 cm & 20 lvs as-ripe system. In 1994, total alkaloids ranged from 3.74 to 4.27% among systems evaluated with no statistically significant ($P>0.05$) differences observed.

Reducing sugars among the management systems ranged from 18.2 to 8.6% in 1993 and 11.5 to 4.8% in 1994 (Table 3.4). On average, reducing sugars were considerably lower in 1994 than 1993. Drought conditions are associated with high alkaloids and low reducing sugars (Weybrew et al., 1983); however, the 1994 growing season was more favorable than that of 1993. Tobacco in 1994 was grown following rotation, where as, that in 1993 followed tobacco. This may have led to the 1994 crop being over-fertilized resulting in lower reducing sugars and higher total alkaloids (Elliot, 1975). In 1993, treatments T1 and T6 resulted in the highest reducing sugars concentrations, with all treatments spaced 61 cm within the row having similar concentrations. Reducing sugars declined with closer plant spacing due to increased inter-row competition for light which reduced photosynthetic assimilation and increasing respiration. Treatments T9 (30cm & 15lvs) and T10 (30cm & 20lvs) resulted in significantly lower reducing sugars and treatments T7 (46cm & 15 lvs) and T8 (46cm & 20lvs) were intermediate in reducing sugars concentration compared to treatments spaced 61 cm within the row. Reducing sugars in 1994 were highly variable. Management systems of greater plant density resulted in lower reducing sugars. However, the 61 cm as-ripe treatments (T1 and 2) were considerably lower than those reported by Collins et al. (1965) for conventionally cultured flue-cured tobacco. In general, high plant and leaf populations lowered reducing sugars more than total alkaloids thus reducing the sugar to alkaloid ratio. Although the sugar to nicotine ratio of the close spaced once-over harvested management systems was lower than five (Tso, 1990), a smoking panel at American Tobacco Company had no preference among management systems and found all to be acceptable in flavor. Harvest method did not result in any consistent effect on reducing sugars of tobacco grown at similar leaf populations.

Smoke Analysis

Chemical analysis of the cut and blended tobacco for the manufacture of the model cigarettes conducted by the American Tobacco Company resulted in similar trends for total alkaloids reported earlier (Table 3.4 and 5). Nicotine content was very similar for the 5 treatments (T2, T4, T6, T9, and T10) evaluated (Table 3.5). Nicotine and total volatile bases (TVB) for all treatments were well within ranges considered acceptable for flue-cured tobacco. Sugar content of the 61cm-20lvs treatments (T2, T4, and T6) were very similar. However, the close spaced treatments (T9 and T10) were considerably lower in sugar content than the 61 cm plant spacing treatments (T2, T4, and T6). The lower sugar content of treatments T9 and T10 is consistent with replicated data.

Physical analysis of the properties of the model cigarettes indicated an increase in filling power and corresponding decrease in cigarette weight with the closer spaced treatments (Table 3.6). Harvest method, however, did not produce any change in filling power of cigarette weight among the 61cm-20lvs treatments. Cigarette weight of treatments T2, T4, and T6 was 135 g/100 cigarettes whereas cigarette weight decreased to 126 and 115 g/100 cigarettes for the 30 cm treatments topped to 15 and 20 leaves, respectively.

Smoke analysis of the model cigarettes found a decrease in the number of puffs per cigarette for the closer spaced treatments (T9 and T10) (Table 3.6). The 30cm-20lvs treatment (T10) produced a puff count similar to that of a blended cigarette (11 puffs). On a per cigarette basis, "tar" was unchanged across treatments, however, the "tar" delivery per puff increased for the once-over harvested treatments (T6, T9, and T10). The 30cm-20lvs treatment produced the greatest amount of "tar" per puff. The once-over harvested treatments produced smoke with lower nicotine content on a per cigarette basis.

On a per puff basis, the close spaced treatments had a higher nicotine level in the smoke. This can be attributed to the lower puff count per cigarette of the closer spaced treatments.

Panel smoke flavor evaluation of the model cigarettes resulted in no discrimination of tobacco harvested once-over or grown at higher leaf populations (Table 3.7 and 8). None of the paired comparisons resulted in a clear preference between the control treatment (T2) and the other treatments evaluated (Table 3.7). In all of the smoke-flavor comparisons, panelists unanimously judged all treatments including the close spaced treatments acceptable in terms of flavor and found no off-taste among any of the treatments.

Physical Characteristics

SLW Various physical leaf characteristics by stalk position measured immediately prior to harvest and after curing were influenced by reducing plant spacing for plants topped to 15 and 20 leaves. Specific leaf weight (SLW) immediately prior to harvest and after curing of the 5th, 10th, and 15th leaves of tobacco topped to 15 leaves decreased significantly in a linear manner with closer plant spacing (Fig. 3.5a and 6a). Reducing plant spacing from 61 to 30 cm reduced leaf SLW prior to harvest 25, 33, and 20% for stalk positions 5, 10, and 15, respectively. The reduction in SLW due to closer plant spacing did not result in any alteration in grade group designation as harvested once-over (100% leaf) for the 15 leaf topping height treatments. However, when evaluated by stalk position (Fig. 3.4b), only the upper stalk position group of the 30 cm treatment graded leaf (B) , where as, the two upper leaf groups of the 61 cm treatment graded leaf (B). Specific leaf weight prior to harvest of leaves from plants topped to 20 leaves decreased with plant spacing for each stalk position (Fig. 3.5b). Reducing plant spacing from 61 to 30 cm reduced leaf SLW 33, 29, 21, and 19% for stalk positions 5, 10, 15, and 20, respectively. The change in SLW with closer plant spacing was consistent for each stalk position, averaging 1.99 mg/cm^2. In contrast, cured leaf SLW did not respond significantly to plant spacing at the lower stalk positions 5 and 10 (Fig. 3.6b). This may be explained by the smaller number of intact leaves for the 30 cm plant spacing treatment from which the sample of five leaves was drawn due to more severe leaf loss. Thus, the intact leaves sampled were of above average body for the lower stalk positions. The 20 leaf topping height treatment also resulted in a decrease in number of stalk position groups grading leaf (B) with closer spacing. Only the upper stalk position group of the 30 cm treatment graded leaf (B) with the lower groups grading lug (X) and nondescript (N). In contrast, the two upper stalk position groups of the 61 cm treatment graded leaf (B) and the lower groups graded lug (X) without any nondescript (N). The inclusion of nondescript tobacco that does not meet the specifications of the lowest grade of any other group with closer plant spacing corresponds to the greater reduction in SLW at lower leaf positions of the stalk. Although the effect of closing plant spacing on leaf SLW altered group designation of lower stalk positions, the upper 5 leaves of the stalk of the 30 cm treatment produced the majority of yield resulting in 100% leaf (B) tobacco when harvested once-over.

Lamina and Midrib Lamina weight by stalk position of plants topped to 15 leaves immediately prior to harvest and after curing decreased with closer plant spacing for each stalk position (Fig. 3.7a and 8a). Lamina weight of cured leaves decreased 34, 40, and 30% for stalk positions 5, 10, and 15 when plant spacing was reduced from 61 to 30 cm. Midrib weight of the cured leaves by stalk position decreased with closer plant spacing (Fig. 3.10a). A significant linear response in percentage midrib to plant spacing was not observed (Fig. 3.12a). Cured lamina weight of plants topped to 20 leaves decreased significantly for each stalk position declining 21, 26, 35, and 23% for stalk positions 5, 10, 15, and 20, respectively, with closer plant spacing (Fig. 3.18b). Cured midrib weight decreased with closer plant spacing for leaf positions 5, 10, and 15 (Fig. 3.10b). Midrib weight of the 20th leaf did not respond to closer plant spacing, thus percentage midrib increased with closer plant spacing (Fig. 3.12b). Percentage midrib of the other stalk positions of plants topped to 20 leaves were not influenced by plant spacing (Fig. 3.12b). The equal reduction in lamina and midrib weight due to closer spacing suggests midrib weight is a function of leaf size and thickness. The decrease in lamina weight is consistent with the reduction in leaf SLW observed and the expected reduction in leaf size with higher plant densities (Gardner *et al.*, 1985). The lack of response in percentage midrib to closer spacing is advantageous because the ratio of midrib to lamina has a significant effect on utility of the cured leaf and the economics of cigarette manufacture.

<u>Leaf Length, Width, and Area</u> Immediately prior to harvest, leaf length, width, and area by stalk position of plants topped to 15 leaves did not respond significantly to plant spacing. After curing, leaf width decreased significantly ($P<0.05$) for each stalk position as plant spacing decreased from 61 to 30 cm (Fig. 3.13c). The average leaf width of the three stalk positions was 3.8 cm less for plants spaced 30 cm within the row compared to 61 cm. Leaf length and area of the cured leaves of the 15 leaf topping height treatments decreased with plant spacing for stalk positions 10 and 15 (Fig. 3.13a and e). Topping plants to 20 leaves intensified the effects of plant spacing on leaf dimensions of middle stalk positions. Leaf length, width, and area prior to harvest decreased with plant spacing for the 10th and 15th leaves of plants topped to 20 leaves. The width of leaves from each stalk position of the 20 leaf topping height was also influenced more by plant

spacing than was leaf length. The width of cured leaves decreased significantly for each stalk position with closer plant spacing (Fig. 3.13d). Cured leaves of the 61 cm plant spacing treatment were on average 3.69 cm wider than those of the 30 cm treatment. The reduction in cured leaf width with closer plant spacing especially for leaves from the mid-portion of the stalk explains the absence of cutters (C) grade tobacco with closer plant spacing. A cutter (C) leaf is described as a leaf that is very broad in relation to its length and has a rounded tip (Anonymous, 1989). Closer plant spacing reduced leaf width in relation to length producing a more pointed leaf resembling leaf (B) or lug (X) tobacco.

Stalk Height and Diameter Stalk height and diameter measured after the completion of harvest were significantly influenced by plant spacing and topping height. Stalk height of plants topped to 15 leaves per plant was significantly greater when plants were spaced 30 cm within the row (T9) compared to those spaced 46 (T7) and 61 (T5) cm (Fig. 3.14a). However, the effect of plant spacing on stalk height of tobacco topped to 15 leaves was not found to be significant (P=0.1911) under linear regression analysis (Fig. 3.15a). This suggests that for flue-cured tobacco topped to 15 leaves per plant there is a threshold where closer spacing results in increasing plant height through restriction of light and space. Stalk diameter of plants topped to 15 leaves decreased significantly with closer plant spacing from 61 to 46 to 30 cm (Fig. 3.14b and 15b). Stalk diameter decreased by 19% as spacing between plants decreased from 61 to 30 cm; a reduction of 0.195 mm per cm decrease in plant spacing.

Stalk height of plants topped to 20 leaves per plant increased significantly with decreasing plant spacing (Fig 3.14a). The 30 cm (T10) plant spacing treatment resulted in a 46% increase in stalk height compared to the 61 cm (T6) treatment (Fig. 3.15a). Stalk diameter of plants topped to 20 leaves per plant decreased significantly with closer plant spacing (Fig. 3.15b). Stalk diameter was greater by 15 and 13% for plants spaced 61 (T6) and 46 (T8) cm apart, respectively, than those spaced 30 cm (T10) within the row (Fig. 3.14b).

Internode length was influenced (P=0.0538) by increasing leaf population per hectare; increasing from 3.85 cm to 4.31 cm with an increase in leaf population from 201,819 to 538,205 leaves per hectare (Fig. 3.16a). Internode length responded similarly to decreasing plant spacing for each topping height (Fig. 3.16b).

Stalk strength and standablity are very important when considering harvesting flue-cured tobacco mechanically. Internode length (distance between successive leafs) is also an important consideration for efficient mechanical harvesting in multiple passes. Varieties are generally rated for internode length to evaluate their suitability for mechanical harvesting. Decreasing plant spacing between plants for each topping height effectively reduced the stalk diameter measured just above ground level (Fig. 3.15b). This raises the concern that stalks of closer spaced tobacco would not possess the strength to allow mechanical harvesting to be performed efficiently. The effect of closer spacing on stalk diameter and presumably stalk strength is increased by topping to 20 leaves. Topping tobacco to 20 leaves and reducing plant spacing substantially increased the height of stalks at harvest (Fig. 3.15a). The additional height of closer spaced plants presumably would increased the leverage force exerted on the stalk by the mechanical harvester. In addition to the cumulative effect of increasing stalk height and reducing stalk diameter on stalk strength, the 30 cm plant spacing treatments produced a phototrophic response in stalk growth. Stalks of the 30 cm plant spacing topped to 20 leaves (T10) were not aligned parallel with the bed of the row, but were crooked and twisted randomly toward row middles. The phototropism exhibited by stalks of the 30cm

& 20lvs treatment (T10) would impede mechanical harvesting as would a wind blown crop. In contrast to the negative effect of closer plant spacing on stalk diameter, internode length was improved with closer spacing as a result of increased stalk height (Fig. 3.16b). Increased internode length, theoretically, would increase the efficiency and selectively of mechanically harvesting flue-cured tobacco in several passes as leaves ripen. Increasing internode length would allow the mechanical harvester to harvest fewer leaves in a single pass, thus, more selectively harvesting those deemed ripe.

Leaf Loss Once-over harvest was conducted when the upper leaves of the stalk were judged to cure without producing any immature, green tobacco. Performing the once-over harvest at this stage of maturity, the lower leaves (priming leaves) were expected to be lost as a result over-maturity and senescence (burn-off). The loss of lower leaves increased significantly with increasing leaf population per hectare (Fig. 3.16c). The average number of leaves lost per plant increased from 1.4 to 5.67 leaves per plant as leaf population increased from 210,819 to 538,205 leaves per hectare. Topping height influenced the number of leaves per plant lost before harvest. The 20 leaf topping height treatments lost more leaves than did the 15 leaf topping height treatments (Fig. 3.16d). The 20 leaf topping height treatments averaged over plant spacing treatments lost 4.00 leaves per plant compare to only 2.25 leaves per plant for the 15 leaf topping height treatments. Closer plant spacing and greater topping height increased the number of lower leaves lost to over-maturity and senescence by effectively reducing the amount of light to reach the lower leaves. The restriction of light infiltration to the lower leaves reduced photosynthesis and increased respiration which accelerated deterioration of leaf lamina. The loss of lower leaves before harvest with closer plant spacing concentrated yield to the upper leaves of the plant which were not as severely influenced by closer plant spacing. The greater proportion of yield produced by the upper leaves of the plant with closer plant spacing combined with the loss of thinner bodied, less valuable lower leaves reduced mixing of stalk positions. Higher plant densities reduced the characteristic physical differences of leaves from different stalk positions demonstrated by the lack of tobacco from the 30 cm treatments to possess the characteristics of the cutter (C) group (Fig. 3.4b).

Leaf Area Index (LAI) The amount of leaf area per unit ground area (LAI) (Fig. 3.17a and b) and the total leaf area per plant (Fig. 3.17c and d) was significantly affected by plant spacing and topping height treatments. Leaf area index (LAI) of both the 15 and 20 leaf topping height treatments increased with decreasing plant spacing from 61 to 30 cm. The LAI of the 15 leaf topping height treatments was significantly different between each plant spacing 5 and 17 days after topping and immediately prior to harvest (Fig. 3.17a). The LAI 5 days after topping of the 30 cm & 15 lvs (T9) treatment was 42.5% greater than that of the 61 cm & 15 lvs (T5) treatment. At 17 days after topping, the LAI of the 30 cm & 15lvs treatment was 37% greater than the 61 cm & 15 lvs treatment following a larger in increase in LAI by 61 cm & 15 lvs treatment. Differences in LAI between the plant spacing treatments remained relatively constant from 17 days after topping until harvest. The LAI index of treatments topped to 20 leaves also increased significantly with decreasing plant spacing (Fig. 3.17b). The difference between plant spacing treatments remained relatively constant from topping until harvest. Unlike the treatments topped to 15 leaves, LAI of the 20 leaf treatments increased substantially for each plant spacing between 5 and 17 days after topping reaching a maximum and then declining until harvest. The greater increase in LAI of the 20 leaf treatments from 5 to 17 days after topping than the 15 leaf treatments was due to later maturity and more leaf expansion after topping. The decline in LAI was more severe with closer plant spacing corresponding to the differential loss of lower leaves to senescence of each plant spacing. The LAI of the 30cm & 20lvs (T10) treatment was 39% greater 17 days after topping than the 61cm & 20lvs (T6) treatment, however immediately prior to harvest the difference had declined to 32%. The LAI of the 30cm & 20lvs (T10) treatment declined 1.1 units between 17 days after topping and immediately prior to harvest, where as, the LAI of the 61cm & 20lvs (T6) treatment declined 0.3 units.

Although differences in LAI between plant spacing treatments for each topping height were relatively constant between topping and harvest, total leaf area per plant was similar immediately after topping for plant spacing treatments within topping heights (Fig. 3.17c and d). Differences in total leaf area among plant spacing treatments increased with expansion and maturity of the upper leaves after topping and total leaf area reached a maximum 17 days after topping corresponding to that observed with LAI. Total leaf area followed a similar trend as LAI declining from 17 days after topping until harvest.

LAI increased in a linear manner with increasing leaf population per hectare at each sample date. LAI immediately prior to harvest increased 0.062 units per 10,000 addition leaves per hectare (Fig. 3.18a). A significant linear response in total leaf area to leaf population was not observed (Fig. 3.18c). A significant linear response in LAI to increasing plant spacing occurred for both topping heights (P=0.0149, r^2=0.9995 and P=0.0088, r^2=0.9998, respectively) (Fig. 3.18b). Slopes and intercepts were not significantly different although the 20 leaf topping height produced a greater LAI for each plant spacing. Total leaf area did not respond to plant spacing in a linear manner (Fig. 3.18d), however, the 20 leaf topping height produced greater leaf area per plant for each plant spacing treatment. Although greater plant density increased leaf area, the tobacco plants were occupying essentially the same amount area within the row since row width was constant. The available photosynthetic radiation intercepted per area of row occupied by the tobacco plants was diluted over more leaf with closer plant spacing. The reduction in light intercepted per unit of leaf area resulted in less photosynthesis and therefore thinner bodies tobacco. This suggests that a more uniform plant and row spacing arrangement allowing increased interception of available light during the growing season would reduce the negative effects of competition for light.

Summary

A once-over harvest of flue-cured tobacco grown at a 2X normal leaf population did not produce a significant increase in yield compared to a normal leaf population harvested as-ripe in 5 sequential harvests. Flue-cured tobacco harvested in a single harvest was demonstrated by Miner (1980) to decrease yield by 8.7% compared to normal multi-pass harvesting at equal leaf populations per acre. The results of this study suggest that yields can be maintained under once-over harvesting by increasing plant population without detrimental effects on grade index and price. An expert smoking panel had no preference among systems and found all systems to possess acceptable flavor for flue-cured tobacco, although reducing sugars content was lowered by closer plant spacing. Yields of the close spaced tobacco harvested once-over did not increase to the extent that the cured leaf could be marketed at a substantially lower price without sacrificing gross income. Once-over harvesting would improve the efficiency of mechanically harvesting flue-cured tobacco, however, the phototrophic growth of stalks of 30 cm spaced plants would make efficient operation of a mechanical harvester difficult. In contrast, the loss of lower leaves and resulting concentration of yield in upper stalk positions would improve the adaptation of presently utilized last-over harvesting machines for once-over harvesting close spaced tobacco. The increased internode length and resulting less compact bud of tobacco spaced 30 cm within the row should allow better utilization of chemical topping thus, reducing associated costs. One hundred percent of the yield from once-over harvested treatments graded leaf (B) tobacco. This is consistent with earlier reports by Miner (1980). Grade group distribution of once-over treatments separated by stalk position revealed elimination of priming (P) grade tobacco from lower stalk positions compared to the as-ripe harvest. The lower leaves (primings) of the plant were lost to over-maturation and senescence before once-over harvesting. Substitution of nondescript (N) grade for priming grade at lower stalk positions occurred with higher leaf populations harvested once-over. Closer plant spacing reduced light infiltration to lower stalk positions producing thinner bodied lower leaves that deteriorated more rapidly than those from wider plant spacings. The leaves from the lower half of the stalk of the 30 cm treatment that remained at harvest graded nondescript (N) tobacco. The reduction in leaf width at middle stalk positions with closer plant spacing eliminated cutter (C) tobacco. Percentage midrib was not influenced significantly by closer plant spacing, although lamina and midrib weight decreased. Filling power of the cured leaf increased with closer plant spacing. Results from this study indicate that tobacco from the 30 cm plant spacing harvested once-over is of acceptable quality to be an acceptable substitute for other filler-type tobacco.

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Table 3.1. Plant spacing, topping height, and harvest treatments evaluated in 1993 and 1994.

Treatment		Plant	Leaf		
No.	Description[1]	population	population	N[2]	Harvest method
		pl/ha	lvs/ha	kg/ha	
T1	61 cm & 15 lvs as ripe	13,455	201,819	67	4 to 5 sequential harvests as-ripe
T2	61 cm & 20 lvs as ripe	13,455	269,092	90	4 to 5 sequential harvests as ripe
T3	61 cm & 15 lvs lastover	13,455	201,819	67	2 harvests, remove primings (P) and lugs (X) and harvest remaining leaves
T4	61 cm & 20 lvs lastover	13,455	269,092	90	2 harvests, remove primings (P) and lugs (X) and harvest remaining leaves
T5	61 cm & 15 lvs onceover	13,455	201,819	67	1 harvest, allow primings (P) to burnoff and harvest remaining leaves
T6	61 cm & 20 lvs onceover	13,455	269,092	90	1 harvest, allow primings (P) to burnoff and harvest remaining leaves
T7	46 cm & 15 lvs onceover	17,939	269,092	90	1 harvest, allow primings (P) to burnoff and harvest remaining leaves
T8	46 cm & 20 lvs onceover	17,939	358,789	120	1 harvest, allow primings (P) to burnoff and harvest remaining leaves
T9	30 cm & 15 lvs onceover	26,909	403,638	135	1 harvest, allow primings (P) to burnoff and harvest remaining leaves
T10	30 cm & 20 lvs onceover	26,909	538,205	179	1 harvest, allow primings (P) to burnoff and harvest remaining leaves

1 Treatment description, plant spacing within row (cm) & topping height (leaves/plant).
2 Nitrogen was applied at a constant rate per 1,000 leaves (0.33 kg/1,000 leaves).

Table 3.2. Physical properties of manufactured cigarettes for smoke and panel evaluations.

Physical Property	Treatment [1]				
	T2	T4	T6	T9	T10
Moisture, %	12.20	12.30	12.60	12.90	12.50
Firmness, as is, mm	1.95	1.81	1.87	2.00	2.04
Pressure Drop					
Cigarette open, cm	11.70	12.30	12.00	11.50	11.70
Tip closed, cm	6.70	6.80	7.40	7.20	7.10
Tobacco Column, cm	5.00	5.50	4.60	4.40	4.60
Circumference, mm	24.38	24.37	24.48	24.47	24.44

[1] T2, 61 cm & 20 lvs as-ripe; T4, 61 cm & 20 lvs last-over; T6, 61 cm & 20 lvs once-over; T9, 30 cm & 15 lvs once-over; T10, 30 cm & 20 lvs once-over.

Table 3.3. Agronomic characteristics of flue-cured tobacco as influenced by management systems in 1993 and 1994.

Treatment		1993				1994			
No.	Description [1]	Yield	Grade index	Price	Value	Yield	Grade index	Price	Value
		kg/ha	0 to 100	$/kg	$/ha	kg/ha	0 to 100	$/kg	$/ha
T1	61 cm & 15 lvs as-ripe	3,240*	71	3.92	12,700*	3,300	66	3.77	12,400
T2	**61 cm & 20 lvs as-ripe**	**3,880**	**72**	**3.90**	**15,100**	**3,480**	**60**	**3.68**	**12,800**
T3	61 cm & 15 lvs last-over	2,940**	70	4.01**	11,800**	2,890**	79**	3.92**	11,400
T4	61 cm & 20 lvs last-over	3,370	77	4.01**	13,500	3,410	81**	3.90**	13,300
T5	61 cm & 15 lvs once-over	2,630**	81	4.10**	10,800**	2,780**	81**	4.04**	11,200
T6	61 cm & 20 lvs once-over	3,570	79	4.10**	14,600	2,940**	78**	4.01**	11,700
T7	46 cm & 15 lvs once-over	3,240*	80	4.10**	13,300	3,210	80**	3.97**	12,700
T8	46 cm & 20 lvs once-over	3,440	80	4.10**	14,100	3,340	75**	3.99**	13,300
T9	30 cm& 15 lvs once-over	3,450	79	4.10**	14,100	3,590	74**	3.97**	14,200
T10	30 cm & 20 lvs once-over	4,210	75	4.06**	17,100	3,650	74**	3.97**	14,500

* , significantly different from 61 cm & 20 lvs as-ripe (Dunnett's test, $P<0.10$).
**, significantly different from 61 cm & 20 lvs as-ripe (Dunnett's test, $P<0.05$).
[1] Treatment description, plant spacing within the row (cm) & topping height (leaves/plant).

Table 3.4. Total alkaloids and reducing sugars of flue-cured tobacco as influenced by management systems in 1993 and 1994.

