Nitrogen and Potassium Fertilization Effects on Yield and Quality of Burley Tobacco[1]

G. K. Evanylo and J. L. Sims[2]

ABSTRACT

Field studies were conducted in 1983 and 1984 at Lexington, KY to examine the effects of N and K fertilizer on yield and chemical quality of burley tobacco (*Nicotiana tabacum* L. cv. Ky 14). Treatments included: NH_4NO_3 at rates of 112, 280, and 448 kg N ha^{-1}; and two sources (K_2SO_4 and KCl), each at rates of 0, 112, 224, and 448 kg K ha^{-1}. The following agronomic and chemical characteristics were examined: yield, price, leaf N, P, K, Ca, Mg, Cl, Mo, total alkaloid, and solanesol concentrations. Cured leaf yield, price, and solanesol concentration were strongly influenced by N × K interactions. Each was raised by increasing N rates when no K was applied; however, at higher K levels, increasing N rates resulted in smaller price increases, no yield changes, and reductions in solanesol concentrations. Reductions in cured leaf Mo concentration relative to N, K, and Mg levels with increasing K fertilization beyond 0 kg ha^{-1} were exaggerated as N rates were raised. No effect of N rates on total alkaloids or solanesol concentrations were noted while increased K rates increased concentrations of both. Greater cured leaf yields and Mo concentrations were achieved with KCl than with K_2SO_4. The positive effect of KCl on Mo concentration at low N application rates was reduced by increased N fertilization suggesting that Mo uptake was enhanced by Cl^- but reversed at high levels of NO_3^- application.

Additional Index Words: Nicotiana tabacum L., Cl^-, Mo, SO_4, solanesol, alkaloids, P, Ca, Mg.

NITROGEN FERTILIZATION affects yield, quality, and usability of cured tobacco to a greater extent than does any other nutrient (McCants and Woltz, 1967; Atkinson and Sims, 1971; Miner and Sims, 1983). Yield and concentrations of most N constituents in the cured leaf are elevated as N fertilizer rates are increased up to about 215 kg N ha^{-1}, a level that normally produces maximum dry matter in burley tobacco. At higher N rates, NO_3^-, and total N concentration of cured leaf may continue to increase; however, concentrations of total alkaloids, secondary amines, and other reduced N compounds usually increase at a much slower rate or not at all. Alkaloids and solanesol concentrations of tobacco are of interest from a human health standpoint since they are precursors, respectively, of carcinogenic nitrosamines ((US-DHEW, 1982) or polynuclear aromatic hydrocarbons (Schlotzhaver et al., 1976).

Reports of the effects of N on leaf quality are often varied. Ammonium absorption by tobacco is known to increase Cl^- accumulation (McCants et al., 1959;

McCants and Woltz, 1967), which is detrimental to tobacco quality. Fuqua et al. (1974, 1976) reported interactive effects of NO_3^- and Cl^- on their accumulation by plants. Increasing rates of NO_3^- fertilizer increased nitrogenous constituents of leaf and smoke and greatly lessened the detrimental effects of Cl^- on grades assigned by federal inspectors. Atkinson and Sims (1971) reported leaf quality to be lowered with either very low (0–85 kg ha^{-1}) or very high (300–450 kg ha^{-1}) applications of N fertilizer.

The response of tobacco to K nutrition was reviewed recently (Sims, 1985). Yield increases with rates of K application up to 560 kg ha^{-1} have been reported, but maximum yields were usually obtained with applications in the range of 60 to 225 kg ha^{-1}. Amounts of K greater than that required for maximum yields often resulted in improved quality, market value, and burning properties (Myhre et al., 1956; Nichols et al., 1956; McCants and Woltz, 1967; and Leggett et al., 1977). Increased K application decreased the accumulation of Ca and Mg by tobacco, but had erratic effects on carbohydrate and nitrogenous constituents of tobacco leaf.

