EFFECT OF POTASSIUM SOURCE AND RATE ON YIELD, QUALITY, AND TOBACCO-SPECIFIC NITROSAMINES IN DARK AND BURLEY TOBACCO

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Field trials were conducted in Princeton, Murray, and Lexington, KY in 2016–2018 to determine response of dark and burley tobacco to potassium source (potassium sulfate or potassium chloride) and potassium rate (0, 93, 186, or 279 kg K ha^{-1}). Field sites that showed higher potential for potassium yield response were selected based on low soil test potassium levels from soil samples collected in early spring each year. All potassium applications were made between 1 and 10 days before transplanting. Significant yield responses to potassium were seen in 5 of 12 trials at sites that had initial soil test potassium levels of ≤150 kg K ha^{-1}. Although cured leaf chloride levels were >1% on average where potassium chloride was used, negative effects on cured leaf moisture were only seen in 1 of 12 trials, and negative effects on quality grade index were not seen in any trial. The most consistent effect of potassium chloride application seen in this research was a 28% reduction in average total tobacco-specific nitrosamines (TSNA) compared to potassium sulfate application. These results showing lower TSNA from potassium chloride applications, along with minimal effects on moisture and quality grade index, may cause the tobacco industry to reconsider the long-standing preference for potassium sulfate as the potassium source for tobacco production.

Additional key words: chloride, quality grade index, *Nicotiana tabacum* L., moisture

INTRODUCTION

Potassium is an essential element for tobacco production. Potassium has been associated with optimization of yield, overall leaf quality, and combustibility of tobacco (8,12,15). The University of Kentucky recommends 0 to 279 kg K ha^{-1} for dark tobacco and 0 to 372 kg K ha^{-1} for burley tobacco, depending on soil test potassium levels. Differences in potassium recommendations between dark and burley tobacco are due to differences in crop removal of potassium. Burley tobacco removes 2.82 kg K per 100 kg of cured leaf, and dark tobacco removes 2.28 kg K per 100 kg of cured leaf (10).

The standard potassium source used for tobacco production in Kentucky has been potassium sulfate. Although potassium chloride is more economical, its use in tobacco production has been mainly limited to fall applications because of concerns over reduced quality and combustibility (5,6). As a result of these concerns over spring-applied chloride to tobacco fields, regulations under the Kentucky Fertilizer Law (12 KAR 4:170) limit chloride applications to no more than 56 kg Cl ha^{-1}, which equates to no more than 123 kg KCl ha^{-1} after January 1. However, there has been some evidence that low rates of potassium chloride applied in the spring may actually increase tobacco yields compared to potassium sulfate, with minimal effects on the quality and value of the cured leaf (12,13).

Little is known about the effects that potassium chloride may have on other chemical properties of cured tobacco leaf. Tobacco-specific nitrosamines (TSNA), formed from nitrosation of tobacco alkaloids during curing, are primary carcinogens in cured tobacco leaf (7). Djordjevic et al. (4) showed that there is a positive correlation between alkaloids and TSNA accumulation. There has also been evidence showing that there is a positive correlation between the amount of nitrate and TSNA in cured tobacco leaf (3). Increasing the amount of added potassium chloride or potassium sulfate applied has been shown to increase the total alkaloid concentration in cured leaf (5), while other research showed that leaf nitrate concentrations were lower in tobacco treated with spring-applied potassium chloride than with spring-applied potassium sulfate (8). Decreased nitrate concentrations could result in lower activity of chemical reactions involved in TSNA formation. Previous research has not directly compared the effect of potassium chloride and potassium sulfate on TSNA in cured leaf of dark or burley tobacco.

The objectives of this research were 1) to determine if potassium source and rate has an effect on yield and leaf quality of dark and burley tobacco, and 2) to determine what effect potassium source and rate may have on TSNA content of dark and burley tobacco.

