ABSTRACT

SLONE, JEREMY DARRYL. Overcoming Barriers to IPM adoption in Flue Cured Tobacco. (Under the direction of Hannah Burrack).

Although established integrated pest management (IPM) recommendations for flue cured tobacco are available, many North Carolina (NC) growers do not follow these guidelines at a potential cost to their operation. Surveys suggest that many growers may not utilize scouting recommendations or economic thresholds (ETs) and may be making unnecessary chemical applications.

Small plot experiments at two NC research stations allowed us to determine the average number of insecticidal applications necessary to maintain foliar feeding pests below ET. Several insecticides were evaluated across a range of rates, and an average of two sprays per season was sufficient to reduce pest populations below ET without compromising yield.

We next conducted field-scale trials on NC farms over the course of two years comparing IPM practices to grower standards. Weekly scouting was conducted at all sites in which a random sample of plants were evaluated for pest presence. The number of stops was determined based on field size, with five consecutive plants inspected at each stop. Each site included a grower standard field, which was managed according to standard practice for each cooperator with insecticide applications at their discretion, and an IPM field, which only received insecticide applications if pest populations surpassed the ET. During 2014, fewer insecticides were applied to IPM fields, but there was no difference in yield between treatments. In 2015, fewer insecticides were applied to all IPM fields again without an impact on yield, with the exception of one site where the same number of insecticide applications were made to both fields. Although there is a cost associated with the labor of scouting, it was offset by the

reduction of insecticide input costs at the majority of our sites. Additionally, fewer chemical applications have the potential to result in lower pesticide residues on cured leaf. When residues were detected, they were generally lower on cured leaf samples collected in IPM fields compared to those from grower standard fields.

During 2015 we performed additional scouting in each field to validate recommendations for sampling path through the field and number of stops. Each field was scouted weekly according to current guidelines, with stops randomly distributed through fields and was then scouted a second time along a strip path, where stops were made while passing down entire rows. Pest populations were estimated at different stop frequencies using subsampled observations from all stops to determine if pest populations had reached the ET. Both evaluated paths resulted in similar estimates of infestation levels, but the strip path took longer. Few differences were detected among stop rates, suggesting that scouting labor inputs could be reduced without compromising ET efficacy.

Grower surveys reported an average of over four insecticide applications over the season. Treating only when pests exceed economic thresholds (ET) may reduce the number of chemical applications to two or fewer per season. Therefore, if growers utilize ETs based on scouting observations, they may reduce the total number of insecticide applications per season, reduce pesticide residues on the earliest primings, and promote natural enemy populations, all without compromising yield.

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Overcoming barriers to IPM adoption in flue-cured tobacco

by
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DEDICATION

To my wife, my best and oldest friend. It was through her unending support and willingness to listen to my ramblings that I found inspiration. Thank you for always being there and for being willing to support my decisions along our journey.

To my friends and family for always believing in me and for providing the foundation that helped me become the man I am today. Through all of the choices I've made in my life, I have always had guidance and thoughtful support when I needed it, and for that I am forever grateful.

BIOGRAPHY

Jeremy Slone was born on 24 November, 1988. Although born in Kentucky, he spent his early elementary school years in South Carolina before spending his middle and high school years in North Carolina. Although always interested in science and the outdoors, it wasn't until attending UNC Charlotte for a bachelor's degree in Biology that he developed a fascination for Entomology. After joining the honeybee lab, he conducted independent research leading to two publications. He graduated from UNC Charlotte in 2010, with honors, and a concentration in Ecology, Evolution, and the Environment. Those experiences led him to pursue graduate education in the Entomology program at NC State University where he worked with farmers and extension agents to align grower management decisions with sustainable IPM guidelines. Upon completion of this Masters work, he intends to pursue PhD candidacy at NC State.

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CHAPTER 1

Slone and Burrack: Evaluating IPM in
Flue cured tobacco

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Field scale validation of IPM guidelines in flue cured tobacco production

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Abstract

Integrated pest management (IPM) recommendations, including scouting and economic thresholds (ETs), are available for North Carolina flue cured tobacco growers, although ETs for key pests have not been updated in several decades. Moreover, reported IPM adoption rates by flue-cured tobacco growers remain low, at less than 40%, according to NC cooperative extension surveys conducted during the last four years. Previous research has suggested that timing insecticide treatments using currently available ETs can reduce the average number of applications to two or fewer per season. We conducted field-scale trials at nine commercial tobacco farms, three in 2014 and six in 2015, to quantify inputs associated with current scouting recommendations, to determine if current ETs were able to reduce insecticide applications as compared to grower standard practices, and to assess the impacts of reduced insecticide applications on end of season yield and pesticide residues. Two fields were identified at each farm and were scouted weekly for insects. One field was only treated with insecticides if pests reached ET (IPM), while the other field was managed per grower discretion (Grower Standard). IPM fields received an average of two fewer insecticide applications without compromising yield. More insecticide applications resulted in higher pesticide residues in cured leaf samples from grower standard fields than those from IPM fields. Reductions in insecticides and management intensity also resulted in larger beneficial insect populations in IPM fields.

Keywords: economic threshold, integrated pest management, tobacco budworm, tobacco hornworm, tobacco flea beetle

Flue-cured tobacco (*Nicotiana tabacum* L.) is a high value crop for North Carolina (NC) farmers. At an average value of \$4.41/ kg (\$2.00/ lb) (USDA NASS 2014), the NC 2015 tobacco crop, grown on a total acreage of approximately 68,797 hectares (170,000 acres) and yielding 2410 kg/ha (2150lbs/A), was valued at over \$730 million dollars. With fluctuations in domestic and international supply and price of tobacco, US growers are under increasing pressure to reduce input costs (Brown 2015), which can be up to \$7413/ha (\$3000 USD/acre) (Bullen 2013). With high input costs relative to other row crops, growers may make unnecessary, preventative pesticide applications. There are a limited number of economically important pests present in tobacco (Gunasena et al. 1990), and it is therefore a relatively simple system in which to measure the benefits associated with integrated pest management practices.

Integrated pest management (IPM) guidelines, including economic thresholds (ETs) and scouting recommendations aimed at maximizing the efficiency of pest control, are available for tobacco growers (Burrack 2015). ETs are the population density at which the costs associated with pest management may be offset by the value of potential yield loss associated with pest feeding or damage. Insect observations from scouting are used to estimate pest density, and if populations reach ET, insecticide application is economically warranted. Current scouting recommendations outline a random sampling plan where scouts navigate through fields while making stops to inspect plants. Random sampling increases the likelihood that plant inspections are representative of the majority of the field and that ET determination is accurate.

Crop value, pest control costs, efficacy, and plant responses to insect damage are important considerations when developing economic injury levels (EILs) and associated ETs (Horn 1988). Many of the current tobacco IPM recommendations were developed over 40 years

ago (Mistric 1972, Reagan 1976), and numerous changes have occurred in the tobacco production system during this time period. First, tobacco farm number and size have changed due to the end of federal price supports and quotas (Brown 2013). Over the past few decades, the number of NC tobacco farms has decreased by over 78% while tobacco acreage has remained relatively high (Clauson and Grise 1994, Capehart 2004). This has resulted in consolidation of farms and substantially greater acreage per farm, resulting in a tendency for growers to invest in more efficient, mechanized production processes (Capehart 2004).

