THE EFFECT OF SUCKERCIDE PRODUCT AND APPLICATION RATE ON CHEMICAL TOPPING OF BURLEY TOBACCO

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The act of topping tobacco (*Nicotiana tabacum* L.) involves the removal of the terminal bud or inflorescence of the tobacco plant. This practice ordinarily is accomplished by manually removing the top of each tobacco plant in an entire field, which is labor intensive and costly. The major objectives for this research were to determine which labeled suckercides could be used effectively for chemical topping of burley tobacco and the effect of suckercide rate on sucker control, yield, leaf quality, maleic hydrazide (MH) residues, and leaf chemistry. A study was initiated at Murray, Princeton, and Lexington, KY that investigated the efficacy of suckercide applications using combinations of MH, butralin, and fatty alcohols (FA). The terminal bud was not well controlled with FA or butralin alone, nor was adequate sucker control or total yield achieved. A significant reduction in total yield and sucker control were observed when plants were chemically topped with MH alone compared to manually topped or chemically topped with a tank mixture of MH and butralin at Princeton only. At the other locations, all chemically topped plants had similar yield to manually topped plants. Our data suggested that chemical topping of burley tobacco with a tank mixture of MH and a local systemic can be an acceptable alternative to manual topping as total yield and leaf quality grade index were not significantly different at any location. Total tobacco-specific nitrosamine (TSNA) content and MH residues were significantly lower with chemical topping treatments in some years and locations.

Additional key words: Sucker Control, burley, Maleic Hydrazide, labor reduction

INTRODUCTION

Kentucky is the leading state for production of type 31 light air-cured burley tobacco (*Nicotiana tabacum* L.), accounting for over 70% of the estimated 68,000 metric tons produced in the United States (37). The estimated average yield of burley tobacco produced in Kentucky for 2014, 2015, and 2016 was 2,400, 2,000, and 1,950 kg ha^{-1}, respectively (37). Burley tobacco is predominately used as a component in the manufacturing of blended cigarettes (23), along with flue-cured and oriental tobacco.

The intensive labor requirement for producing tobacco coupled with fluctuating market prices and increased costs for labor and other inputs has led to declining profit margins for burley growers. Studies on tobacco production have indicated that it takes 150–200 hr of labor to grow 1 acre of burley tobacco even with advances that have increased labor efficiency (11,32). Current challenges within the tobacco industry involve delivering increasingly regulated, reduced-risk tobacco products to a decreasing number of consumers (31). Maximizing yields and reducing input costs will be vital in maintaining a profitable tobacco operation in a changing marketplace. Therefore, research on improving the efficiency of production is worth investigating, because burley tobacco is significant to Kentucky's agricultural economy.

One area with potential for increased efficiency involves the practice of removing the terminal bud or inflorescence of the tobacco plant. This practice, commonly known as topping, is ordinarily accomplished by manually removing the apical meristem of each tobacco plant in an entire field, which is labor intensive and costly (35). Removal of the terminal bud or inflorescence prevents reproductive development (i.e., seed head) and results in energy transferred to increased leaf size, weight, nicotine content, and other chemical constituents (36). Subsequently, topping suppresses apical dominance in the plant, resulting in axillary bud growth, known as suckers (9). Each leaf axil of a mature tobacco plant can potentially produce three suckers, but it has been noted that only two suckers develop under normal commercial production (28). Effective sucker control and yield are positively correlated (5). It is well documented that topping and control of sucker growth is required to achieve acceptable yields and higher-quality leaf (10,14,18,20,30). There are three types of chemicals that can be used for chemical inhibition of axillary bud growth. These three types are contact (fatty alcohols), local systemic (butralin or flumetralin), and systemic (maleic hydrazide) suckercides (1).

Maleic hydrazide (MH) has been shown to result in excellent sucker control and equivalent cured leaf yield, compared to hand suckering, without adversely influencing leaf quality (4). Chemically, MH is a very stable molecule in and on plants, as several of the degradation and transfer processes for organic chemicals are not effective (5,22,26). MH is stable under ultraviolet irradiation and decomposes at 260°C (38), thus field and curing conditions associated with these factors are not likely

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to influence residual amounts of MH on cured tobacco leaves. In addition to UV and temperature, the vapor pressure of MH is nearly zero, which leads to insignificant amounts of MH lost to volatilization (5). Therefore, there is a higher potential for MH residues to be present in and on the surface of cured tobacco leaf, because MH can become fixed and is not believed to be highly metabolized (5,38). However, MH is formulated as a potassium salt of MH, which possesses a high water solubility and has a twofold implication: sucker control and MH residues can be significantly influenced by rainfall and irrigation (5,12,29) and higher penetration efficiency in plants (7). Nonetheless, higher chemical residues can be explained by the chemical properties of MH molecules and use patterns by tobacco producers (5).

Increased root growth in response to manual topping and hand suckering has been shown to increase the potential for the tobacco plant to absorb water and nutrients as well as an increased ability to synthesize nicotine (5). Woltz (39) showed that topping and suckering flue-cured tobacco resulted in better yield and quality and that untopped plants had substantially lower nicotine and sugar content. Tso (36) concluded that topping increases nicotine content and results in a net gain in total alkaloid content. Cui et al. (8) found a reduction in total alkaloid levels when MH was applied compared to manual sucker control. Long et al. (19) found that chemically topped plants had a reduced percentage of total alkaloids compared to manually topped tobacco plants. It has been shown that applications of MH decreased lamina tobacco-specific nitrosamine (TSNA) content because of altering the precursor–TSNA relationship (8). TSNAs are nitrogenous compounds that are formed only from tobacco alkaloids, and are detectable in the tobacco leaf and in the particulate phase of tobacco smoke. There are four major TSNAs: N-nitrosonornicotine (NNN), 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK), N-nitrosoanatabine (NAT), and N-nitrosoanabasine (NAB) (3,13,15,16,17).

