THE EFFECT OF POTASSIUM RATE ON THE YIELD AND QUALITY OF FLUE-CURED TOBACCO (*NICOTIANA TABACUM* L.)

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Research was conducted at 2 locations in 2009 and 2010 to determine the effect of potassium rate on the yield and quality of flue-cured tobacco. Treatments included 8 rates of potassium from sulfate of potash magnesia (K-Mag, 0–0–22): 0, 84, 112, 140, 168, 196, 224, and 252 kg K_2O ha^{-1}. A complete (N–P–K) fertilizer that supplied 134 kg K_2O ha^{-1} was also included as a control treatment. All fertilizer was applied in a single band application within 10 days after transplanting. Yield was measured and samples were assigned an official U.S. Department of Agriculture (USDA) grade. Crop value was determined based on yield and grade. Tissue samples were collected throughout the season at 3 separate times: at layby, at topping, and after curing. Tissue samples were analyzed for total alkaloid and reducing sugar content as well as N, P, K, and Mg content at North Carolina State University. Soil samples were also collected at transplanting, which corresponded with potassium fertilizer application, and were analyzed by the North Carolina Department of Agriculture and Consumer Services Agronomic Division in Raleigh, North Carolina. Data were subjected to an analysis of variance (ANOVA) with the use of the PROC GLM procedure in SAS. Treatment means were separated with the use of Fisher's protected least significant difference (LSD) test at $P \leq 0.05$. A yield or quality response was not observed with potassium rates at and above 84 kg K_2O ha^{-1}. Current potassium recommendations are adequate, and in fact may be higher than necessary for fine-textured soils with medium to high potassium indices. In contrast, recommendations appear to be accurate for coarse-textured soils in tobacco-producing areas of North Carolina, where potassium indices are often low.

Additional key words: *Nicotiana tabacum* L., potassium rate, sulfate of potash magnesia

INTRODUCTION

Potassium (K^+) is an essential plant nutrient for the production of high-yielding, high-quality flue-cured tobacco with a healthy crop typically requiring about 100 kg K_2O ha^{-1} from the soil for optimum growth (15). The tobacco plant is known to be a luxury consumer of K^+ (15) and, historically, potassium application has occurred at rates that are 2–3 times that needed for maximum yield (17). Excessive rates of K_2O have long been used to prevent K deficiencies as well as to improve certain leaf and burn qualities (3). Despite excessive rates of applied K_2O, potassium deficiencies are still common in tobacco production and occur across a wide range of soil types.

Rates of K application often vary across growing locations. Recommendations for K fertilization rates vary based on soil type, residual soil potassium, application timing, application method, and even across tobacco varieties over time (18). The current minimum recommendation for flue-cured tobacco production in North Carolina is 100 kg K_2O ha^{-1} (19); however, growers often apply as much as 168–196 kg K_2O ha^{-1}.

Past research results are mixed concerning general K recommendations for producers. Soils testing low (Mehlich-3 K 0.06 meq 100 cc^{-1}–0.12 meq 100 cc^{-1}) (8) in K have demonstrated responses to applied K at rates as low as 75 kg K_2O ha^{-1} (23) and rates as high as 134 kg K_2O ha^{-1} (2,7). Research conducted on deep sands in north Florida demonstrated a yield response to rates as high as 224 kg K_2O ha^{-1} (16). Additional experiments conducted across a variety of soils with varying K indices have demonstrated responses to application rates as low as 45 kg K_2O ha^{-1} (7) and high as 112 kg K_2O ha^{-1} (9). Overall, K application rates based on K indices have given inconsistent results at various locations.

Ultimately, with newer, higher-yielding cultivars and with variation in K recommendations based both on residual soil K and soil texture, it is often difficult to determine how much supplemental K is needed. Research is currently unavailable in regards to improving K efficiency in current times. The objective of this study was to determine if current K recommendations are adequate and to determine if K fertilizer efficiency can be improved.