Registered pesticides and pesticide use patterns have also changed. For example, tobacco flea beetles (*Epitrix hirtipennis*) were historically a significant early-season pest (Mistric 1972, Semtner 1984, Duke 1986), but greenhouse treatment with neonicotinoid insecticides, primarily imidacloprid, provides protection against this pest for several weeks post-transplant, and may result in lower flea beetle populations throughout the growing season (Burrack 2015). In addition to reducing flea beetle populations, systemic neonicotinoids also provide long-term control of tobacco thrips (*Frankliniella fusca*), a vector of tomato spotted wilt virus, and green peach aphids (*Myzus persicae*) (McPherson 2005). Additionally, popular tobacco varieties regularly shift over time, and newer varieties may differ in susceptibility to insect pests (Juba et al. 2007).

Finally, external demands by tobacco purchasers have changed. Tobacco leaf purchasers now require growers to obtain Good Agricultural Practice (GAP) certification and submit to periodic audits. Growers must maintain scouting reports and spray records as documentation of pest management decision-making for GAP compliance. Leaf purchasers have also raised concerns about pesticide residues. The US government does not regulate pesticide residues on

tobacco, but with rising exports, the tobacco industry has been under greater pressure to monitor pesticide residues on cured leaf (Vann et al. 2008).

Although existing IPM recommendations are part of GAP guidelines and are intended to enhance economic and environmental sustainability, documented adoption has been low in tobacco, as in other row crop systems (Puente et al. 2011). NC cooperative extension agent surveys conducted prior to 2014 report that formalized scouting program implementation remains low, at less than 40% for NC tobacco growers (Toennisson, 2016). Formalized scouting programs generate the information necessary to make insecticidal management decisions based on pest density and ETs. Preliminary GAP audits report 75-80% compliance with IPM documentation requirements (Paul Denton, personal communication); however, at this early stage, growers are only required to maintain written documentation that scouting is being performed, not actual scouting observations. Currently, GAP audits do not specifically evaluate scouting methodology or pest management decision-making. Audits and agent surveys provide snapshots of how tobacco growers make pest management decisions broadly, but individual grower practices and how management decisions are reached remain unknown.

Production practices and pest infestation can be evaluated through small plot experiments; however, on farm, whole-field evaluations of pest management may allow us to better understand standard grower management practices and decision-making. We conducted a two year, on farm project with the goal to determine if grower-scale, commercial fields managed using current insect scouting and economic threshold recommendations differed from fields managed using grower standard practices with respect to insect density, number of insecticide applications, cured leaf pesticide residue, and yield. We also quantified the inputs associated

with fields managed using recommended practices versus those managed using growers standard practices in order to understand the economic ramifications of recommended practices.

Materials and Methods

Grower surveys.

We conducted surveys of tobacco growers at 13 and 12 North Carolina tobacco GAP meetings each during 2015 and 2016, respectively. Responses were obtained from a total of 989 and 540 growers in 2015 and 2016, respectively. Surveys were designed to measure self-reported insect management practices and to identify grower-perceived barriers to IPM. Our survey was determined to be exempt from approval by the North Carolina State University institutional review board because it did not pose a risk to participants. Survey questions are included in Appendices A and B. Responses were pooled to determine averages for NC tobacco growers.

On farm assessment of scouting recommendations.

Insect Densities.

We conducted on farm comparisons of insect density, number of insecticide applications, cured leaf pesticide residue, and yield in two fields per farm on nine farms over two years. We identified grower cooperators through county extension personnel, and selected field sites distributed across NC (Table 1.1). At each farm site, we identified two close, but spatially separate, fields ranging from 0.61 to 5.7 hectares in size, and assigned them either to IPM or grower standard (GS) treatments. Plants at all sites, except one, received systemic imidacloprid applications in the greenhouse (Table 1.1) prior to transplant. No additional greenhouse or pre-transplant soil insecticide applications were made in IPM fields, but these were allowed at the

discretion of grower cooperators in GS fields. Both fields were scouted on a weekly basis, and insecticide applications in IPM fields were arranged with the grower only when insect populations reached ETs. Insecticide applications in GS fields were made at the grower's discretion.

Currently recommended flue cured tobacco scouting practices were followed (Burrack 2015). Scouting locations were randomized weekly within fields, and five plants per in-field location ("stops") were visually inspected for insect pests, parasitoids, and predators. The number of stops was scaled based on field size (Table 1.1). The number of tobacco budworm larvae (*Heliothis virescens*), tobacco or tomato hornworm larvae (*Manduca sexta* or *M. quinquemaculata*), tobacco flea beetle adults (*Epitrix hirtipennis*), and green-peach aphids (*Myzus persicae*) were recorded at each stop. We also recorded beneficial insects, specifically the number of visibly parasitized budworm or hornworm larvae and spined stilt bugs (*Jalysus wickhami*), which are the most common predator in tobacco (Elsey 1971).

Yield and scouting time.

In addition to insect counts, we recorded the time required to complete weekly scouting and end of season yield estimates within each field. Flue cured tobacco is harvested beginning at the bottom of the stalk and moving up, as leaf matures, in harvest events often referred to as primings. We weighed leaf samples from 10 plants each at 10 randomly selected spots in each field for each priming and calculated total green leaf yield by summing the average weight from all harvest dates from a field. In a few instances, growers harvested their fields without warning, and we were unable to collect harvest samples. In these cases, we omitted the missed harvest dates from yield totals for both fields within a location.

Pesticide applications and residues.

We obtained grower spray records for each field and compared the number of insecticide applications between treatments. During 2014, a total of four pesticide residue samples were collected per field at each priming, and three were collected per field, per priming, in 2015. Pesticide residue samples were oven-dried in paper bags in the lab and analyzed using gas chromatography/mass spectrometry at Global Labs (Wilson, NC). Leaf samples were ground and homogenized prior to analysis. Because only applications of either flubendiamide (Belt™, Bayer CropSciences) or acephate differed between IPM and grower standard fields, only residues of these materials, or in the case of acephate, its metabolite methamidophos, were measured. Flubendiamide residues were detectable to 0.125 LoQ while methamidophos residues were detectable to 0.100 LoQ.

Economic assessment.

We used tobacco enterprise budgets to compare differences in input costs between treatments (Bullen 2013). Pesticide prices used in economic analyses was calculated by averaging independent, anonymous price quotes in 2014 from three pesticide dealers in North Carolina (Table 1.2). We assumed that insecticide treatments would be applied independent of cultivation and calculated labor and equipment operation costs totaling \$4.19 USD per application. We assumed an hourly wage of \$12 USD/hour for both scouting and pesticide application labor. In both years, insect monitoring was conducted for at least 17 weeks. To determine scouting costs, we calculated the average time per stop (1.65min/stop) multiplied by the average number of stops per field (9.66 stops), and divided by the average area per field (2.16

ha) for an average scouting time of 7.41 min/ha (3min/ac) within fields. Costs associated with scouting labor were determined to be \$25.21 USD/ha (\$10.20 USD/ac) for the entire season.

Statistical analysis.

Data were analyzed using SAS v. 9.3 (SAS Institute, Cary NC). Insect observations were standardized by dividing insect counts per plant (pest/plant) by week. Caterpillar parasitism was determined by dividing the number of parasitized caterpillars observed by the total number of caterpillars. Pest observations, scouting time, and yield were pooled among sites and compared by week and field treatment; site and year were treated as random. All insect observations were log transformed and subjected to repeated measures analysis of variance (ANOVA) via the MIXED procedure. Stilt bug analysis was performed using the Satterthwaite adjustment to calculate degrees of freedom to correct for heteroscedasticity. Aphid infestations were too infrequent to be analyzed. Scouting time was subjected to repeated measures ANOVA via the MIXED procedure with a Satterthwaite degrees of freedom adjustment. Yield was analyzed using ANOVA via the MIXED procedure. Means separation was performed using the Tukey-Kramer adjustment. Residues were compared between field treatments and among primings. Flubendiamide residue analysis was done via the GLIMMIX procedure with a logn distribution for sites 1, 4, 6, 7, and 8 while a normal distribution was used for sites 2 and 6. Acephate residue analysis was performed via the GLIMMIX procedure with a logn distribution for sites 3, 4, and 6 while a normal distribution was used for site 2. Residue samples could only be obtained at one priming from Site 9 so no analysis was performed. Pesticide residues from site 5 were analyzed as the same chemical treatments were made in both the IPM and GS fields.