MATERIALS AND METHODS

Field trials were conducted in 2016, 2017, and 2018. In 2016, dark air-cured (DAC) and dark fire-cured (DFC) trials were conducted at the University of Kentucky Research and Education Center in Princeton, KY. In 2017 and 2018, DAC and DFC trials were conducted at Princeton, and at the West Farm of Murray State University in Murray, KY, and burley tobacco trials were conducted at the Kentucky Agricultural Experiment Station North Farm in Lexington, KY.

Soil types at Princeton, Murray, and Lexington were Crider silt loam (fine-silty, mixed, active Typic Paleudalfs), Grenada silt loam (fine-silty, mixed, active, thermic

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Oxyaquic Fraglossudalfs), and Bluegrass-Maury silt loam (fine-silty, mixed, active mesic Typic Paleudalfs), respectively. Initial soil samples were taken at 15-cm depths at field sites in early spring (at least 6 weeks prior to transplanting) each year to determine existing potassium levels at each site. Field sites were selected based on 1 bulk soil analysis at each potential site. University of Kentucky Regulatory Services determined soil pH and used Mehlich 3 to determine K levels (10). Initial soil sample results showed low–medium initial potassium levels at all sites (Table 1). Initial soil pH at each site was 6.2, 6.8, and 6.4 at Princeton in 2016, 2017, and 2018, respectively; 6.0 and 7.2 at Murray in 2017 and 2018, respectively; and 5.7 and 5.9 at Lexington in 2017 and 2018, respectively.

Nitrogen was applied to all dark tobacco test sites at Princeton and Murray as a pretransplant broadcast application at 308 kg N ha^{-1} within 10 d prior to transplanting. Nitrogen and phosphorus sources were ammonium nitrate and diammonium phosphate (DAP) at Princeton and urea and DAP at Murray. Broadcast phosphorus was also applied with the nitrogen application at 20–89 kg P ha^{-1}, depending on soil test recommendations for each of the dark tobacco test sites. Broadcast nitrogen and phosphorus applications were incorporated by disking immediately after application at Princeton and Murray.

Nitrogen was applied to both Lexington trials as a pretransplant broadcast application at 308 kg N ha^{-1} within 2 weeks of transplanting. Nitrogen source used at Lexington was urea. There was no phosphorous applied in either year at Lexington because soil test P values were very high. In 2017, 8,965 kg ha^{-1} of lime was added, and 6,724 kg ha^{-1} of lime was added in 2018. Broadcast nitrogen and lime applications were incorporated by disking immediately after application at Lexington.

Plots were 4.1 m wide by 9.1 m long at Princeton in 2016 and 2017, and 4.1 m wide by 12.2 m long in 2018. Plots at Murray were 4.1 m wide by 12.2 m long in 2017 and 2018. Plots were 4 rows with a row spacing of 101.6 cm and a plant spacing of 81.3 cm at Princeton and Murray. Burley plots in Lexington were 4 rows, 4.3 m wide by 10.6 m long with a row spacing of 140.1 cm and plant spacing of 53.3 cm.

Potassium sources used at all locations and in all years were potassium sulfate (K_2SO_4) with an analysis of 415 g K kg^{-1} and potassium chloride (KCl) with an analysis of 500 g K kg^{-1}. Application rates for all years and locations were 93, 186, and 279 kg K ha^{-1}, along with an untreated control that received no potassium. Potassium treatments were broadcast applied by hand on a plot-by-plot basis 1–10 days before transplanting for all years and locations, then immediately incorporated with a disk or field cultivator at Princeton and Lexington, or a PTO-driven horizontal rotary tiller at Murray.

The 2016 trials were arranged in a randomized complete block design (RCBD) with 4 replications, and the 2017 and 2018 trials were a split-plot design with 4 replications. Trials in 2017 and 2018 included low converter (LC) and high converter (HC) cultivar selections to aid in quantification of the effect of potassium source and rate on TSNA. When LC and HC selections are grown

Table 1. Initial soil K index values, potassium application dates, and transplant and harvest dates for all experiments.