MATERIALS AND METHODS

Field experiments were conducted in 2009 and 2010 at the Upper Coastal Plain Research Station (UCPRS) near Rocky Mount, North Carolina and the Oxford Tobacco Research Station (OTRS) in Oxford, North Carolina to determine the effect of potassium rate on the yield and quality of flue-cured tobacco (*Nicotiana tabacum* L.). Cultivars used in this study were NC 71 at UCPRS and NC 297 at OTRS. Tobacco was produced with the use of practices recommended by the North Carolina Cooperative Extension Service, except for treatments imposed. Cured tobacco was weighed for yield and assigned a USDA government grade. Each USDA grade has an associated monetary value; this value was multiplied by crop yield to establish overall crop value.

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Table 1. Soil series, transplanting date, soil pH, phosphorus index, and potassium index at each test site.

Test sites	Soil Series	Transplanting Date	pH	P Index	K Index
				mg P/dm^3	meq K/100 cc
UCPRS-09[a]	Goldsboro loamy sand	April 29, 2009	6.2	45.6	0.25
OTRS-09[b]	Helena sandy loam	May 21, 2009	5.8	49.2	0.19
UCPRS1-10[c]	Norfolk loamy sand	April 27, 2010	5.8	162	0.30
UCPRS2-10[d]	Goldsboro loamy sand	April 27, 2010	6.0	112.8	0.45

[a] UCPRS near Rocky Mount, NC in 2009.
[b] Oxford Tobacco Research Station in Oxford, NC in 2009.
[c] UCPRS near Rocky Mount, NC in 2010.
[d] UCPRS near Rocky Mount, NC in 2010.

Treatments were replicated 4 times and arranged in a randomized complete block design. Plots were 4 rows wide by 12.19 m long, with all 4 rows treated and the 2 center rows harvested for yield and quality. Individual plant spacing was 55 × 122 cm. Soil samples were collected the same day as K fertilizer application from plots receiving 0 kg K_2O ha^{-1}, the first from 0 to 15 cm deep and the second from 15 to 30 cm deep. Soil samples were analyzed by the North Carolina Department of Agriculture and Consumer Services Agronomic Division in Raleigh, North Carolina. Tissue samples were also collected at 3 separate times during the season. One tissue sample was collected from 5 random plants in the center 2 rows of each plot. Leaves collected were the third or fourth leaf from the bud at each respective interval, and were roughly 10 cm wide and 15 cm long. Once tissue samples were collected, dried, and ground they were analyzed at the Environmental and Agricultural Testing Service (EATS) Lab at North Carolina State University for elemental analysis of N, P, K, and Mg.

Field Conditions. Field conditions (soil series, transplanting date, pH, P index, and K index) and monthly rainfall are described by test site in Tables 1 and 2. The tobacco was transplanted on April 29, 2009 at UCPRS, May 21, 2009 at OTRS, and April 27 at both locations in 2010. All K fertilizer was applied as sulfate of potash magnesia (0–0–22, K-Mag) within 10 days after transplanting in a banded application. Treatments included 0, 84, 112, 140, 168, 196, 224, and 252 kg K_2O ha^{-1}. An additional treatment that was included as a control was the complete fertilizers 6–6–18 at 747 kg ha^{-1} at UCPRS and 8–8–24 at 560 kg ha^{-1} at OTRS, each providing 134 kg K_2O ha^{-1}.

Table 2. Monthly total precipitation from pretransplant to harvest at all 4 test sites (20).

Month	OTRS-2009[a]	UCPRS-2009[b]	UCPRS-2010[c]
	cm		
March	12.7	18.1	20.0
April	2.1	2.0	2.8
May	18.4	8.7	13.2
June	11.3	9.1	3.2
July	6.4	8.9	5.4
August	8.1	7.4	11.3
September	1.0	12.1	26.2
October	2.8	3.5	3.9
Total	62.8	69.8	86.0

[a] OTRS in Oxford, North Carolina in 2009.
[b] UCPRS near Rocky Mount, NC in 2009.
[c] UCPRS near Rocky Mount, NC in 2010.