Suckercides that are currently registered were not intended specifically for chemically topping tobacco, but some experiments have evaluated use of such chemicals for this purpose (19,24,33,34). Fatty alcohols (FA) with chain lengths of C_9, C_{10}, and C_{11} could inhibit the terminal bud if applied before the flowers were open and terminate suckers after the FA contacted leaf axils (34). Another study showed that chemically topped tobacco yielded significantly higher when the FA was applied at the button stage compared to manual topping at the full bloom stage, but not significantly different than manually topped and sprayed with FA at the button stage (33). Long et al. (19) evaluated chemical topping with MH, flumetralin, FA, and tank mixtures, and found that suppression of the terminal and axillary buds were successful in all treatments; however, MH alone produced significantly less yield because of reduced sucker control. Peek (24) found that a tank mixture of MH with flumetralin resulted in the highest total yield and MH alone resulted in the lowest yield of all chemically topped treatments. Chemical topping with a tank mixture of MH and flumetralin on photoperiod-sensitive cultivars of flue-cured tobacco resulted in no differences in yield compared to tobacco that was manually topped and sprayed (19). Long et al. (19) found that split treatments of a half rate of MH or one application of a full rate of MH sprayed without manually topping resulted in reduced yield compared to other treatments because of poor sucker control. The primary objective of this research was to determine if burley tobacco could be chemically topped while simultaneously controlling axillary bud growth (suckers) using currently registered rates of suckercide products without detrimentally impacting yield and leaf quality.

MATERIALS AND METHODS

Field experiments were initiated in 2015 at the Spindletop Farm and the West Farm of Murray State University near Murray, KY. In 2016 and 2017, these experiments were repeated at the Agricultural Experiment Station Spindletop Farm near Lexington, KY and the University of Kentucky Research and Education Center near Princeton, KY. Plants of late-maturing burley tobacco ('KT 210' or 'KT 215' depending on location) were produced in a greenhouse float system according to current University of Kentucky recommendations (25). Tobacco plants were transplanted to the field in late May/early June in all years and locations of these experiments. All field production practices, other than topping, followed University Extension guidelines (25). Prior to harvest, sucker control data and plant measurements were collected from the center two rows of each four-row plot.

The experimental design was a randomized complete block with four replications. Suckercides were applied based on product labels with a CO_2-pressurized sprayer calibrated to deliver 468 L ha^{-1} through an over-the-row three-nozzle-per-row configuration using solid cone spray tips (TG3, TG5, TG3, Spraying Systems Co.). Treatments included maleic hydrazide (Royal® MH-30, 0.18 kg L^{-1}, Arysta LifeSciences), butralin (Butralin, 0.36 kg L^{-1}, Arysta LifeSciences), and a fatty alcohol (Off-Shoot-T, 0.31 kg octanol + 0.41 kg decanol + 0.002 kg dodecanol L^{-1}, Arysta LifeSciences). All treatments, suckercide application rates, and dates are listed in Table 1. There were six chemically topped treatments including applications of MH alone at 2.24 (full MH) or 1.68 (reduced MH) kg a.i. ha^{-1}, a tank mixture of MH and butralin at 2.24 + 0.56 (full mix) or 1.68 + 0.56 (reduced mix) kg ha^{-1}, respectively. A local systemic (butralin) or contact (FA) alone at 1.12 kg ha^{-1} or at 10% v/v, respectively, was also included in 2015 only. There was also a manually topped and not sprayed (untreated control or UTC) and a manually topped and sprayed (grower standard or GS) treatment with the full mixture of MH and butralin. Chemically topped treatments were applied at the prebud (10% button) stage and manually topped treatments were imposed at the 10% bloom stage. Button percentage was calculated by dividing the total number of plants in the two center rows of each plot by the number of plants with a visible terminal bud between the apical leaves, or growth stage 51 (6). Bloom percentage was calculated by dividing the total number of plants in the two center rows of each plot by the number of plants with at least one flower open,

Table 1. Suckercide application rate and date for manual and chemical topping treatments.

				Treatment Applied					
		Application Rate	Manually Topped	Spindletop			Princeton		
Treatment	Suckercides	kg a.i. ha^{-1}	Yes/No	2015	2016	2017	2015[b]	2016	2017
UTC[a]	–	–	Yes	7/27	8/9	7/28	8/28	8/14	7/31
GS	MH + B	2.24 + 0.56	Yes	7/27	8/9	7/28	8/28	8/14	7/31
Full MH	MH	2.24	No	7/20	8/2	7/20	8/20	8/8	7/26
Reduced MH	MH	1.68	No	7/20	8/2	7/20	8/20	8/8	7/26
Full mix	MH + B	2.24 + 0.56	No	7/20	8/2	7/20	8/20	8/8	7/26
Reduced Mix	MH + B	1.68 + 0.56	No	7/20	8/2	7/20	8/20	8/8	7/26
Butralin	B	1.12	No	7/20	–	–	8/20	–	–
FA	C_8–C_{10}–C_{12}	10% v/v	No	7/20	–	–	8/20	–	–

[a] UTC = untreated control; GS = grower standard; MH = maleic hydrazide; FA = fatty alcohol; B = butralin.
[b] 2015 location was at Murray, KY.

or growth stage 60 (6). Sucker control data were collected within 7 d prior to tobacco harvest and are shown in fresh weight of suckers (g). All treatment application dates are provided in Table 1.