Treatment		1993		1994	
No.	Description [1]	Total Alkaloids	Reducing Sugars	Total Alkaloids	Reducing Sugars
		Percentage			
T1	61 cm & 15 lvs as-ripe	3.21	18.1	3.85	8.5
T2	**61 cm & 20 lvs as-ripe**	**3.71**	**15.0**	**3.80**	**5.9**
T3	61 cm & 15 lvs last-over	2.57**	14.6	3.81	10.0
T4	61 cm & 20 lvs last-over	2.84	14.4	3.82	10.1
T5	61 cm & 15 lvs once-over	2.58**	15.7	3.74	11.1**
T6	61 cm & 20 lvs once-over	2.49**	18.2	3.91	9.0
T7	46 cm & 15 lvs once-over	3.06	12.5	3.83	11.5**
T8	46 cm & 20 lvs once-over	2.81	11.4	4.27	6.2
T9	30 cm& 15 lvs once-over	2.98	8.6**	4.22	5.7
T10	30 cm & 20 lvs once-over	2.45**	9.5*	3.86	4.8

* , significantly different from 61 cm & 20 lvs as-ripe (Dunnett's test, $P<0.10$).
**, significantly different from 61 cm & 20 lvs as-ripe (Dunnett's test, $P<0.05$).
[1] Treatment description, plant spacing within row (cm) & topping height (leaves/plant).

Table 3.5. Chemical analysis of the cut and blended tobacco of selected treatments in 1993 before the manufacture of cigarettes.

	Treatment [1]				
Constituent	T2	T4	T6	T9	T10
Nicotine, %	3.72	3.41	3.17	3.75	3.62
TVB as NH_3, %	0.525	0.500	0.452	0.593	0.552
TVB-Nicotine	0.135	0.142	0.119	0.179	0.171
Nic/TVB	0.74	0.72	0.74	0.69	0.69
Sugars					
Before Inversion, %	19.5	20.7	22.1	12.8	12.6
After Inversion, %	22.2	2.35	24.1	15.5	15.1
Difference, %	2.7	2.9	2.0	2.7	2.5
Ash, %	10.77	10.23	9.63	11.84	11.09
Sand, %	0.9	0.5	0.5	0.6	0.3
Cl, %	0.31	0.35	0.39	0.34	0.33
pH	5.1	5.0	5.1	5.1	5.1

[1] T2, 61 cm & 20 lvs as-ripe; T4, 61 cm & 20 lvs last-over; T6, 61 cm & 20 lvs once-over; T9, 30 cm & 15 lvs once-over; T10, 30 cm & 20 lvs once-over.

Table 3.6. Physical and smoke analysis conducted by American Tobacco Company on the manufactured cigarettes of the selected treatments from 1993.

	Treatment [1]				
	T2	T4	T6	T9	T10
Physical Properties					
Tobacco Filling Power, cc/g	3.2	3.3	3.3	3.5	3.8
Cigarette Weight, g/100	135	135	135	126	115
Smoke Analysis					
Puffs per cigarette	15.6	15.2	14.9	13.9	11.8
Tar					
mg/cigarette	27.29	26.84	27.83	26.36	25.28
mg/puff	1.75	1.77	1.87	1.89	2.15
Nicotine					
mg/cigarette	4.01	3.61	3.24	3.54	3.15
mg/puff	0.26	0.24	0.22	0.25	0.27
Sum of Tar and Nicotine					
mg/cigarette	31.30	30.45	31.07	29.80	28.43
mg/puff	2.01	2.01	2.09	2.14	2.42

[1] T2, 61 cm & 20 lvs as-ripe; T4, 61 cm & 20 lvs last-over; T6, 61 cm & 20 lvs once-over; T9, 30 cm & 15 lvs once-over; T10, 30 cm & 20 lvs once-over.

Table 3.7. Panel smoke flavor evaluations of manufactured cigarettes for selected treatments[1] from 1993 by preference to the control treatment (T2).

	Paired Comparisons											
Property	T2	T4	No choice	T2	T6	No choice	T2	T9	No choice	T2	T10	No choice
More Impact	9	0	1	3	5	2	2	8	0	3	7	0
More Flue-cured character	6	1	3	4	2	4	4	5	1	4	2	4
Smoother	2	8	0	5	4	1	5	3	2	5	1	4
Smoke												
Sweeter Smoke	2	2	6	4	3	3	3	4	4	3	3	4
Dryer Smoke	3	4	3	2	3	5	1	4	5	2	5	4
More Resinous	8	0	2	2	4	4	3	6	1	2	4	4
Preference	**4**	**5**	**1**	**5**	**2**	**3**	**2**	**4**	**4**	**4**	**3**	**3**

[1] T2, 61 cm & 20 lvs as-ripe; T4, 61 cm & 20 lvs last-over; T6, 61 cm & 20 lvs once-over; T9, 30 cm & 15 lvs once-over; T10, 30 cm & 20 lvs once-over.

Table 3.8. Panel smoke flavor evaluation of the manufactured cigarettes for the selected two close spaced once-over harvested treatments[1] by preference.

Property	(T9)	(T10)	No choice
More Impact	2	4	4
More Flue-cured character	2	2	6
Smoother Smoke	3	6	1
Sweeter Smoke	3	4	3
Dryer Smoke	0	2	7
More Resinous	3	5	2
Preference	**4**	**4**	**2**

[1] T9, 30 cm & 15 lvs once-over; T10, 30 cm & 20 lvs once-over.

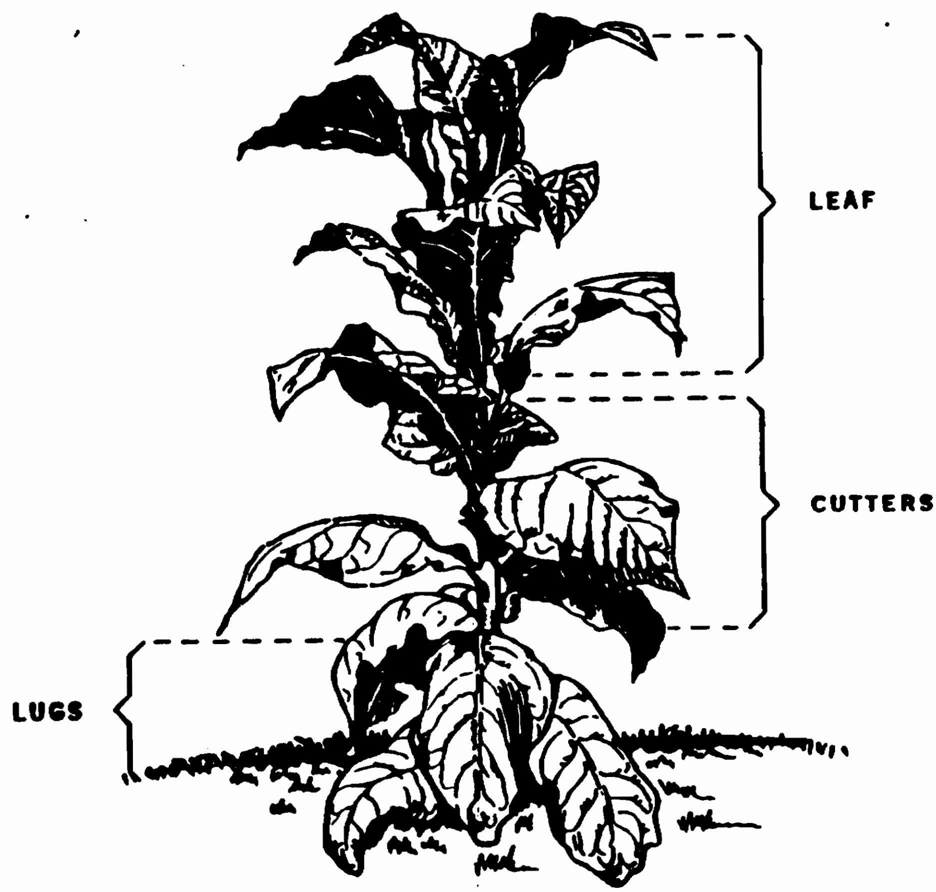


Fig. 3.1. Approximate location of flue-cured tobacco leaf groups.

Smoke Flavor Evaluation

Flue-Cured Tobacco - Production Study

Panel Number ____________ Date __________

Panelist _________________

Sample Code	**Paired Comparison**		
	______	______	**No Choice**
More Impact?	______	______	______
More Flue-Cured Character?	______	______	______
Smoother Smoke?	______	______	______
Dryer Smoke?	______	______	______
More Resinous?	______	______	______
Acceptable? (Yes/No)	______	______	______
Preference?	______	______	______
Off-taste? (Yes/No)	______	______	

Describe: ____

Comments ____

____

____

Fig. 3.2. Smoke panel evaluation form used by the expert smoking panel of American Tobacco Company to evaluate the selected treatments from 1993 by paired comparisons.

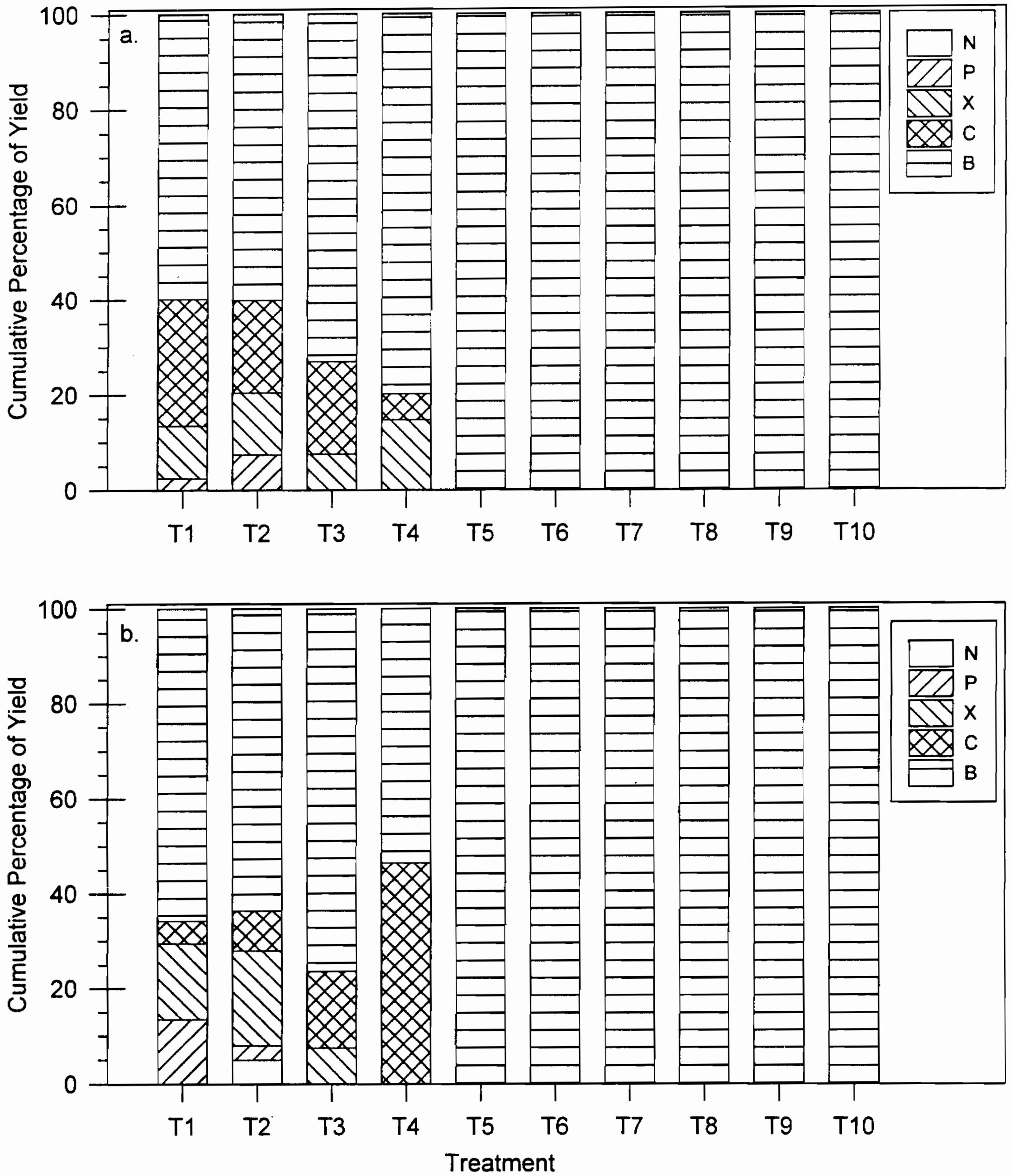


Fig. 3.3. Influence of management systems on the percentage of yield by grade group in 1993 (a) and 1994 (b).

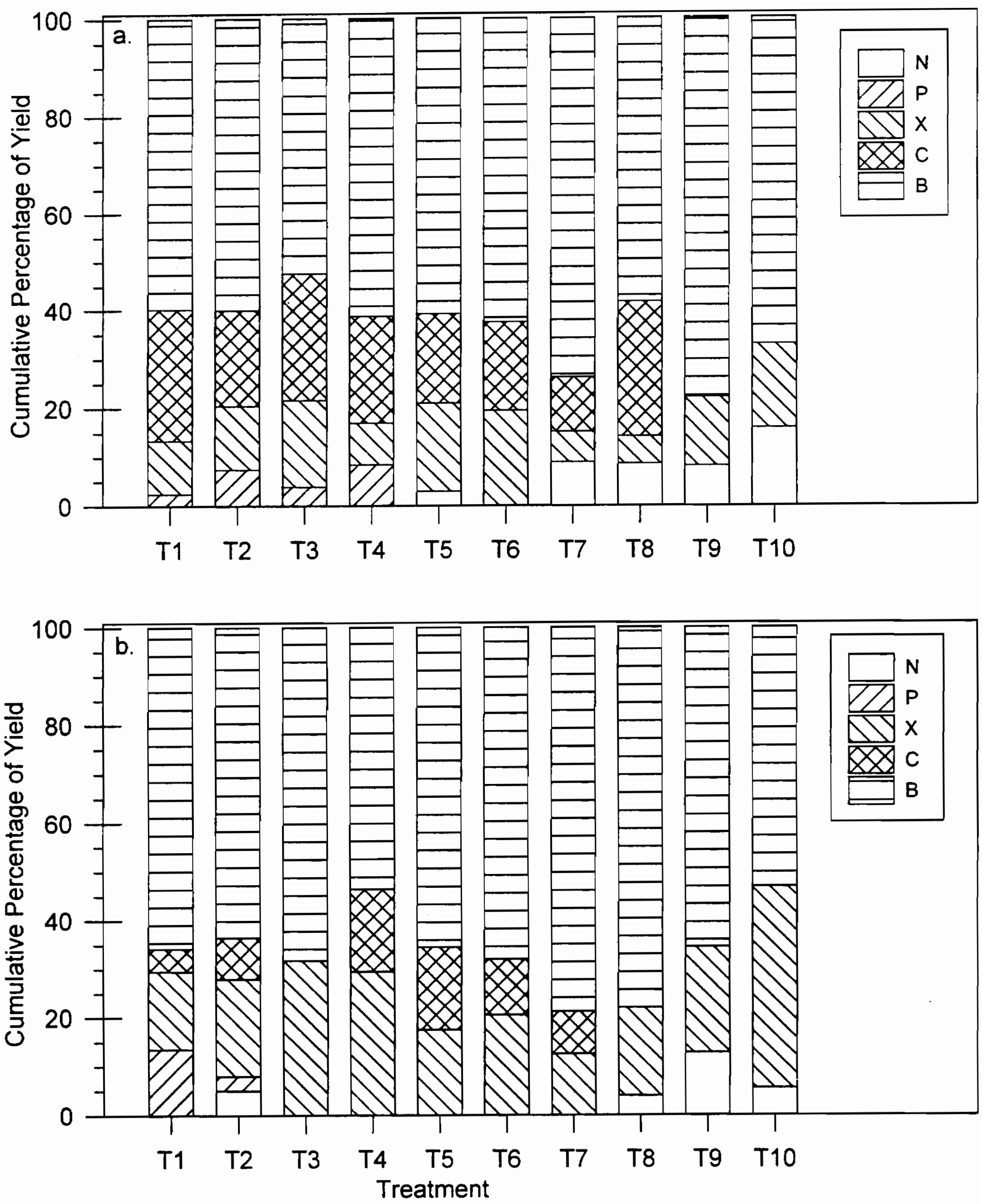


Fig. 3.4. Influence of harvest method, plant spacing, and topping height treatments on the percentage of yield by grade group in 1993 (a) and 1994 (b) separated by stalk position.

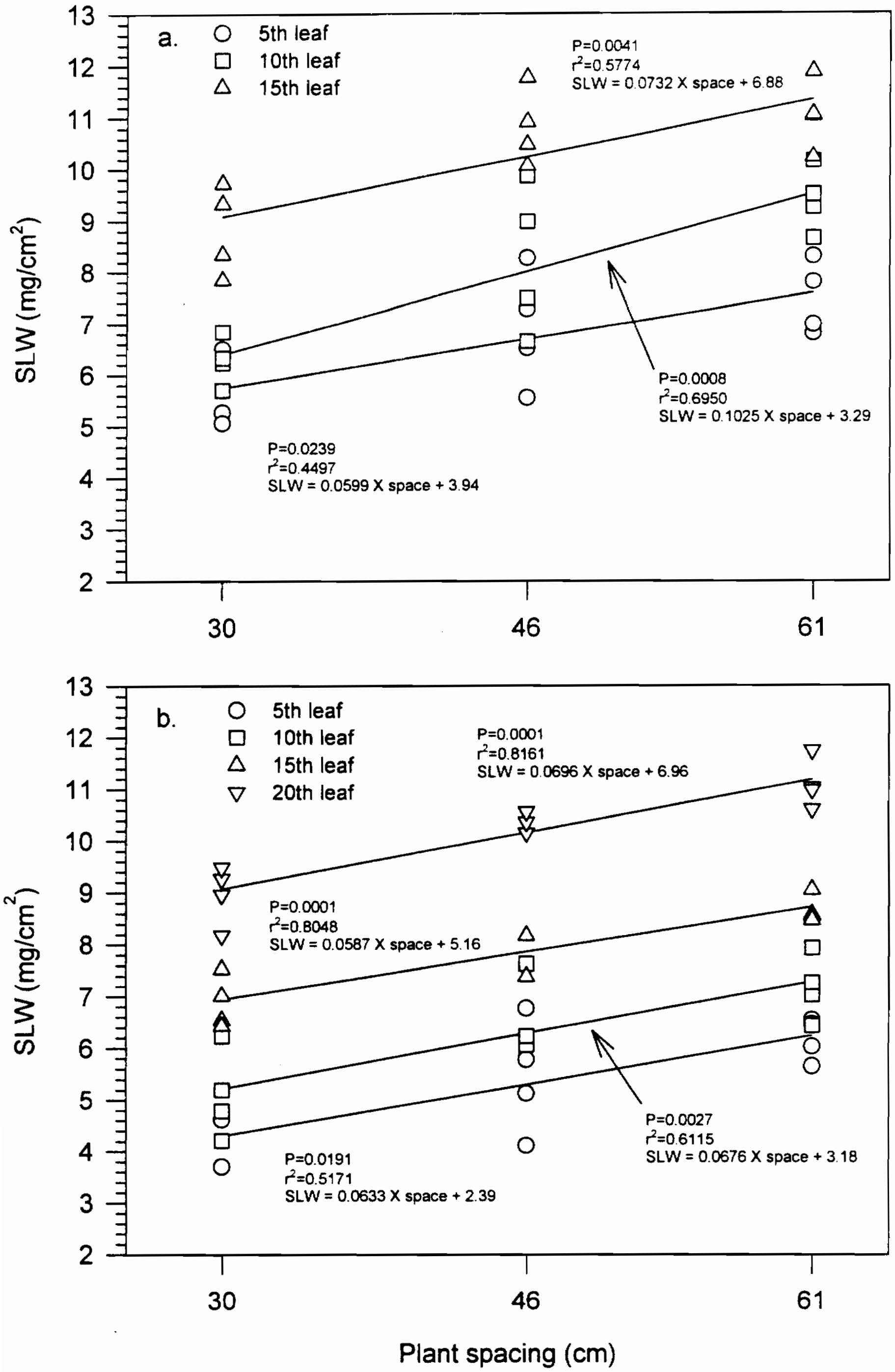


Fig. 3.5. Influence of plant spacing on specific leaf weight (SLW) by stalk position of fresh leaves immediately prior to harvest of flue-cured tobacco topped to 15 (a) and 20 (b) leaves.

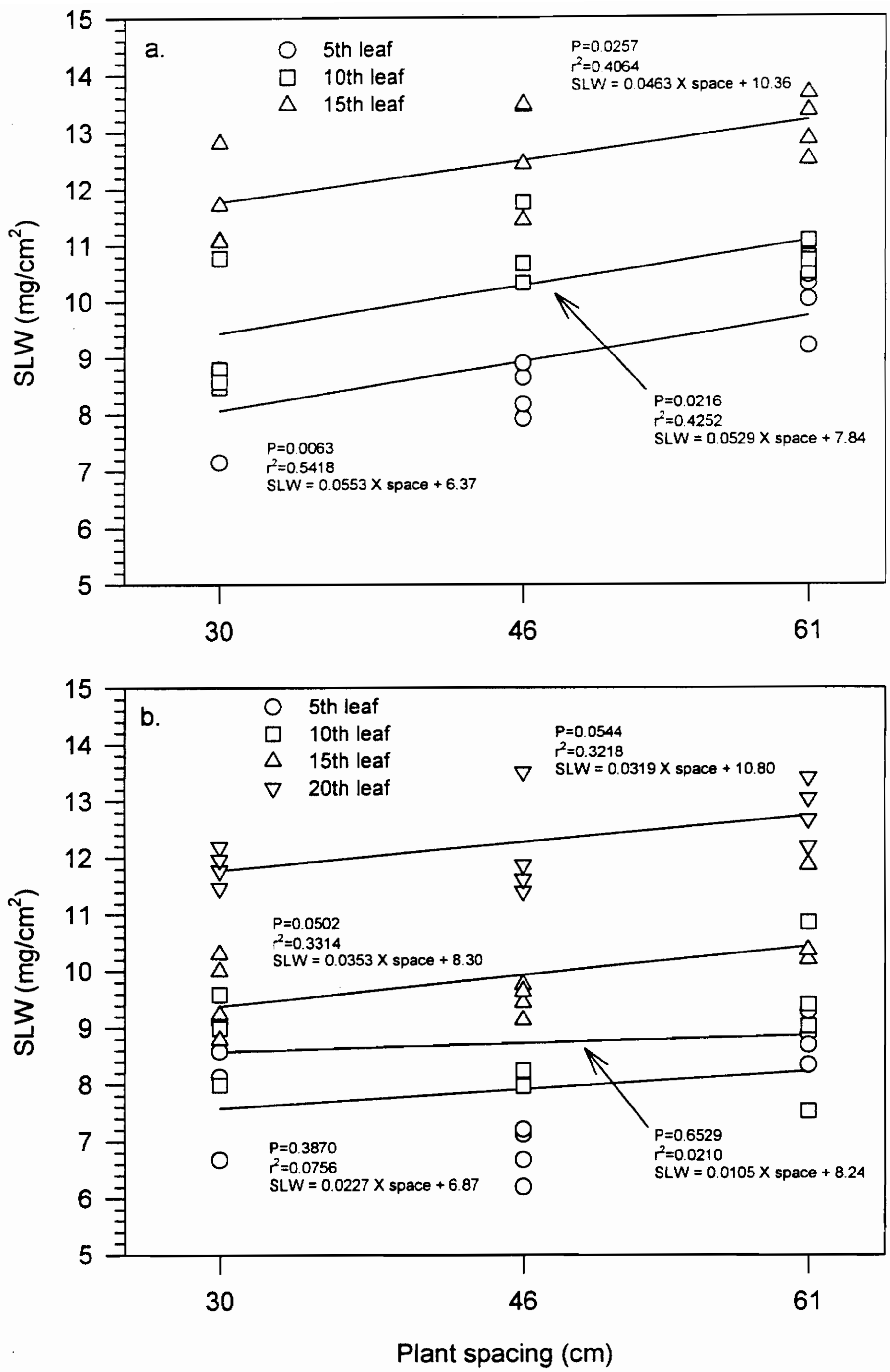


Fig. 3.6. Specific leaf weight (SLW) by stalk position of cured leaves of flue-cured tobacco topped to 15 (a) and 20 (b) leaves as influenced by plant spacing.