K-Mag supplied Mg (11%) and S (22%), and rates of sulfate of potash magnesia were chosen that provided adequate amounts of both nutrients. Nitrogen was supplied in split applications from 30% urea ammonium nitrate (UAN) applied at 103 L ha^{-1} at UCPRS and from calcium nitrate (15.5–0–0) applied at 217 kg ha^{-1} at OTRS, except for plots receiving a complete fertilizer, which only received UAN or calcium nitrate during the second or layby N application.

Potassium applications were made by hand. Plots were established on March 27, 2009 at UCPRS and April 21, 2009 at the OTRS when soil fumigants were applied and plant beds were formed. Tobacco was transplanted April 29, 2009 at the UCPRS and May 21, 2009 at the OTRS. In 2010, plots were established at the UCPRS on March 25 and tobacco was transplanted on April 27. Applications were made within 10 days of transplanting with a single band application placed 12 cm away from the plant and 12 cm deep.

Tissue samples were collected at 3 time points: at layby (when plants were roughly 38 cm tall), at topping (just after flower removal), and after curing (weighted composite sample of all 4 priming intervals). Samples were collected at UCPRS on June 18, July 16, and mid-September for each respective time. Samples were collected at OTRS on June 25, July 31, and late September for each respective interval. Soil samples were collected prior to transplanting and at planting. Soil samples were collected at UCPRS in the early winter of 2009 to establish a baseline for residual soil potassium with further sampling taking place April 29. Sampling at OTRS occurred in early winter of 2009 and May 21, which corresponded to transplanting. In 2010, tissue samples were collected at UCPRS on June 4, June 28, and in early November for each respective interval. Soil samples were collected in the late fall of 2009 to establish a baseline for residual soil potassium with further sampling taking place on April 27, which corresponded to transplanting.

Analytical Procedures. *Total alkaloids and reducing sugars.* Total alkaloids and reducing sugars were determined by the North Carolina State University Tobacco Analytical Services Lab. Fifty-gram cured leaf samples were prepared for each plot by compositing cured leaf from each priming on a weighted-mean basis.

Table 3. P values for yield, quality, value, total alkaloids, reducing sugars, and elemental leaf content.[a]

Variable	$P > F$ Test Sites * K_2O Rate	$P > F$ K_2O Rate
Yield	0.4033	0.0923
Grade index	0.3581	0.3391
Crop value	**0.0159**	**0.0257**
Crop value, UCPRS 2009	–	0.0679
Crop value, OTS 2009	–	0.3589
Crop value, UCPRS1 2010	–	**0.0393**
Crop value, UCPRS2 2010	–	**0.0224**
Total alkaloids	0.5316	0.1639
Reducing sugars	0.6457	0.3941
Nitrogen, layby	0.8998	**0.0004**
Nitrogen, topping	0.6391	0.3827
Nitrogen, after curing	0.4171	**0.0054**
Phosphorus, layby	0.8510	**0.0119**
Phosphorus, topping	0.3925	0.1402
Phosphorus, after curing	0.3353	0.9368
Phosphorus, without P, layby	0.7564	0.1176
Phosphorus, without P, topping	0.5944	0.1148
Phosphorus, without P, after curing	0.2076	0.8992
Potassium, layby	0.6610	**0.0356**
Potassium, topping	0.3208	**0.0033**
Potassium, after curing	0.8228	**<0.0001**
Magnesium, layby	0.2778	**0.0024**
Magnesium, topping	0.0860	0.2939
Magnesium, after curing	0.8735	0.4169

[a] Bold font indicates significance at $P \leq 0.05$.

Oven-dried samples were ground to pass through a 1-mm sieve and analyzed for percent total alkaloids and percent reducing sugars under the method of Davis (4).

Nitrogen. Total N content was determined by weighing out 10 mg of each ground sample in a consumable tin capsule with a precision balance. Once each sample was weighed, capsules were placed in a Perkin Elmer CHN Elemental Analyzer (model 2400 series II), where elemental gas content was determined.