Thirty tobacco plants from the center two rows in each plot were stalk harvested 3–4 weeks after manual topping, placed on sticks, and cured in traditional air-curing barns. After curing, tobacco leaves were removed from the stalk, sorted into four stalk positions including flyings (lower stalk), lug (lower mid-stalk), leaf (upper mid-stalk), and tip (upper stalk), and weighed to calculate yield per hectare. MH residue analyses on cured leaf from lower (flyings and lug) and upper (leaf and tip) stalk positions were performed by Global Laboratory Services, Wilson, NC. A U.S. Department of Agriculture (USDA) grader evaluated cured leaf to USDA standards for type 31 light air-cured burley tobacco, and grades were assigned an index value between 1 and 100 (2). Grade index data are a weighted average of grade across stalk positions based on the grade received for each stalk position, and the percent contribution of that stalk position to total yield. TSNA samples consisted of 20 cured leaves, collected from the fourth leaf position from the top of 20 plants in each plot. Samples were then air-dried, ground to 1 mm, and sent to the University of Kentucky Tobacco Analytical Laboratory located at the Kentucky Tobacco Research and Development Center for TSNA analysis following the method described by Morgan et al. (21). TSNAs are presented as total TSNA in micrograms per gram, which is the sum of all individual TSNAs (NNN, NAT, NAB, NNK). All data were subjected to analysis of variance (ANOVA) with the general linear model procedure (proc GLM), and means were separated using the LS-means multiple comparison procedure at $P = 0.10$ using SAS 9.4 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Data for sucker control effectiveness, plant height, tobacco yield, MH residue, and total TSNA are presented by year and location as there were significant environment by treatment interactions. Data for quality grade index are presented by treatment, as there was not a significant environment by treatment interaction.

Sucker Control. All sucker control data are shown as percent control that was calculated from the fresh weight (g) of axillary sucker growth from a treated plot compared to the respective UTC. There was a significant treatment effect in each site-year on sucker control. In 2015, there was a significant reduction in sucker control for treatments that did not include MH. Butralin and FA used alone resulted in significantly less sucker control and were not successful in chemically topping the apical meristem at Murray and Lexington and were discontinued for 2016 and 2017. Treatments that included MH (GS, full MH, reduced MH, full mix, and reduced mix) ranged from 87 to 100% control.

Sucker growth ranged from 82 to 100% in treated plots in 2016 at each location. There was a significant reduction in control when MH was used alone as compared to the GS and mix treatments at Princeton. In Lexington, however, only the reduced MH treatment resulted in significantly less sucker control (94%) when compared to all other treated plots. There were no significant differences in sucker control between the GS and full or reduced mix treatments at either location in 2016.

The range of sucker control effectiveness in treated plots was 99 to 100% in 2017 at Lexington. Therefore, the addition of butralin in the treatment did not improve the control of axillary bud growth when compared to the full and reduced MH treatments. There was a statistically significant reduction with the reduced MH only treatment at Lexington (99%) but this difference is likely not biologically relevant, as most MH-treated plots controlled all sucker growth. Treatments at Princeton in 2017 followed a similar trend as 2016 with MH-alone treatments resulting in reduced sucker control. There was a benefit of using the full rate when compared to the reduced rate of MH; however, only the full and reduced mix treatments provided equivalent sucker control to the GS (94–100% control).

Plant Height. Investigating the total length of the tobacco plant to be harvested and cured was of interest to determine if there would be limitations with the stalk harvesting and curing as a result of the chemical topping system compared to traditional manual topping. There was a significant treatment effect on plant height in all years and locations (Table 3). There was variability in plant height across all environments and treatments

Table 2. Percent sucker reduction prior to harvest for manual and chemical topping treatments.[a]

Treatment[c]	Suckercides	Application Rate[d]	Manually Topped	2015[b] Murray (g)	2015[b] Lexington (g)	2016 Princeton (g)	2016 Lexington (g)	2017 Princeton (g)	2017 Lexington (g)
GS	MH + B	2.24 + 0.56	Yes	99 a	99	100 a	100 a	100 a	100 a
Full MH	MH	2.24	No	98 a	93	83 b	98 a	69 b	100 a
Reduced MH	MH	1.68	No	91 b	91	82 b	94 b	50 b	99 b
Full mix	MH + B	2.24 + 0.56	No	99 a	94	96 a	100 a	99 a	100 a
Reduced Mix	MH + B	1.68 + 0.56	No	99 a	87	99 a	99 a	94 a	100 a
P value				0.0224	0.1639	0.0045	0.0002	0.0004	0.0013

[a] Data are presented as percent sucker reduction compared to the control and calculated from a sample of 10 plants per plot.
[b] Means within a column followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) at P = 0.10.
[c] GS = grower standard, MH = maleic hydrazide, B = butralin.
[d] Application rate of active ingredient (kg a.i. ha^{-1}).

ranging from 121 to 190 cm. In 2015, plant heights in the UTC, butralin, and FA exceeded 200 cm at each location because of the lack of chemical topping of the apical bud (data not shown) and these plants were excluded from further evaluation. Tobacco in chemically topped treatments was significantly shorter than the GS at both locations in 2015, except for the reduced mix treatment at Lexington. There was a total range of 12 cm in plant height at Princeton in 2016 across all treatments. Chemically topped treatments resulted in significantly reduced plant height when compared to the GS at Lexington in 2016. The total range in plant height between the GS and chemically topped treatments for Princeton in 2017 was 11 cm. However, chemically topped treatments at Lexington resulted in significantly taller tobacco when compared to the GS. To summarize, differences in plant height between treatments were observed. However, these differences did not result in difficulties in the process of harvesting, handling, and curing.