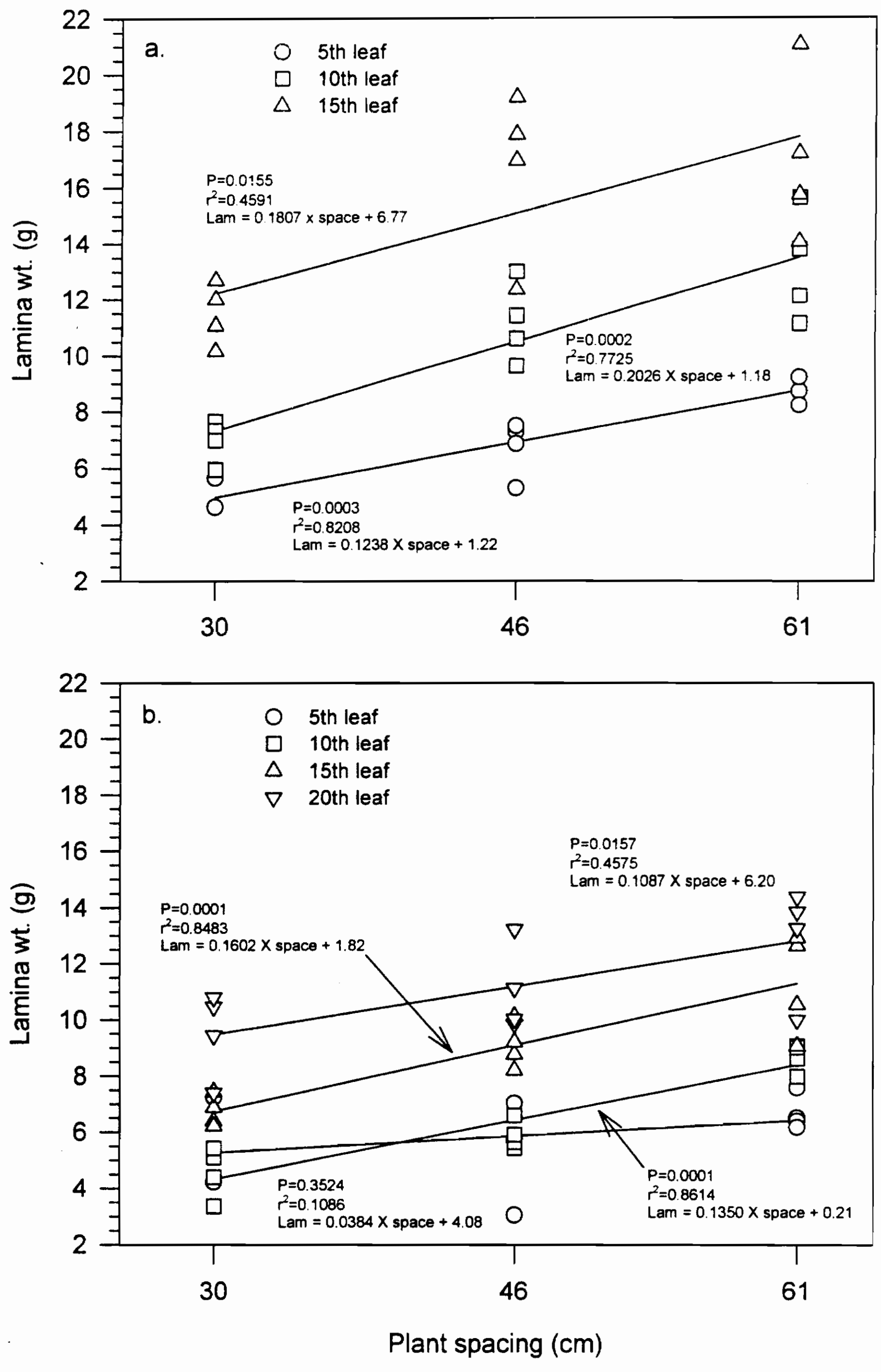


Fig. 3.7. Influence of plant spacing on lamina weight by stalk position of fresh leaves of flue-cured tobacco topped to 15 (a) and 20 (b) leaves immediately prior to harvest.

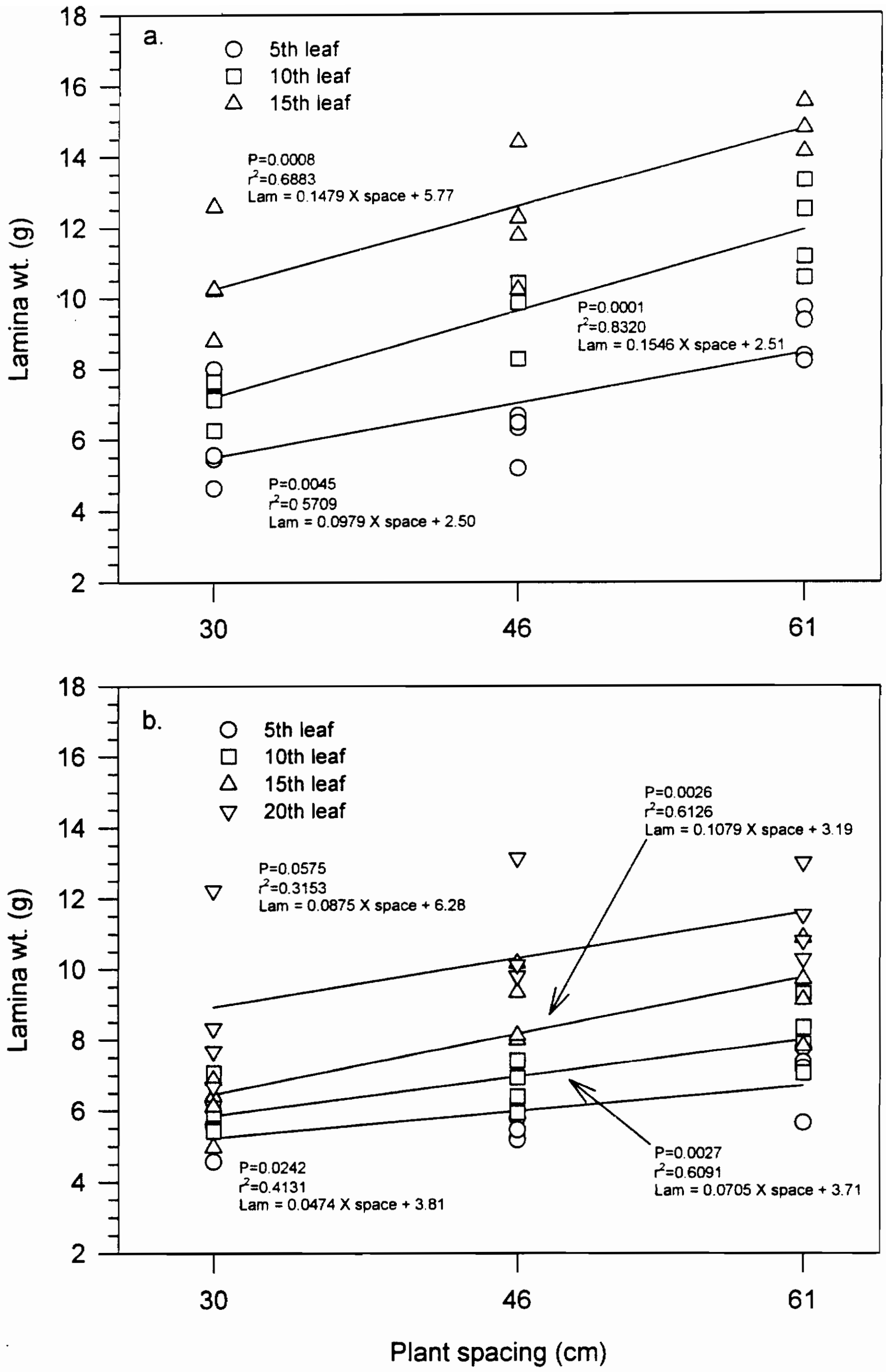


Fig. 3.8. Lamina weight by stalk position of the cured leaves of flue-cured tobacco topped to 15 (a) and 20 (b) leaves as influenced by plant spacing.

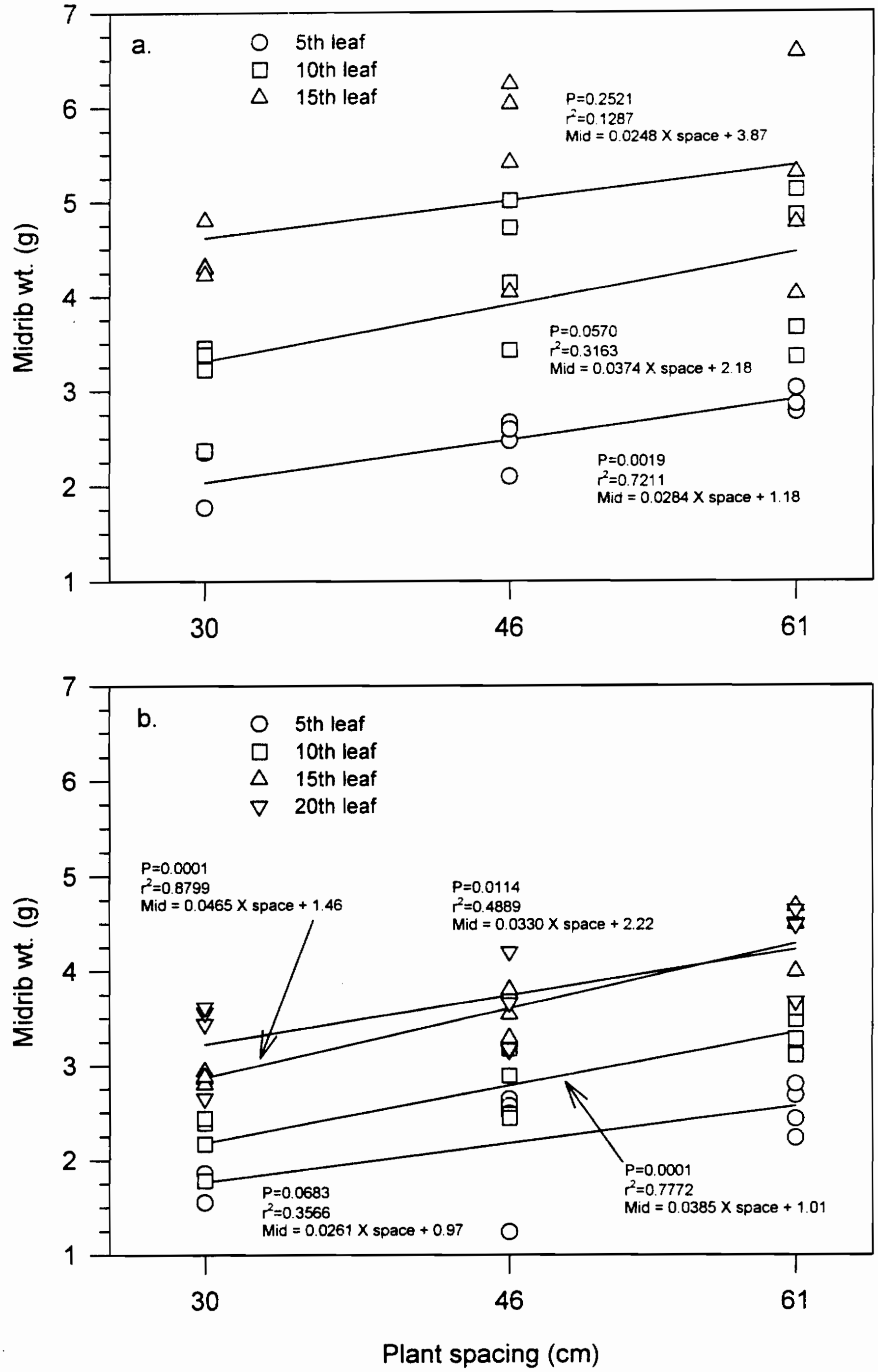


Fig. 3.9. Influence of plant spacing by stalk position on midrib weight immediately prior to harvest of leaves of flue-cured tobacco topped to 15 (a)and 20 (b) leaves.

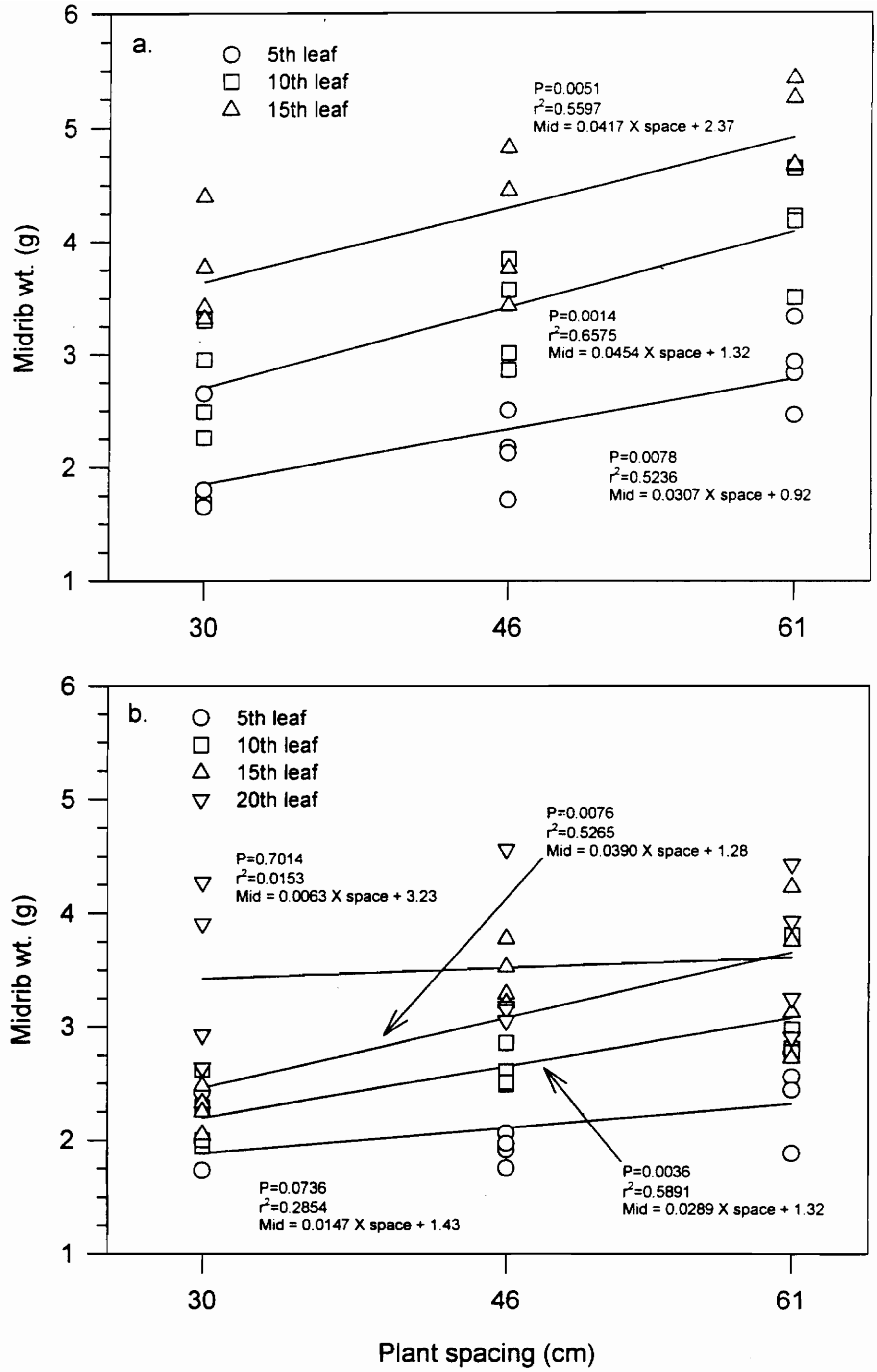


Fig. 3.10. Influence of plant spacing by stalk position on midrib weight of the cured leaves of flue-cured tobacco topped to 15 (a) and 20 (b) leaves.

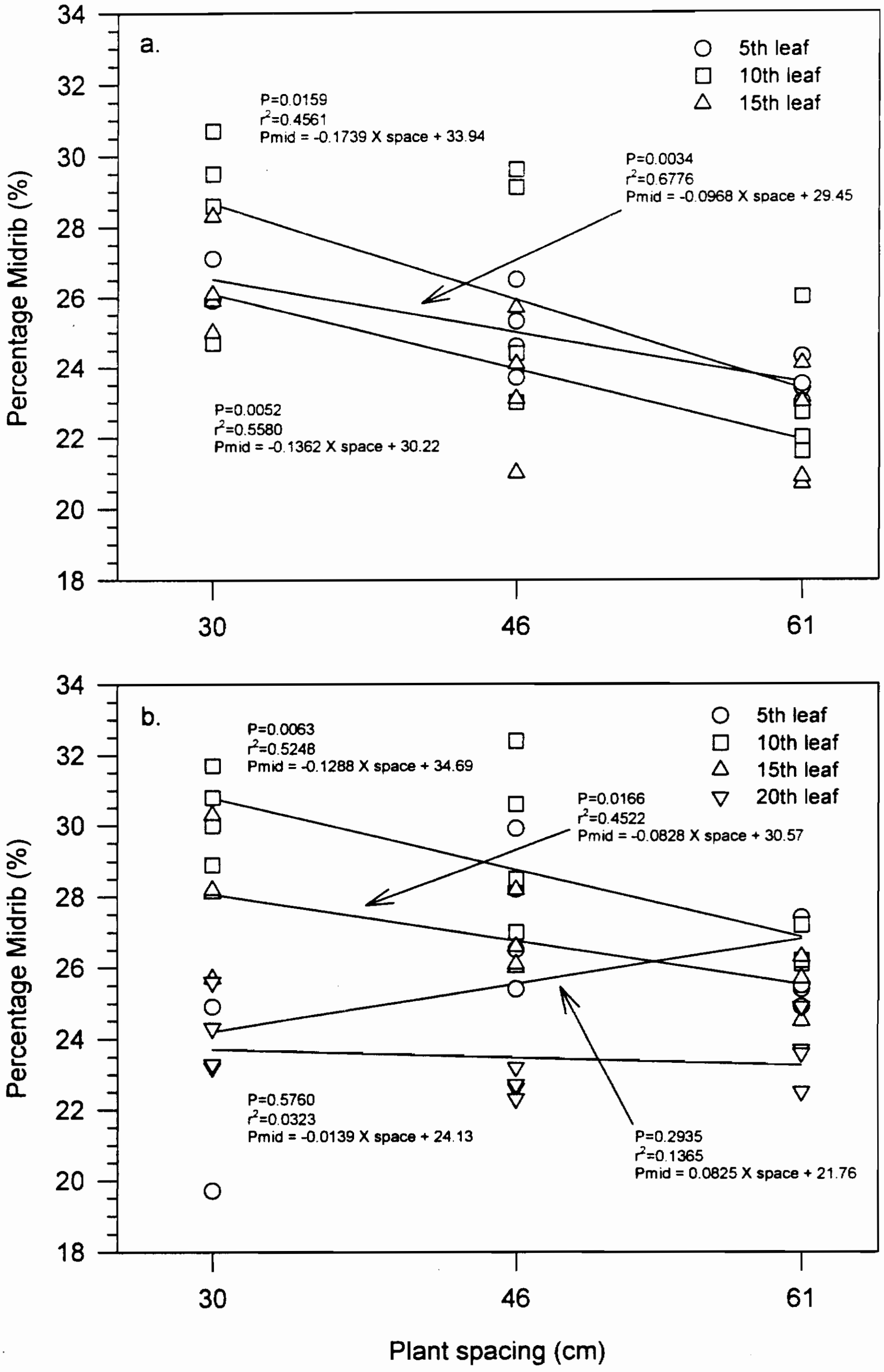


Fig. 3.11. Influence of plant spacing by stalk position on percentage midrib of leaves immediately prior to harvest of flue-cured tobacco topped to 15 (a) and 20 (b) leaves.

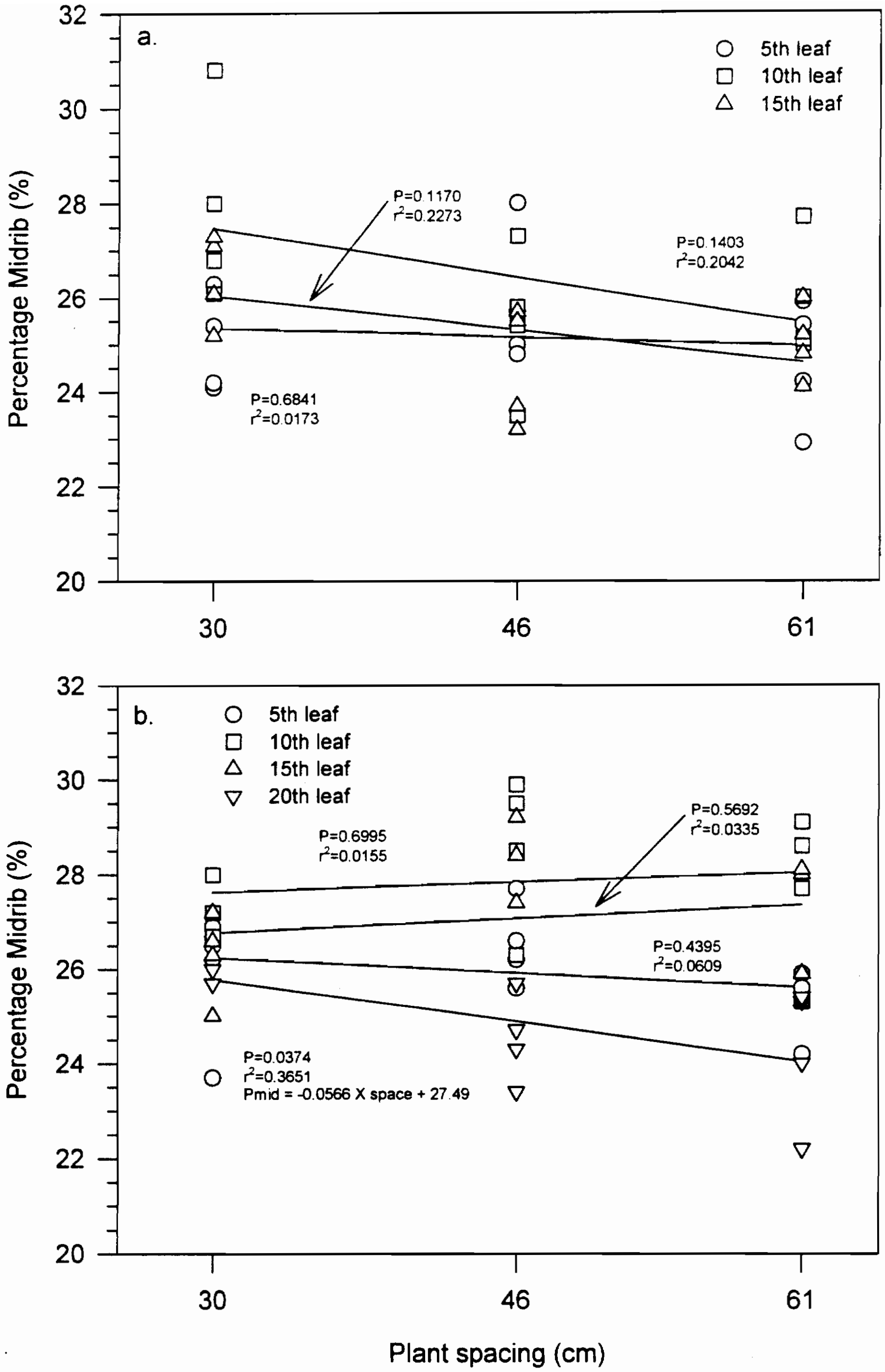
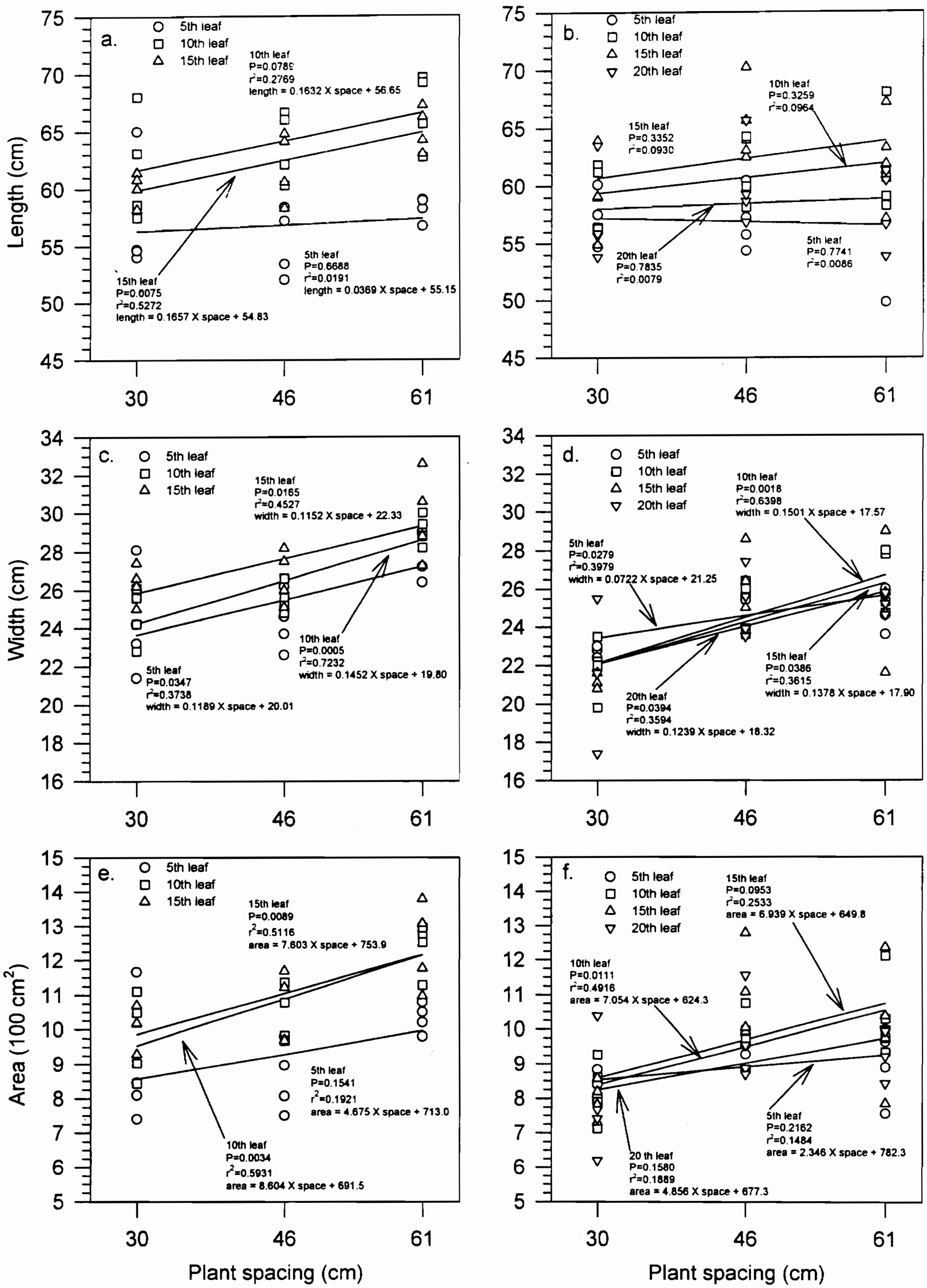


Fig. 3.12. Influence of plant spacing by stalk position on percentage midrib of the cured leaves of flue-cured tobacco topped to 15 (a) and 20 (b) leaves.