Phosphorus, potassium, and magnesium. The elemental composition of P, K, and Mg was determined by weighing 1.25 g of each sample in a porcelain crucible on a precision balance. Samples were ashed in a muffle furnace at 500°C overnight and dehydrated with 4 ml of 6N HCl. After dehydration was complete another 4 ml of 6N HCl was added back to the sample and heated. Samples were then washed into 50-ml Erlenmeyer flasks and brought to volume with distilled water and properly mixed. Samples were filtered into polypropylene centrifuge tubes at a volume of 12 ml and analyzed with the use of a Perkin Elmer ion-coupled plasma spectrophotometer.

Soil samples. Soil samples were analyzed at the North Carolina Department of Agriculture and Consumer Services Agronomic Lab in Raleigh, North Carolina. Samples were analyzed for P, K, Ca, Mg, S, Na, Mn, Cu, and Zn by means of Mehlich-3 extractant with the use of inductively coupled argon plasma spectroscopy on a volume basis (8,12). Cation exchange capacity (CEC) was determined by summation of basic cations (excluding sodium) and buffer acidity (8,14). Soil pH was determined on a 1:1 soil/water volume ratio. Humic matter determinations were made with the use of a NaOH digestion with colorimetric determination (8,13).

Table 4. Plant tissue sufficiency and deficiency ranges for ripe flue-cured tobacco.

Constituent	Sufficiency Range	Deficiency Level
	%	
Total alkaloids	0.20–7.87 (23)	n/a
Reducing sugars	0.80–22.20 (23)	n/a
Total nitrogen	1.30–2.25 (1)	<1.50 (11)
Phosphorus	0.12–0.30 (1)	<0.12 (1)
Potassium	1.30–2.50 (1)	<1.00 (7)
Magnesium	0.18–0.60 (1)	<0.15 (22)

Statistical analysis. Data for crop yield, crop quality, crop value, percent total alkaloids, percent reducing sugars, and elemental leaf content were subjected to an analysis of variance (ANOVA) with the use of the PROC GLM procedure in SAS. Treatment means were separated with the use of Fisher's protected LSD test at $P \leq 0.05$.

RESULTS AND DISCUSSION

A significant location effect was noted for all parameters (Table 3) because of varying soil types and environmental conditions; however, the interaction of treatment by test site was only significant for crop value per hectare; therefore data were combined over test sites where appropriate.

Physical Characteristics, Chemical Characteristics, and Crop Value. *Yield.* Cured leaf yield was not affected by rates of K_2O from 0 to 252 kg ha^{-1} (Tables 3 and 5). The lack of response to applied K_2O is likely due to soils having medium to high K levels as well as adequate soil moisture throughout the growing season. Visual symptoms of K deficiency were observed in 2010 at UCPRS on the Norfolk soil series, but generally were not observed at rates greater than 134 kg K_2O ha^{-1}. Yield and other factors were ultimately unaffected in treatments exhibiting deficiency symptoms at this location. Deficiency symptoms are believed to have been present as a result of the coarse Norfolk sandy loam, which had a deeper clay layer and did not maintain adequate soil moisture for most of the growing season. In 2009, rainfall events occurred at both locations during the months of June and July (Table 2), the critical period of plant growth. In 2010, cumulative rainfall for the months of March through October was significantly more than for the same period in 2009; however, the majority of rainfall occurred early and late in the season (Table 2).

Grade index. Cured leaf quality was not affected by K_2O rates from 0 to 252 kg ha^{-1} (Tables 3 and 5). Results are similar to those from Chaplin and Miner (2) and Collins and Hawks (3), which did not consistently find a correlation between K_2O rate and quality when rates in excess of those needed for maximum yield were used.