Results

Grower surveys.

Survey forms are included in appendices A and B, while complete survey responses are summarized in appendices C and D. We obtained approximately 51% response rate in 2015 but a lower rate, approximately 31%, in 2016. Grower responses were similar between years for demographic information, average total farm size, and average tobacco acreage per grower. Approximately 80% of growers responding in both years intend to continue growing tobacco for at least the next five years. In 2015, over 91% of responding growers reported the use of scouting reports for pest management decision making; however, in 2016 when we offered the option of scouting reports or use of economic thresholds, the response rates were 50.9% and 50.7% agreement for each, respectively. In both years, approximately 70% of responding growers reported inspecting plants on a weekly basis, while around 10% report scouting less than weekly. Additionally, nearly 40% reported driving fields regularly in both years. This may entail a grower taking a vehicle between or around crop rows to make observations of plant health and insect damage, without physically inspecting plants. Few growers reported either the use of a crop consultant or intentionally not scouting for insects. Although only on the 2016 survey, when asked about the frequency of insecticidal applications most growers reported making one to two applications in the greenhouse, one to two before topping, and one to two again post-topping with a season long average of 4.41 insecticide treatments.

On farm assessment of scouting recommendations.

Insect densities.

There were no differences between the GS and IPM field treatments for flea beetles ($F=0.93$; $df=1,248$; $P=0.33$), budworms ($F=0.15$; $df=1,216$; $P=0.69$), budworm parasitism ($F=0.11$; $df=1,216$; $P=0.74$), hornworms ($F=0.39$; $df=1,184$; $P=0.53$), or hornworm parasitism ($F=2.77$; $df=1,184$; $P=0.10$). Stilt bugs were the most common natural enemy present in the system during both field seasons and were present in higher numbers in IPM fields relative to GS fields ($F=13.26$; $df=1,232$; $P=0.0003$) (Table 1.3).

Most insect populations varied significantly over time. Flea beetle populations were low at the beginning of the season and increased significantly over time until the end of the season ($F=24.96$; $df=15,248$; $P<0.0001$). Budworm populations also significantly increased over time during the first half of the season but were not present post topping ($F=12.81$; $df=13,216$; $P<0.0001$). The rate of budworm parasitism increased significantly as budworm populations increased and peaked around week 8 and again around week 12 ($F=2.62$; $df=13,216$; $P=0.002$). Stilt bug populations also increased significantly over the season and peaked in week 16 before declining until the end of the season ($F=1.87$; $df=14,232$; $P=0.03$). Hornworm pressure was low during both years and did not differ between weeks ($F=1.23$; $df=11,184$; $P=0.27$) nor did the rate of hornworm parasitism ($F=1.18$; $df=11,184$; $P=0.31$). There were no treatment-by-week interactions for any observations.

Yield and scouting time.

Total yield did not differ between IPM and GS fields ($F=0.023$; $df=1,8$; $P=0.64$) (Tables 1.4, 1.5). Scouting time per person per stop was not different between fields ($F=2.15$; $df=1,190$;

P=0.1438) but was different between weeks ($F=3.41$; $df=12,190$; $P=0.0002$) with IPM fields taking longer to scout during the beginning of the growing season (Table 1.4, Figure 1.1). There were no significant interactions in yield or scouting time analyses.

Pesticide applications and residues.

IPM fields received an average of two fewer chemical treatments than grower standard fields (Table 1.6). Most insecticide applications were foliar, but a total of nine pre-transplant soil incorporated or transplant water applications were made in seven of the nine GS fields. In general, residues were lower when fewer insecticide applications were made (Tables 1.7, 1.8). At site 1, flubendiamide residues were higher in GS fields ($F=24.84$; $df=1,12$; $P=0.0003$), varied with priming ($F=55.18$; $df=2,12$; $P<0.0001$), and had a significant field by priming interaction ($F=9.76$; $df=2,12$; $P=0.003$). At site 2, flubendiamide residues were similar between fields ($F=0.00$; $df=1,16$; $P=0.9906$), varied with priming ($F=9.18$; $df=3,16$; $P=0.0009$), and had a significant field by priming interaction ($F=9.20$; $df=3,16$; $P=0.0009$). At site 2, acephate was used only in the GS field, and methamidophos residues did not vary with priming ($F=0.25$; $df=3,8$; $P=0.8577$). At site 3, methamidophos residues were higher in GS fields ($F=5.16$; $df=1,12$; $P=0.0423$), varied with priming ($F=14.16$; $df=2,12$; $P=0.0007$), and had a significant field by priming interaction ($F=15.49$; $df=2,12$; $P=.0005$). At site 4, flubendiamide residues were higher in the IPM field ($F=37.79$; $df=1,12$; $P<0.0001$), varied with priming ($F=156.19$; $df=2,12$; $P<0.0001$), and had a significant field by priming interaction ($F=6.94$; $df=2,12$; $P=0.01$). At site 4, acephate was only used in the GS field, and methamidophos varied with priming ($F=17.94$; $df=2,6$; $P=0.0029$). At site 6, flubendiamide residues were not different between fields ($F=1.46$; $df=1,8$; $P=0.2618$), varied between primings ($F=14.75$; $df=1,8$; $P=0.0049$), and did not have a

significant field by priming interaction ($F=0.02$; $df=1,8$; $P=0.8814$). Post-hoc Tukey's test revealed a significant field by priming interaction for flubendiamide at site 6. At site 6, acephate was only used in the GS field, and methamidophos varied between primings ($F=15.18$; $df=1,4$; $P=0.0176$). At site 7, flubendiamide residues were higher in GS fields ($F=23.64$; $df=1,12$; $P=0.0004$), did not vary with priming ($F=3.46$; $df=1,12$; $P=0.088$), and did not have a significant field by priming interaction ($F=0.89$; $df=1,12$; $P=0.36$). A post-hoc Tukey's test revealed a significant field by priming interaction for flubendiamide at site 7. At site 8, flubendiamide was only used in the IPM field and varied with priming ($F=14.44$; $df=1,6$; $P=0.009$). The first priming had greater residues than the last.

Economic assessment.

Economic analysis of the management practices between fields suggests average savings of \$67.57 USD/ha (\$27.34 USD/A) in IPM fields (Table 1.6). In general, increased scouting costs were offset by reductions in insecticide application expenses in IPM fields. At eight of the nine sites, more chemical applications were made in the GS field relative to the IPM field. The grower at site 5 treated both fields exactly the same, and costs associated with scouting resulted in extra expenses in the IPM field in that situation.

Discussion

Our results demonstrate that when currently available economic thresholds are used to trigger and time insecticide applications in flue cured tobacco, the number of foliar insecticide applications can be reduced without effecting yield. GS field spray records provided insight into the typical management decisions made by growers (Table 1.6). Growers made on average two

additional insecticidal sprays in the GS fields relative to IPM fields, even though both experienced similar pest pressure. This suggests that grower standards for insect management in tobacco may not be strictly in line with current IPM recommendations. Further, the greater management intensity in GS fields did not significantly reduce pest populations relative to IPM fields (Table 1.3). Interestingly, the same trend was reported in extension surveys from 1972 where growers made an average of 2 to 3 times the number of sprays compared to the number of ETs reached (Reagan 1974).