Source of K is critical in tobacco nutrition. Potassium sulfate is the recommended K source, but it costs about 2.5 times more than KCl per unit of K. Increased hygroscopic properties of tobacco leaf from excess Cl^- uptake results in reduced burn rate and problems during storage and aging (Myhre et al., 1956; Nichols et al., 1956; McCants and Woltz, 1967). Greater growth and crop yields sometimes achieved with KCl, compared with K_2SO_4, have been attributed to increased moisture of Cl^--treated leaf and to improved Cl^- and/or Mo nutrition (Stout et al., 1951; Eivazi et al., 1983; Miner and Sims, 1983). A cured leaf Cl^- level of 20 g kg^{-1} has been established by Zehler et al. (1981) as the upper limit of the acceptable range for combustibility of leaf. This is higher than the commonly accepted critical level of 10 g kg^{-1} found in the USA for burley and flue-cured tobaccos.

Although the individual effects of N and K fertilization on yields and quality-related components have been studied extensively, little data are available which examine the interactions of N and K fertilizers, including both K_2SO_4 and KCl, on yield, price, and health-related constituents of burley tobacco. The objectives of this study were to determine the existence and/or significance of such interactions in tobacco nutrition.

MATERIALS AND METHODS

Field studies were conducted in 1983 and 1984 at the University of Kentucky Spindletop Research Farm on Maury silt loam soil (Typic Paleudalf). Ammonium nitrate at rates of 112, 280, and 448 kg N ha^{-1} and two K sources (KCl and K_2SO_4) each at rates of 0, 112, 224, and 448 kg K ha^{-1} were employed in a split-split plot design and replicated three times. Nitrogen rates were assigned to the whole plots, K rates to the subplots, and K sources to the sub-subplots. All fertilizer was broadcast onto plowed ground and disked into the surface 7 d prior to transplanting burley tobacco (*Ni-*

[2] Former Postdoctoral Student (now Assistant Professor of Agronomy, VPI & SU, Painter, VA 23420) and Professor of Agronomy, Dep. of Agronomy, Univ. of Kentucky, Lexington, KY 40546-0091, respectively.

cotiana tabacum L. cv. KY 14). Molybdenum, as $Na_2MoO_4 \cdot 2H_2O$, was supplied to all plots in the transplant water at the rate of 0.22 kg ha^{-1}. Individual plots consisted of four rows, 12-m-long and 1 m between rows. Plants were transplanted at a distance of 46 cm within rows. All cultural practices followed were conventional methods for burley tobacco production in Kentucky.

Composite soil samples (15 cores to the 15-cm depth) were taken in each plot 2 weeks after transplanting in both 1983 and 1984. The samples were air dried and ground to pass a 2-mm sieve in preparation for chemical analyses. Soil samples were subjected to saturation (Bower and Wilcox, 1965) extraction procedures for determination of solution phase Cl$^-$.

The above ground parts of five tobacco plants were collected from each plot 35 d after transplanting for early leaf analysis. When mature, the whole plants in the two central rows of each plot were harvested and air-cured. Following curing, the leaves were stripped from the stalks, sorted into grade groups, and weighed for yield. U.S. Standard grades were assigned to each grade group by a USDA Tobacco Inspector and dollar values per kilogram (price) and per hectare (value) were calculated. Subsamples of cured leaf were collected, dried at 70 °C, and ground in a Wiley mill to pass a 0.425 μm (40-mesh) sieve in preparation for chemical analyses. Cured leaf yields were reported on an oven-dry basis.

Chemical analyses of plant tissue were determined following methods used in the Univ. of Kentucky Agron. Dep.'s Anal. Serv. Lab. The leaf tissue samples were subjected to a nitric–perchloric acid digestion then analyzed for K, Ca, and Mg by atomic absorption spectroscopy. Leaf Mo levels were determined by means of the automated method of Eivazi et al., (1982) after ashing of the plant material. Total alkaloids, total N, and P concentrations in cured leaf were determined on an autoanalyzer system following, respectively, methods of Harvey et al., (1969), Bradstreet (1965), and Technicon Industrial Method 348R-6-31-5, (Fiske and Subbarow, 1925). Chlorides were determined with a Buchler-Cotlove automatic titrator after extraction with water. Solanosal levels were determined by procedures described by Severson et al. (1977).

RESULTS AND DISCUSSION

Significant N rate × K rate interactions influenced various cured leaf indices (Table 1). Yields increased with each increment of N fertilizer when no K was

Table 1. Mean squares (MS) and probability levels of significance from analysis of variance for effects of N × K interactions and orthogonal single degree of freedom comparisons on selected cured tobacco leaf variables.