Total Yield. There was a significant treatment effect on total yield at Princeton in 2016 and 2017 but all other environments were not significantly different (Table 4). Total yield ranged from 2,121 to 2,252 kg ha^{-1} at Murray and 2,141 to 2,244 kg ha^{-1} at Lexington in 2015. In 2015, butralin and FA alone were not different from the UTC and resulted in a significant reduction in total yield compared to the GS and chemically topped treatments that included MH (data not shown). The higher-yielding treatments also had a corresponding increase in sucker control effectiveness. The butralin and FA alone treatments were discontinued after the 2015 season, as these treatments were not successful in chemically topping the plant, controlling axillary bud growth, and producing yields that were comparable to the GS.

Total yield ranged from 2,074 to 2,647 kg ha^{-1} at Princeton in 2016 (Table 4). The GS, full mix, and reduced mix treatments resulted in equivalent total yield at Princeton in 2016 and 2017; however, the MH alone (full MH and reduced MH) treatments resulted in significantly reduced total yield. The reduction in total yield in the full MH and reduced MH treatments at Princeton were accompanied by a significant reduction in sucker control effectiveness (Table 2). The addition of butralin (full mix and reduced mix) provided significantly better sucker control and higher total yield. There were no significant differences in total yield at Lexington in 2016 ($P = 0.6447$) with a narrow range of 3,320–3,397 kg ha^{-1} in all treatments. Therefore, chemically topped treatments did not result in a significant decrease in yield as compared to the GS. This result can be attributed to a high degree of sucker control at Lexington in 2016 (Table 2). There were no statistically significant differences between

Table 3. Plant height following manual topping and chemical topping treatments.

Treatment[b]	Suckercides	Application Rate[c]	Manually Topped	2015[a] Murray (cm)	2015[a] Lexington (cm)	2016 Princeton (cm)	2016 Lexington (cm)	2017 Princeton (cm)	2017 Lexington (cm)
GS	MH + B	2.24 + 0.56	Yes	190 a	167 a	178 c	185 a	142 a	121 c
Full MH	MH	2.24	No	169 c	154 c	185 b	168 b	143 a	148 ab
Reduced MH	MH	1.68	No	179 b	159 bc	189 ab	171 b	142 a	149 ab
Full mix	MH + B	2.24 + 0.56	No	167 c	161 b	190 a	168 b	132 b	150 a
Reduced Mix	MH + B	1.68 + 0.56	No	171 bc	168 a	189 ab	166 b	135 b	143 b
P value				<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] Means within a column followed by the same letter are not significantly different according to Fisher's protected least significant difference P = 0.10.
[b] GS = grower standard; MH = maleic hydrazide; B = butralin.
[c] Application rate of active ingredient (kg a.i. ha^{-1}).

Table 4. **Effect of manual or chemical topping treatments on burley tobacco yield.**

Treatment[b]	Suckercides	Application Rate[c]	Manually Topped	2015[a] Murray (kg ha^{-1})	2015[a] Lexington (kg ha^{-1})	2016 Princeton (kg ha^{-1})	2016 Lexington (kg ha^{-1})	2017 Princeton (kg ha^{-1})	2017 Lexington (kg ha^{-1})
GS	MH + B	2.24 + 0.56	Yes	2121	2155	2627 a	3372	2725 a	2598
Full MH	MH	2.24	No	2166	2229	2074 b	3339	2297 b	2779
Reduced MH	MH	1.68	No	2233	2141	2127 b	3397	2112 b	2705
Full mix	MH + B	2.24 + 0.56	No	2252	2157	2647 a	3356	2690 a	2828
Reduced Mix	MH + B	1.68 + 0.56	No	2148	2244	2611 a	3320	2614 a	2576
P value				0.9617	0.9971	0.0049	0.9964	0.0004	0.1839

[a] Means within a column followed by the same letter are not significantly different according to Fisher's protected least significant difference at P = 0.10.
[b] GS = grower standard; MH = maleic hydrazide; B = butralin.
[c] Application rate of active ingredient (kg a.i. ha^{-1}).

the GS and any chemically topped treatment at Lexington in 2017, and sucker control was 99–100% across all treated plots.

The full mix and reduced mix treatments were most consistent and were not significantly different from the GS in any year–location combination for total yield and sucker control effectiveness (Tables 2 and 4). Chemical topping with MH alone (full or reduced MH) did provide yields that were comparable to the GS and tank mix treatments (MH + butralin) in four of the six environments that were tested.