It is difficult to determine the actual rate of IPM adoption or compliance due to the broad scope of such a management system (Hammond et al. 2006), and it is possible for growers to implement some facets of IPM while ignoring other aspects (Puentes et al. 2011). When growers responding to our survey were asked to rate their knowledge of IPM relative to other growers, 76% felt they were similar to others while about 21% felt they were more knowledgeable. Similarly, when asked about their interest in IPM, 72% felt they were similar to other growers and 26% felt they were more interested than others. Some growers may be implementing scouting programs and treating based on ETs but many may be relying more heavily on extensive farming experience to make insect management decisions. Many growers have been farming tobacco for more than 20 years; in our surveys, 41% of growers in 2015 and 68% in 2016 had been farming at least this long.

The labor and effort required to perform weekly scouting and maintain records was expected to be a barrier to IPM adoption, despite GAP guidelines. Scouting is time consuming, but to simplify grower responsibilities, scouts could be hired to perform weekly inspections. Our results suggest that costs associated with hiring labor will likely be offset by a reduction in

pesticide costs for the typical grower. The majority of growers surveyed in 2015 agreed that IPM is not too expensive (64%), is not too time consuming (68%), and does not take excessive effort (65%). Further, 80% disagreed with the statement that “scouting is not necessary to get adequate pest control,” and 68% agreed that “the advantages of IPM outweigh the disadvantages.” These responses would suggest that growers are in favor of IPM, but the increased insecticide-based management intensity in GS fields relative to IPM fields would suggest otherwise.

Soil insecticide treatments targeted at soil pests prior to transplant were allowed at grower discretion in the GS field but were not applied to IPM fields. These treatments are considered preventative rather than remedial and only provide benefit in fields where significant soil insect pressure is likely. Despite this, many growers are increasingly relying on preventative control measures that are more of an insurance policy than a response to actual pest pressure (Allen 2015, Ruen 2016). Perspectives on pesticides, toxicity, and the impact of chemicals on the environment have changed substantially since the 1970’s. Despite this, IPM adoption has remained lower than desired since the onset of USDA IPM compliance programs in the early 1990’s (Allen 1990, Ehler 2006). Preventative management, coupled with reduced support for extension infrastructure, may result in area-wide management that is no longer in line with established IPM guidelines, not just in tobacco, but also in cotton, corn, and many other agriculturally important crops (Cumming and Spiesman 2006, Allen 2015).

Reducing insecticide applications and selecting narrow spectrum materials may support higher natural enemy populations and provide greater biological control of key pests. There were more stilt bugs in the IPM fields, which is likely due to differences in insecticides used in GS fields. IPM fields were almost exclusively treated with flubendiamide, which is selectively active

against lepidopteran pests, such as budworms and hornworms, but less active against hemipterans, such as stilt bugs. Conversely, acephate, a broad spectrum organophosphate, was commonly used in GS fields. Although a grower has options for which insecticide to use, the cost of management can vary greatly by the class of chemical and application requirements. Acephate is generally less expensive than other commonly used tobacco pesticides (Table 1.2) but may potentially disrupt valuable naturally occurring biological controls.

Insecticides also vary with respect to residue persistence within the plant. Detected residues varied between IPM and GS fields, but multiple applications are more likely to result in higher residues. Flubendiamide residues were generally highest at the first priming, especially with multiple applications (Tables 1.7, 1.8). Similar observations have been made about the lower, more mature leaves in previous flubendiamide residue evaluations (Vann et al. 2008). Pests occupy different regions within the plant, and residues disproportionally impact some pests more than others (Burrack 2015). Budworms escape residual toxicity by feeding on the tender new growth that may not have been present during prior insecticidal applications. Conversely, late instar hornworms can defoliate entire plants, but are more likely to ingest residues as a result of extensive feeding on older leaves.

IPM practices have been proven to maintain yield while reducing management costs in many crops and countries (Birthal et al. 2000, Bueno et al. 2013, Kim and Yun 2013). Our results further demonstrate that IPM recommendations provided sufficient insect control to prevent yield loss at field relevant scales. However, a common assumption among growers is that fewer sprays results in higher insect densities, and, in turn, greater crop damage (Damalas and Koutroubas 2014). In 2016, 24% of surveyed tobacco growers agreed that fewer insecticide

applications will result in lower yields, 28% remained neutral and 48% disagreed. That mindset may present a barrier to IPM adoption and likely influences pest management decisions.

Scouting and ETs are fundamental components of IPM, and implementing such practices can lead to more informed pest management decision-making, with the potential to enhance profits for NC tobacco growers. Insect management accounts for a relatively small percentage of pest management expenses in tobacco, so growers may be reluctant to invest sufficient time to evaluate their practices. Yet the potential savings demonstrated in this experiment and the sustainable environmental profile of IPM should encourage grower compliance with best agricultural practices. However, as production practices change it remains important to review what is considered best practice and to perform validations of recommended pest sampling techniques in the context of currently available management tools (Castle and Naranjo 2009).

Future improvements to IPM recommendations may include the development of dynamic thresholds, which more specifically integrate the cost of management, crop value, and rate of control. Dynamic thresholds can therefore be tailored to the circumstances of an individual grower. Currently available tobacco insect thresholds may be overly conservative, as they are based on calculations of average costs and yields from over 40 years ago. Future research should address the validation of scouting recommendations and sampling methodology under current production systems to further simplify tobacco IPM recommendations, which may in turn enhance adoption rates (Binns and Nyrop 1992, Castle and Naranjo 2009).

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TABLES

Table 1.1 Site location, year, size, number of stops and preventative management practices.

Site	County	Year	Imidacloprid treatment	Grower Standard			IPM	
				Pre- transplant soil treatment	Area (ha)	Stops	Area (ha)	Stops
1	Johnston	2015	Yes	Yes	1.7	10	1.7	10
2	Johnston	2015	No	Yes	5.7	14	5.7	14
3	Wilson	2015	Yes	Yes	2.4	10	2.0	10
4	Oxford	2015	Yes	Yes	1.8	10	.61	6
5	Surry	2015	Yes	No	1.6	10	1.6	10
6	Stokes	2015	Yes	No	1.6	10	0.81	6
7	Johnston	2014	Yes	Yes	2.5	10	2.5	10
8	Wilson	2014	Yes	Yes	0.81	8	.81	8
9	Stokes	2014	Yes	No	1.6	8	3.2	10

Table 1.2 Insecticide active ingredient, application rate, and material cost

Insecticide (A.I.; rate)	Cost/ha, (USD)
Admire (imidacloprid; 263.2 ml/ha)	\$ 11.12
Belt (flubendiamide; 218.8 ml/ha)	\$ 42.03
Besiege (chlorantraniliprole & lambda-cyhalothrin; 730.5 ml/ha)	\$ 42.75
Blackhawk (spinosad; 144.9 ml/ha)	\$ 32.96
Coragen (chlorantraniliprole; 511.6 ml/ha)	\$ 99.98
Orthene (acephate; 0.86 kg/ha)	\$ 14.75
Sniper (bifenthrin; 511.6 ml/ha)	\$ 7.83
Warhawk (chlorpyrifos; 4.6 liters/ha)	\$ 36.97

Table 1.3 Mean season long insect densities between treatments.