Crop value. Crop value was affected by increasing K_2O rates (Table 3). In 2009 at both locations, no K_2O

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Table 5. Yield, quality, alkaloid content, and sugar content response to increasing rates of K_2O. Data are pooled over all test sites in both years.[a]

K_2O rate	Yield	Grade Index[b]	Total Alkaloids[c]	Reducing Sugars[c]
kg ha^{-1}			%	
0	3,077 a	81 a	4.20 a	11.89 a
84	3,449 a	83 a	4.25 a	12.37 a
112	3,408 a	82 a	4.20 a	11.60 a
134	3,403 a	80 a	4.40 a	10.70 a
140	3,335 a	81 a	4.28 a	11.89 a
168	3,407 a	81 a	4.17 a	12.27 a
196	3,353 a	81 a	4.14 a	12.26 a
224	3,400 a	81 a	4.00 a	12.38 a
252	3,466 a	79 a	4.18 a	11.75 a

[a] Means followed by the same letter within the same category are not significantly different.
[b] Grade index is a measure of tobacco quality on a ranking scale from 1 to 100, with 100 having the highest quality.
[c] Total alkaloid and reducing sugar data were collected from a weighted composite sample of all 4 stalk positions.

rate affect was observed (Tables 3 and 6). However, in 2010 at the UCPRS, 1 of the 2 sites showed a decrease in value when no K_2O was applied (Table 6). Differences at the other site in 2010 were not consistent with increasing K_2O rates (Table 6).

Total alkaloids. Total alkaloid accumulation in cured leaves was not affected by K_2O rate (Tables 3 and 5). Results are similar to those by Woltz et al. (24), Elliot (6), and Chaplin and Miner (2), who could not establish a correlation between increased rates of K_2O and total alkaloid content. Total alkaloids are typically only influenced by K_2O rate when a corresponding yield affect is observed (2,10).

Reducing sugars. Reducing sugar content was not affected by K_2O rate (Tables 3 and 5). As with total alkaloid levels, reducing sugar levels are not typically correlated with K_2O rate within a rate range where no yield affect is observed (2,6,24).

Elemental Leaf Content. *Nitrogen.* Total N content was measured at 3 separate intervals during the growing season: at layby, at topping, and after curing. At layby, the 140-kg K_2O ha^{-1} treatment had a lower N level than the 0-kg K_2O ha^{-1} treatment (Tables 3 and 7). All other K_2O rates were not different from the 0-kg K_2O ha^{-1} or the 6–6–18/8–8–24 control (Tables 3 and 7). There were no differences in N levels in the leaf at topping (Table 3). Several K_2O rates had slightly lower N levels in the cured leaf, but no consistent trend was observed (Table 7). Tso (21) reported that as rates of K_2O increase, total N content is decreased. In this study the trend could not be established, and total N content at all sampling intervals (Table 7) was well above accepted deficiency levels (Table 4).

Table 6. Crop value response to increasing rates of K_2O at individual locations.[a]

K_2O rate	UCPRS[b] 2009	OTRS[c] 2009	UCPRS1[d] 2010	UCPRS2[e] 2010
kg ha^{-1}		\$ ha^{-1}		
0	8,811 a	12,743 a	8,602 b	10,787 ab
84	10,154 a	15,585 a	12,092 a	10,767 ab
112	11,179 a	14,780 a	12,172 a	9,885 bc
134	7,155 a	12,757 a	12,408 a	12,000 a
140	8,711 a	14,679 a	11,712 a	9,658 bc
168	8,862 a	13,573 a	11,259 a	11,896 a
196	8,560 a	14,553 a	11,487 a	9,028 c
224	10,131 a	14,623 a	11,907 a	10,056 bc
252	8,091 a	14,600 a	11,688 a	10,495 abc

[a] Means followed by the same letter within the same category are not significantly different.
[b] UCPRS near Rocky Mount, NC in 2009.
[c] OTRS in Oxford, North Carolina in 2009.
[d] UCPRS near Rocky Mount, NC in 2010.
[e] UCPRS near Rocky Mount, NC in 2010.