Fig. 3.13. Influence of plant spacing by stalk position on length (a), width (c), and area (e) of cured leaves of once-over harvested flue-cured tobacco topped to 15 leaves per plant. The influence of plant spacing by stalk position on length (b), width (d), and area (f) of cured leaves of once-over harvested flue-cured tobacco topped to 20 leaves per plant.


a.
5th leaf
10th leaf
15th leaf
10th leaf P=0.0789 r²=0.2769 length = 0.1632 X space + 56.65
15th leaf P=0.0075 r²=0.5272 length = 0.1657 X space + 54.83
5th leaf P=0.6688 r²=0.0191 length = 0.0369 X space + 55.15
b.
5th leaf
10th leaf
15th leaf
20th leaf
10th leaf P=0.3259 r²=0.0964
15th leaf P=0.3352 r²=0.0930
20th leaf P=0.7835 r²=0.0079
5th leaf P=0.7741 r²=0.0086
Length (cm)
c.
5th leaf
10th leaf
15th leaf
15th leaf P=0.0165 r²=0.4527 width = 0.1152 X space + 22.33
10th leaf P=0.0005 r²=0.7232 width = 0.1452 X space + 19.80
5th leaf P=0.0347 r²=0.3738 width = 0.1189 X space + 20.01
d.
5th leaf
10th leaf
15th leaf
20th leaf
10th leaf P=0.0018 r²=0.6398 width = 0.1501 X space + 17.57
5th leaf P=0.0279 r²=0.3979 width = 0.0722 X space + 21.25
15th leaf P=0.0386 r²=0.3615 width = 0.1378 X space + 17.90
20th leaf P=0.0394 r²=0.3594 width = 0.1239 X space + 18.32
Width (cm)
e.
5th leaf
10th leaf
15th leaf
15th leaf P=0.0089 r²=0.5116 area = 7.603 X space + 753.9
5th leaf P=0.1541 r²=0.1921 area = 4.675 X space + 713.0
10th leaf P=0.0034 r²=0.5931 area = 8.604 X space + 691.5
f.
5th leaf
10th leaf
15th leaf
20th leaf
15th leaf P=0.0953 r²=0.2533 area = 6.939 X space + 649.8
10th leaf P=0.0111 r²=0.4916 area = 7.054 X space + 624.3
5th leaf P=0.2162 r²=0.1484 area = 2.346 X space + 782.3
20 th leaf P=0.1580 r²=0.1889 area = 4.856 X space + 677.3
Area (100 cm²)
Plant spacing (cm)
Plant spacing (cm)
30
46
61

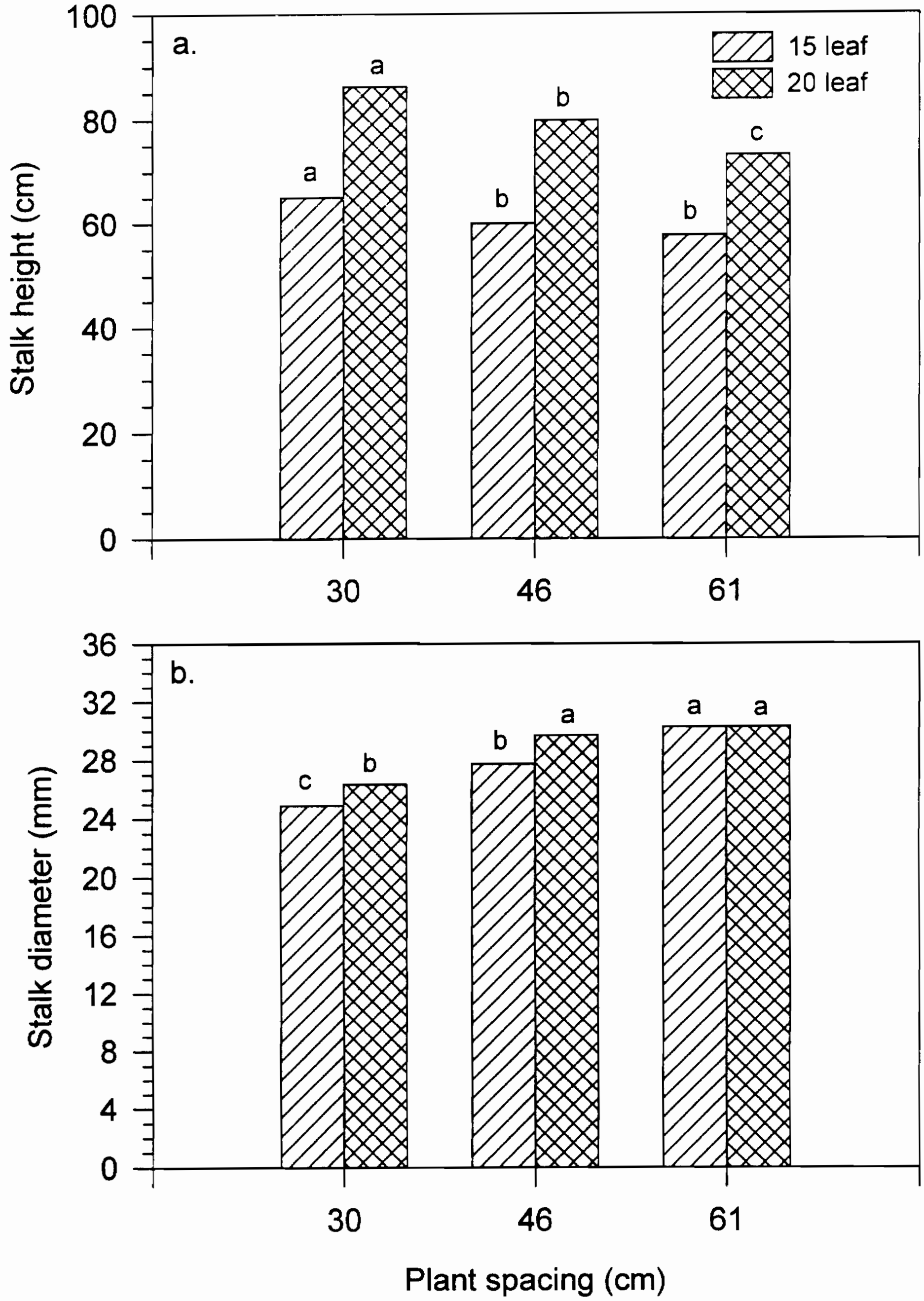


Fig. 3.14. Mean stalk height (a) and stalk diameter (b) as influenced by plant spacing and topping height of flue-cured tobacco. (Topping height means followed by the same letter are not significantly different, Waller-Duncan K-ratio test, P<0.05).

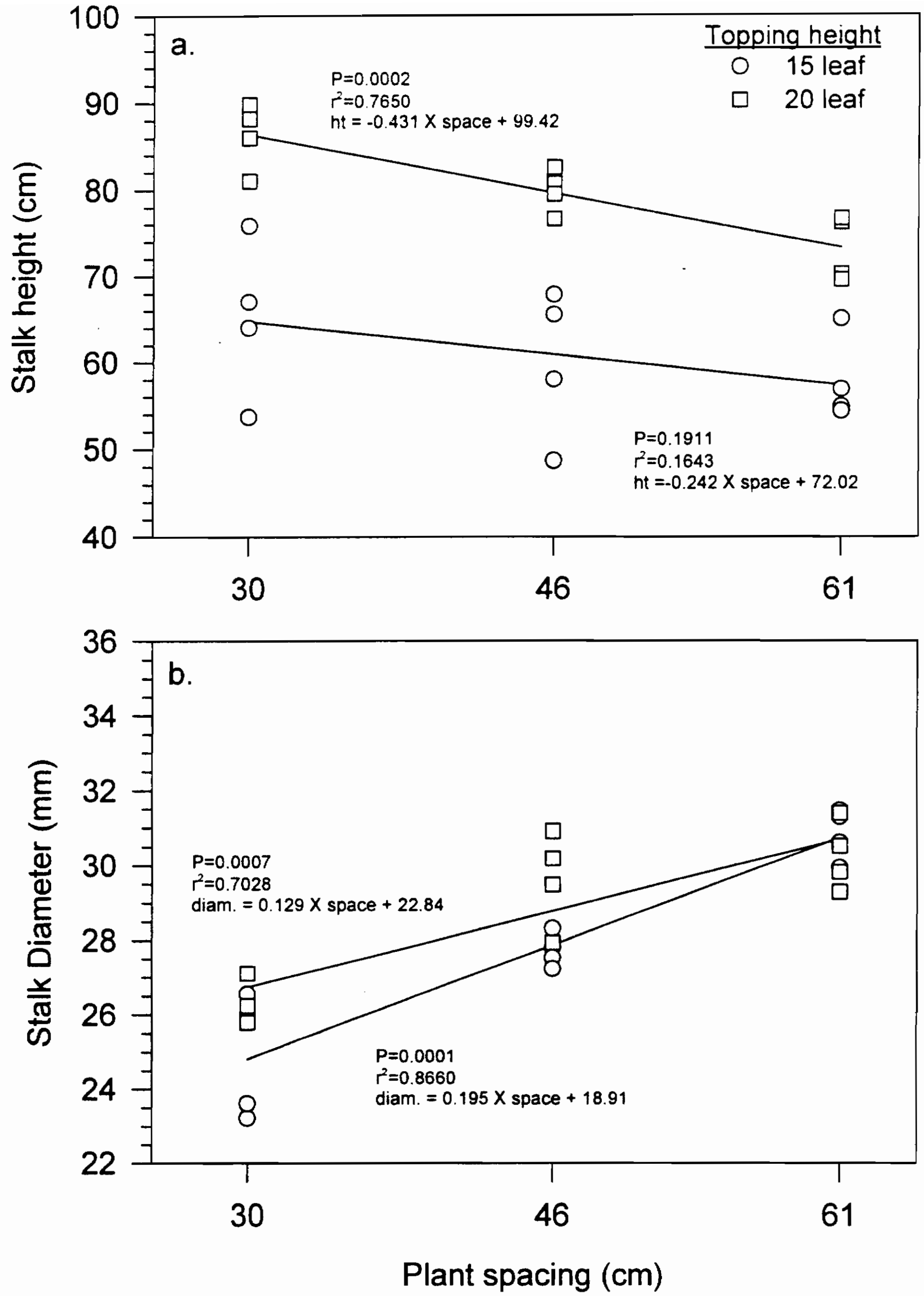


Fig. 3.15. Influence of plant spacing on stalk height (a) and stalk diameter (b) of flue-cured tobacco topped to 15 and 20 leaves

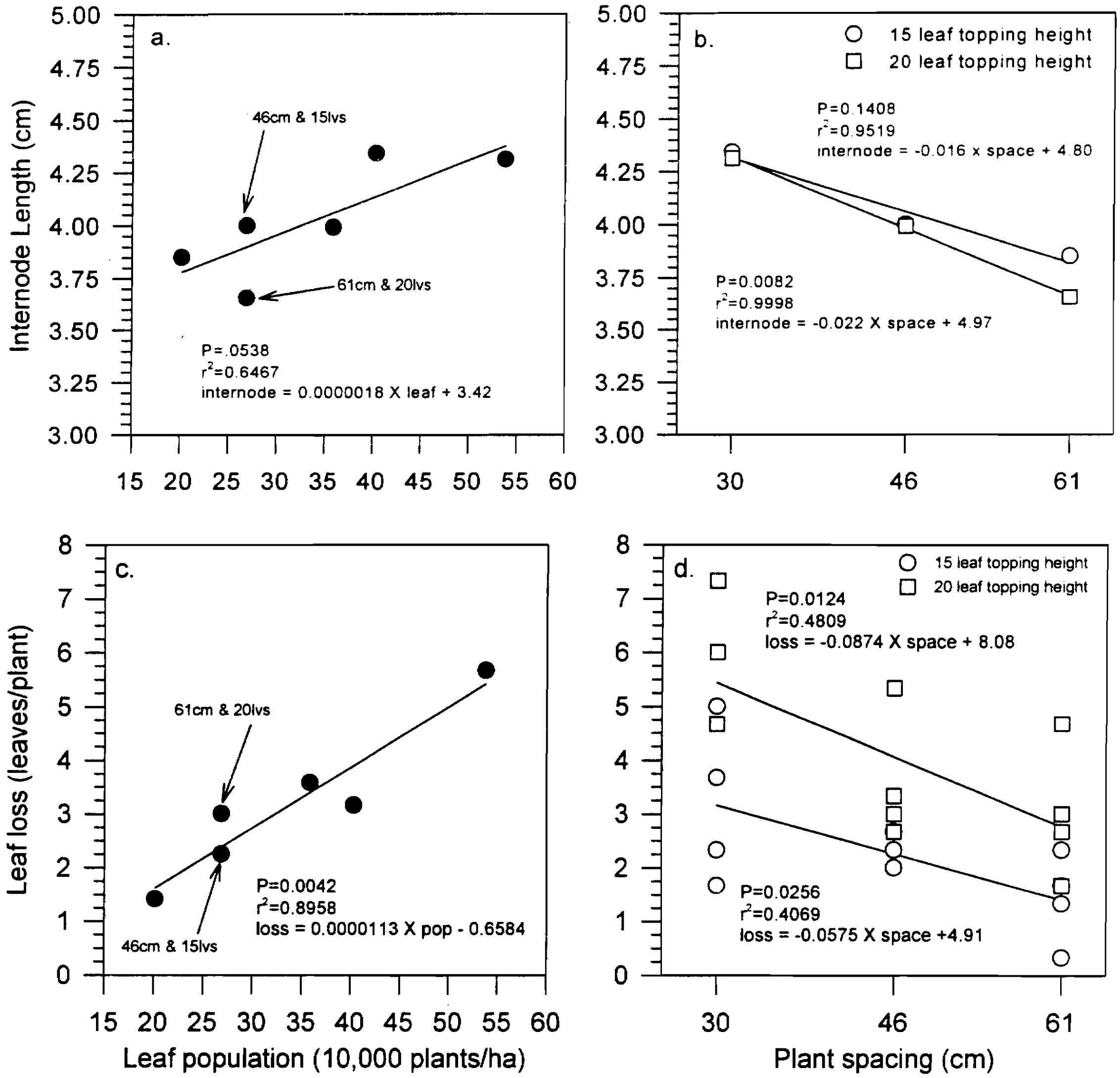


Fig. 3.16. Influence of leaf population (a) and plant spacing (b) on the internode length of flue-cured tobacco. Influence of leaf population (c) and plant spacing (d) on the number of leaves to deteriorate before once-over harvesting flue-cured tobacco.

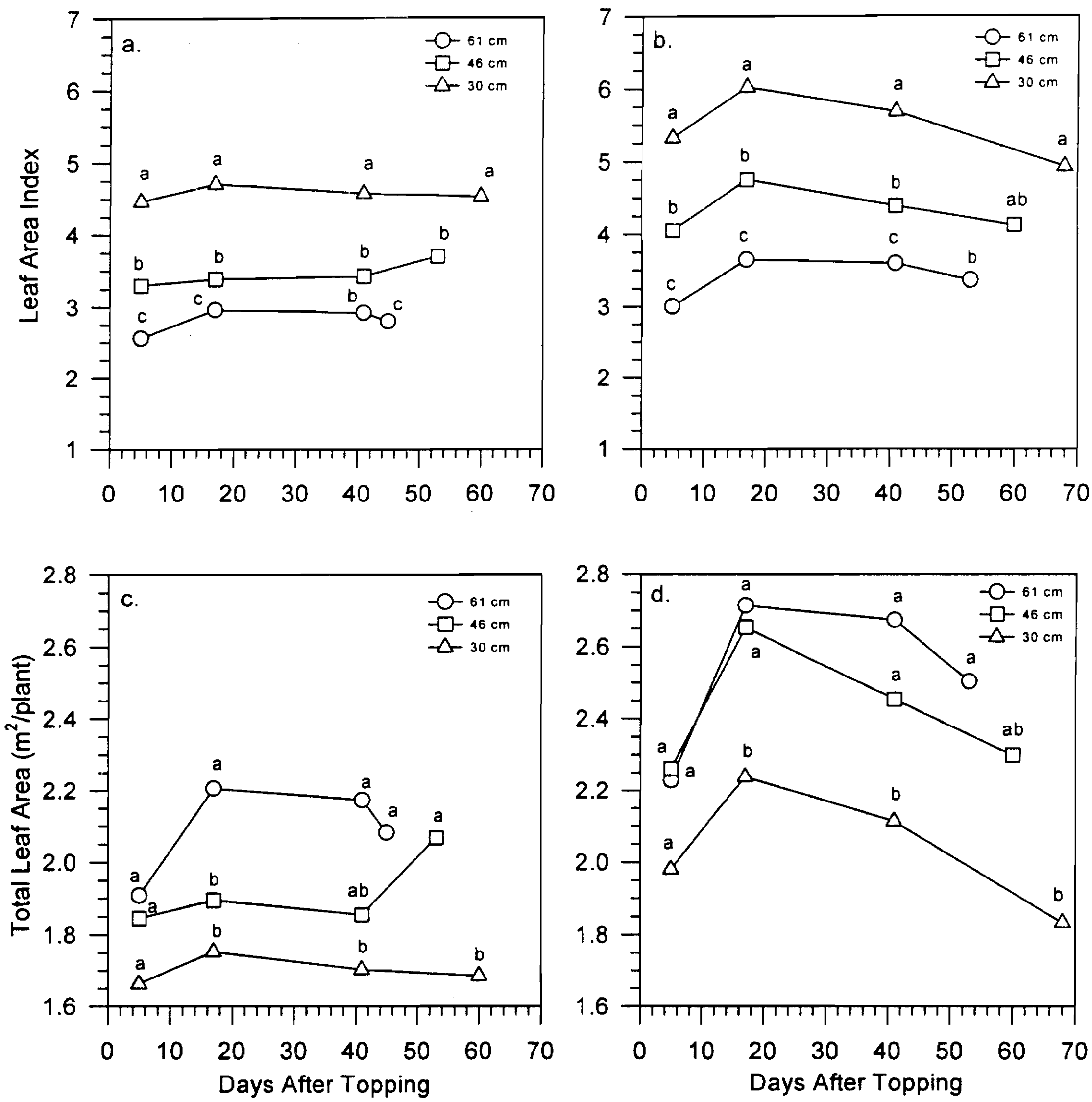


Fig. 3.17. Mean leaf area index (a) and total leaf area (m^2/plant) (c) of flue-cured tobacco topped to 15 leaves as influenced by days after topping. Mean leaf area index (b) and total leaf area (m^2/plant) (d) of flue-cured tobacco topped to 20 leaves as influenced by days after topping. (Date means followed by the same letter are not significantly different, Waller-Duncan K-ratio test, P<0.05).

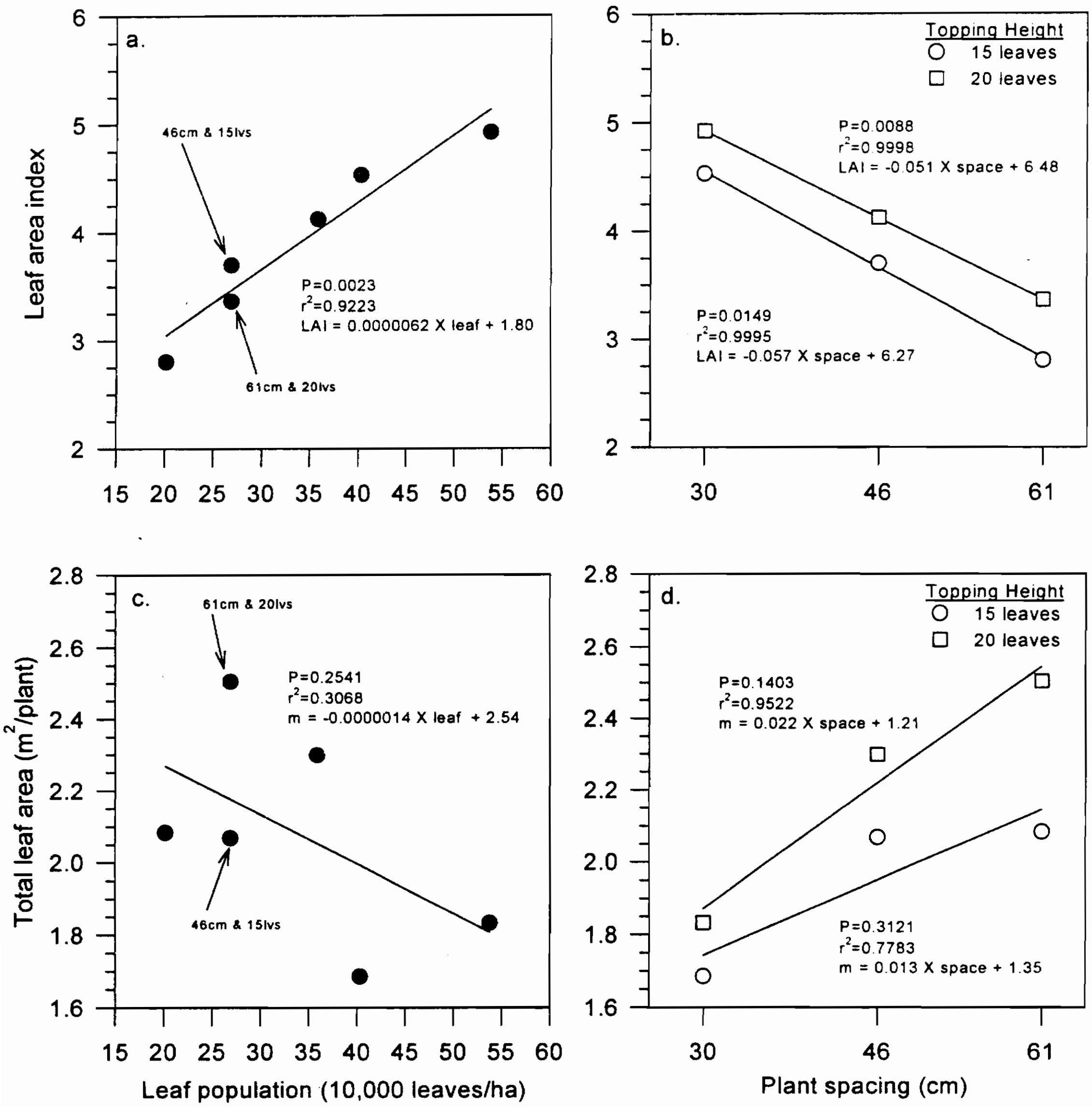


Fig. 3.18. Influence of leaf population (a) and plant spacing (b) on leaf area index immediately prior to harvest of flue-cured tobacco. Influence of leaf population (c) and plant spacing (d) on total leaf area (m^2/plant) immediately prior to harvest of flue-cured tobacco.

Chapter IV.

Influence of Row and Plant Spacing on the Yield and Quality of Flue-cured Tobacco Harvested Once-over

Abstract

A management study was conducted to evaluate the influence of four row widths (91, 102, 112, and 122 cm) and two plant spacings (41 and 56 cm) on the agronomic characters of flue-cured tobacco harvested once-over. As plant population increased from 14,702 to 26,976 per hectare, yield, value, and grade index increased while price per kg was unchanged. The response in yield and value to decreasing row widths was greater at the 41 cm plant spacing and yield and value was significantly greater when plants were spaced at 41 cm for each row width. The proportion of yield from the upper stalk increased with increasing population while yield of lower leaves decreased due to increasing over-maturation and senescence with increasing plant population. The decrease in the number of leaves harvested with higher population increased uniformity of the harvest resulting in no change in grade index between evaluation as harvested once-over and by stalk position. In contrast, grade index of the lower population treatments was significantly greater when evaluated by stalk position than as harvested once-over. Total alkaloids and reducing sugars content decreased with increasing plant population. Total alkaloids by stalk position group decreased with increasing plant population while reducing sugars were only affected by increasing population for the lower stalk positions. Specific leaf weight (SLW), lamina weight, and midrib weight of lower leaves of the plant were negatively influenced by plant population while no

consistent effects were observed for upper stalk leaves. Plant spacing generally was more restrictive of physical leaf characteristics than was row width.

Introduction

Flue-cured tobacco growers face a number of challenges due to increasing cost of production and competition in a global market. International competitors are increasing production of tobacco that is both cheaper than U.S. leaf and well suited for the manufacture of less expensive discount cigarettes. As a result, the U.S. share of the world flue-cured tobacco market has declined over the last decade. Although there is still a strong market for the high quality tobacco characteristic of U.S. leaf, this demand is not enough to sustain current production levels. To remain price competitive, U.S. flue-cured tobacco growers are seeking strategies to lower costs of production. Labor accounts for 36% of operating costs (Peedin et al. 1994) and the majority of labor is required for harvesting (Gwynn, 1974). In a effort to reduce costs, growers have reduced the number of harvests utilized for a crop and are increasingly adopting mechanization.