Location	Year	Soil K Value (kg K ha^{-1})	Soil Test K Level	Recommended K (kg ha^{-1})	K Application Date	Transplant Date	Harvest Date
Princeton	2016	143	Low	223	May 24	May 25	August 23
Princeton	2017	150	Low	214	May 23	May 26	September 21
Murray		108	Low	261	June 16	June 21	October 12
Lexington		149	Low	266	June 11	June 13	September 18
Princeton	2018	209	Med	168	May 14	May 24	September 12
Murray		175	Low	217	June 12	June 20	October 19
Lexington		113	Low	344	June 18	June 19	September 21

Table 2. Effect of potassium source[a] on cured leaf chloride content (%) of dark air-cured, dark fire-cured, and burley tobacco in Princeton, Murray, and Lexington, KY, 2016 and 2018.

	2016		2018									
	Princeton		Princeton				Murray				Lexington	
	DAC[b]	DFC	DAC		DFC		DAC		DFC		Burley	
K source	LC		LC	HC	LC	HC	LC	HC	LC	HC	LC	HC
K_2SO_4	0.40	0.55	0.13	0.12	0.46	0.37	0.83	0.68	0.66	0.58	0.11	0.15
KCl	3.46	3.20	1.38	1.23	3.80	3.28	2.62	2.55	2.58	2.51	1.75	2.43
	***c	***	***	***	***	***	***	***	***	***	***	***
No K[d]	0.40	0.41	0.12	0.10	0.39	0.36	0.74	0.60	0.63	0.58	0.10	0.15

[a] Chloride data are presented by potassium source, averaged over potassium rate. Chloride data not collected in 2017.
[b] Abbreviations: DAC = dark air-cured trials; DFC = dark fire-cured trials; LC = low nicotine to nornicotine converter variety selection (KT D14LC in dark tobacco trials, TN 90LC in burley tobacco trials); HC = high nicotine to nornicotine converter variety selection (NL Madole HC in dark tobacco trials, TN 90HC in burley tobacco trials).
[c] Asterisks indicate significant differences between potassium sources (* = $P < 0.10$–0.05; ** = $P < 0.05$–0.01; *** = $P < 0.01$–0.0001, ns = not significant).
[d] In all chloride comparisons, untreated tobacco (No K) had chloride levels that were similar to tobacco treated with potassium sulfate (K_2SO_4) and lower than tobacco treated with potassium chloride (KCl).

and cured under the same conditions, HC selections have greater potential to convert nicotine to nornicotine, and thus have higher potential to form NNN. Dark tobacco cultivars used were 'KT D14LC' at Princeton in 2016, and 'KT D14LC' and 'Narrowleaf Madole HC' at Princeton and Murray in 2017 and 2018. 'TN 90LC' and 'TN 90HC' were the cultivar selections used in the burley trials for both 2017 and 2018. In all 2017 and 2018 trials, main plot factors were potassium source and rate, and the split plot factor was cultivar selection. Within each 4-row plot, 2 rows were the LC selection and 2 rows were the HC selection. Cultivar selection arrangements within each plot were completely randomized, and potassium source and potassium rate were arranged in a randomized complete block design for all 2017 and 2018 trials. Where only 1 cultivar was used in 2016, only the center 2 rows of each 4-row plot were used for data collection. Where 2 cultivars were used in 2017 and 2018 in the DAC and DFC trials, a 2-row border that received no potassium was included between plots to ensure that there was no overlap in potassium application between each 4-row plot, and each 2-row subplot (LC and HC) were used for data collection. In the burley trials, a 2-row border was included to ensure no overlap in potassium application, although these borders did receive potassium.

In all trials, 24–30 tobacco plants were stalk harvested at maturity and allowed to field wilt before 5–6 stalks of tobacco were placed evenly on tobacco sticks. Sticks of tobacco from the dark air-cured and burley trials were placed in typical air-curing barns, and dark fire-cured tobacco was placed in standard fire-curing barns. Recommended air- and fire-curing methods were used (14). The Princeton fire-cured trials were fired 3 times in 2016, 2017, and 2018 and the Murray fire-cured trials were fired 4 times in 2017 and 2018.