Source of variation	df	Cured leaf variables					
		MS	$P > f$	MS	$P > f$	MS	$P > f$
		N/Mo		K/Mo		Mg/Mo	
N × K	6	1653.36	0.10	1197.27	0.03	24.64	0.11
Error	6	535.11		206.85		8.47	
K$_1$ vs. all others							
× N$_L$	1	1516.77	0.02	755.02	0.03	13.28	0.12
Error	22	231.82		134.34		5.19	
		Yield		Price		Solanesol	
N × K	6	0.0894	0.07	304.99	0.27	25.51	0.11
Error	6	0.0247		178.79		8.65	
K$_1$ vs. all others							
× N$_L$	1	0.1038	0.19	1824.58	0.09	29.77	0.01
Error	22	0.0564		580.78		3.41	

applied (Fig. 1). At higher K rates, (224 and 448 kg K ha^{-1}) the response to N was erratic with yield reductions sometimes observed at the highest N rate.

Plant nutrient concentrations did not appear to be associated with the N × K yield response; however, the cured leaf ratios N/Mo, K/Mo, and Mg/Mo were significant for the N × K interaction (Fig. 2; Table 1). While the values of the nutrient ratios increased in response to N fertilization, the increase was strengthened at the higher K rates. The response of nutrient ratios to N rate (linear) was especially different between the zero K and all the other K rates as noted by the orthogonal single degree of freedom comparisons. The demonstrated importance of nutrient balance as a yield-determining factor (Chapman, 1967; Kenworthy, 1973; Sumner, 1977) suggests that the balance of Mo with N, K, and/or Mg may have controlled the yield response.

Both cured leaf Mo concentrations (Fig. 3) and tobacco yields (2.10 vs. 1.96 Mg ha^{-1}; $P < 0.15$) were greater with KCl than with K_2SO_4 fertilization in both years. The differences in Mo concentrations between sources of K fertilizer were likely due to a lessening of the depressive effects of SO_4^{2-} on MoO_4^{2-} (Stout et al., 1951; Pal et al., 1976), to a Cl$^-$ enhancement effect (Eivazi et al., 1983), or both. The increased yield in the presence of KCl may be due to improved Mo or Cl$^-$ nutrition since the yield data are reported on an oven-dry weight basis (Fig. 4).

Cured leaf Mo concentrations decreased with increasing rates of both K sources; however, a greater reduction occurred with K_2SO_4 than with KCl (Fig. 3). The decreased concentrations at higher rates of KCl can be explained on the basis of dry weight dilution since yields and actual weight of Mo uptake (data not shown) were greater at the higher rates of KCl. The decreased concentrations of Mo in the presence of K_2SO_4 may be attributed to both dry weight dilution and the competitive effects of SO_4^{2-} on MoO_4^{2-} (Pal et al., 1976).

Nitrogen rates appeared to have an additive effect in contributing to the Mo decline with K rates. With KCl, a slight increase in concentration, possibly due to Cl$^-$ enhancement, was obtained with 112 kg K ha^{-1} at N rates of 112 and 280 kg N ha^{-1} (Fig. 3A). The elevated Mo at the second K level disappeared as the
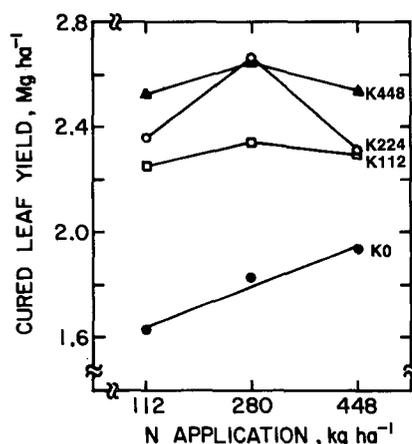