Increasing yields of flue-cured tobacco would reduce per unit cost of production. However, acceptable quality and usability must be maintained. Woltz and Mason (1966) using various plant spacings and topping heights established a positive relationship between yield and the number of leaves per hectare. Total leaf number per area is a function of plant population and topping height (leaves per plant). Kittrell et al. (1972) and Collins et al. (1969) studied populations ranging from 296,520 to 444,780 leaves/ha and obtained an increased yield and value as leaf population increased but price/kg decreased. Miner (1980) reported a 17% increase in net returns with a 50% increase in leaf population. Reducing the number of harvests of flue-cured tobacco has produced favorable results in yield and quality (Gwynn, 1969, Gooden et al., 1976, and Suggs, 1980). Harvesting flue-cured tobacco in a single harvest (once-over) has been demonstrated to reduce yield (Brown and Terrill, 1972, Miner, 1980, Gwynn, 1974, and Gooden et al., 1976) and under certain conditions alter chemical composition of the cured tobacco (Neas et al., 1978, Brown and Terrill, 1973, and Gwynn, 1974). Harvesting flue-cured tobacco once-over generally results in the cured leaf grading USDA leaf (B) grade (Neas et al., 1978) with an average chemical composition comparable to the middle leaves of the stalk (Brown and Terrill, 1973). Terrill (1975) stated most modifications of harvest schedule, particularly the once-over harvest, result in maturation differences between stalk position extremes which produce significant changes in the chemical composition of the cured leaf. The objective of this experiment was to evaluate the effect of row width and plant spacing on the agronomic characteristics of flue-cured tobacco harvested once-over.

Materials and Methods

A field experiment was conducted at the Virginia Polytechnic Institute and State University, Southern Piedmont Agricultural Research and Extension Center near Blackstone, Virginia in 1994 on a Mayodan sandy loam soil (Typic Haplaudult, fine loamy, siliceous, thermic). The experiment was conducted as a randomized complete block design in a split plot arrangement. Treatments were replicated four times with row spacing (91, 102, 112, and 122 cm) as whole plots and plant spacing (41 and 56 cm) as sub-plots. Row spacing and plant spacing combinations allowed evaluation of leaf populations ranging from 295,000 to 540,000 leaves per hectare (Table 4.1). Plots consisted of 4 rows that were 15.25 m in length and were separated by an unplanted row (153 cm wide) to allow for cultivation and spraying. Topping was performed at the early flower stage with tops removed to leave 18 to 20 leaves per plant. The effect of nitrogen fertilization was not specifically evaluated and was applied on a per 1,000 leaf basis at a rate of 0.23 kg per 1,000 leaves. Pre-plant fertilizer (785kg/ha of 6-12-18) was applied in a deep band at bedding and additional sidedress nitrogen with 15-0-14 (Table 4.1). Tobacco was harvested once-over allowing the bottom leaves (primings) to burn-off and harvesting the remaining leaves in a single pass. All treatments were harvested on the same date when remaining leaves were judged to be mature. At harvest, tobacco was separated by stalk position to allow sampling and grading by stalk position and recombined to facilitate sampling and grading as a once-over harvest. Plot weights and official grades were recorded and plot yield (kg/ha), average price (US$/kg), value (US$/ha), and grade indexes calculated. Grade index (Bowman *et al.*, 1988) provides a means of uniform evaluation of the visual quality of the cured leaf, average price represents the average auction price of the representative grades of the cured leaf for the respective market season, and value per acre reflects the average gross revenue of cured leaf produced on a hectare. Total alkaloids and reducing sugars were analyzed from a 15 g core sample by stalk position and as a once-over harvest (Davis 1976; Horwirtz, 1980).

Official standard grades of flue-cured tobacco (Anonymous, 1989) are comprised of three factors consisting of a letter designating the group, followed by a numerical quality rating, and lastly a letter or combination of letters denoting color. The group designation is a division of type covering closely related grades based on certain characteristics related to stalk position, body or the general quality of the tobacco. Groups of flue-cured tobacco are leaf (B), smoking leaf (H), cutters (C), lugs (X), primings (P), and nondescript (N). The leaf (B) and smoking leaf (H) group consists of leaves normally grown at or above the midportion of the stalk. Leaves of the B and H groups have a pointed tip, tend to fold and are usually heavier in body than other groups.

Body is an appraisal of the thickness and density of the leaf which can be described as weight per unit surface area (SLW). Smoking leaf (H) differs in relative maturity from the B group. Smoking leaf (H) is characterized by a higher degree of maturity, more open leaf structure, and shows a material amount of injury characteristic of excessively ripe leaf tobacco. The cutter (C) group consists of leaves normally grown at or just below the midportion of the stalk. Leaves of the C group have a rounded tip and are thin to medium bodied and have a tendency to roll and conceal the stem of the leaf. The lugs (X) group consists of leaves grown near the bottom of the stalk, usually have a blunt tip and open face, and show some ground injury. The priming (P) group consists of the bottom-most leaves of the stalk that have a characteristic round tip. Leaves of the P group ripen prematurely due to starvation and show a material amount of ground injury.

Quality is a division of a group based on the relative degree of one or more elements. There are 10 elements of quality and degrees within each element. Quality is denoted as the second factor of a grade by a numeric scale (1-5) representing choice, fine, good, fair, and low, respectively. Each quality for a specific group represents a minimum degree of the elements of quality. The third factor of a grade designates the color which is based on relative hues and saturations of the tobacco. A physiologically mature leaf that has been cured properly will generally express a clear lemon (L) or reddish yellow (F) color.

Leaf length and width of all leaves were measured for 4 plants per plot over three replications. Measurements were taken 8 and 37 days after topping and prior to harvest and used to calculate leaf area (Suggs *et al.,* 1964) and leaf area index (Gardner *et al.*, 1985).

$$\text{Leaf Area} = \text{length} \times \text{width} \times 0.6354$$

$$\text{Leaf Area Index} = \frac{\text{total leaf area per plant}}{(\text{row width x plant spacing})}$$

Destructive sampling of every fifth leaf, beginning with the uppermost, of 3 plants per plot for 3 replications was conducted 14 days after topping. Immediately prior to harvest, destructive sampling of all leaves deemed harvestable was performed. Observations made included determination of specific leaf weight (SLW) (Gardner *et al.*, 1985), measurement of leaf length and width, and separating and weighing lamina and midrib. Leaf disks ($32.47 cm^2$/disk) for the determination of SLW were removed, one from the tip of the leaf, one from above the fourth lateral vein adjacent the midrib and the other from above the fourth lateral vein near the margin of the leaf.

$$\text{Specific Leaf Weight (SLW)} = \frac{\text{weight of 3 disks}}{\text{area of 3 disks } (97.42\ cm^2)}$$

Linear regression analysis (PROC REG in SAS) was used to quantify the effect of plant population per hectare on treatment variables (SAS Institute, 1989). Linear regression models for the effect of row width were compared to evaluate the effect of plant spacing by means of *t*-tests for parallelism and a common intercept (Kleinbaum et al., 1988). Arcsin transformations were performed on grade group data as required (Zar, 1984).

Results and Discussion

Yield

Yield and value of flue-cured tobacco harvested once-over increased significantly as plant population increased from 14,702 to 26,976 plants per hectare (Fig. 4.1a and c). Yield increased by 48 kg per 1,000 additional plants per hectare (Fig. 4.1a). Increasing plant population by 45% increased yield by 24.5%. The yield increase of 24.5% at plant population 45% greater than considered optimal (Woltz and Mason, 1966) and harvested once-over is considerably greater than the yield increase (7.9%) reported by Collins *et al.* (1969) under convention multi-pass harvest management. Value increased 25% when plant population was increased from 14,702 to 26,976 plants per hectare (193 US$ per 10,000 additional plants per hectare) (Fig. 4.1c). Grade index was also positively influenced by higher plant population (Fig. 4.2a). Grade index increased from 76 to 81 as plant population increased from 14,702 to 26,976 plants per hectare. Increasing plant population resulted in no effect on the average price of the cured tobacco harvested once-over (Fig. 4.2b). The lack of response in average price per kg to increasing plant population is in contradiction of several earlier plant and leaf population studies (Carr and Neas, 1957, Collins *et al.*, 1969, and Kittrell *et al.*, 1972).

Yield and value of flue-cured tobacco harvested once-over was influenced in a linear manner by plant spacing over the four row widths investigated (Fig. 4.1b and d). Reducing row width for tobacco spaced 41 or 56 cm within the row had no effect on grade index and average price per kg of the cured leaf. Yield of the 41 cm plant spacing treatments increased 18.6 kg/ha with each cm reduction in row width (Fig. 4.1b). Yield of plants spaced 56 cm apart increased 13.7 kg/ha with each cm reduction in row width ($P=0.0976$) (Fig. 4.1b). Slopes of the 41 and 56 cm regression lines were significantly different ($t= 135.5$). Reducing distance between rows of flue-cured tobacco spaced 41 cm within the row produced a significantly greater response in yield than reducing row width for tobacco spaced at 56 cm. Yield of flue-cured tobacco spaced 41 cm within the row was significantly ($t= 5.8$) greater than yield of tobacco spaced at 56 cm. Value of the cured leaf of flue-cured tobacco spaced 41 and 56 cm within the row increased 73.0

(P=0.0737) and 48.4 (P=0.0688) US dollars/ha, respectively, per cm reduction in row width (Fig. 4.1d). The increase in value of tobacco spaced 41 cm apart with decreasing row width was significantly greater (t= 1229.7) than the increase in value of the 56 cm plant spacing treatments. The effect of plant spacing on value of the cured leaf was also found to be significant (t= 12.29). Value, like yield, was significantly greater for plants spaced 41 cm apart compared to 56 cm.

Value of flue-cured tobacco harvested once-over and separated into stalk positions for evaluation increased significantly with increasing plant population (P=0.0053 and P=0.0057) (Fig. 4.3a). No significant effect in value of the cured leaf was observed between evaluation as an once-over harvest and that harvest being separated into stalk positions (slope t= 0.38 and intercept t=1.01). Average price per kg of the cured leaf of flue-cured tobacco separated into stalk positions was not influenced by increasing plant population (Fig. 4.3b). No significant effect on average price was observed for once-over harvested tobacco evaluated as harvested and separated into stalk positions. Price of the cured leaf of flue-cured tobacco harvested once-over averaged US$ 3.98/kg and US$ 3.89/kg when evaluated by stalk position. Grade index of once-over harvested leaf increased significantly with increasing plant population (Fig. 4.3c). Grade index of the cured leaf separated into stalk positions, however, was not found to be significantly influenced by plant population (Fig. 4.3c).

Grade Group Distribution

The once-over harvest procedure resulted in none of the cured tobacco grading as priming (P) or nondescript (N) leaf when evaluated by stalk position (Fig. 4.4a). No significant differences in grade group distribution were observed due to plant population when evaluated by stalk position. Grade group distribution of total cured leaf yield for all leaf population treatments evaluated by stalk position averaged 11.0% lugs (X), 30.7% cutters (C), and 57.5% leaf (B).

Evaluation of quality grade of the cured leaf as a once-over harvest resulted in the majority of each treatment's yield grading as leaf (B) tobacco (Fig. 4.4b). However, plant population treatments of 17,663, 19,605, 22,051, and 24,302 plants per hectare resulted in 25% of their yield grading as cutters (C) grade tobacco and plant population treatments of 19,605, 20,233, and 22,051 plants per hectare resulted in 25% of their yield being evaluated as smoking leaf (H) (Fig. 4.4b).

Yield by Stalk Position

The proportion of total tobacco harvested by stalk position was influenced significantly by plant population (Fig. 4.5a-d). The proportion of yield produced by the uppermost three leaves (tips) and leaves 4-8 below the tip leaves increased significantly with increasing plant density (Fig. 4.5a anb b). The proportion of yield from leaves 9-13 was not significantly influenced by plant population (Fig. 4.5c). The proportion of total yield produced by the lower leaves (>13) declined with increasing plant population (Fig. 4.5d).

The proportion of yield from the lower leaves was not influenced significantly by altering spacing between rows for plants spaced 41 cm apart, while yield of the lower leaves increased with increasing row width for plants spaced 56 cm apart (Fig. 4.6d). The proportion of total yield from the middle stalk positions (leaves 4-8 and 9-13) was not influenced significantly by row spacing for either plant spacing (Fig. 4.6b and c). Yield of the three tip leaves decreased significantly as row width became wider for both plant spacing treatments (Fig. 4.6a).

Leaves Harvested per Plant

The objective of the once-over harvest procedure conducted on this experiment was to allow the lower ground leaves to over-mature and senesce, while the remaining leaves of the plant matured and ripened. Under the once-over harvest method applied here, a disparity in the number of leaves present at the time of harvest developed between plant populations (Fig. 4.7). The number of harvestable leaves per plant decreased significantly as plant population increased from 14,702 to 26,976 plants per hectare. The 14,702 plant per hectare treatment averaged 18.4 leaves per plant upon harvest, while 16.0 leaves per plant were present at harvest for the plant population treatment of 26,976 plants per hectare. At topping, all treatments were topped to average 20 leaves per plant. Therefore, increasing plant density produced an environment promoting more severe senescence and loss of the lower ground leaves of the plant. This is evident in the proportion of yield obtained from the lower stalk position (leaves >13).

Grade index (separated by stalk position vs. once-over harvest)

Grade index of the cured tobacco evaluated by stalk position was not influenced significantly by increasing plant population (Fig. 4.3c). However, grade index of the lower population treatments was greater when evaluated by stalk position than combined as a once-over harvest. The reduction in grade index at the lower population treatments when harvested once-over compared to being separated by stalk position can be attributed to greater difference in leaf characteristics by stalk position of the lower leaf population treatments. The lower plant populations tended to produce better quality leaf from the lower half of the stalk which constituted more of the total yield (Fig. 4.5a-d) than did the higher plant populations. Harvesting the lower plant population treatments once-over resulted in the blending of more lower stalk tobacco of better quality that upon evaluation as a once-over harvest more readily influenced the grade designation resulting in a variegated grade (K) of tobacco with a lower grade index score.

Color group distribution of the cured tobacco did not vary significantly between plant populations when evaluated by stalk position or as a once-over harvest (Fig. 4.8a and b). Color group of the cured tobacco by stalk position averaged 75.5% orange (F) grade (Fig. 4.8a). Cured leaf as a once-over harvest averaged only 28% orange (F) grade with the remainder of yield being variegated (K) (Fig. 4.8b). The plant population treatments 14,702 and 16,024 made the most dramatic transition in color group distribution from evaluation by stalk position to the evaluation as harvested once-over (Fig. 4.8a and b). The color group distribution of the 14,702 and 16,024 plants/ha populations changed significantly ($P<0.01$) from the evaluation separated by stalk position to that as a once-over harvest. Cured tobacco evaluated by stalk position resulted in 78.25% orange (F) grade (Fig. 4.8a). However, as an once-over harvest 100% of the yield was evaluated variegated (K) and none as orange (F) (Fig. 4.8b). The revised North Carolina Flue-cured Tobacco Grade index (Bowman *et al.*, 1988) ranks orange leaf (F) 10 points higher than variegated leaf (K). The reduction in grade index of the lower plant population treatments under the once-over harvest evaluation , thus resulted from the change in color grade.

Chemical Constituents

Total alkaloids and reducing sugar content evaluated as a once-over harvest were significantly influenced by increasing plant population (Fig. 4.9a and c). Total alkaloids and reducing sugar content decreased by 16.6% and 13.3%, respectively, as plant population increased from 14,702 to 26,976 plants per hectare. Weybrew and Woltz (1975) reported reduction in total alkaloids with increasing plant density was a result of dilution. Elliot (1970) observed a reduction in reducing sugars content and the sugar to nicotine ratio with increasing plant population. Total alkaloids of cured tobacco separated by stalk position declined significantly with increasing plant population for the upper three stalk position groups (tips, leaves 4-8 and 9-13) (Fig. 4.10a-c). Reducing sugar content of cured tobacco separated by stalk position was not influenced significantly for the upper two leaf position groups (tips and leaves 4-8) (Fig. 4.11a and b). However reducing sugar content of the lower leaf position groups (leaves 9-13 and leaves <13) declined with increasing plant population (Fig. 4.11c and d). The greater reduction in light infiltration to the lower leaves at high plant densities reduced photosynthesis and increased respiration. Thus, reducing the amount of starch accumulated in lower leaves before harvesting. Brown and Terrill (1973) observed that reducing sugars content of the lowest stalk position of sequentially harvested tobacco was significantly higher than that of once-over harvested tobacco. They concluded that over-maturity of lower stalk positions in the once-over treatments resulted in increased respiration and thus depletion of accumulated starch.

Total alkaloids of the cured tobacco harvested once-over were not influenced significantly by row width for plants spaced 56 cm apart, but increased significantly with increasing row width for plants spaced 41 cm apart (Fig. 4.9b). No significant influence by row width in reducing sugar content was observed for either plant spacing (Fig. 4.9d). Total alkaloids and reducing sugar content of cured tobacco separated by stalk position did not respond to changes in row spacing.

Specific Leaf Weight (SLW)

Specific leaf weight (SLW) of the 11th and 16th leaf positions measured 67 days after topping (immediately prior to harvest) was significantly reduced by increasing plant population (Fig. 4.12c and d). SLW of the 11th and 16th leaves decreased 23.6% and 29.0%, respectively, as plant population increased from 14,702 to 26,976 plants per hectare. Higher plant population did not result in significant effects on SLW of the 1st and 6th leaves (Fig. 4.12a and b). The SLW of the 16th leaf of plants spaced 41 and 56 cm apart (Fig. 4.13d) increased significantly with increasing row width, while other leaf positions (1st, 6th, and 11th) (Fig. 4.13a-c) were not significantly affected. The reduction in leaf SLW of the 16th leaf with increasing plant population corresponds to the decline in percentage of yield from the lower stalk position (leaves >13).

Average SLW of all leaves harvested per plant 67 days after topping decreased significantly (P=0.0034, r^2=0.7854) as plant population increased (Fig. 4.14a). Average SLW decreased by 11.1% as plant population increased from 14,702 to 26,976 plants per hectare. No significant influence on SLW by row width was observed for either plant spacing treatment.

Lamina Weight

Lamina weight measured 67 days after topping of leaf positions 1, 6, 11 and 16 followed similar trends as SLW (Fig. 4.15a-d). Lamina weight of the 11th and 16th leaves decreased significantly as plant population increased (Fig. 4.15c and d). Lamina weight of the 6th leaf, also, tended to decrease (P=0.0908, r^2=0.4031) with increasing plant population (Fig. 4.15b). No significant effect due to plant population was observed for the uppermost leaf (1st leaf) (Fig. 4.15a). Lamina weight of plants spaced 56 cm apart increased significantly for leaf positions 6, 11, and 16 as row width increased (Fig. 4.16b-d). Significant effects due to row width were not observed for any leaf position for plants spaced 41 cm apart (Fig. 4.16a-d). This suggests that the 41 cm plant spaicng produced competition for light that was not releived by wider row spacing.

Average lamina weight of all leaves harvested per plant decreased significantly ($P=0.0224$, $r^2=0.6084$) as plant population increased (Fig. 4.15b). Lamina weight decreased 22.2% as plant population increased from 14,702 to 26,976 plants per hectare. Significant effects in lamina weight due to row width were not observed for either plant spacing.

Midrib Weight

Midrib weight of the 16th leaf measured 67 days after topping decreased significantly with increasing plant population (Fig. 4.17d). A negative response in midrib weight of the 11th leaf to increasing plant population was also observed ($P=0.0729$, $r^2=0.4401$) (Fig. 4.17c). Midrib weight of the 1st, and 6th leaves were not influenced significantly by increasing plant population (Fig. 4.17a and b). Significant effects of increasing row width were not observed for any leaf position at either plant spacing.

Percentage Midrib

Percentage midrib 67 days after topping increased significantly with increasing plant population for leaf positions 1, 11, and 16 (Fig. 4.18a, c and d). The increase in percentage midrib would have a negative effect on strip yield and consequently on the utility of the cured leaf for the manufacture of cigarettes. When plants were spaced 41 cm apart, percentage midrib of the 16th leaf increased with closer row spacing (Fig. 4.19d). Other leaf positions were not influenced significantly by altering row width for plants spaced 41 cm apart (Fig. 4.19a-c). The percentage midrib of leaves from positions 11 and 16 increased significantly with closer row spacing when plants were spaced 56 cm apart within the row (Fig. 4.19c and d). No effect on percentage midrib of plants spaced 56 cm apart was observed due to altering row width for the 1st and 6th leaves (Fig.4.19a and b).

Leaf Area Index (LAI) and Total Leaf Area

LAI and total leaf area per plant 67 days after topping were influenced significantly by increasing plant population (Fig. 4.20a and c). LAI increased significantly as plant population increased (Fig. 4.20a). LAI increased by 44.6% as plant population increased from 14,702 to 26,976 plants per hectare. Total leaf area was an inverse linear function of plant population. Total leaf area declined significantly as plant population increased (Fig. 4.20c). Total leaf area per plant decreased by 21.1% as plant population increased form 14,702 to 26,976 plants per hectare. LAI increased significantly as row width become narrower when plants were spaced 41 cm apart, however, no significant response to decreasing row width was observed when plants were spaced 56 cm apart (Fig. 4.20b).

Summary

Yield and value of flue-cured tobacco harvested once-over increased approximately 25% with an 45% increase in plant population. The 25% increase in yield is considerably greater than the 7.9% increase reported by Collins et al. (1969) under conventional multi-pass harvest. In contradiction to earlier population studies (Carr and Neas, 1957, Collins et al., 1966, and Kittrell et al., 1972), grade index improved with increasing population and average price per kg was not influenced. The response in grade index to plant population can be attributed to the increased proportion of yield from the upper stalk positions and concurrent loss of lower leaves characteristic of once-over harvest management. Leaves from the upper portion of the stalk of high plant populations produced the majority of yield. The physical characteristics of the upper leaves were not influenced by higher plant densities, as were lower leaves. Therefore once-over harvesting of increased plant populations minimized the associated blending of stalk positions compared to normal populations. Alkaloid and reducing sugars content decreased with increasing plant density, however, a clear response in their ratio was not observed. While not substantially altering the chemical balance of the cured leaf, increasing plant population did decrease average weight per unit area of leaves harvested which should improve filling power. Increasing plant population with more uniform row and plant spacing arrangement and harvesting once-over increased yield while minimizing detrimental effects on quality associated with higher plant densities.

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Table 4.1. Spacing treatments (row and plant) evaluated in 1994 with corresponding plant and leaf populations.

Treatment	Row Width	Plant Spacing	Plant Population	Leaf Population[1]	N	P_2O_5	K_20
	cm	cm	plants/ha	leaves/ha	kg/ha	kg/ha	kg/ha
1	122	56	14,702	294,400	78	94	170
2	122	41	20,233	404,660	108	94	174
3	112	56	16,024	320,480	86	94	178
4	112	41	22,051	441,020	117	94	206
5	102	56	17,663	352,660	94	94	185
6	102	41	24,302	486,040	129	94	217
7	91	56	19,605	392,100	104	94	195
8	91	41	26,976	539,520	143	94	231

[1] Assuming 20 leaves per plant topping height.
[2] Nitrogen was applied at a constant rate per 1,000 leaves (0.23 kg/1,000 leaves).

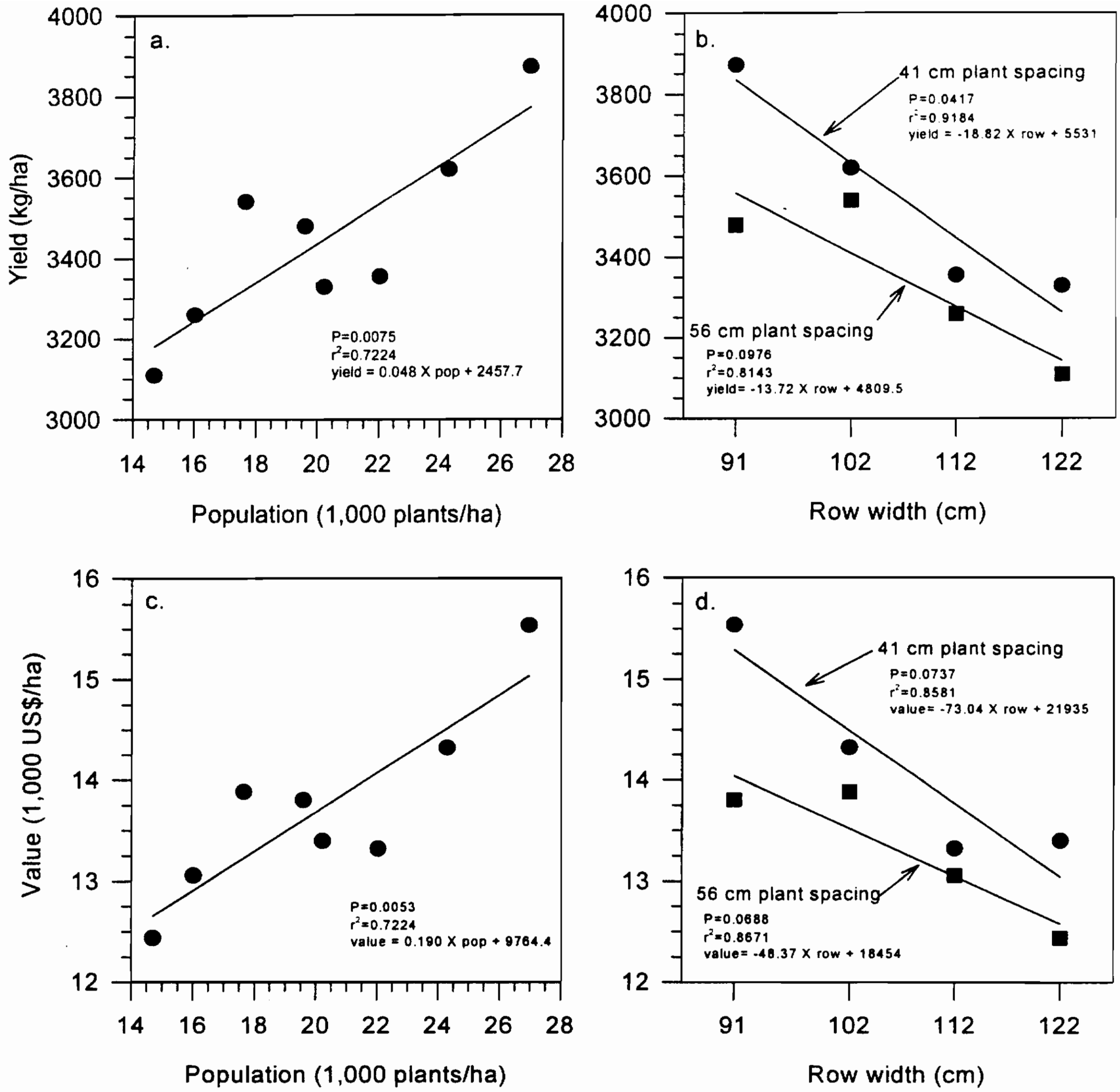

Fig. 4.1. Cured leaf yield (a) and value (c) of flue-cured tobacco harvested once-over as influence by plant population and the influence of row width on the yield (b) and value (d) of flue-cured tobacco spaced 41 and 56 cm within the row.