Phosphorus. Phosphorus content was measured at 3 separate intervals during the growing season: at layby, at topping, and after curing. At layby, P level was not affected by K_2O rate when compared to the 0-kg K_2O ha^{-1} treatment (Tables 3 and 7). There was a trend for lower P levels at layby when K_2O rates were compared to the 6–6–18/8–8–24 control (Table 7), likely because that was the only treatment that received a P fertilizer application (Table 3). There were no differences in P levels in the plant at topping or after curing (Table 7). Despite a treatment affect at layby, the P content at each sampling interval fell within the accepted range for healthy tissue (Table 4).

Potassium. Potassium content was measured at 3 separate intervals during the growing season: at layby, at topping, and after curing. Potassium levels increased compared to the 0-kg K_2O ha^{-1} control with 6 of 8 K_2O rates at layby, 7 of 8 at topping, and all K_2O rates in the cured leaf sample (Tables 3 and 8). Potassium rates of 84 kg K_2O ha^{-1} or greater resulted in similar K levels in the leaf at layby and topping (Table 8). Differences in %K among K_2O rates were observed in cured leaf samples (Table 8), but trends were not related to increasing rates of K_2O. All treatments resulted in sufficient K levels (Table 4).

Chaplin and Miner (2) determined that K in cured tobacco leaves increased as rates of K_2O increased. They conducted research on a Norfolk soil series that had a low K level compared to medium and high K levels in this study.

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Table 7. Total nitrogen and phosphorus content at layby, topping, and after curing across all treatments. Data are pooled over all 4 test sites.[a]

K_2O rate	Layby[b]		Topping[c]		Cured leaf[d]	
	N	P	N	P	N	P
kg ha^{-1}	%					
0	5.92 abc	0.56 abc	4.93 a	0.39 a	2.69 ab	0.22 a
84	5.74 cd	0.52 c	4.87 a	0.42 a	2.49 d	0.20 a
112	5.84 bcd	0.55 bc	4.76 a	0.39 a	2.53 bcd	0.22 a
134[e]	6.12 a	0.61 a	4.69 a	0.39 a	2.70 a	0.22 a
140	5.63 d	0.52 bc	4.71 a	0.39 a	2.51 cd	0.21 a
168	6.05 ab	0.58 ab	4.80 a	0.42 a	2.58 a–d	0.22 a
196	5.72 cd	0.52 c	5.07 a	0.45 a	2.50 cd	0.21 a
224	5.76 cd	0.57 abc	4.68 a	0.41 a	2.43 d	0.22 a
252	5.71 cd	0.51 c	4.56 a	0.38 a	2.65 abc	0.22 a

[a] Means followed by the same letter within the same category are not significantly different.
[b] Layby samples were collected from the upper stalk position when plants were approximately 38 cm tall.
[c] Topping samples were taken from the upper stalk position immediately following flower removal.
[d] Cured leaf data were collected from a weighted composite sample of all 4 stalk positions.
[e] K_2O supplied by either 747 kg ha^{-1} 6–6–18 or 560 kg ha^{-1} 8–8–24.

Magnesium. Magnesium (Mg) content was measured at 3 separate intervals during the growing season: at layby, at topping, and after curing. At layby, Mg content increased with increasing rates of sulfate of potash magnesia, except with the highest rate in the study, 252 kg K_2O ha^{-1} compared to the 0-kg K_2O ha^{-1} control (Tables 3, 8). The 6–6–18/8–8–24 K source did not increase Mg levels at layby (Table 8). No treatment affected Mg levels at topping or in cured leaves (Table 8). All treatments resulted in sufficient levels of Mg at all sampling dates (Table 4).

According to research conducted by Raper and McCants (15), the tobacco plant has accumulated the majority of Mg required by topping. This may explain why increasing rates of Mg are not significantly different at topping and after curing.