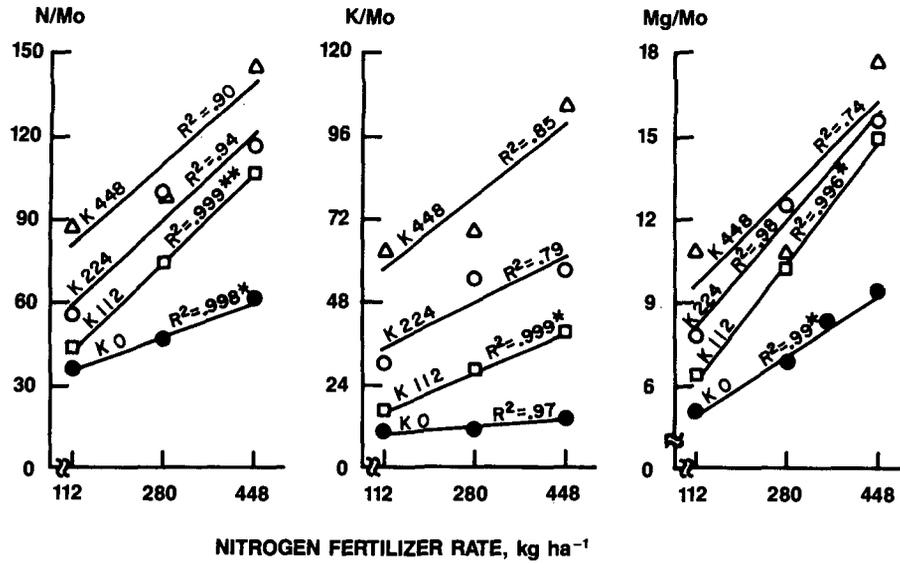Fig. 1. Tobacco leaf yield response to N fertilizer rates at each K rate.

Fig. 2. Cured leaf N/Mo, K/Mo, and Mg/Mo ratios as a function of N and K fertilizer levels. *, ** Significant at 0.05 and 0.01 probability levels, respectively.

N rate was raised to 448 kg N ha^{-1}. Since NO_3^- is known to interfere with Cl$^-$ uptake (McCants and Woltz, 1967; Fuqua et al., 1974, 1976), the application of the highest N rate may have reduced the level of Cl$^-$ uptake thereby reducing the Cl$^-$ enhancement effort on Mo. The NO_3^--Cl$^-$ antagonism is illustrated in Fig. 4 where the effect of increasing N rates on cured leaf Cl$^-$ concentration can be seen. Tissue Cl$^-$ concentrations were reduced by increasing N rates under KCl fertilization, but no differences in Cl$^-$ concentrations were effected by N when the SO_4^{2-} source was employed.

Quality of cured tobacco leaf, as evaluated by leaf price, responded to the N × K interaction (Fig. 5). A greater rise in price was obtained with increasing N rate when no K was applied than at the three highest K rates (Table 1). Tobacco leaf price, which generally improved with addition of intermediate N rates (100–300 kg N ha^{-1}), is usually reduced by levels of N corresponding to the highest rate in the study (Atkinson and Sims, 1971); however, even at the 448 kg ha^{-1} N rate only positive responses were elicited. The price response may be partly due to the lowering of Cl$^-$ by NO_3^-, although this would not account for the positive N effect on price observed under K_2SO_4 fertilization.

Plant uptake of Cl$^-$ depended primarily upon its concentration in the soil. Early and cured tobacco leaf

Cl$^-$ concentrations have been plotted as functions of saturated paste Cl$^-$ concentrations sampled to a 15-cm soil depth (Fig. 6a and b, respectively). While greater concentrations of Cl$^-$ were present in early season leaf in 1983 than in 1984, the greater growth experienced by the 1984 crop (due to more favorable soil moisture) resulted in greater Cl$^-$ concentrations in the cured leaf. This is probably explained by the dependence of Cl$^-$ uptake on plant metabolism (Mengel and Kirkby, 1979). Despite its good growth and high yields, the 1984 burley crop may be considered of unsatisfactory quality due to its high Cl$^-$ content (Zehler et al., 1981). While good correlations between saturated paste Cl$^-$ concentrations and early season leaf Cl$^-$ concentrations were obtained, the use of a soil test in the humid east to predict how Cl$^-$ may accumulate in cured leaf is questionable.