Following curing, tobacco was removed from curing barns, and DAC and DFC trials were stripped into 2 stalk positions. Burley trials were stripped into 3 stalk positions in 2017 and 4 stalk positions in 2018. Leaf from each stalk position was weighed individually, and samples of each stalk position were assigned a Federal grade that was converted into a quality grade index (2,9). Quality grade index is a weighted average of grade indices received for each stalk position. Stalk positions that contribute more to total yield also contribute more to total quality grade index. At the time of stripping, cured leaf samples from

Table 3. Effect of potassium chloride rate[a] on cured leaf chloride content (%) in dark fire-cured tobacco at Princeton in 2016, dark air-cured and fire-cured tobacco at Princeton in 2018, and dark fire-cured at Murray in 2018.

	2016	2018					
	Princeton	Princeton				Murray	
	DFC[b,c]	DAC		DFC		DFC	
KCl rate (kg K ha^{-1})	LC	LC	HC	LC	HC	LC	HC
93	1.58 b	0.82 c	0.73 c	2.44 c	1.84 c	1.81 c	1.80 c
186	4.15 a	1.35 b	1.32 b	3.89 b	3.33 b	2.61 b	2.38 b
279	3.87 a	1.95 a	1.64 a	5.06 a	4.68 a	3.33 a	3.11 a
	**d	***	***	***	***	***	***

[a] Chloride data shown are only from tobacco that received potassium chloride. Chloride data not collected in 2017.
[b] Abbreviations: DAC = dark air-cured trial; DFC = dark fire-cured trial; LC = low nicotine to nornicotine converter variety selection (KT D14LC in dark tobacco trials); HC = high nicotine to nornicotine converter variety selection (NL Madole HC in dark tobacco trials).
[c] Data followed by the same letter within a column are not statistically different according to LSD at $\infty = 0.10$.
[d] Asterisks indicate significant differences between potassium chloride rates (* = $P < 0.10$–0.05; ** = $P < 0.05$–0.01; *** = $P < 0.01$–0.0001).

the fourth leaf from the top of 20 plants per plot were collected and shipped to R. J. Reynolds Tobacco Company laboratory in Winston-Salem, NC, for leaf chemistry analysis. In 2016, whole-leaf samples were analyzed with the midrib still intact. In 2017 and 2018, leaf chemistry samples were destemmed and air-dried prior to shipping. Moisture percentage was determined from the same cured leaf samples at the time samples were received for leaf chemistry analysis.

Data were analyzed using Statistical Analysis Software (SAS) version 9.4 (11). In 2016, a RCBD was chosen to determine the main effects of potassium source and potassium rate on tobacco cultivar 'KT D14LC'. Analyses conducted in 2016 were total yield, moisture, chloride content, grade index, and total TSNA. In 2017 and 2018, a split-plot RCBD was chosen so that the main effects of potassium source and potassium rate on tobacco cultivars 'KT D14LC', 'NL MadoleHC', 'TN 90LC', and 'TN 90HC' could be determined. Analyses conducted in 2017 and 2018 were yield, moisture, chloride content (only in 2018), grade index (in dark trials only), and TSNA. Following curing, tobacco was removed from curing barns when adequate moisture was present in the leaf to allow handling and leaf removal from stalks. Standard market preparation practices were used for all trials (1). Total yield was calculated on a plot-by-plot basis by weighing each stalk position to determine the yield of the plot, and then converted to yield per hectare. Total TSNA content was determined by the summation of NNN, NAB, NAT, and NNK. For the 2016 data, a mixed model was used with source and rate as fixed effects and block as a random effect. For the 2017 and 2018 data, a mixed model was used with potassium source, rate, and cultivar as fixed effects and block as a random effect. All data were analyzed by year, location, tobacco type, and cultivar. The untreated control that received no potassium was not included in the overall factorial data analysis, because there was only 1 untreated control. PROC GLIMMIX was used as the statistical model to determine an analysis of variance (ANOVA) and means were separated using least-square means at an alpha of <0.10. Data were sliced if there was an interaction between variables; that is, fix a value of 1 factor, and then examine the differences as the other factor changes. The untreated control was included in separate pairwise comparison analyses to compare the untreated control to both potassium chloride and potassium sulfate treatments. Contrasts were constructed for TSNA analysis to test for effects of potassium chloride or potassium sulfate compared to tobacco from the untreated control that received no potassium.