Insect Density	-----Treatment¹-----	
	IPM	GS
Flea Beetle (pests/plant)	0.47 a	0.42 a
Budworm (% infested plant)	2.8% a	3.0% a
Para Budworm (PBW/BW+PBW)	7.08% a	6.33% a
Hornworm (pests/plant)	0.017 a	0.012 a
Para Hornworm	3.5% a	0.91% a
Stilt bug (insects/plant)	0.061 a	0.029 b

¹Values within a row followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

Table 1.4 Mean scouting time and yield between treatments.

Time and Yield	-----Treatment¹-----	
	IPM	GS
Scout time (min/person/stop)	1.71 a	1.58 a
Yield (kg)	11.2 a	11.0 a

¹Values within a row followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

Table 1.5 Mean total yield (kg) for all sites

Site	Year	Harvest number	-----Treatment ¹ -----	
			IPM	GS
1	2015	1	2.9	2.8
2	2015	3	14.8	15.1
3	2015	4	12.0	11.5
4	2015	3	13.6	14.9
5	2015	2	11.0	10.4
6	2015	2	11.6	8.7
7	2014	3	15.2	17.0
8	2014	4	16.9	15.7
9	2014	1	3.2	3.0

¹Values were not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

Table 1.6 Insecticide applications and cost comparison (\$USD/ha) by site.

Site	Year	Insecticide applications and scouting inputs		Input cost (USD)		Difference
		GS	IPM	GS	IPM	
1	2015	Belt (2x), Besiege, Warhawk	Belt, Scouting labor	216.32	88.71	127.61
2 ¹	2015	Admire, Belt, Coragen, Orthene (2x), Sniper	Belt, Scouting labor	242.55	77.59	164.96
3	2015	Coragen, Orthene	Orthene, Scouting labor	146.17	61.04	85.13
4	2015	Belt,,Orthene(2x)	Belt, Scouting labor	112.94	88.71	24.23
5	2015	Belt, Blackhawk	Belt, Blackhawk, Scouting labor	106.83	132.03	-25.20
6	2015	Belt, Orthene	Belt, Scouting labor	88.22	88.71	-0.49
7	2014	Belt (2x), Besiege, Warhawk	Belt, Scouting labor	216.32	88.71	127.61
8	2014	Coragen, Orthene, Warhawk	Belt, Scouting labor	193.49	88.71	104.78
9	2014	Belt, Orthene	Belt, Scouting labor	88.22	88.71	-0.49

¹Site 2 did not receive greenhouse imidacloprid treatment, cost not included

Table 1.7 Pesticide residues (ppm) for the interaction effect of field by priming

Site	Insecticide	Residue measured	Year	Field and harvest ¹							
				IPM1	IPM2	IPM3	IPM4	GS1	GS2	GS3	GS4
1	Belt	Flubendiamide	2015	5.23b	4.46bc	1.61d	.	24.0a	5.16b	2.33cd	.
2	Belt	Flubendiamide	2015	4.23b	4.61ab	5.35ab	3.45bc	11.2a	2.61bc	2.70bc	1.14c
4	Belt	Flubendiamide	2015	12.0a	4.19b	0.23c	.	6.55ab	0.69c	0c	.
6 ²	Belt	Flubendiamide	2015	1.69a	0.35ab	.	.	1.24ab	0b	.	.
7 ²	Belt	Flubendiamide	2014	5.03ab	1.86b	.	.	20.2a	14.6a	.	.
3	Orthene	Methamidophos	2015	0.46bc	0.43bc	0.085bc	.	0c	1.38a	0.53b	.

¹ Values within a row followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

²Site 6 and 7 had significant Field by Priming interaction for flubendiamide residues only after Tukey post-hoc analysis.

FIGURES

Figure 1.1 Scouting times between field treatments averaged within week.

Figure 1.2 Total yield estimates including the average for 10 plants from all harvest dates by site. Values were not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

CHAPTER 2

Slone and Burrack: Validating scouting guidelines
In flue cured tobacco

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Assessing scouting recommendations in North Carolina flue cured tobacco (*Nicotiana tabacum*)

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Abstract

Scouting guidelines should be validated over time to ensure they provide accurate estimations of insect populations, yet the economic thresholds (ETs) and scouting methodologies for the key pests in North Carolina flue cured tobacco were developed over 40 years ago. The consolidation of farms and changes in production practices, including new plant varieties and insecticides, may influence pest dynamics. The ease of implementation and scouting labor efficiency may directly influence IPM adoption, and grower surveys and farm audits suggest that many growers do not employ formal scouting programs and may not be treating for insects based on ETs.

Understanding the appropriate amount of scouting labor needed to accurately estimate pest populations is necessary if growers are to apply extension recommendations. We manipulated sampling path and the number of stops, the observed sample size per field, to compare estimated insect densities. Fields on six commercial tobacco farms were assigned to either a threshold-based insect management program (IPM) or a grower standard (GS) program. IPM fields received insecticidal applications only when pests reached ET while GS fields were treated at the grower's discretion. Both treatments were scouted weekly during the 2015 growing season. Results suggest stop rate could be lowered while still predicting field infestation as accurately as current recommendations. A strip scouting path which minimized the number of times row were crossed, took longer but estimated pest densities similar to a random path. Few differences in pest populations were detected between paired fields, so differences in management intensity did not influence insect densities.

Keywords: Integrated pest management, scouting, economic threshold, tobacco budworm,

Integrated pest management (IPM) practices, in particular the use of scouting and economic thresholds (ETs), are intended to control pest populations with reduced pesticide inputs without compromising yield (Birthal et al. 2000, Bueno et al. 2013, Kim and Yun 2013). Pest observations from scouting can be used to estimate field infestation rates, and ETs are used to time insecticidal applications (Horn 1988). If growers treat preventatively rather than based on ETs, they may be making unnecessary sprays that do not provide additional pest control benefits (Bueno et al 2013). There is an increasing trend in agriculture towards preventative management (Allen 2015, Ruen 2016). IPM encompasses many practices that can complicate efforts to measure wholesale adoption, but the development of on-farm assessment and industry standards allows for evaluation of specific grower management practices (Ehler 2006, Puente et al. 2011). North Carolina cooperative extension services and industry-supported certification programs (GAP 2013) encourage the implementation of scouting-based insect management, and industry programs measure compliance. Despite this, documented scouting program adoption remains low. Grower surveys, farm audits, and field scale evaluations suggest that many growers may not utilize a formal scouting program and may be making insecticidal applications independent of pest ETs (Slone, Chapter 1). To increase adoption of IPM recommendations, tactics must be easy to implement and have demonstrated efficacy and economic benefit at field-relevant scales.

Validation of scouting methodologies over time, along with the development of new management and production practices, are necessary to maintain efficiency (Castle and Naranjo 2009, Bueno et al. 2013, Chasen et al. 2015). Sampling plans must incorporate knowledge about pest dispersal and field level infestation to be effective at estimating whether pest densities have reached ET (Castle and Naranjo 2009) and should be designed to include enough observations to

achieve the necessary level of accuracy in estimating population sizes while minimizing time and effort (Binns and Nyrop 1992, Castle and Naranjo 2009).

Current tobacco scouting guidelines recommend observing insects on five adjacent plants at multiple stops randomly distributed within a field. The number of stops is scaled based on field size, and the total number of plants inspected per field is the sample size from which insect populations must be estimated. Current recommendations are 8 stops for fields less than 1.62 ha (4 ac), 10 stops for fields 1.62-3.24 ha (4-8 ac), and 2 additional stops for every 1.62ha (4 ac) over 3.24 ha (8 ac), which results in an average of about 5 stops per ha (2 per ac) for fields less than 4.86 ha (12 ac) (Burrack 2015). These scouting recommendations were developed when average tobacco farms were substantially smaller than they are now and have not been critically examined in decades (Mistic 1972, Reagan 1976, Capehart 2004). As overall farm size has increased, growers are particularly interested in determining if a reduced density of stops provides as accurate estimation of pest populations. To address this, we compared insect densities calculated based on observations collected at our recommend stop rate, a lower than recommend rate, and a higher than recommended rate.