The observation that cured leaf total alkaloid concentrations were increased by K fertilization (Table 2) is contradictory to results of other studies (Hutcheson et al., 1959; Leggett et al., 1977) in which negative correlations between the rate of K fertilizer and the concentration of nicotine or total alkaloids in cured leaves were found. The previously reported effects of K on total alkaloids may have been due to dilution
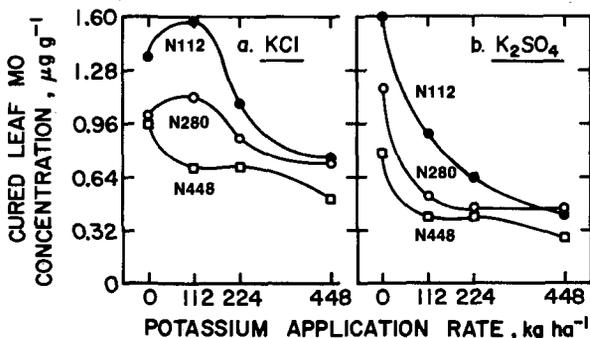

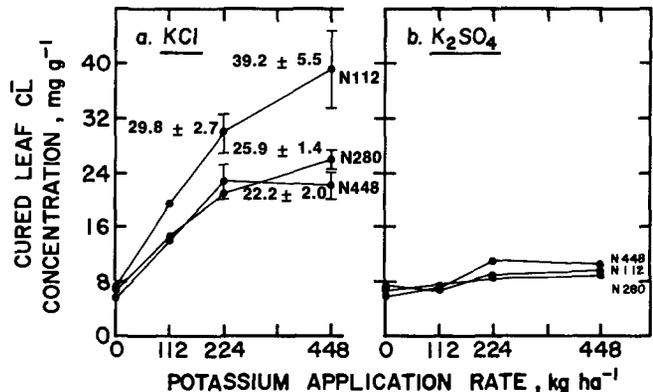Fig. 3. Effect of source and rate of K fertilizer on cured leaf Mo concentration at various rates of N.

Fig. 4. Cured leaf Cl$^-$ concentration as affected by KCl and K_2SO_4 at various rates of N. I = standard error of mean.
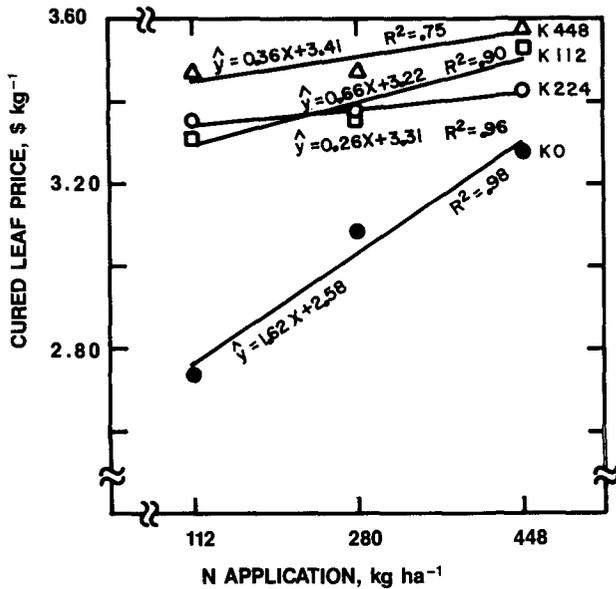
Fig. 5. Influence of rates of N and K on cured leaf price.

by dry matter since there are no known functions of K in the synthesis of nicotine. Solanesol levels were increased by N when no K was applied, but were reduced by increased N with increased K application (Fig. 7). The N × (K$_1$ vs. K$_2$, K$_3$, and K$_4$) contrast was significant at the 0.01 level of probability.

CONCLUSIONS

The N rate × K rate interaction has been shown to influence tobacco yield and quality components which are critical in determining the value of the crop. Yield, price, and solanesol concentrations were increased by N when K was limiting; however, as K rates were increased, N marginally affected yield and price and tended to decrease solanesol. The yield response to the N × K interaction may have been related to Mo nutritional balance. Molybdenum uptake appeared to be enhanced by Cl$^-$ and depressed by NO$_3^-$ (which
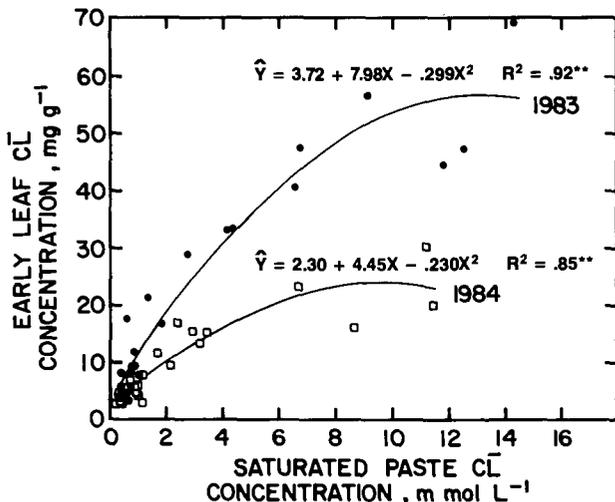