RESULTS AND DISCUSSION

Trial specifications are shown in Table 1. Composite soil samples taken at each site in early spring showed low to medium initial soil test K levels at each site, with potassium recommendations ranging from 168 to 344 kg K ha^{-1}. Potassium applications were made 1–10 days prior to transplanting.

Data analyses indicated that the strongest effect detected in any of the data was that of potassium source.

Table 4. Effect of potassium source[a] on cured leaf moisture content (%) of dark air-cured, dark fire-cured, and burley tobacco in Princeton, Murray, and Lexington, KY, 2016–2018.

	2016[b]		2017										2018									
	Princeton		Princeton				Murray				Lexington		Princeton				Murray				Lexington	
	DAC[c]	DFC	DAC		DFC		DAC		DFC		Burley		DAC		DFC		DAC		DFC		Burley	
K source	LC	LC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC
K_2SO_4	10.4	10.7	6.7	6.3	6.1	5.7	6.4	6.0	5.9	5.8	6.4	6.4	5.8	5.4	6.2	5.8	6.0	5.5	6.0	5.6	6.5	6.5
KCl	12.3	10.9	6.7	6.4	6.0	5.6	6.3	6.1	5.7	5.8	6.4	6.2	5.8	5.3	6.2	5.9	5.9	5.6	6.0	5.7	6.4	6.2
	**[d]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
No K	11.5	10.6	7.1	6.5	6.0	5.9	6.6	5.9	6.1	6.2	6.7	6.4	6.1	5.5	6.3	5.8	6.3	5.7	6.1	5.7	6.5	**6.2**[e]

[a] Moisture data are presented by potassium source, averaged over potassium rate.
[b] Moisture levels were higher in 2016 because samples were submitted as whole-leaf samples that were not air dried, whereas 2017 and 2018 samples were destemmed lamina only and air dried prior to moisture analysis.
[c] Abbreviations: DAC = dark air-cured trials; DFC = dark fire-cured trials; LC = low nicotine to nornicotine converter variety selection (KT D14LC in dark tobacco trials, TN 90LC in burley tobacco trials); HC = high nicotine to nornicotine converter variety selection (NL Madole HC in dark tobacco trials, TN 90HC in burley tobacco trials).
[d] Asterisks indicate significant differences between potassium sources (* = P < 0.10–0.05; ** = P < 0.05–0.01; ns = not significant).
[e] Boldface indicates that untreated tobacco (no K) had cured leaf moisture levels that were significantly different from tobacco that received potassium application from at least 1 potassium source.

As the effect of potassium source was also the primary focus of this research, most data are presented by potassium source, averaged over potassium rate. In addition, pairwise comparisons and contrasts were used to compare untreated tobacco to tobacco receiving potassium sulfate or potassium chloride. Data are also presented by cultivar converter classification (LC or HC) within each trial, as there were differences observed between cultivars in several data measurements in addition to obvious known differences in TSNA formation. However, these cultivar differences seen in dark tobacco trials may have been due more to actual differences in cultivars rather than converter classification, as LC and HC cultivar selections were from 2 different cultivars (KT D14 and NL Madole). These differences were not apparent in burley trials where LC and HC selections of the same variety (TN 90) were used.

Chloride. Chloride levels in cured leaf are shown in Table 2. As expected, chloride levels were significantly higher in tobacco that received potassium chloride than in tobacco that received potassium sulfate in all 7 trials where chloride was measured. Average chloride levels ranged from 0.11 to 0.83% Cl in tobacco that received potassium sulfate, and from 1.23 to 3.80% Cl in tobacco that received potassium chloride.