As plants grower larger, it becomes more difficult to navigate between them, and a scout may damage leaves as they cross rows. Stop distributions other than random may provide similar estimates of insect density, require less time, and result in less incidental crop damage (Way and van Emden 2000, Jeger 1999). We compared insect density estimates and scouting time for randomly distributed stops to stops distributed in a serpentine path along rows to determine if the later was as effective and efficient.

Materials and Methods

We compared insect density estimates between paired fields at six farm locations during 2015 (Table 2.1). At each site, we identified two close, but spatially separate, fields ranging from 0.60 to 5.7 ha (1.5-14.0 ac) in size and assigned them to either “IPM” or “grower standard” (GS) treatments. IPM fields only received insecticidal treatment when insect populations reached ETs. GS fields received insecticidal treatment at the grower’s discretion. All fields were scouted weekly using two scouting paths, either randomly selected stops or strip-scouting stops in which two stops each were made along randomly selected rows to minimize crossing rows. The total number of stops per field using either scouting path was based on current recommendations (Table 2.1). At each scouting stop, five adjacent plants were visually inspected for insect pests, parasitoids, and predators. Pests present included tobacco budworm larvae (*Heliothis virescens* (F.)), tobacco and tomato hornworm larvae (*Manduca sexta* (L.) and *M. quinquemaculata* (Haworth)), and tobacco flea beetle adults (*Epitrix hirtipennis* (Melsheimer)). Beneficial insects included visibly parasitized budworms, visibly parasitized hornworms, and spined stilt bugs (*Jalysus wickhami* (Van Duzee)), a common predator in tobacco (Elsey and Stinner 1971). Budworms are most often internally parasitized by small wasps including, *Toxoneuron nigriceps* (Viereck) and *Campoletis sonorensis* (Cameron); however, if caterpillar carcasses and wasp cocoons are visible on leaves the wasp was most likely *C. sonorensis* (Taylor 2015). Hornworms are most often parasitized by the wasp, *Cotesia congregata* (Say), and wasp cocoons are readily visible on the back of fourth or fifth instar caterpillars.

Stop rate was also compared between fields. Observations were recorded for three stop frequencies, approximately 2.47 stops/ha, 4.94 stops/ha, and 9.88 stops/ha (low, recommended,

and high, respectively; 1stop/ac, 2stops/ac, and 4stops/ac). The number of stops for the smallest and largest fields were adjusted to capture a practical range of observations (Table 2.1). For fields that were 2 acres or less, our high rate actually resulted in the recommended rate for fields of this size. Therefore, the high and low rate were kept the same but the middle rate was shifted to 3 stops per acre rather than 2 stops per acre. For the two 14 acre fields, the low rate resulted in the recommended rate so we shifted the low rate to less than 1 stop/acre and kept the medium rate at 1stop/acre to match recommendations.

The low stop rate treatment compared a subsample for the random path, from the first stop until 2.47 stops/ha rate was reached. The middle rate included all observations from the random path, and the high rate consisted of all stops made within a field from both paths. If more than twice the middle rate of stops was necessary to reach the high rate number of stops, then additional stops were made along a random path to reach the high rate. We recorded the time required to complete scouting for the medium stop rate to determine scouting speed per stop between the two paths.

Statistical Analysis.

Data were analyzed using SAS v. 9.3 (SAS Institute, Cary NC). Insect observations were standardized by dividing insect counts, or infested plants, by total observations (pest/plant). Caterpillar parasitism rates were standardized by dividing the number of parasitized individuals observed by the total number of budworms or hornworms observed (Parasitized/Total). Scouting time was standardized by dividing the scouting time by the number of scouts and the number of stops (time/person/stop). Insect densities were compared by week, field, and either path or stop rate while scouting time was compared by week, field, and path only. Site was considered a

random effect, and field treatment (GS and IPM) was considered a fixed effect. All insect data were log transformed and subjected to repeated measures analysis of variance (ANOVA) via the MIXED procedure. Scouting time was subjected to repeated measures ANOVA via the MIXED procedure, without transformation. All means were separated using the Tukey-Kramer adjustment.

Results

Scouting Path.

There were no significant differences between paths for any insect observations; flea beetles ($F=0.03$; $df=1,315$; $P=0.85$), budworms ($F=0.8$; $df=1,235$; $P=0.37$), parasitized budworms ($F=0.05$; $df=1,235$; $P=0.82$), hornworms ($F=0.07$; $df=1,235$; $P=0.79$), parasitized hornworms ($F=0$; $df=1,235$; $P=0.97$), or stiltbugs ($F=0.22$; $df=1,355$; $P=0.64$) (Table 2.2).

There were also no differences between the GS and IPM field treatments for flea beetles ($F=0$; $df=1,315$; $P=0.96$), budworms ($F=0.02$; $df=1,235$; $P=0.89$), parasitized budworms ($F=0.18$; $df=1,235$; $P=0.67$), or hornworms ($F=1.16$; $df=1,235$; $P=0.28$). However, the rate of parasitized hornworms was higher in IPM fields ($F=4.42$; $df=1,235$; $P=0.04$), and there were more stilt bugs in IPM fields ($F=20.45$; $df=1,355$; $P<0.0001$).

The density of flea beetles ($F=27.5$; $df=15,315$; $P<0.0001$), budworms ($F=7.83$; $df=11,235$; $P<0.0001$), parasitized budworms ($F=3.11$; $df=11,235$; $P=0.0006$), hornworms ($F=2.27$; $df=11,235$; $P=0.012$), and stilt bugs ($F=3.57$; $df=16,355$; $P<0.0001$) increased over time, but parasitized hornworms ($F=1.59$; $df=11,235$; $P=0.10$) did not.

It took scouts longer to move along strip scouting paths than random paths ($F=82.96$; $df=1,252$; $P<0.0001$). Scouting time also varied among weeks ($F=4.12$; $df=12,252$; $P<0.0001$), but did not differ between GS and IPM fields ($F=1.48$; $df=1,252$; $P=0.22$). (Figure 2.4; Table 2.3).

There were significant interactions between field and week for parasitized hornworms ($F=1.91$; $df=11,235$; $P=.04$) and stilt bugs ($F=2.08$; $df=16,355$; $P=0.009$). Further analysis showed that the rate of hornworm parasitism varied over time but was generally similar between IPM and GS fields within any given week (Figure 2.1). There were more stilt bugs per plant in IPM fields during week 16 ($t=-4.37$; $df=355$; $P=0.0073$) but there were no statistical differences between fields for any other week (Figure 2.2). There were no other significant interactions between independent variables.

Stop Rate.

There were no significant differences among stop rates for flea beetles ($F=0.4$; $df=2,475$; $P=0.67$), budworms ($F=0.25$; $df=2,355$; $P=0.78$), hornworms ($F=0.22$; $df=2,355$; $P=0.81$), or parasitized hornworms ($F=1.09$; $df=2,355$; $P=0.34$). There were differences for parasitized budworms ($F=3.62$; $df=2,355$; $P=0.03$), with the lower stop rate underestimating the rate of observable budworm parasitism by *C. sonorensis* as compared to the recommended and high stop rate, which did not differ from each other (Table 2.4).