Quality Grade Index. There was not a significant interaction between environment and treatment for quality grade index; therefore, the main effect of treatment is shown averaged over all years and locations. There was a significant main effect of treatment on quality grade index, with the reduced mix treatment providing a better quality grade index compared to the GS, reduced MH, and full mix, but was not different than full MH, as shown in Table 5 ($P = 0.0232$). Although statistically significant, this result is not likely relevant as the overall range was from 58 to 64. There was a significant main effect of environment with Lexington, 2016 having higher grade index compared to all other environments (data not shown).

Maleic Hydrazide Residues. MH residue samples for GS, full mix, and reduced mix treatments were collected in all years and locations of this experiment. Within all years and locations, MH residues were higher in the upper leaf positions than the lower leaf positions except Lexington, 2015 and Princeton, 2017 (Table 6). There was no consistent reduction in MH residues due to the application of a reduced rate of MH, as the full mix contained only 25% more product and did not always produce higher MH residues. Generally, precipitation occurring after topping and prior to harvest provided some explanation for differing MH residues in the different environments with the rainfall between chemically topped and manually topped treatments seeming to be less important than overall rainfall between the treatment date and harvest date. The highest rainfall from treatment to harvest (103.9 mm) resulted in the lowest residues at Princeton in 2016. Higher MH residues were observed in Murray, 2015 and Lexington, 2016 where lower amounts of rainfall occurred after topping and prior to harvest.

At Murray in 2015, the GS treatment had numerically higher MH residues (64 ppm) than the full and reduced mix treatments (33 and 59 ppm, respectively), although this was not statistically significant. The reduced mix treatment (19 ppm) had significantly less MH residues than the GS (49 ppm) with the full mix (32 ppm) treatment not significantly different from either at Lexington in 2015 (Table 6). In 2016 at Princeton, the GS treatment resulted in significantly higher MH residues compared to the full and reduced mix treatments ($P = 0.0233$). Overall, MH residues at Princeton in 2016 were lower than all other location and year combinations, likely because

Table 5. Effect of manual or chemical topping treatments on quality grade index for type 31 burley tobacco.[a]

Treatment[b]	Suckercides	Application Rate[c]	Manually Topped	Quality Grade Index[d]
GS	MH + B	2.24 + 0.56	Yes	58 b
Full MH	MH	2.24	No	61 ab
Reduced MH	MH	1.68	No	60 b
Full mix	MH + B	2.24 + 0.56	No	60 b
Reduced mix	MH + B	1.68 + 0.56	No	64 a
P value				0.0232

[a] Quality grade index is a numerical representation of federal quality grade index received for tobacco and is a weighted average of grade index for all stalk positions following Bowman et al. (2).
[b] GS = grower standard; MH = maleic hydrazide; B = butralin.
[c] Application rate of active ingredient (kg a.i. ha^{-1}).
[d] Means within a column followed by the same letter are not significantly different according to Fisher's Protected least significant difference at P = 0.10.

Table 6. Maleic hydrazide residues as affected by manual or chemical topping, upper and lower stalk positions, and precipitation.

	2015[a]		2016		2017	
	Murray (ppm)	Lexington (ppm)	Princeton (ppm)	Lexington (ppm)	Princeton (ppm)	Lexington (ppm)
Treatment[b]						
GS[c]	64	49 a	15 a	62	41 a	29
Full mix	33	32 ab	10 b	54	10 b	50
Reduced mix	59	19 b	11 b	51	36 a	44
P value	0.1886	0.0944	0.0233	0.7038	0.0231	0.1168
Position						
Upper	78 A	38	13 A	85 A	35	53 A
Lower	26 B	26	10 B	27 B	24	29 B
P value	0.0011	0.1692	<0.0001	<0.0001	0.2279	0.0078
Precipitation[d] (mm)						
Manual topping to harvest	29.2	61.7	103.9	44.7	31.2	74.9
Chemical to manual topping	1.8	11.9	7.6	34.3	10.4	28.2

[a] Means within a column followed by the same uppercase or lowercase letter are not significantly different according to Fisher's protected least significant difference at $P = 0.10$.
[b] Full MH and reduced MH were excluded from residue analysis to make better comparisons to the GS.
[c] GS = manually topped followed by MH (2.24 kg a.i. ha^{-1}) and butralin (0.56 kg a.i. ha^{-1}); full mix = chemically topped with MH (2.24 kg a.i. ha^{-1}) and butralin (0.56 kg a.i. ha^{-1}); reduced mix = chemically topped with MH (1.68 kg a.i. ha^{-1}) and butralin (0.56 kg a.i. ha^{-1}).
[d] Total rainfall (mm) between topping through harvest or between chemical topping and manual topping treatments.

of heavy rainfall (10.39 cm) after topping through harvest. There were no significant differences at Lexington in 2016; however, the GS had numerically higher MH residues than chemically topped treatments. Unexpectedly, the full mix chemically topped treatment resulted in significantly lower MH residues compared to the reduced mix and GS at Princeton in 2017. Although not significant, the GS had numerically less MH residues compared to chemically topped treatments at Lexington in 2017. This is likely because of a rainfall event that occurred within 3–6 hr after application. The decision was made not to reapply this treatment, as it may have influenced results; however, sucker control and yield were not negatively affected (Tables 2 and 4). Theoretically, chemical topping may result in lower MH residues because of the timing of application, as chemical topping applications are typically made about 7 days prior to when growers would normally apply MH following manual topping. Assuming both are harvested at the same time, the increased time between application and harvest would allow more time for precipitation and degradation to reduce MH residue levels. There was no clear evidence of a reduction in MH residues with chemical topping in this study, but MH residues were not higher compared to the current grower standard for sucker control.