There was also a significant effect of potassium rate for chloride content within potassium chloride treatments in 4 of 7 trials where chloride was measured (Table 3). In the dark fire-cured trial at Princeton in 2016, cured leaf chloride levels from potassium chloride treatments increased from 1.58 to 4.15% as K rate increased from 93 to 186 kg K ha^{-1}, but did not increase further when 279 kg K ha^{-1} was applied. In the other 6 trials, significant increases in chloride were seen with each increase in potassium chloride rate.

Moisture. Cured leaf moisture levels from all trials are shown in Table 4. Moisture levels were higher in 2016 trials (10.4–12.3% moisture) than in 2017 and 2018 trials, as these data were collected from whole leaf that was not air-dried prior to moisture analysis. In 2017 and 2018, samples were destemmed and lamina was air-dried prior to moisture analysis being conducted on lamina only. Moisture differences between tobacco receiving potassium sulfate or potassium chloride were only seen in 2 of 12 trials. In 1 of those trials (2018 Lexington burley), moisture was significantly higher in tobacco that received potassium sulfate compared to tobacco receiving potassium chloride or no potassium. The only trial where potassium chloride application resulted in significantly higher moisture content in these experiments was in the dark air-cured trial at Princeton in 2016 (12.3% moisture from potassium chloride treatments compared to 10.4% moisture from potassium sulfate treatments). However, tobacco receiving potassium chloride treatments did not have higher moisture than tobacco from control plots that received no potassium.

Tobacco Yield. Tobacco yield data are shown in Table 5. In 5 of 12 trials, pairwise comparisons indicated a significant positive response to potassium, where tobacco treated with either source of potassium produced significantly greater total yield than tobacco that received no

Table 5. Effect of potassium source[a] on total yield (kg ha^{-1}) of dark air-cured, dark fire-cured, and burley tobacco in Princeton, Murray, and Lexington, KY, 2016–2018.

	2016		2017										2018									
	Princeton		Princeton				Murray				Lexington		Princeton				Murray				Lexington	
	DAC[b]	DFC	DAC		DFC		DAC		DFC		Burley		DAC		DFC		DAC		DFC		Burley	
K source	LC		LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC
K_2SO_4	1,863	1,690	2,241	2,125	2,684	2,673	2,273	2,119	2,181	2,124	2,495	2,407	3,584	3,040	3,955	3,634	3,434	2,969	3,499	3,324	1485	1,515
KCl	2,097	1,710	2,290	2,210	2,788	2,601	2,262	2,191	2,226	2,193	2,413	2,305	3,549	3,040	4,221	3,632	3,386	3,024	3,421	3,347	1,700	1,573
	*[c]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
No K	**1,615**[d]	1,981	2,261	2,049	**2,300**	**2,298**	**1,612**	**1,860**	2,018	1,990	**2,139**	**1,981**	3,492	2,864	4,161	3,619	3,364	3,205	3,566	3,330	**849**	**658**

[a] Yield data are presented by potassium source, averaged over potassium rate.
[b] Abbreviations: DAC = dark air-cured trials; DFC = dark fire-cured trials; LC = low nicotine to nornicotine converter variety selection (KT D14LC in dark tobacco trials, TN 90LC in burley tobacco trials); HC = high nicotine to nornicotine converter variety selection (NL Madole HC in dark tobacco trials, TN 90HC in burley tobacco trials).
[c] Asterisks indicate significant differences between potassium sources (* = $P < 0.10$–0.05; ns = not significant).
[d] Boldface indicates significant yield responses to applied potassium where untreated tobacco (no K) yielded significantly less than tobacco that received potassium applications.

potassium. When yields are averaged between the 2 potassium sources, yield response to potassium in these 5 trials generally ranged from 300 to 600 kg ha^{-1} in dark tobacco trials, and 300 to 400 kg ha^{-1} in burley tobacco trials, although yield response was greater in the 2018 burley trial where yields were depressed due to excess rainfall. Within tobacco that received potassium, significant differences in total yield between potassium sources were only seen in 2 of 12 trials. In both of these trials, tobacco that received potassium chloride had significantly higher total yield than tobacco that received potassium sulfate. However, in 1 of these 2 trials (2016 Princeton DAC), this yield difference may have been due to higher moisture content in potassium chloride treatments.