Soil Analysis. *Soil analysis.* Soil samples were taken from plots receiving treatment 1 (0 kg K_2O ha^{-1}) at planting from 0–15 cm and from 15–30 cm. Soil samples were not statistically analyzed, because they were not taken across all treatments; however, it is worth noting the lab analysis for each location. Variability in soil fertility was observed across locations (Table 9), and it is this variability that ultimately has an effect on crop production. Although there are no specified critical nutrient levels for tobacco, it is a safe assumption to say that piedmont soils with less than 30 mg/dm^3 of P and Coastal Plain soils with less than 50 mg/dm^3 may exhibit deficiency symptoms without supplemental fertilization (8). Soils with less than 0.50 meq 100 cc^{-1} of K and 0.25 meq 100 cc^{-1} of Mg may also exhibit deficiencies when no supplemental fertilizer is applied (8). Soil samples taken from control plots during research were used to make generalizations about location characteristics.

At all locations soil P was adequate throughout the entire sampling profile (Table 9). In 2009 at the UCPRS

Table 8. Potassium and magnesium content at layby, topping, and after curing across all treatments. Data are pooled over all 4 test sites.[a]

K_2O rate	Layby[b]		Topping[c]		Cured leaf[d]	
	K	Mg	K	Mg	K	Mg
kg ha^{-1}	%					
0	3.76 c	0.52 cd	2.47 c	0.52 a	1.85 e	0.68 a
84	4.14 a	0.55 abc	2.93 b	0.52 a	2.18 d	0.65 a
112	3.99 abc	0.55 abc	2.75 bc	0.52 a	2.41 abc	0.65 a
134[e]	4.13 a	0.50 d	3.31 a	0.59 a	2.55 a	0.64 a
140	4.13 a	0.55 abc	2.96 ab	0.55 a	2.28 bcd	0.67 a
168	4.07 ab	0.55 abc	2.90 b	0.58 a	2.24 cd	0.69 a
196	4.15 a	0.56 abc	2.93 b	0.58 a	2.26 cd	0.67 a
224	4.04 ab	0.57 a	2.94 b	0.57 a	2.50 ab	0.66 a
252	3.87 bc	0.53 bc	3.01 ab	0.57 a	2.58 a	0.71 a

[a] Means followed by the same letter within the same category are not significantly different.
[b] Layby samples were collected from the upper stalk position when plants were approximately 38 cm tall.
[c] Topping samples were taken from the upper stalk position immediately following flower removal.
[d] Cured leaf data was collected from a weighted composite sample of all 4 stalk positions.
[e] K_2O supplied by either 747 kg ha^{-1} 6–6–18 or 560 kg ha^{-1} 8–8–24.

Table 9. Composite soil analysis of plots not receiving supplemental potassium at transplanting.

Location	Sampling date	Depth	P	K	Mg
		cm	mg dm^{-3}	meq 100 cc^{-1}	
UCPRS-09[a]	April 29, 2009	0–15	65.6	0.42	0.99
		15–30	27.5	0.20	0.96
OTRS-09[b]	May 21, 2009	0–15	80.8	0.26	0.93
		15–30	34.6	0.16	1.12
UCPRS1-10[c]	April 27, 2010	0–15	133.2	0.15	0.78
		15–30	173.7	0.21	0.62
UCPRS2-10[d]	April 27, 2010	0–15	75.9	0.38	1.12
		15–30	66.1	0.33	0.80

[a] UCPRS near Rocky Mount, NC in 2009.
[b] OTRS in Oxford, North Carolina in 2009.
[c] UCPRS near Rocky Mount, NC in 2010.
[d] UCPRS near Rocky Mount, NC in 2010.

location soil P was low at 15 to 30 cm (Table 9); however, deficiencies were not observed because phosphorus was adequately supplied in the 0–6-cm portion of the profile (Table 9), where it is often absorbed in the largest quantity. Soil P is not easily leached from the upper portion of the soil profile; which is evident across locations (Table 9). The exception to this was at the UCPRS1 location in 2010, where soil P measurements were higher at a deeper sampling depth (Table 9).