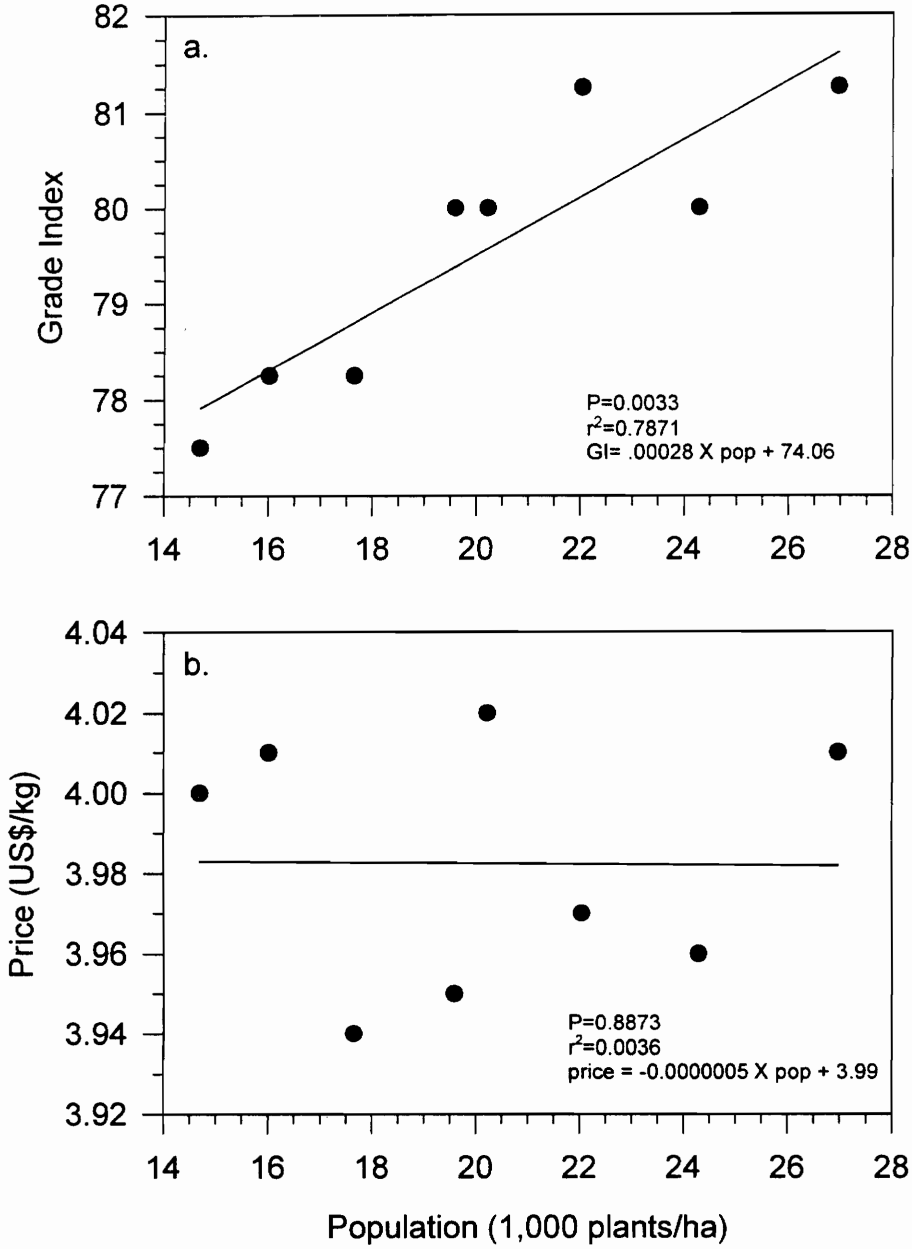

Fig. 4.2. Influence of plant population on grade index (a) and average price (b) of the cured leaf of flue-cured tobacco harvested once-over.

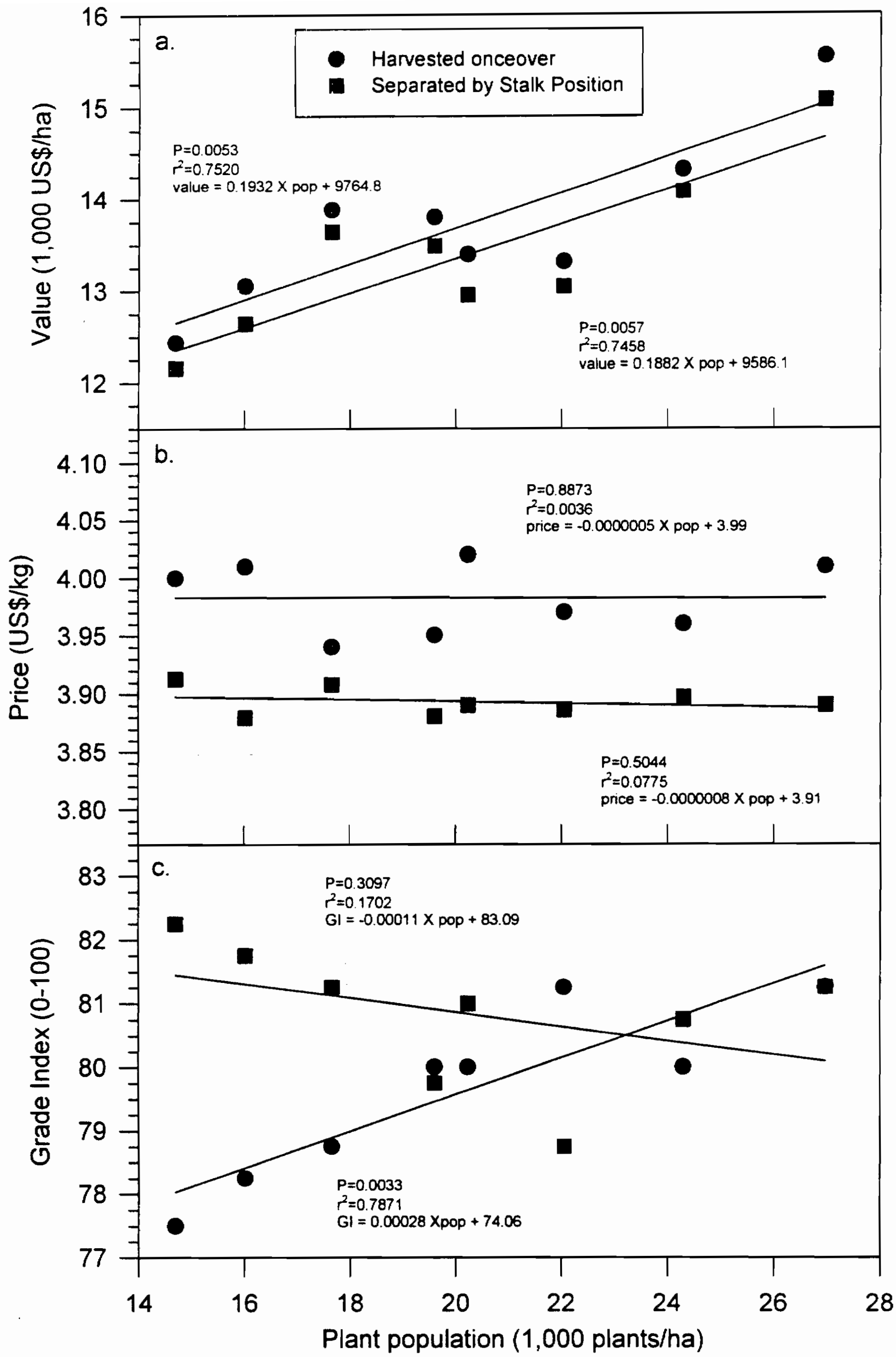

Fig. 4.3. Influence of plant population on value (a), average price (b), and grade index (c) of the cured leaf of flue-cured tobacco harvested once-over and separated by stalk position.

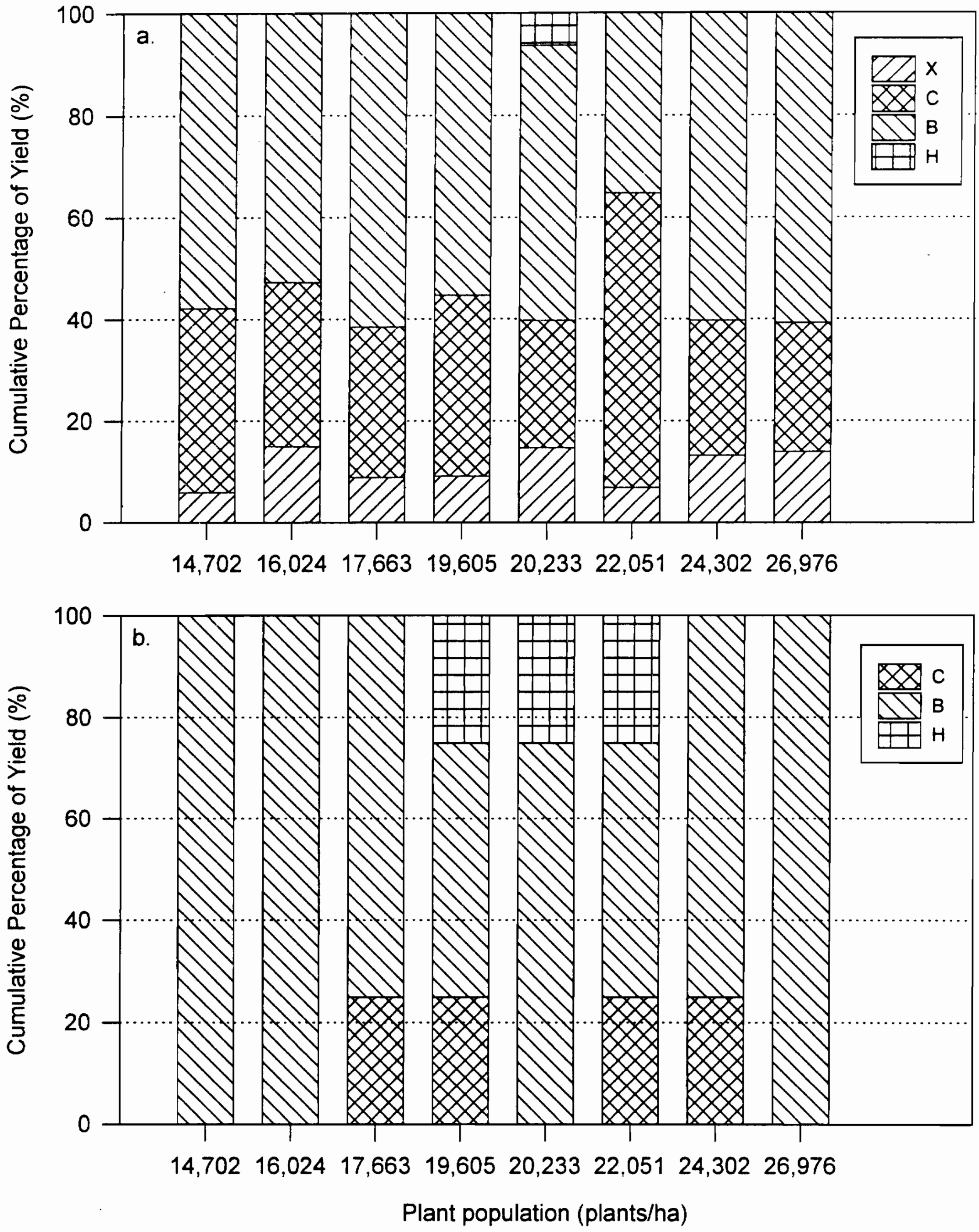

Fig. 4.4. Influence of plant population per hectare on the cumulative percentage of yield by grade group designation of the cured leaf of flue-cured tobacco (a) separated by stalk position and (b) harvested once-over.

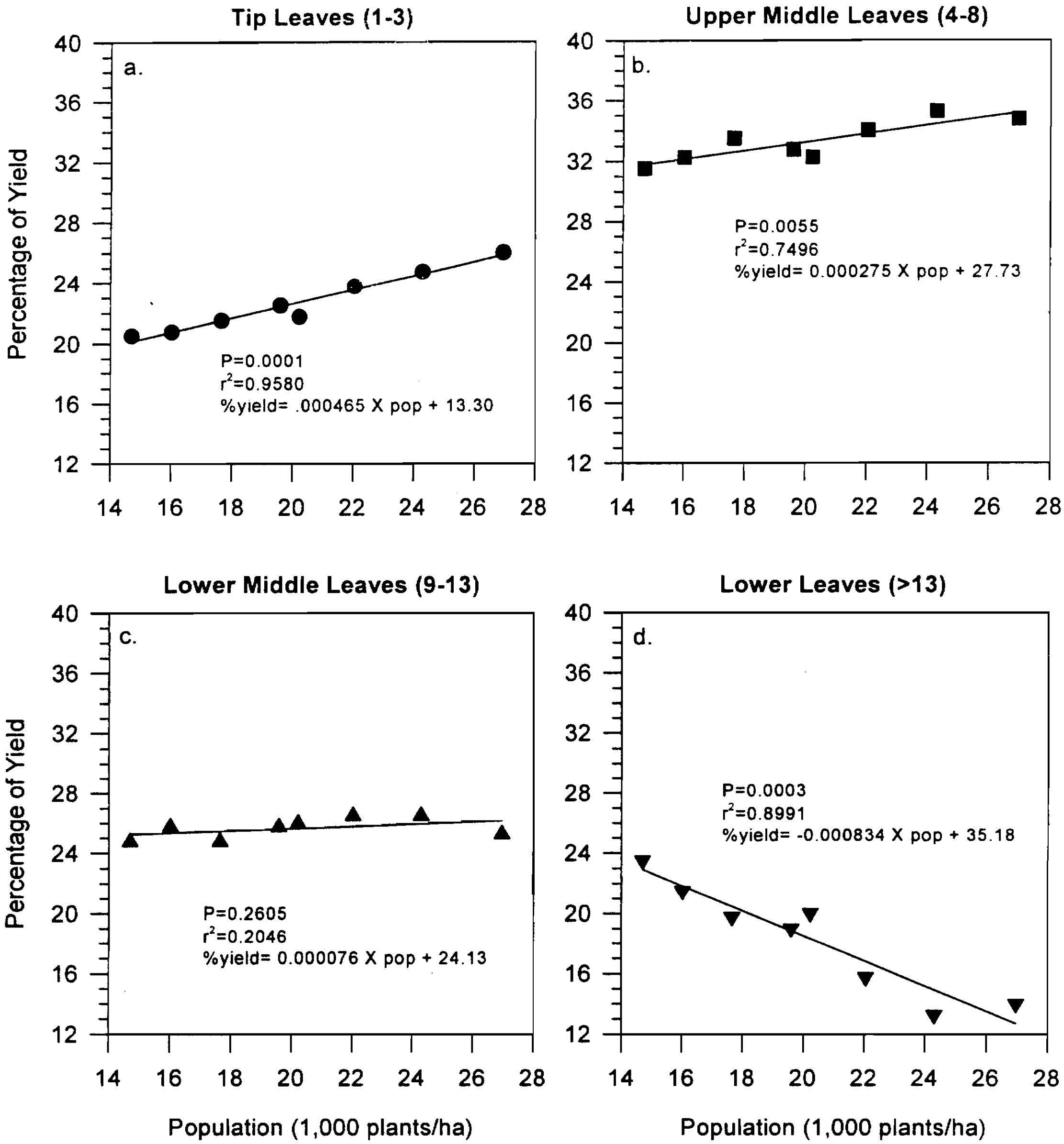

Fig. 4.5. Influence of plant population on the percentage of total cured leaf yield from the tip leaves (a), the upper middle leaves (b), the lower middle leaves (c), and the lower leaves (d) of the stalk of flue-cured tobacco harvested once-over.

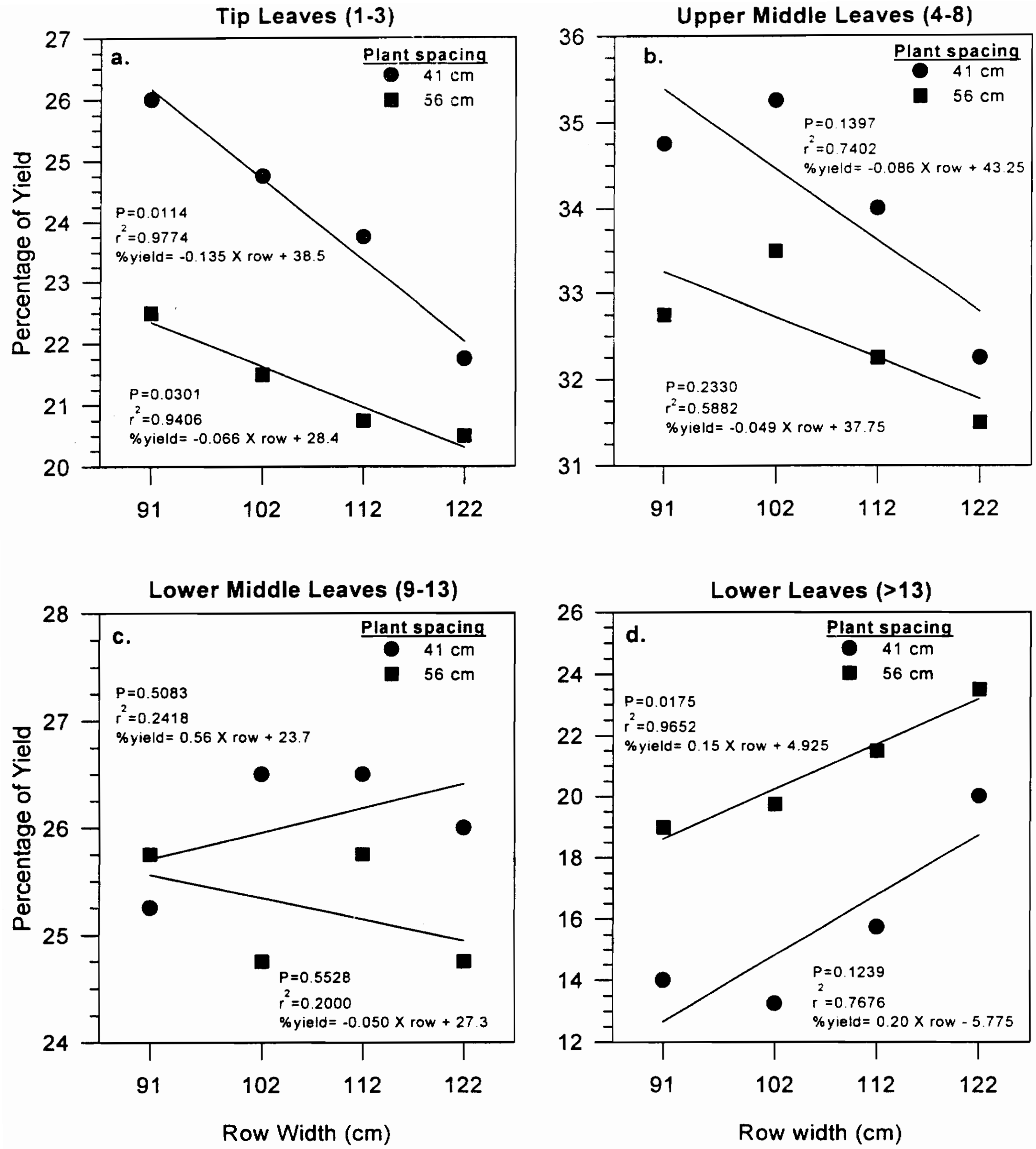

Fig. 4.6. Percentage of cured leaf yield from (a) the tip leaves, (b) the upper-middle leaves, (c) the lower-middle leaves, and (d) the lower leaves of the stalk of flue-cured tobacco as influenced by row width and plant spacing.

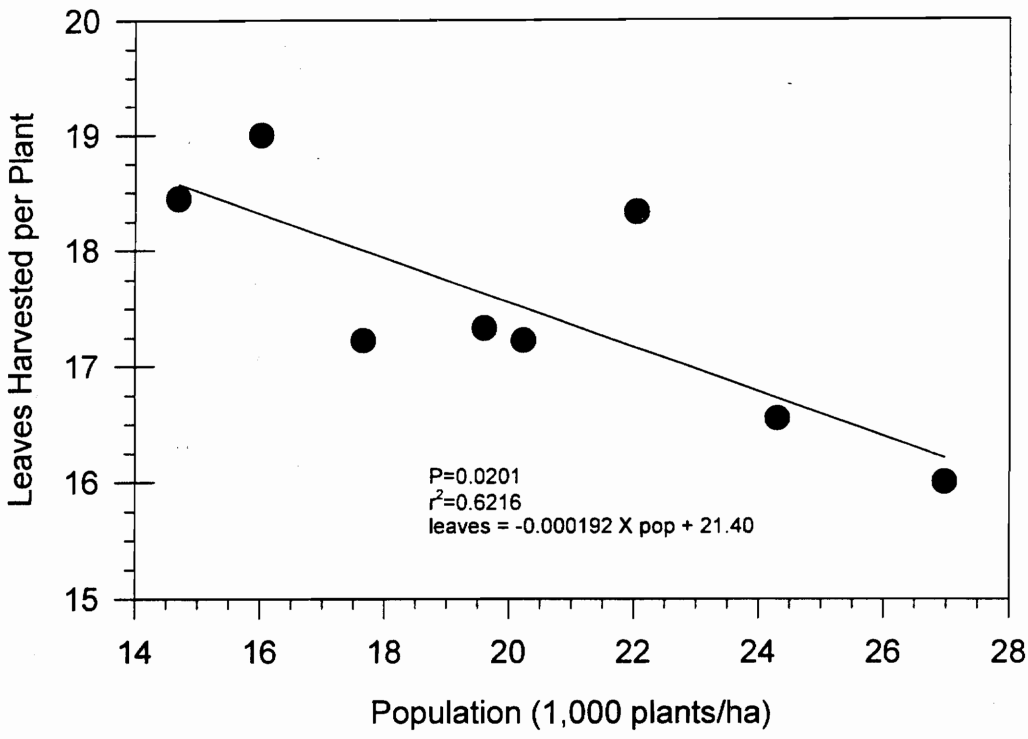

Fig. 4.7. Influence of plant population on the mean number of leaves harvested as an once-over harvest.