Quality Grade Index. Quality grade index data are shown in Table 6. In only 3 of 10 trials was there a significant response to potassium in quality grade index. Also, there were differences in quality grade index between the 2 potassium sources in only 3 of 10 trials. In all 3 of these trials, quality grade index was higher in tobacco that received potassium chloride. Although these quality differences were not substantial, they were statistically significant.

Tobacco-Specific Nitrosamines. TSNA data are presented in Table 7. Perhaps the most interesting result in this research was the effect that potassium source had on TSNA. In 10 of 12 experiments, total TSNA of 1 or both cultivar selections were significantly lower in tobacco treated with potassium chloride as compared to tobacco treated with potassium sulfate. In 21 of 22 potassium source comparisons over the 12 trials, total TSNA were numerically lower in tobacco treated with potassium chloride compared to potassium sulfate, and significantly lower in 14 of these 22 comparisons. Overall, average total TSNA reduction from potassium chloride was 28%, with an average reduction of 32% in LC cultivars and 27% in HC cultivars. By tobacco type, average TSNA reduction from potassium chloride was 24% in DAC, 27% in DFC, and 35% in burley. Tobacco treated with potassium chloride had numerically lower TSNA than untreated tobacco in 16 of 22 comparisons, and significantly lower TSNA in 8 of these comparisons. Conversely, there were no comparisons where tobacco treated with potassium sulfate had significantly lower TSNA than untreated tobacco.

CONCLUSION

Significant yield responses to potassium were observed in 5 of 12 trials. These responsive trial sites had initial soil test potassium levels of $\leq$150 kg K ha^{-1}. Although chloride levels in cured leaf were greater than 1% on average where spring applications of potassium chloride were made in all of these trials, significant increases in cured leaf moisture were only observed in 1 of 12 trials, and adverse effects on quality grade index were not observed in any trial. In fact, quality grade index was actually higher in potassium chloride–treated tobacco than in potassium sulfate–treated tobacco in 3 of 10 trials. The most consistent effect of potassium chloride application seen in this research was the 28% average total TSNA reduction compared to potassium sulfate application.

Table 6. Effect of potassium source[a] on total quality grade index[b] (0–100) of dark air-cured and dark fire-cured tobacco in Princeton and Murray, KY, 2016–2018.

	2016		2017								2018							
	Princeton		Princeton				Murray				Princeton				Murray			
	DAC[c]	DFC	DAC		DFC		DAC		DFC		DAC		DFC		DAC		DFC	
K source	LC		LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC
K_2SO_4	48.0	61.0	47.6	45.3	71.1	68.4	20.6	29.6	69.7	61.5	34.5	43.6	61.5	59.0	20.2	30.6	71.8	67.7
KCl	52.1	57.6	50.4	47.4	73.9	71.0	21.7	37.7	74.9	70.5	35.6	47.3	58.1	56.3	20.0	33.3	70.6	69.3
	ns	ns	ns	ns	**[d]	**	ns	*	***	***	ns	ns	ns	ns	ns	ns	ns	ns
No K	57.3	**55.2**[e]	48.6	47.8	70.2	**66.4**	23.8	34.8	**69.5**	**52.4**	36.9	45.4	65.8	63.3	24.2	39.4	68.6	71.4