Fig. 6a. Early sampled tobacco leaf Cl$^-$ concentration as a function of saturated-paste Cl$^-$ concentration at the 0–15 cm soil depth. ** Significant at P ≲ 0.01. N = 24.
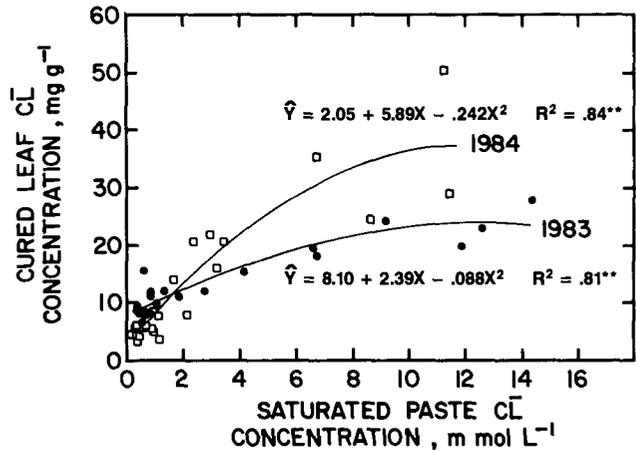

Fig. 6b. Cured-leaf Cl$^-$ concentration as a function of saturated-paste Cl$^-$ concentration at the 0–15 cm soil depth. ** Significant at P ≤ 0.01. N = 24.

competes with Cl$^-$ for uptake). Leaf Cl$^-$ accumulated as a function of saturated paste Cl$^-$ concentration but soil Cl$^-$ as a tool for predicting cured leaf Cl$^-$ concentration (and quality) appears to be of little value under varying environmental conditions.

Table 2. Cured leaf solanesol and total alkaloid concentrations as influenced by K fertilization.

Leaf constituent	K rate (kg ha^{-1})				
	0	112	224	448	
	g kg^{-1}				
Total alkaloids	37.1	42.0	42.5	42.0	**
Solanesol	15.5	18.5	17.3	19.0	*

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
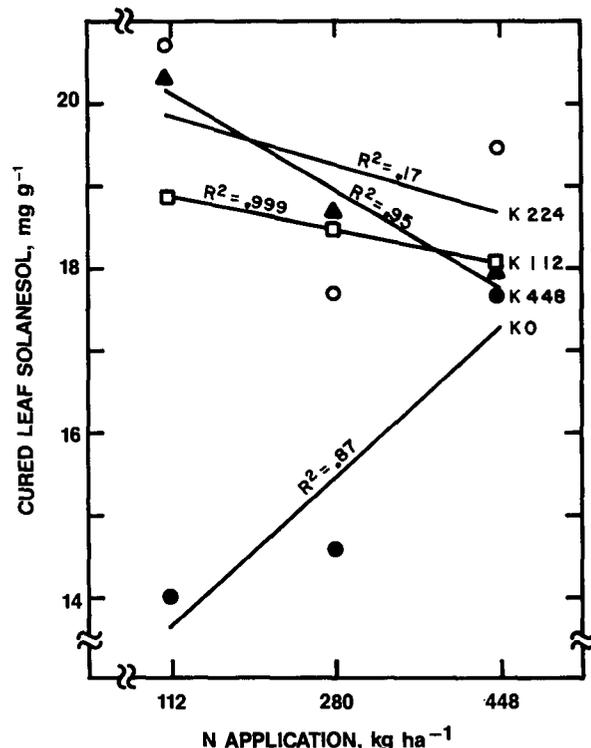
Fig. 7. Influence of rates of N and K on cured leaf solanesol concentration.

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