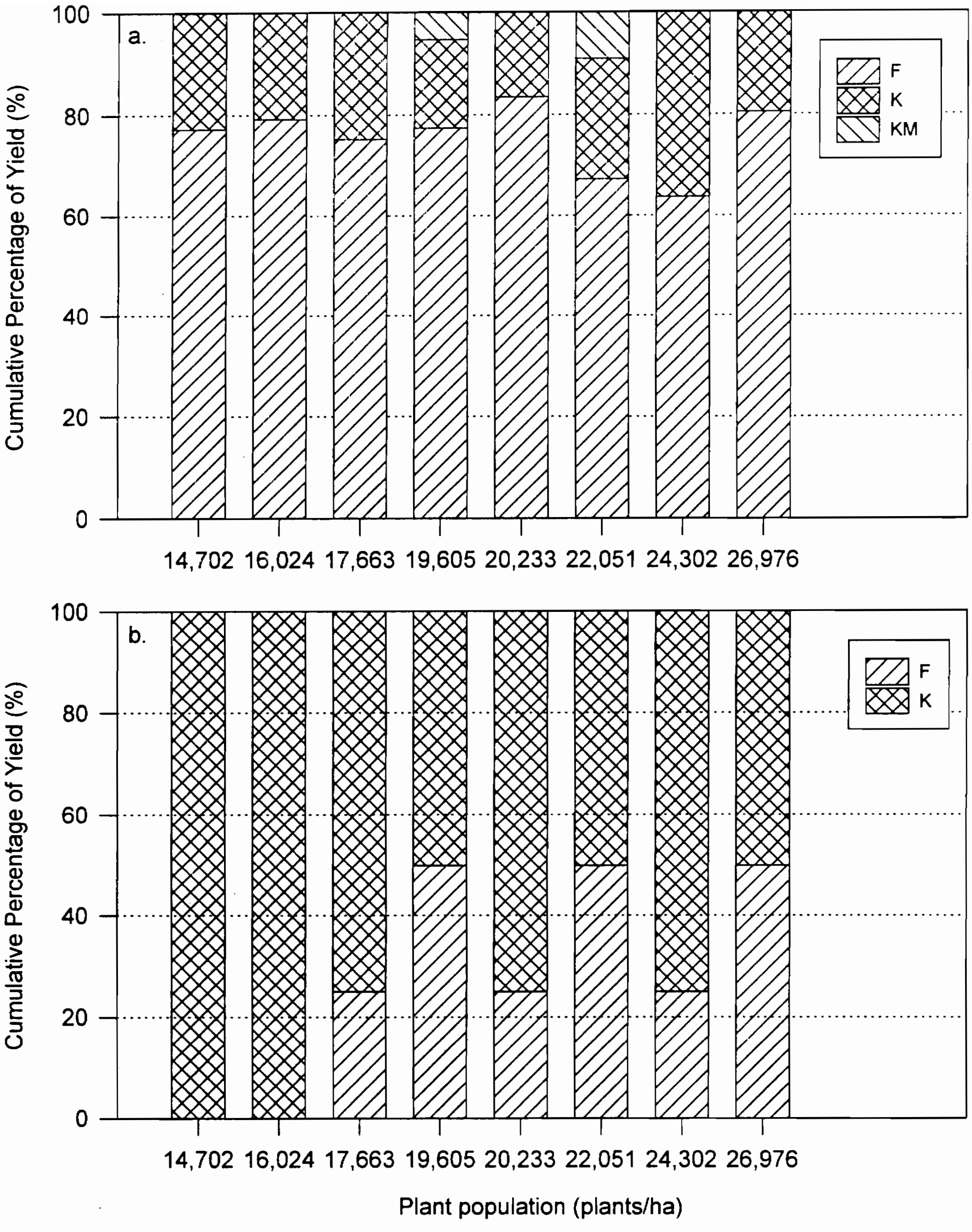

Fig. 4.8. Influence of plant population per hectare on the cumulative percentage of yield by color group designation of the cured leaf of flue-cured tobacco (a) separated by stalk position and (b) harvested once-over.

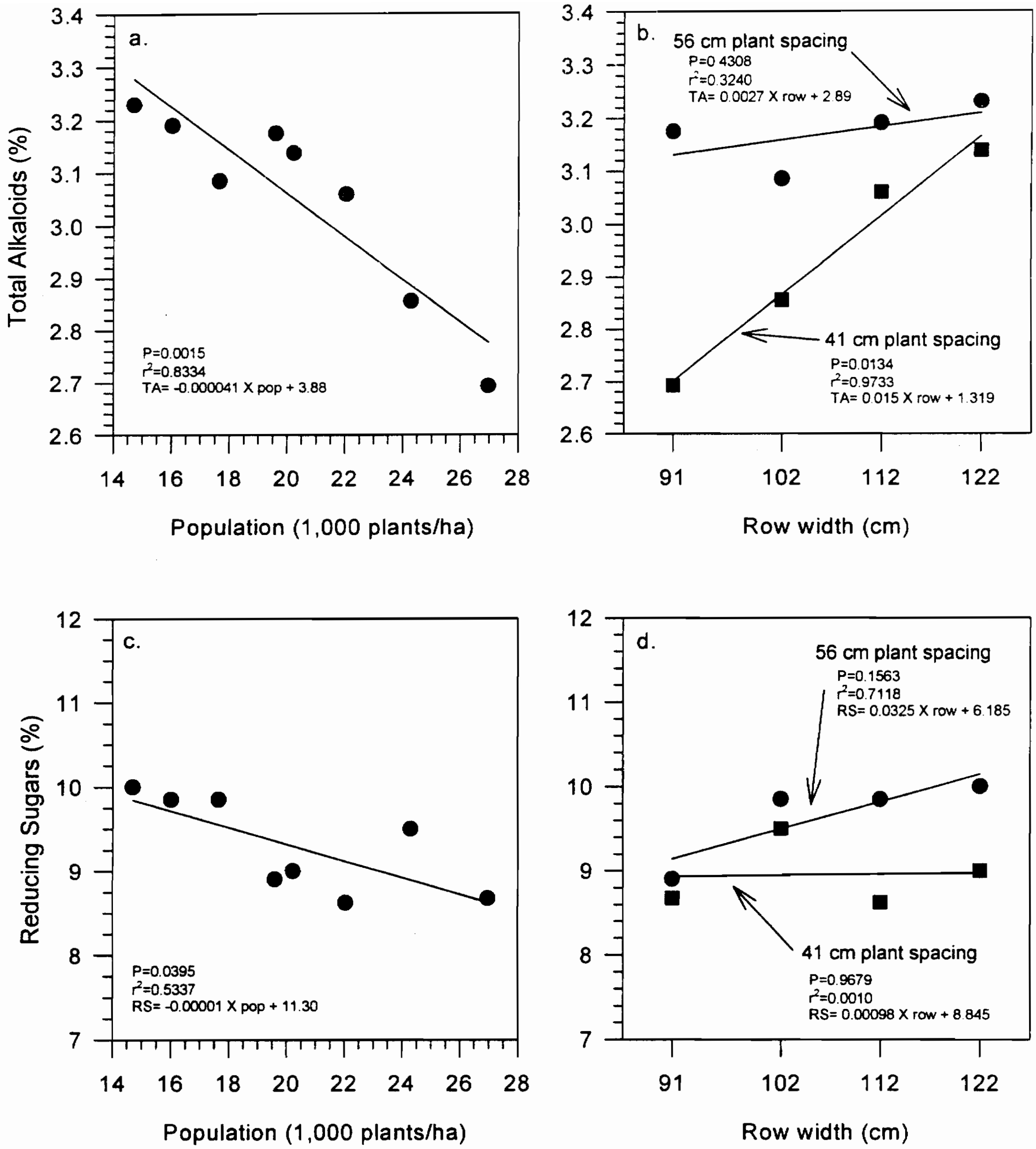

Fig. 4.9. Influence of plant population on total alkaloid (a) and reducing sugars (c) content and the influence of row width on the total alkaloid (b) and reducing sugars (d) content of flue-cured tobacco harvested once-over.

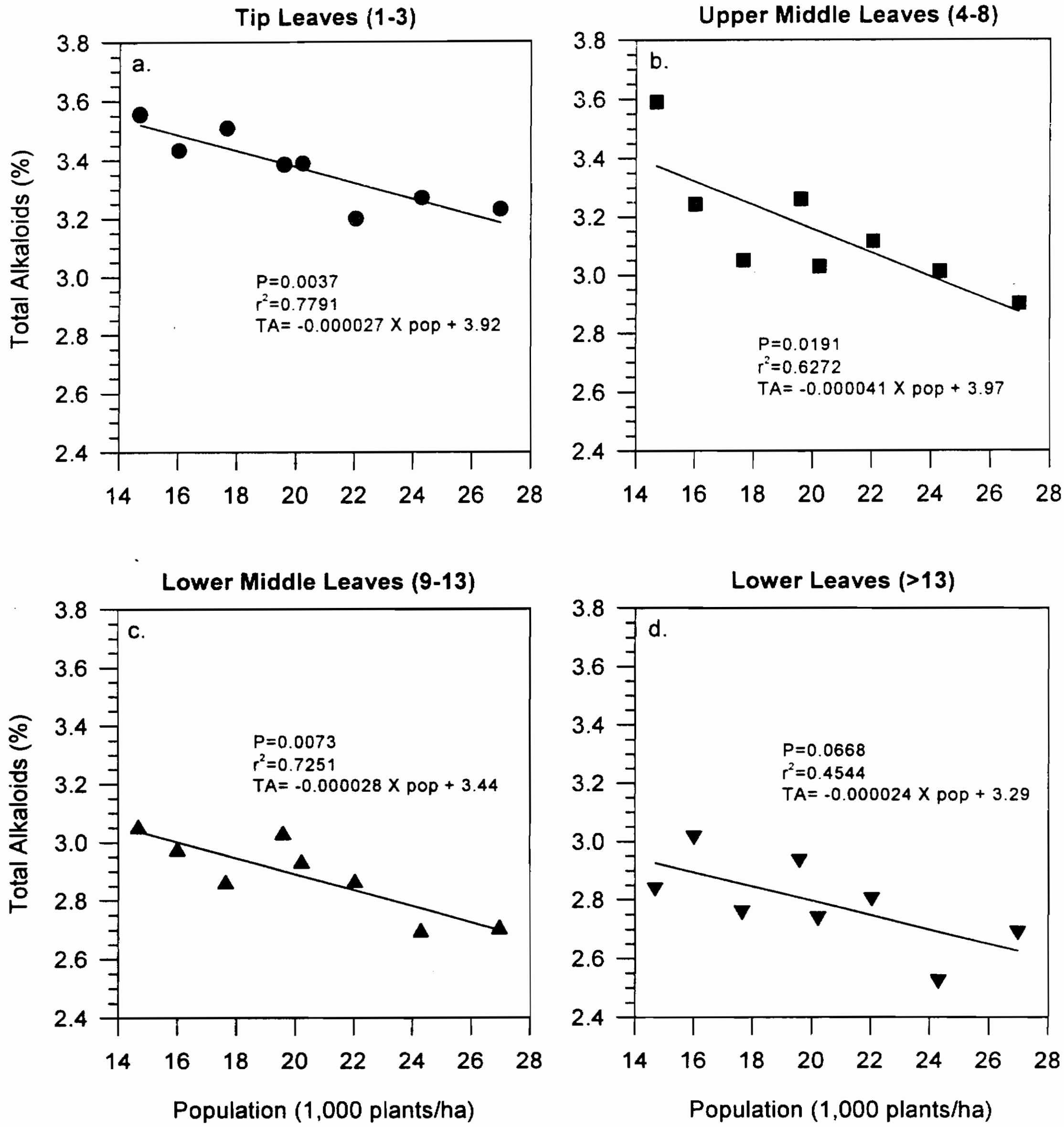

Fig. 4.10. Influence of plant population on the total alkaloid content (%) of the tip leaves (a), the upper middle leaves (b), the lower middle leaves (c), and the lower leaves (d) of flue-cured tobacco harvested once-over.

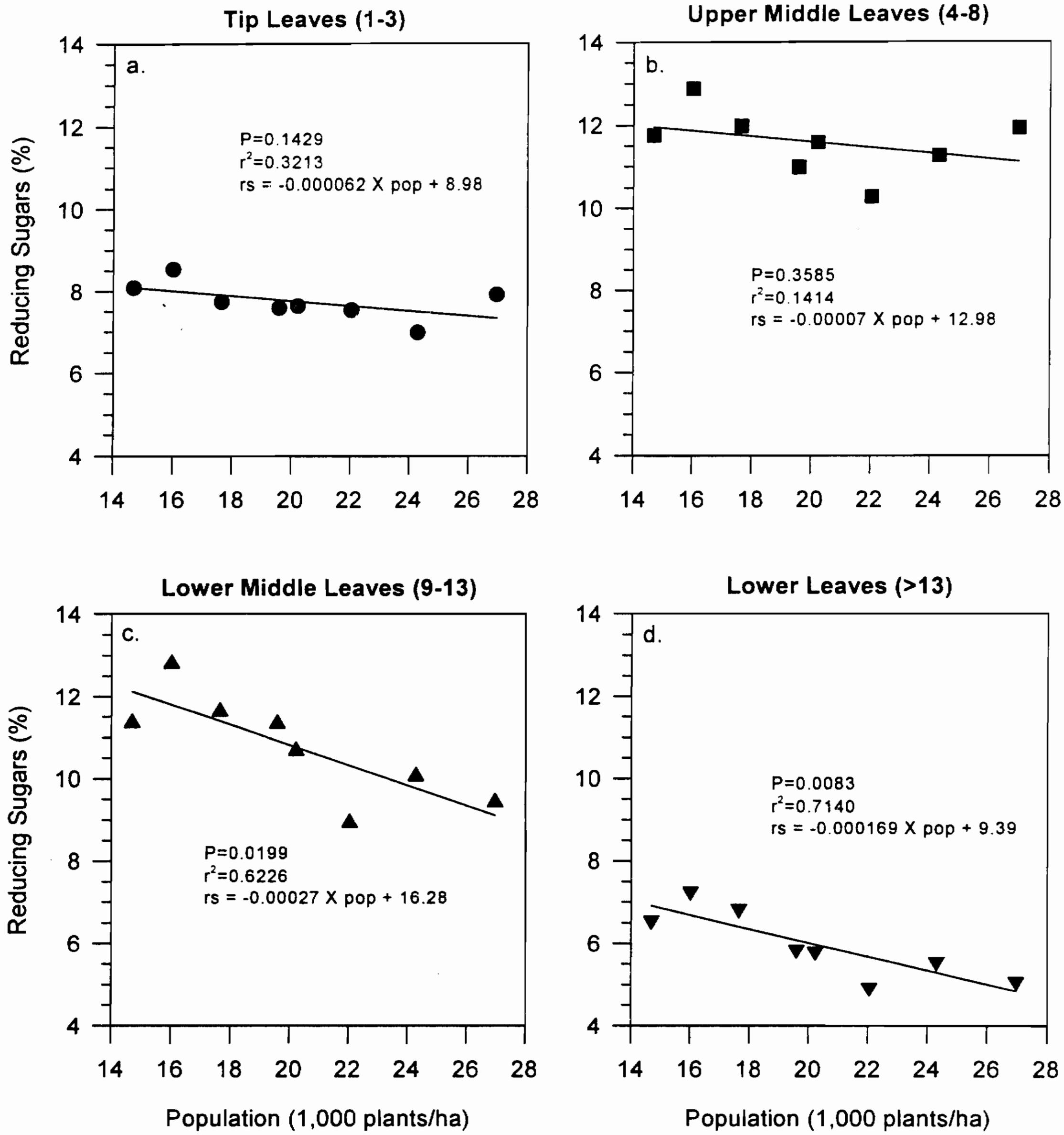

Fig. 4.11. Influence of plant population on the reducing sugars content (%) of the tip leaves (a), the upper middle leaves (b), the lower middle leaves (c), and the lower leaves (d) of flue-cured tobacco harvested once-over.

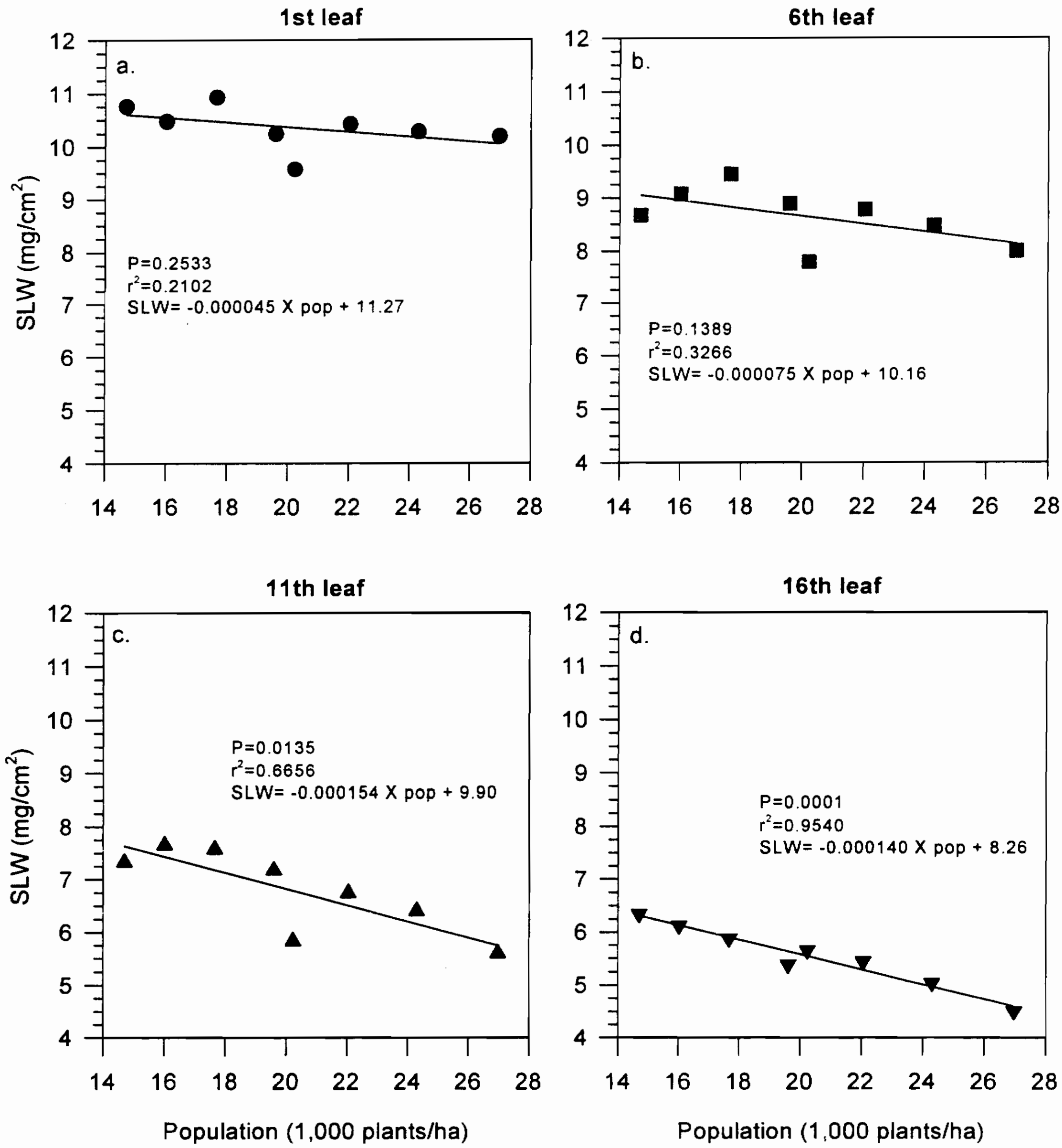

Fig. 4.12. Influence of plant population on the specific leaf weight (SLW) of the 1st (a), 6th (b), 11th (c), and 16th (d) leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

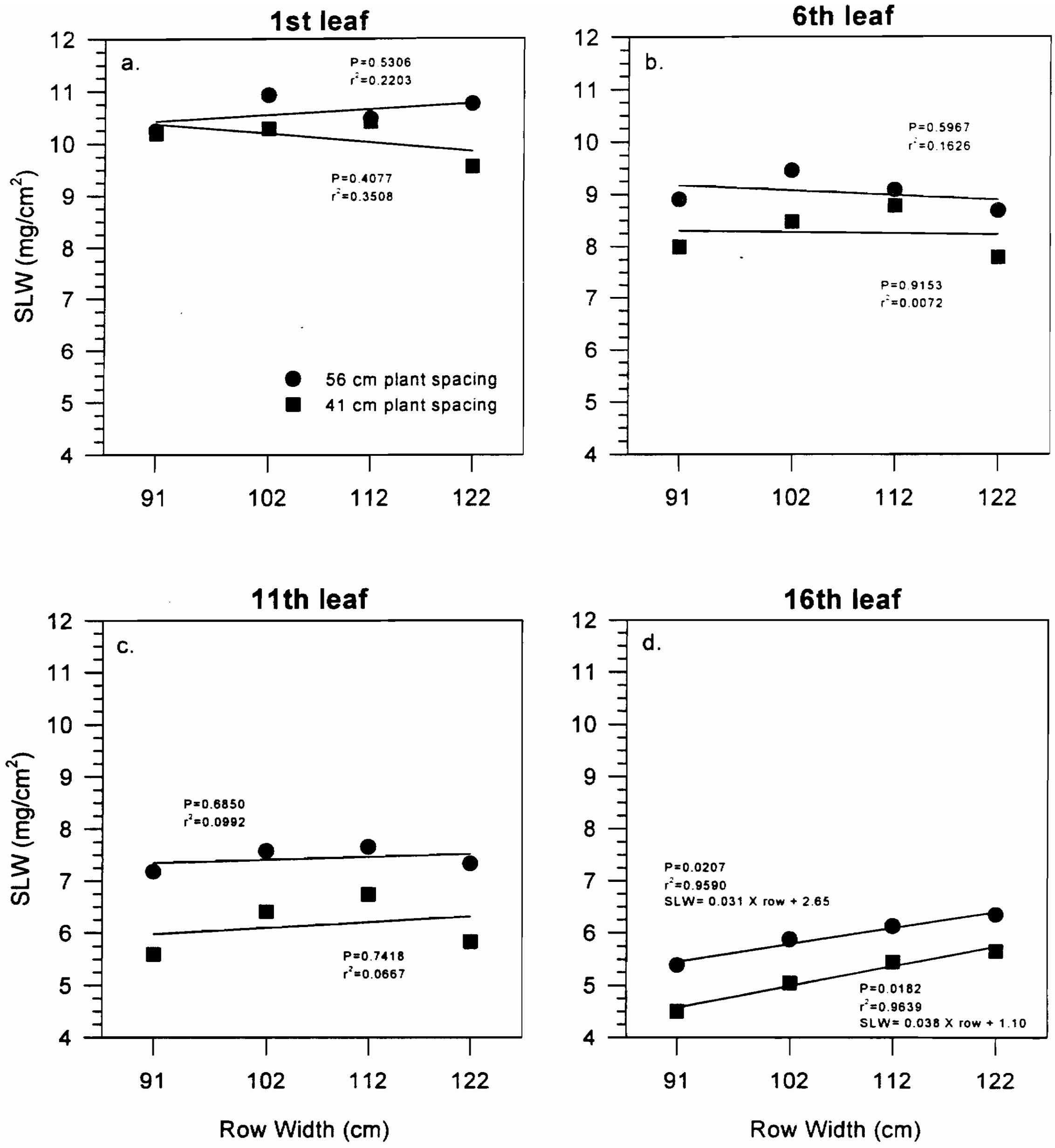

Fig. 4.13. Influence of row width and plant spacing on the specific leaf weight (SLW) of the (a) 1st, (b) 6th, (c) 11th, and (d) 16th leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

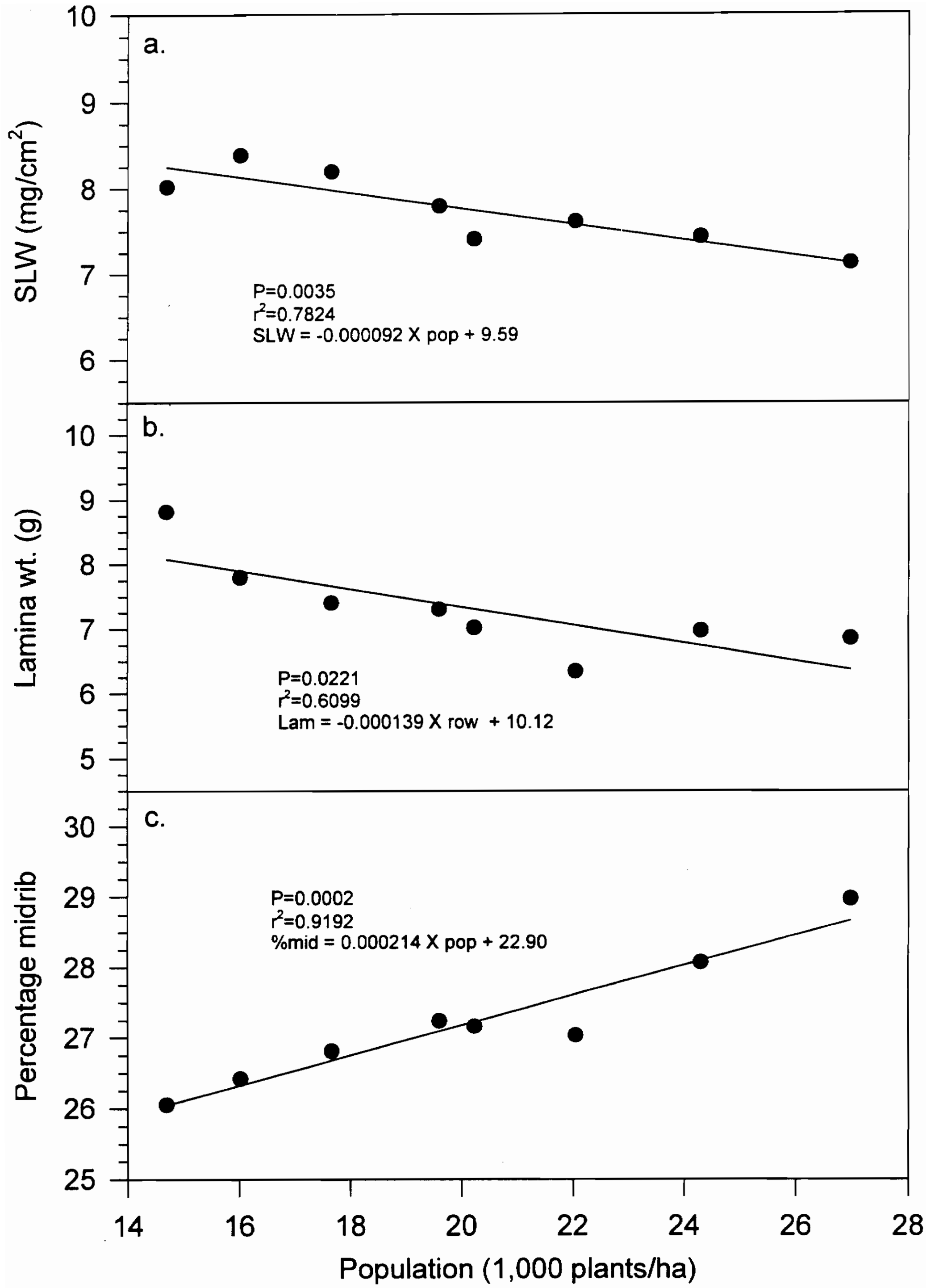

Fig. 4.14. Influence of plant population on (a) specific leaf weight (SLW), (b) lamina weight, and (c) percentage midrib of all harvestable leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