[a] Quality grade index data are presented by potassium source, averaged over potassium rate. Quality grade index data were not collected in burley experiments.
[b] Total quality grade index is a weighted average of index values assigned to Federal grades received for each tobacco stalk position (lug and leaf for dark tobacco) where the proportion of total yield contributed by each stalk position is also used as the proportion of total grade index contributed by each stalk position.
[c] Abbreviations: DAC = dark air-cured trials; DFC = dark fire-cured trials; LC = low nicotine to nornicotine converter variety selection (KT D14LC in dark tobacco trials); HC = high nicotine to nornicotine converter variety selection (NL Madole HC in dark tobacco trials).
[d] Asterisks indicate significant differences between potassium sources (* = $P < 0.10$–0.05; ** = $P < 0.05$–0.01; *** = $P < 0.01$–0.0001; ns = not significant).
[e] Boldface indicates significant quality responses to applied potassium where tobacco that received no potassium had significantly lower quality grade index than tobacco receiving potassium.

Table 7. Effect of potassium source[a] on total tobacco-specific nitrosamines (TSNA; ng g^{-1}) in dark air-cured, dark fire-cured, and burley tobacco in Princeton, Murray, and Lexington, KY, 2016–2018.

	2016		2017										2018									
	Princeton		Princeton				Murray				Lexington		Princeton				Murray				Lexington	
	DAC[b]	DFC	DAC		DFC		DAC		DFC		Burley		DAC		DFC		DAC		DFC		Burley	
K source	LC		LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC	HC
K_2SO_4	174	2,405	440	2,245	5,832	31,158	437	1,939	5,723	34,425	930	3,596	988	5,907	6,237	30,225	926	5,005	2,611	24,029	6,560	17,174
KCl	173	1,836	227	1,326	3,762	22,177	320	1,742	6,703	21,638	617	2,448	813	4,367	2,880	22,106	643	4,109	2,018	20,907	2,626	12,600
	ns	*[c]	***	***	***	***	***	ns	ns	**	***	**	**	***	***	ns	ns	ns	***	ns	**	ns
No K	156	2,407	***340***[d,e]	**1,601**	***6,092***	***29,054***	***334***	**1,199**	9,131	***32,145***	***696***	***2,274***	900	**3,909**	3,401	26,696	488	**2989**	***2,836***	20,941	***8,811***	***29,364***

[a] TSNA data are presented by potassium source, averaged over potassium rate.
[b] Abbreviations: DAC = dark air-cured trials; DFC = dark fire-cured trials; LC = low nicotine to nornicotine converter variety selection (KT D14LC in dark tobacco trials, TN 90LC in burley tobacco trials); HC = high nicotine to nornicotine converter variety selection (NL Madole HC in dark tobacco trials, TN 90HC in burley tobacco trials).
[c] Asterisks indicate significant differences between potassium sources (* = $P < 0.10$–0.05; ** = $P < 0.05$–0.01; *** = $P < 0.01$–0.0001, ns = not significant).
[d] Boldface indicates that untreated tobacco (No K) had TSNA that was significantly different from tobacco treated with 1 or both potassium sources.
[e] Italics indicates that KCl-treated tobacco had significantly lower TSNA than untreated tobacco (no K).

Possible mechanisms involved in this TSNA reduction were not addressed in this research, but could include increased salinity of the leaf tissue because of increased chloride content from potassium chloride, thereby lowering the activity of chemical reactions leading to TSNA formation. Alternatively, nitrate could be antagonized by chloride, resulting in lower nitrite and subsequent TSNA formation. Potassium chloride–treated tobacco had a 38.5% average reduction in nitrite compared to potassium sulfate–treated tobacco (data not shown). Future research should evaluate the mechanism(s) involved.

These results showing lower TSNA from potassium chloride applications, along with minimal effects on moisture and quality grade index, may cause the tobacco industry to reconsider the long-standing preference for potassium sulfate as the potassium source for tobacco production. Use of potassium chloride as the predominate potassium source for tobacco production would also result in 30–50% savings in potassium fertilizer cost for tobacco growers (10). A 28% reduction in TSNA from a simple change in potassium source without any significant negative effects on yield or quality would be a favorable outcome for the tobacco industry.

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