There were no differences between the GS and IPM fields for any insect observations; flea beetles ($F=0.22$; $df=1,475$; $P=0.64$), budworms ($F=0.29$; $df=1,355$; $P=0.59$), parasitized budworms ($F=0.24$; $df=1,355$; $P=0.63$), hornworms ($F=1.88$; $df=1,355$; $P=0.17$), or parasitized hornworms ($F=1.66$; $df=1,355$; $P=0.20$).

The density of insects observed, flea beetles ($F=44.21$; $df=15,475$; $P<.0001$), budworms ($F=14.18$; $df=11,355$; $P<.0001$), parasitized budworms ($F=5.26$; $df=11,355$; $P<.0001$), hornworms ($F=3.57$; $df=11,355$; $P<.0001$), and parasitized hornworms ($F=2.29$; $df=11,355$; $P=0.01$), increased over time.

There was a field by week interaction for budworms ($F=1.99$; $df=11,355$; $P=0.03$) and parasitized hornworms ($F=3.56$; $df=11,355$; $P<.0001$), but not for any other insects. Further analysis showed that there was a higher rate of hornworm parasitism in IPM fields during week 15 ($t=-4.45$; $df=355$; $P=0.0027$) but there were no statistical differences between fields for any other week (Figure 2.1). Budworm populations varied over time but were similar between IPM and GS fields within any given week (Figure 2.3). There were no field by stop rate, stop rate by week, or field by stop rate by week interactions for any observations.

Discussion

We did not detect differences in pest populations between our evaluated scouting paths, but the strip path required more time than the current recommendation (Table 2.3). As plants grow and the process of crossing rows becomes difficult, the strip path may become more practical (Figure 2.4). As most economic damage occurs post-topping, and this may be the point at which altered scouting methodology from current recommendations may provide the greatest benefit. Tobacco remains a labor intensive crop, and some standard practices, including topping or sucker management, require workers to proceed down entire rows. If scouting could be incorporated into these activities, the strip-scouting path may become more practical.

Estimated flea beetle, budworm, and hornworm densities were similar across all stop rates. Although not significantly different, the low rate tended to overestimate populations while the high rate tended to underestimate, relative to current recommendations (Table 2.4). Flea beetle populations remained well below the ET and would not have warranted treatment in any fields we scouted at any stop rate. The rate of parasitism for both hornworms and budworms determined from the standard stop rate was between both high and low rates.

Our results suggest that few changes to management decisions would have been made based on pest densities obtained from varying stop rates. The low stop rate estimated budworms at ET during week 10 in GS fields, but both the medium and high stop rate were below ET. In this case the low stop rate would have prematurely triggered an insecticidal application relative to current recommendations. All three stop rates estimated budworms at ET during week 9 in IPM fields. No stop rate detected hornworms at ET in GS fields; however, in IPM fields the low and medium rates estimated hornworms at ET while the high rate estimated a slightly lower population density just below ET. In this case the high stop rate would not have warranted insecticidal application relative to current recommendations during that week. These results suggest that all rates result in similar management decisions in most weeks, but that lower stop rates may result in slightly more conservative recommendations.

The rate of hornworm parasitism was higher in IPM fields later in the season but parasitism was observed in GS fields earlier (Figure 2.1). Stilt bug populations were similar between IPM and GS fields early in the season, but after week 11, IPM fields had more stilt bugs per plant. Many insecticidal applications are made around this time and it is possible that mid-season treatment with broad-spectrum insecticides used in several GS fields had an effect on stilt

bug populations for the remainder of the season (Figure 2.2). Budworm infestations were similar between field treatments, but the field by week interaction suggests that insecticidal applications made in GS fields before pests had reached ET resulted in slower population growth; however, both treatments still approached ET densities around the same time (Figure 2.3). While hornworm parasitism was detected sooner in GS fields, the rate of parasitism was higher in IPM fields throughout the remainder of the season. However, the rate of parasitism was statistically higher only in IPM fields during week 15 (Figure 2.1).

Scouting and the use of ETs are fundamental components of IPM (Stern et al. 1959). To encourage adoption, IPM recommendations need to be accurate and easily incorporated into current production practices (Way and van Emden 2000). Our results demonstrate that manipulating some aspects of current scouting recommendations may not compromise the effectiveness of pest management decision-making. Reducing scouting labor may result in even greater economic benefits from the use of these IPM tools because this would reduce costs associated with scouting. Different stages of plant phenology may require variable stop frequencies or different paths to encompass pest dispersal behavior and scouting labor constraints. Future studies should continue to measure the efficacy of ETs at different stages of plant phenology and evaluate yield loss associated with pest damage to ensure that current ETs are not too conservative.

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TABLES

Table 2.1 Field site location, size, and stop number for low, recommended, and high treatments.

Site	County	Grower Standard (GS)				IPM			
		Field size (ha)	Stop number			Field size (ha)	Stop number		
			Low	Medium (Rec.)	High		Low	Medium (Rec.)	High
1	Johnston	1.7	4	10	16	1.7	4	10	16
2	Johnston	5.7	12	14	56	5.7	12	14	56
3	Wilson	2.4	6	10	24	2.0	5	10	20
4	Oxford	1.8	4	10	16	.61	2	6	8
5	Surry	1.6	4	10	16	1.6	4	10	16
6	Stokes	1.6	5	10	18	.81	2	6	8

Table 2.2 Mean insect densities for field treatment and scouting path¹

Pest observations	-----Field-----		-----Scouting Path----	
	IPM	GS	Random	Strip
Flea Beetle (insects/plant)	0.50	0.50	0.51	0.50
Budworm (% BW infested plants)	3.1%	3.2%	3.5%	2.7%
Para Budworm (PBW/BW+PBW)	6.5%	7.4%	6.8%	7.2%
Hornworm (insects/plant)	0.030	0.022	0.027	0.025
Para Hornworm (PHW/HW+PHW) ²	-	-	2.3%	2.2%
Stilt bug (insects/plant) ²	-	-	0.044	0.048

¹Values within a row are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

²Field by week interaction

Table 2.3 Mean scouting time for field treatment and scouting path over the entire scouting period.

Scouting labor	-----Field¹-----		-----Scouting Path¹----	
	IPM	GS	Random	Strip
Scout time (minutes/person/stop)	2.51 a	2.42 a	2.14 a	2.78 b

¹ Values followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

Table 2.4 Mean insect densities for field treatment and stop frequency

Pest Observations	-----Field-----		-----Stop Frequency¹-----		
	IPM	GS	Low Stops	Med Stops	High Stops
Flea Beetle	0.53	0.51	0.54 a	0.51 a	0.50 a
Budworm ²	-	-	2.6% a	2.5% a	2.2% a
Para Budworm	2.9%	5.3%	2.8% a	6.8% ab	7.7% b
Hornworm	0.032	0.024	0.031 a	0.027 a	0.026 a
Para Hornworm ²	-	-	1.2% a	2.3% a	3.0% a

¹ Values within a row followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

²Field by week interaction

FIGURES

Figure 2.1 Average rate of hornworm parasitism between fields based on data collected from different paths (A) and stop rates (B). Values within circles are significantly different via pairwise comparisons using a Tukey-Kramer adjustment ($\alpha = 0.05$).

Figure 2.2 Average number of stilt bugs per plant from both paths between fields over time. Values within circles are significantly different via pairwise comparisons using a Tukey-Kramer adjustment ($\alpha = 0.05$).

Figure 2.3 Average budworm infestation across all stop rates between fields over time.

Figure 2.4 Average scouting time (min/person/stop) between sampling paths over time.