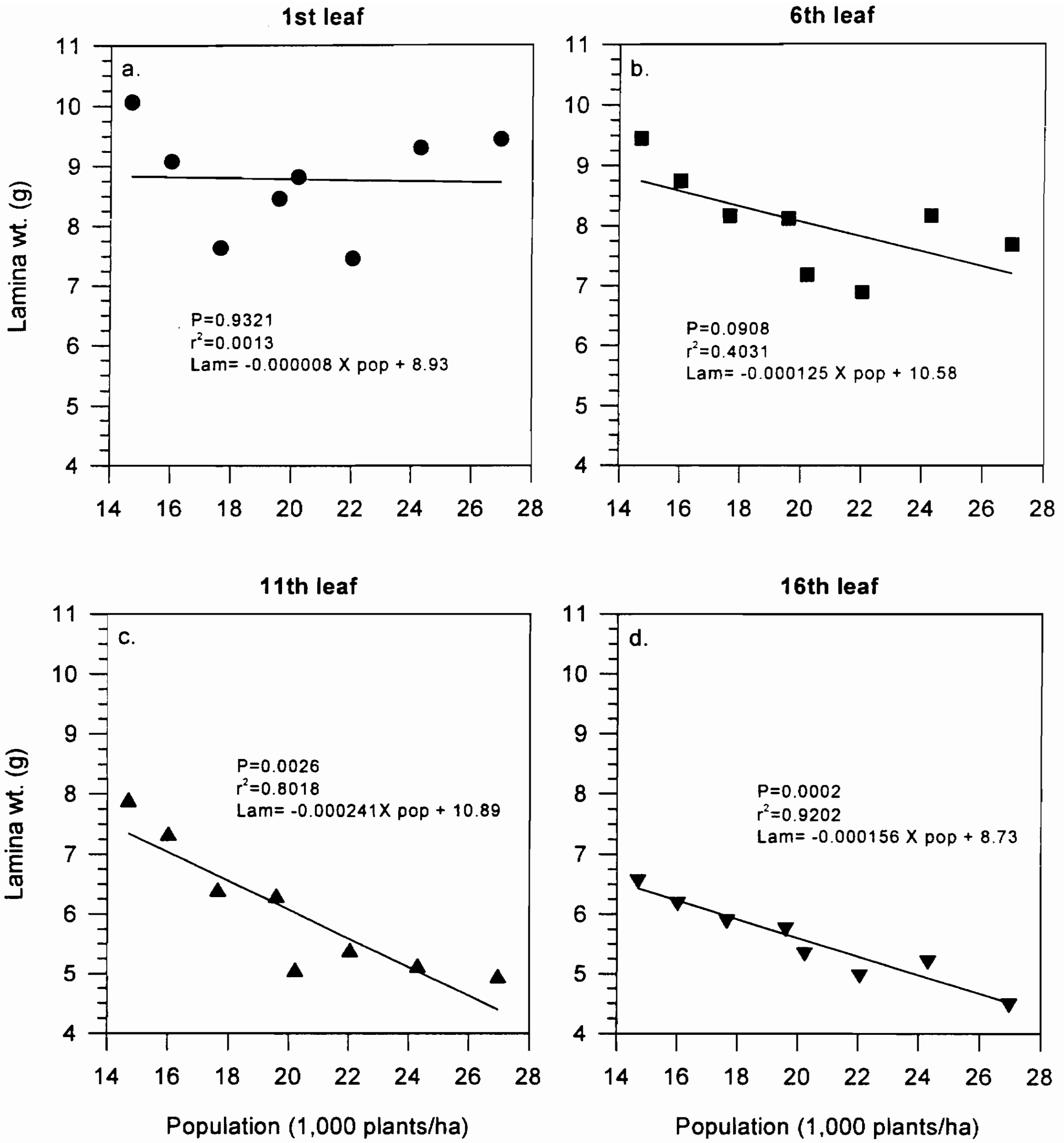

Fig. 4.15. Influence of plant population on the lamina weight of the 1st (a), 6th (b), 11th (c), and 16th (d) leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

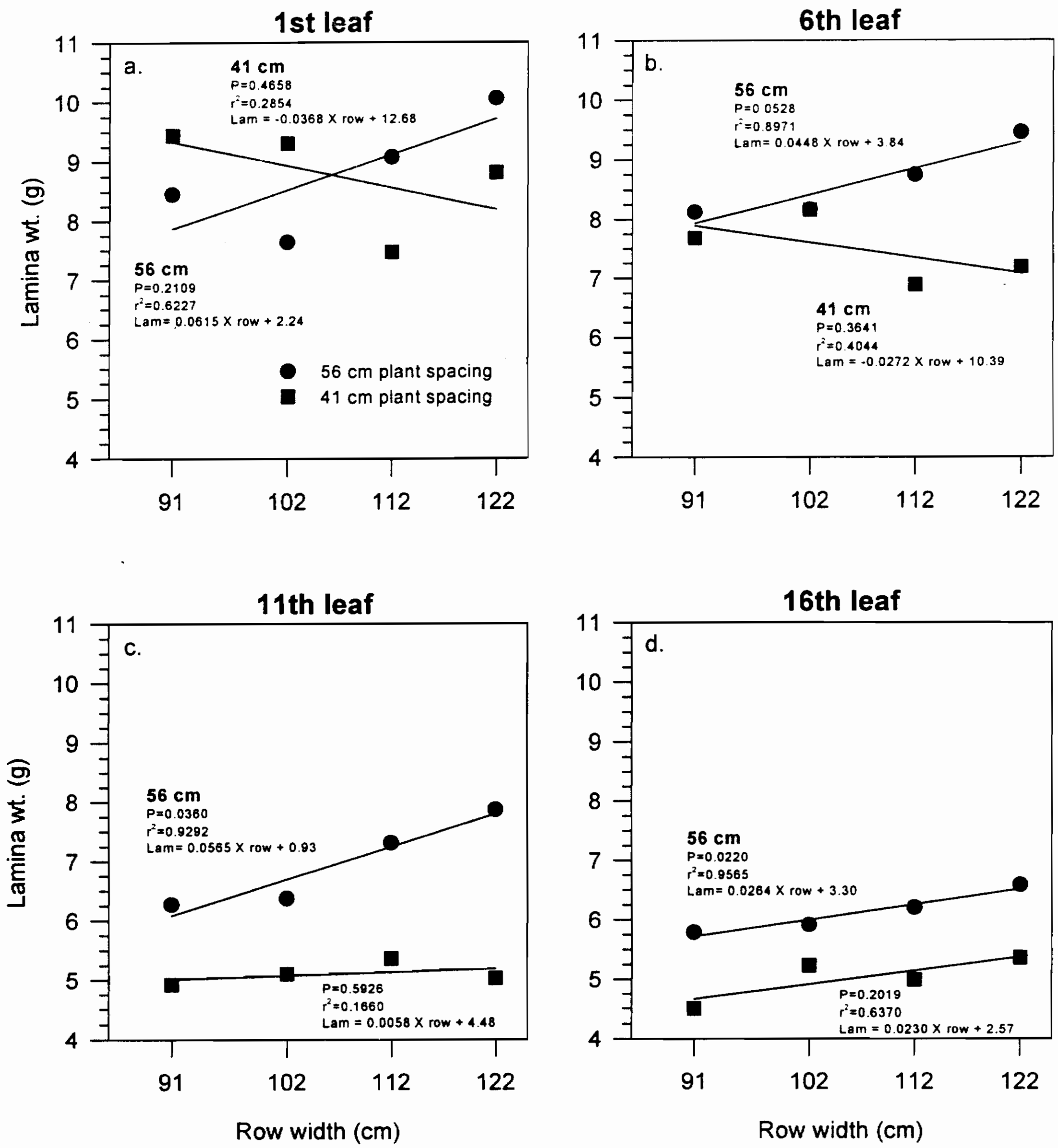

Fig. 4.16. Influence of row width and plant spacing of the lamina weight of the (a) 1st, (b) 6th, (c) 11th, and (d) 16th leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

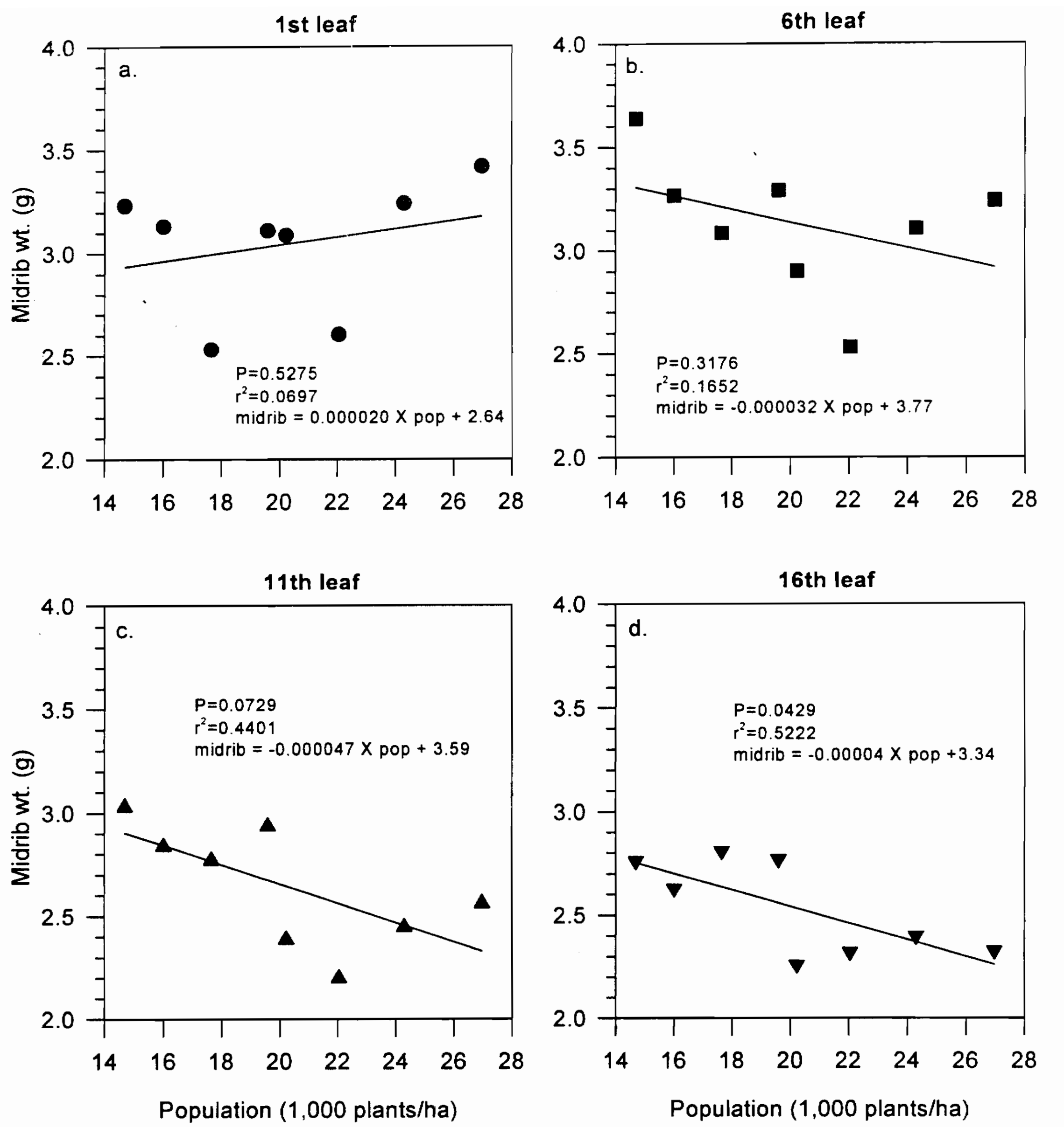

Fig. 4.17. Influence of plant population on the midrib weight of the 1st (a), 6th (b), 11th (c), and 16th (d) leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

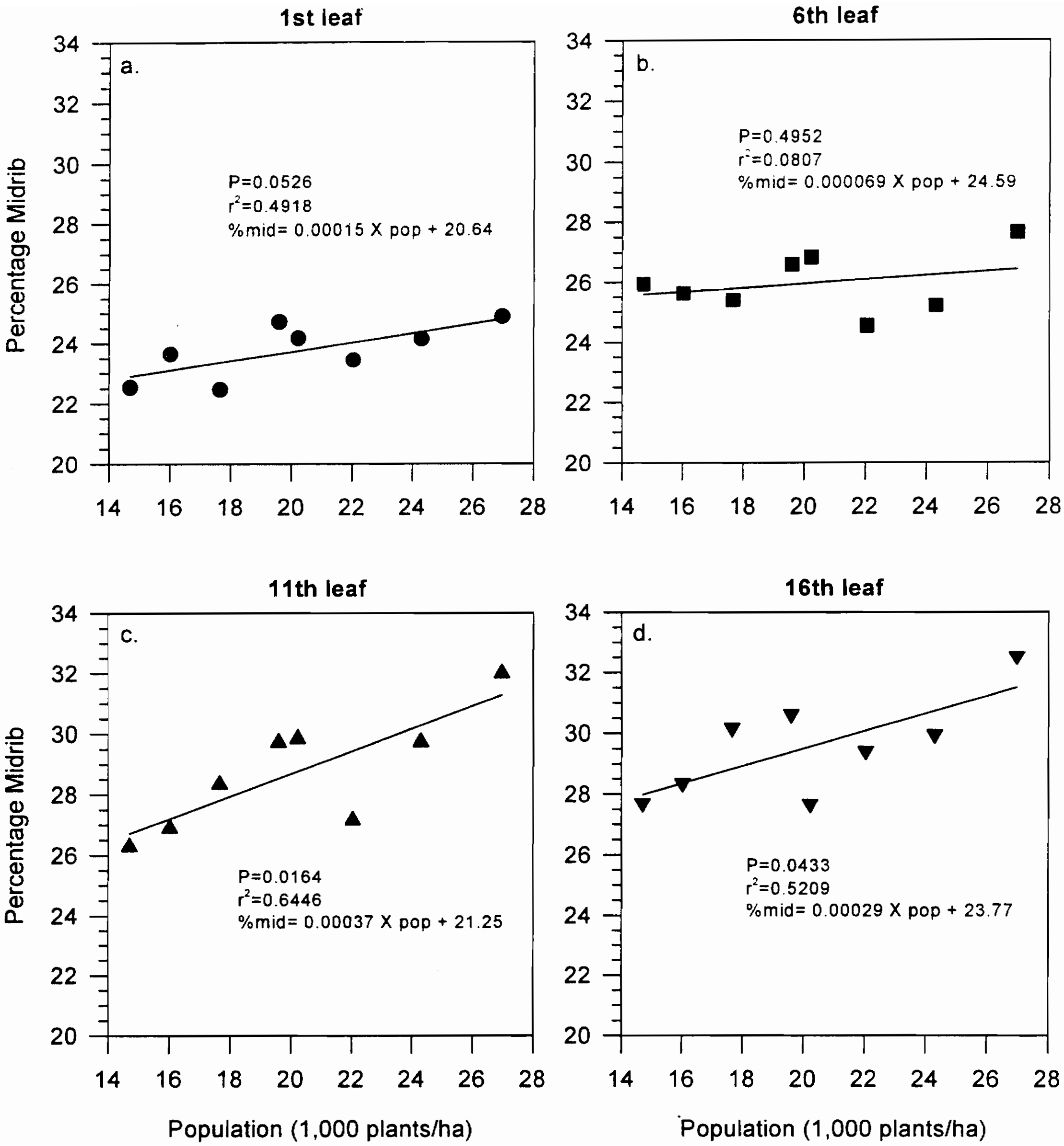

Fig. 4.18. Influence of plant population on the percentage midrib of the 1st (a), 6th (b), 11th (c), and 16th (d) leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

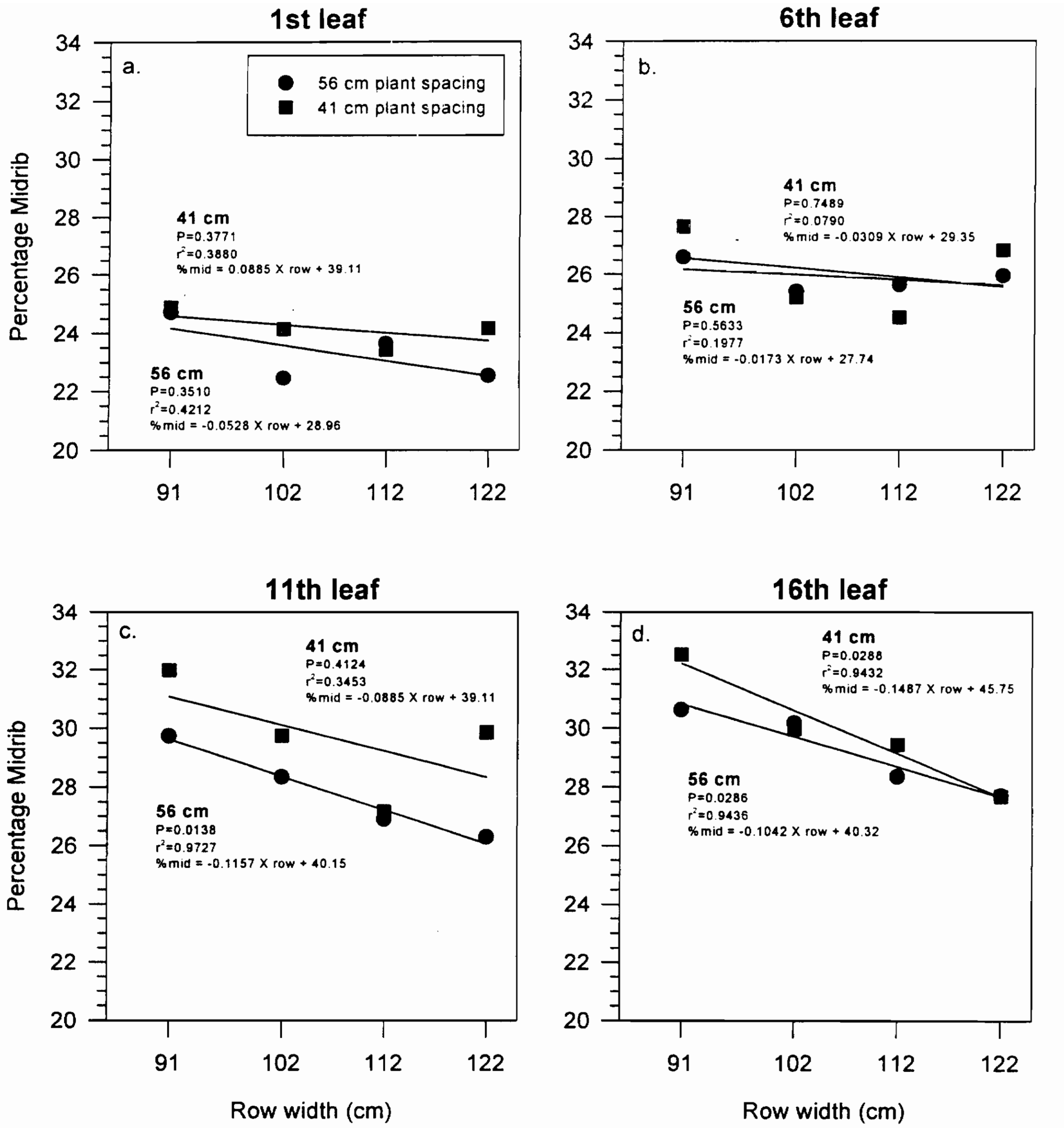

Fig. 4.19. Influence of row width and plant spacing on the percentage midrib of the (a) 1st, (b) 6th, (c) 11th, and (d) 16th leaves of flue-cured tobacco immediately prior to harvest (67 days after topping).

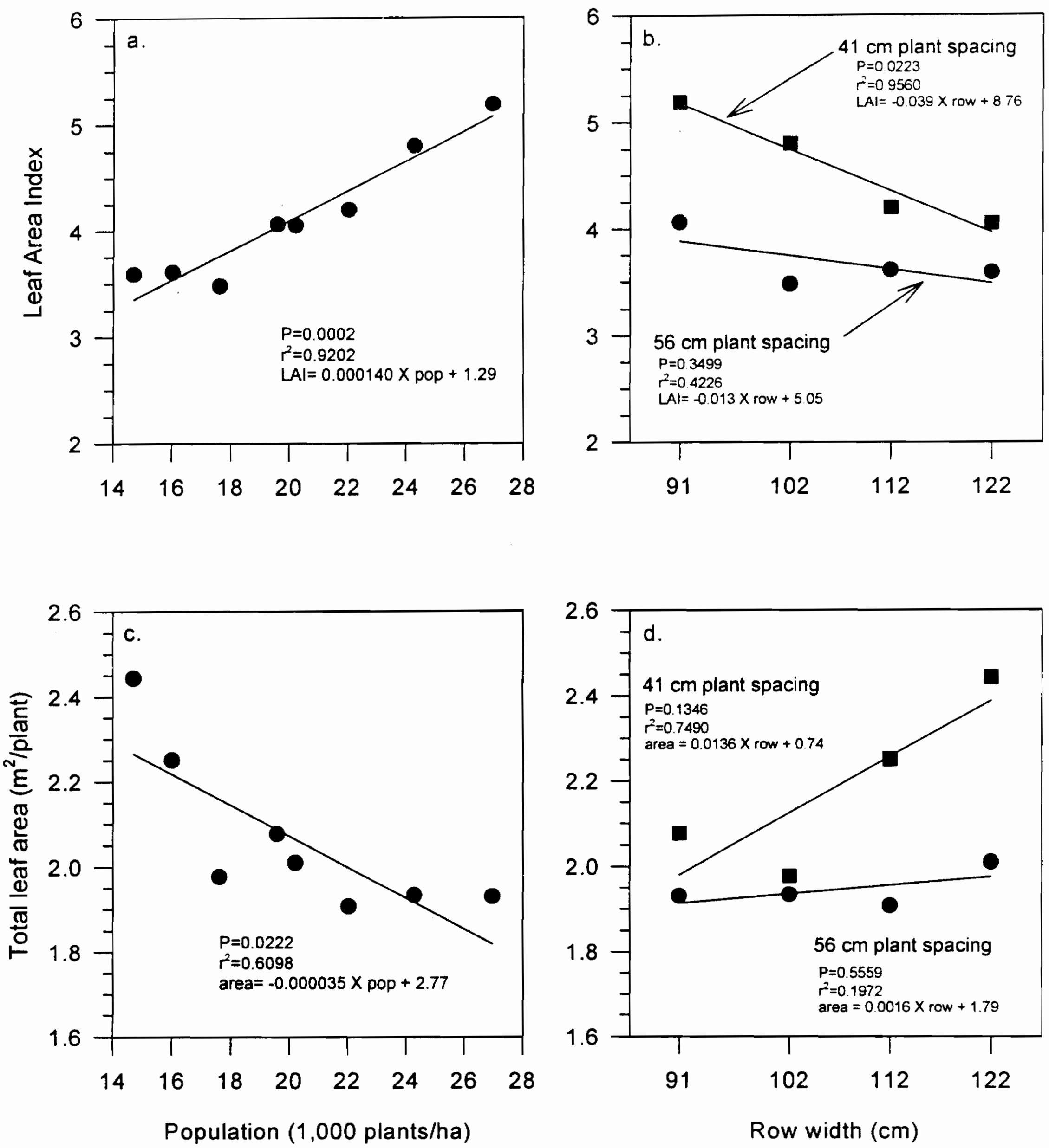

Fig. 4.20. Influence of plant population on the leaf area index (a) and total leaf area (m^2/plant) (c) and the influence of row width on the leaf area index (b) and total leaf area (m^2/plant) (d) of flue-cured tobacco immediately prior to harvest (67 days after topping).

Vita

C. Taylor Clarke Jr. was born October 7, 1970 to Carlton T. and Lynn F. Clarke in Emporia, Virginia. He attended Brunswick County Public Schools and graduated from Brunswick Senior High School in 1989. He enrolled at Virginia Polytechnic Institute and State University in September, 1989 and received a B.S. in Animal Science with a minor in Crop and Soil Enviromental Sciences in May 1993. During the summer after graduation, he worked as a summer intern at the Southern Piedmont Agricultural Research and Extension Center in Blackstone, Virginia. In September of 1993, he enrolled in the graduate school of Virginia Polytechnic Institute and State University to prusue a M. S. degree in Crop and Soil Environmental Sciences under the direction of Dr. T. David Reed and Dr. James Jones at the Southern Piedmont Agricultural Research and Extension Center in Blackstone, Virginia. Upon graduating, he accepted a position as Extension Agent, ANR/Tobacco in Mecklenburg and Brunswick counties, Virginia.

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