Tobacco-Specific Nitrosamines. There were no significant differences in TSNA between manually or chemically topped treatments in 2016 ($P = 0.6831$) or 2017 ($P = 0.3848$) at Princeton as shown in Table 7. However, there was a significant treatment effect on total TSNA at Lexington in 2016 ($P = 0.0441$) and 2017 ($P = 0.0854$). Chemically topped treatments (full mix and reduced mix)

Table 7. Tobacco-specific nitrosamines and nicotine content from differing manual or chemical topping treatments.

				2016		2017	
Treatment[c]	Suckercides	Application rate[a]	Manually topped	Princeton	Lexington	Princeton	Lexington
Total TSNA[b] ($\mu g\ g^{-1}$)							
GS[d]	MH + B	2.24 + 0.56	Yes	5.04	2.22 a	1.24	1.60 a
Full mix	MH + B	2.24 + 0.56	No	4.23	1.01 b	0.87	0.59 b
Reduced mix	MH + B	1.68 + 0.56	No	4.63	1.15 b	0.85	0.57 b
P value				0.6831	0.0441	0.3848	0.0854
Nicotine (%)							
GS	MH + B	2.24 + 0.56	Yes	4.65 a	5.34 a	4.18	5.55 a
Full mix	MH + B	2.24 + 0.56	No	4.02 b	2.23 c	4.43	3.58 b
Reduced mix	MH + B	1.68 + 0.56	No	3.56 b	3.00 b	4.41	3.29 b
P value				0.0069	<0.0001	0.8737	0.0019

[a] Application rate of active ingredient (kg a.i. ha^{-1}).
[b] Means within a column and variable followed by the same letter are not significantly different according to Fisher's protected least significant difference at $P = 0.10$.
[c] Full MH and reduced MH were excluded from leaf chemistry analyses to make better comparisons to the GS.
[d] GS = manually topped followed by MH (2.24 kg a.i. ha^{-1}) and butralin (0.56 kg a.i. ha^{-1}); full mix = chemically topped with MH (2.24 kg a.i. ha^{-1}) and butralin (0.56 kg a.i. ha^{-1}); reduced mix = chemically topped with MH (1.68 kg a.i. ha^{-1}) and butralin (0.56 kg a.i. ha^{-1}).

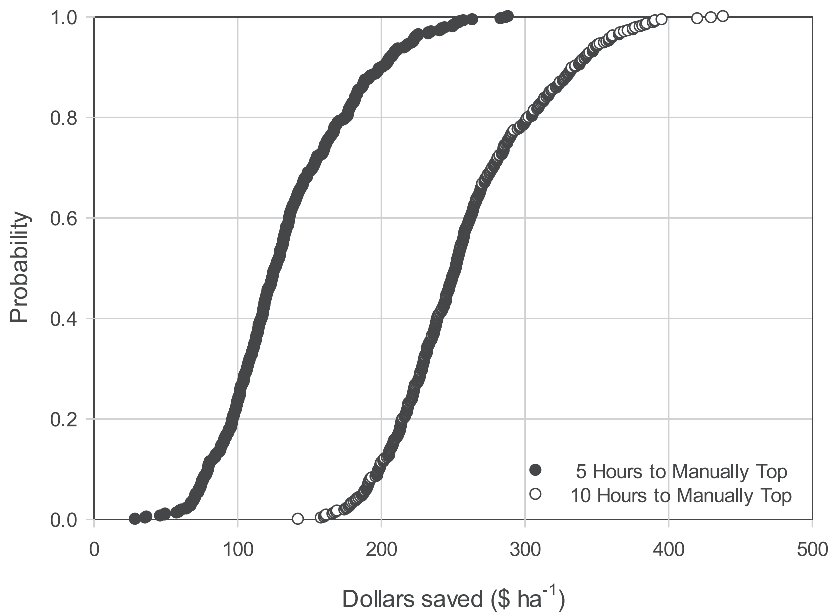

Figure 1. Cumulative density function for manual and chemical topping burley tobacco. The lines represent the cost saved per hectare with the assumption that 5 man hours (light blue) or 10 man hours (dark blue) was required for manual topping.

resulted in significantly lower TSNAs than the GS. Cui et al. (8) suggested that applying MH reduced TSNA in air-cured burley tobacco because of MH altering the precursor–TSNA relationship. Tso (36) concluded that topping increases nicotine content and results in a net gain in total alkaloid content; therefore, tobacco plants that are not manually topped should be expected to have less alkaloids and therefore less precursor to TSNA formation. This is likely because of a combination of increased root growth leading to an increase in nicotine biosynthesis and upregulated plant defenses because of wound signaling pathways. This may help explain reduced total TSNA in chemically topped treatments (full mix and reduced mix) at Lexington in 2016 and 2017, as nicotine content (Table 7) was significantly less in chemically topped treatments. Chemically topped treatments resulted in lower nicotine content at Princeton in 2016 and in both years at Lexington (Table 7). Another possible explanation is the timing of MH application between the GS and the chemically topped treatments, as the chemically topped MH treatments were applied 7 days prior to the GS (Table 1), thus altering the timing of the precursor relationship. Although significant reductions in TSNA were only observed in Lexington, numerical trends were also observed in three out of the four environments.