Soil K was deficient across all locations and at all depths throughout the soil profile (Table 9). It is essential that soil K measurements be very high because of the large amount of K^+ taken up during the growing season. This requirement may explain why potassium deficiencies are commonly observed across a number of soil types. It is of interest to note that severe K deficiencies were observed where supplemental potassium was not applied at the UCPRS1 location in 2010. This location had a soil K level of 0.15 meq 100 cc^{-1} from 0–15 cm and 0.21 meq 100 cc^{-1} from 15–30 cm (Table 9). Other locations did not exhibit deficiency symptoms at any stage of growth. Also, the depth to clay is of concern in regards to the leaching of K^+. Once K^+ is leached out of the upper soil profile the clay subsoil has the ability to catch and retain what has been lost. If the depth to subsoil is less than 25 cm, then a large reserve of K^+ may be present that deeper roots can acquire.

Soil Mg levels were more than adequate across locations and at all depths (Table 9). Magnesium deficiencies were not observed at any of the 4 test sites.

CONCLUSION

Increasing rates of K_2O above 84 kg ha^{-1} does not significantly improve yield, quality, value, or any chemical constituents. Current K recommendations are adequate and may even be higher than necessary on finer-textured soils with medium to high K indices. Alternatively, recommendations appear to be correct for coarse soils with lower K levels that are susceptible to leaching rainfall amounts.

Soil texture and depth to clay have a major impact on potassium application rates, and both must be considered. The loss of K is also of concern on coarse-textured soils similar to the Norfolk soil series. Coarse-textured soils have lower cation exchange capacities and monovalent cations are often lost from the rooting zone by leaching in the event of heavy rainfall. However, if the depth to clay is less than 25 cm, it is likely that K lost to leaching is held in the clay subsoil, where it can be utilized once adequate root growth has occurred.

Locations for this study were selected based on soil texture and depth to clay, and these characteristics had a significant effect on how the crop responded to K application. Potassium deficiencies were only observed at UCPRS in 2010 on the Norfolk soil series, and generally disappeared at rates higher than 134 kg K_2O ha^{-1}. It is of interest to note that the Mehlich-3 K level was 0.30 meq 100 cc^{-1} at this location, which is significantly higher than the K levels of 0.25 and 0.19 meq 100 cc^{-1} at locations used in 2009. The coarse Norfolk soil series was unable to maintain adequate soil moisture throughout the season and despite having significant amounts of residual soil potassium and applied potassium, deficiencies were observed.

Denton et al. (5) reported similar findings for flue-cured tobacco produced across a variety of soil textures. Optimum rates of K_2O were found to differ significantly among fertility capability classification (FCC) soil groups; however, the highest optimum rates were on soils with a sand or loamy sand surface that was greater than 0.5 m thick (5). As previously mentioned, K^+ can leach from the upper soil profile when cation exchange capacity is low; however, if the depth to clay is less than 25 cm it is likely that K^+ lost to leaching is held in the clay subsoil, where it can be utilized once adequate root growth has occurred. Responses to increased rates of K_2O would be expected under these conditions as a result of compensation for the loss of K^+ due to leaching.

Applying K_2O independently, as done in this study, fits extremely well with alternative fertilizer plans that producers are now implementing. As mentioned previously, additional application of P is not necessary on 85% of the soils used for tobacco production in North Carolina, and as a result producers can decouple complete N–P–K fertilizers and apply N and K independently

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of one another. This has allowed producers to explore alternative fertilizer sources for both nutrients. Sulfate of potash magnesia (0–0–22) has gained popularity as a result of it being a relatively inexpensive source of K than when supplied by a complete fertilizer, and because of the additional Mg and S it contains. Also, liquid N (28% UAN, 30% UAN, and 32% UAN) sources are now being implemented as the only source of N for the entire growing season. Liquid N sources are cheaper than other sources and are easier to apply.

Overall, as K recommendations are made for producers, both residual soil potassium as well as soil texture must be considered. There is great potential for producers on fine-textured soils to reduce K_2O rates without reducing yield and quality as well as the option for alternative fertilizer plans, thus creating larger returns.

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