Cumulative Distribution Function for Cost Savings. Chemical topping burley tobacco was found to be a suitable alternative to the traditional manual topping, as there were no significant differences between the grower standard (manually topped, sprayed with MH, and butralin) and chemically topped treatments (full mix and reduced mix; chemically topped with MH and butralin) in all environments tested for sucker control, total yield, and leaf quality grade index. A stochastic simulation model was developed to evaluate the potential savings from the use of chemical versus manual topping. The stochastic variables in the model are the number of man-hours required for manual topping (Min = 3, Mean = 5.5, Max = 10), amount of man-hours required to spray (Min = 0.4, Mean = 0.5, Max = 0.6), hourly wage in $USD hr^{-1} (Min = 8, Mean = 10, Max = 12.5), yield (kg ha^{-1}) (Min = 1,905, Mean = 2,242, Max = 3,138), and the average price in $USD per kilogram (Min = 2.71, Mean = 3.95, Max = 4.41). Minimal research has been conducted on hours to top manually versus spraying a hectare of tobacco and its impact on yield and quality, which impacts price. A Gray, Richardson, Klose, and Schumann (GRKS) distribution was utilized based on parameters using the preceding minimum, mean, and maximum values in variables. The GRKS distribution is an augmented triangle distribution, was developed to simulate random variables when insufficient historical data are available, and used when minimal information is available (27). The critical difference between manual and chemical topping is labor cost savings potential (Figure 1). The foundation for the simulation is the 2016 burley tobacco budget used to calculate the cost reduction of chemical topping as a function of the reduced labor requirement for topping (31). Cost saving ($USD ha^{-1}) is based on the return over variable cost as opposed to return over total costs. Based on the assumptions of this simulation, an average of $134.45 ha^{-1} was saved when chemical topping was used if topping required only 5 man-hours in a manual topping system. The range of cost saving is $28.81 to $288.49 ha^{-1} based on 500 iterations, with an iteration representing a possible outcome given the assumptions, under the assumptions with the simulation. Another simulation was performed assuming that manual topping required 10 man-hours in a manual topping system. An estimated average of $259.23 ha^{-1} was saved when chemical topping was used to replace the labor associated with topping. The range of cost saving would be \$142.21 to \$438.11 ha^{-1} if 10man-hours were required to top manually based on 500 iterations under the assumptions with the simulation.

CONCLUSION

Chemical topping of burley tobacco at 10% button stage with a tank mixture of MH and a local systemic suckercide was a suitable alternative to manual topping as sucker control, total yield, and leaf quality grade index were not different in all years and locations of this study. Application of a local systemic or fatty alcohol alone did not inhibit the terminal bud nor control subsequent sucker growth, resulting in a reduction in total yield. MH residues for chemically topped tobacco were generally similar to residues from manually topped and sprayed tobacco, but were significantly lower with chemically topped tobacco in two of six environments (Murray 2015 and Princeton 2016). Total TSNA was not increased in chemically topped treatments, and at Lexington there was a reduction in total TSNA compared to manual topping. Future work should further investigate these TSNA reductions that were observed. Chemical topping has the potential to reduce labor input and production costs without negatively impacting yield, quality, or chemistry of burley tobacco.

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LITERATURE CITED

1. Bailey WA, Reed TD, Pearce RC. 2017. Topping and sucker control management. Pages 42–47, in: 2017–2018 Burley and dark tobacco production guide, ID-160. R.C. Pearce and W.A. Bailey, eds. University of Kentucky Cooperative Extension Service, Lexington, KY.
2. Bowman DT, Miller RD, Tart AG, Sasscer CM Jr., Rufty RC. 1989. A grade index for burley tobacco. Tobacco Science 33:18–19.
3. Brunnemann KD, Masaryk J, Hoffman D. 1983. Role of tobacco stems in the formation of n-nitrosamines in tobacco and cigarette mainstream and sidestream smoke. Journal of Agricultural and Food Chemistry 31:1221–1224.
4. Chaplin JF. 1967. Influence of various degrees of sucker control on flue-cured tobacco. Tobacco Science 3:75–78.
5. Collins WK, Hawks SN. 1993. Principles of Flue-Cured Tobacco Production. North Carolina State University, Raleigh, NC. Pages 185–211.
6. CORESTA. 2009. Guide No. 7. A scale for coding growth stages in tobacco crops. Task force: Growth stages and identification keys for tobacco. Cooperation Centre for Scientific Research Relative to Tobacco.
7. CORESTA. 2014. Maleic hydrazide. Agrochemicals Analysis Technical Note No. 001. Paris, France.
8. Cui M, Burton HR, Bush LP, Sutton TG, Crafts-Brandner SJ. 1995. Effects of application methods and rates of maleic hydrazide on the composition of burley tobacco. Tobacco Science 39:9–17.
9. Decker RD, Seltmann H. 1971. Axillary bud development in *Nicotiana tabacum* L. after topping. Tobacco Science 14:144–148.
10. Douglass EA, Mackown CT, Gay SL, Bush LP. 1985. Nitrate uptake and assimilation in maleic hydrazide treated tobacco (*Nicotiana tabacum* L. CV. KY 14). Tobacco Science 30:11–15.
11. Duncan GA, Wilhoit JH. 2014. Reduction in labor requirements for burley tobacco production, Part 1: Progress since the 1970's. Tobacco Science Special Publication 2:1–10.
12. Fisher LR, Vann MC, Whitley DS, Seagroves R. 2018. Topping, managing suckers, and using ethephon. Flue-cured tobacco guide. North Carolina State Extension. Raleigh, NC.
13. Fisher S, Spiegelhalder B, Eisenbarth J, Preussmann R. 1990. Investigations on the origin of tobacco-specific nitrosamines in mainstream smoke of cigarettes. Carcinogenesis 11: 723–730.
14. Goins GD, Danehower DA, Butler AR. 1993. Influence of method and degree of sucker control on the concentration of duvatrienediols, yield, and quality of flue-cured tobacco. Tobacco Science 37:78–83.
15. Hecht SS. 1988. Biochemistry, biology, and carcinogenicity of tobacco-specific nitrosamines. Chemical Research in Toxicology 11:559–603.
16. Hecht SS, Hoffman D. 1988. Tobacco-specific nitrosamines, an important group of carcinogens in tobacco and tobacco smoke. Carcinogenesis 9:6875–6884.
17. Hoffman D, Brunnemann KD, Prokopczyk B, Djordjevic MV. 1994. Tobacco-specific n-nitrosamines and Areca-derived n-nitrosamines: Chemistry, biochemistry, carcinogenicity, and relevance to humans. Journal of Toxicology and Environmental Health 41:1–52.
18. Link LA, Atkinson WO, Nichols BC, Seltmann H. 1982. Effects of sucker control practices on amount of suckering time and yield of burley tobacco. Tobacco Science 26:35–36.
19. Long RS, Jones JL, Wilkinson CA. 1989. Chemically topping mammoth cultivars of flue-cured tobacco. Tobacco Science 34:29–31.
20. McKee CG. 1995. Effects of maleic hydrazide and flumetralin on residues, yield, quality, and chemical content of Maryland tobacco. Tobacco Science 39:5–8.
21. Morgan WT, Reece JB, Risner CH, Bennett CB, Midgett CH, Johnson KS, Burton HR. 2004. A collaborative study for the determination of tobacco-specific nitrosamines in tobacco. Beitraege zur Tabakforschung 21:192–203.
22. Nooden LD. 1970. Metabolism and binding of 14C-maleic hydrazide. Plant Physiology 45:46–52.
23. Palmer GK, Pearce RC. 1999. Production practices: Light air-cured tobacco. Pages 143–153, in:

Tobacco: Production, Chemistry and Technology. D.L. Davis and M.T. Nielsen, eds. Blackwell Science, Ltd., Oxford, United Kingdom.

24. Peek D. 1995. Chemical topping burley tobacco [Thesis and Dissertations]. Knoxville, TN: University of Tennessee.

25. Pearce RC, Bailey WA, Walker E, eds. 2017–2018 Burley and dark tobacco production guide, ID-160. University of Kentucky Cooperative Extension Service, Lexington, KY.

26. Ponnampalam R, Mondy NI, Babish JG. 1983. A review of environmental and health risks of maleic hydrazide. Regulatory Toxicology and Pharmacology 3: 38–47.

27. Richardson JW. 2006. Simulation for applied risk management. Unnumbered staff report. Department of Agricultural Economics, Agricultural and Food Policy Center, Texas A&M University, College Station, Texas.

28. Seltmann H, Kim CS. 1964. Anatomy of the leaf axil of *Nicotiana tabacum* L. Tobacco Science 8:86–92.

29. Seltmann H, Sheets TJ. 1987. Sucker control and maleic hydrazide residues after simulated rain and MH reapplication. Tobacco Science 31:79–84.

30. Sheets TJ, Seltmann H, Yelverton FH. 1994. Residues of MH, flumetralin, and butralin on flue-cured tobacco. Tobacco Science 38:25–29.

31. Snell W. 2017. Competing in a global marketplace. Pages 2–3, in 2017–2018 Burley and Dark Tobacco Production Guide (ID-160). R.C. Pearce and W.A. Bailey, eds. University of Kentucky Cooperative Extension Service, Lexington, KY.

32. Snell W, Powers L. 2013. Tobacco marketing and financial management. Pages 3–5, in 2013–2014 Kentucky and Tennessee Tobacco Production Guide, ID-160. K. Seebold and R.C. Pearce, eds. University of Kentucky Cooperative Extension Service, Lexington, KY.

33. Steffens GL, McKee CG. 1969. Chemically topping Maryland tobacco. Tobacco Science 13:48.

34. Steffens GL, Tso TC, Spaulding DW. 1967. Fatty alcohol inhibition of tobacco axillary terminal bud growth. Journal of Agricultural and Food Chemistry 15:972–975.

35. Swetnam LD, Walton LR. 1998. Mechanically topping burley tobacco. Tobacco Science 42:16–17.

36. Tso TC. 1990. The production of tobacco. In: Production, physiology, and biochemistry of tobacco plant. Pages 55–64. IDEALS, Beltsville, MD.

37. [USDA, NASS] United States Department of Agriculture, National Agricultural Statistics Service. Quick Stats Database. 2017. www.nass.usda.gov. Accessed January 1, 2017.

38. Weed Science Society of America (WSSA). 2010. Herbicide handbook. WSSA. Westminster, CO.

39. Woltz WG. 1955. Some effects of topping and suckering flue-cured tobacco. North Carolina Agricultural Experiment Station Technical Bulletin No. 106. Raleigh, NC.