CHAPTER 3

Slone and Burrack: Management of key
Tobacco pests using economic thresholds

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Using economic thresholds for foliar feeding pests in flue cured tobacco (*Nicotiana tabacum*) to reduce insecticide applications and residues

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Abstract

Insecticide treatments are most efficient when timed to the occurrence of economically damaging insect populations. Integrated pest management (IPM) guidelines, including economic thresholds (ETs), are available for key pests in North Carolina (NC) flue cured tobacco. Growers who do not make management decisions based on ETs may be making unnecessary insecticide applications that reduce profits and may result in higher pesticide residues on cured leaf. During 2013 and 2014, we compared the number of chemical applications necessary to maintain foliar feeding caterpillar pests below threshold for a range of foliar insecticides, including chlorantraniliprole, flubendiamide, lambda-cyhalothrin, and spinosad, in field plots at two eastern NC agricultural research stations. During 2013, one to two sprays on average were necessary to control budworms, and one or fewer sprays were necessary to control hornworms. During 2014, two insecticides, chlorantraniliprole and flubendiamide, were applied based on ETs or on a predetermined schedule. Scheduled applications were applied at the maximum label rate, while the threshold applications were made at the lowest rate. Threshold applications were less frequent, less insecticide was used in these plots, and treatments did not differ in yield. Pesticide residues were lower in threshold treatments when differences were detected.

Keywords: Tobacco, integrated pest management, economic threshold, *Heliothis virescens*, *Manduca Sexta*

Reduced insecticidal management intensity associated with IPM recommendations has been shown to control pest populations without compromising yield in many crops (Birtal et al. 2000, Bueno et al. 2013, Kim and Yun 2013). Treating for insect pests at economic thresholds (ETs) minimizes input costs while maintaining yield (Horn 1988), but regular field scouting and plant inspection is required to determine if a pest reaches ET (Binns and Nyrop 1992). Grower surveys suggest that many growers may not be making management decisions based on the use of scouting and ETs (Slone, Chapter 1; Appendices C,D). Treating a field before a pest reaches the ET is economically unnecessary and may increase input costs without a corresponding increase in yield (Bueno et al. 2013, Kim and Yun 2013, Allen 2015). Unnecessary or poorly timed chemical applications can also result in the need for additional applications to control pest populations over time (Elzen et al. 1992, Bueno et al. 2013).

The timings of pest attack, and of management decisions, are linked to plant phenology (Kolodny-Hirsch and Harrison 1982). Yield loss from feeding by a given pest population is reduced as the plants get larger, and some crop varieties are able to fully compensate for moderate injury (Lawson et al. 1961, Juba et al. 2007). Insecticidal applications can be timed to maximize control efficacy while limiting input efforts and costs. Thresholds roughly based on plant phenology are already in place for key pests of tobacco including tobacco budworms (*Heliothis virescens* (F.)), tobacco and tomato hornworms (*Manduca sexta* (L.) and *M. quinquemaculata* (Haworth), respectively). Tobacco budworms feed within the growing bud and are protected by the young, unexpanded leaves before topping (Lampert 1987). Budworm feeding typically causes holes in the foliage but can sometimes result in the destruction of the apical meristem and premature topping of the plant (Burrack 2015). Hornworms are most

common post-topping and can defoliate plants if left uncontrolled (Lawson et al. 1961, Mcfadden 1968). Most tobacco foliage damage occurs when caterpillar pests reach the fourth or fifth instar (Lawson et al. 1961). Given the high levels of natural mortality for budworm and hornworm larvae, it is possible that a grower could observe caterpillars in the field but never observe significant damage or large enough larvae to warrant an insecticidal application (Lawson 1961, Mcfadden 1968).

A total of about 14 insecticides, which vary in effectiveness, are currently registered for foliar pest control in US grown tobacco (Burrack 2015). We conducted a series of experiments to evaluate inputs and risks associated with currently available ETs for the key foliage-feeding tobacco pests, budworms and hornworms, at two NC agricultural research stations during 2013 and 2014. In these experiments, we compared the number of applications necessary to manage key tobacco pests along with varying rates of registered insecticides, and measured end of season pesticide residues. We determined that ETs have the potential to both reduce the number of foliar insecticide applications and pesticide residues in flue cured tobacco.

Materials and Methods

2013 field trials.

Replicated, small plot experiments were conducted at the Upper Coastal Plains Research Station (UCPRS: Rocky Mount, NC) and the Lower Coastal Plains Research Station (LCPRS: Kinston, NC). Greenhouse grown tobacco seedlings (variety NC196) were treated with a tray

drench treatment of imidacloprid (0.6 fl oz/1000 plants Admire Pro, Bayer CropSciences) within five days prior to transplant and then planted in plots consisted of four, ca. 25 plant, rows (0.0073 ha). Plants are treated with tray drench insecticides while in greenhouse float trays and subsequently watered lightly to allow the material to reach the soil media before being transplanted within several days. Rows and plants were spaced approximately 0.91 and 0.56 meters apart, respectively. Each treatment (Table 3.1) was replicated four times and arranged in a randomized complete block design. Plants were transplanted at Kinston and Rocky Mount on 24 April and 29 April 2013 respectively. Plants were topped at Kinston and Rocky Mount on 25 June and 22 July 2013 respectively. Standard fertility and cultural practices for NC tobacco were followed at both research stations.

The middle two rows of each plot were observed weekly for tobacco budworm beginning three weeks after transplant and continuing through topping, while hornworms were observed weekly from topping until the end of the experiment. Insecticide treatments were applied when insect densities reach current ETs, which are 10% infested tobacco budworm plants or 1, 2.54 cm (1 inch) or longer hornworm per 10 plants. We recorded the number of insecticide applications per plot necessary to maintain foliage-feeding pests below ET throughout the season. At Kinston, transplant water treatments (TPW) were applied in furrow in ca. 643.5 liters (170 gals) per acre of water using four, 18.9 liter (5 gals) mini-tanks affixed to the planter. At Rocky Mount, TPW treatments were applied similarly but in ca. 567.8 liters (150 gals) per acre of water. Foliar applications targeting budworms at Kinston were applied using a CO₂ pressurized backpack sprayer fitted with a single flat-fan nozzle with 140 liters/ha (37 gals/ha) spray volume at 45 psi

pressure. Foliar applications at Rocky Mount were applied with the same backpack sprayer but with a T2 solid-cone with 140 liters/ha (37 gals/ha) at 60 psi pressure.

Rocky Mount “A” and “B” stalk positions were harvested for residue analysis on 16 August 2013, and “C” and “D” stalk positions were harvested on 25 August 2013. Stalk position corresponds to where the leaves are on the stalk and the order of multiple harvesting events, such that earlier harvests of the lowest leaves comprise the “A” and “B” positions. Pesticide residues were recorded from leaf samples from plots treated with flubendiamide (Belt, Bayer CropSciences). Pesticide residues were analyzed by Global Labs (Wilson, NC) using gas chromatography/mass spectrometry (GC/MS) performed on ground and homogenized, cured leaf samples.

2014 field trials.

Replicated, small plot experiments were conducted similarly to the 2013 protocol. Plants (Variety NC196) were transplanted at Kinston and Rocky Mount on 8 May, 2014 and 5 May, 2014 respectively. Plants were topped on at Kinston and Rocky Mount on 15 July, 2014 and 29 July, 2014 respectively. Kinston “A” stalk position leaves were harvested on 15 August, 2014, while “B” and “C” positions were harvested on 11 September, 2014. Rocky Mount “A” stalk position leaves were harvested on 19 August, 2014, “B” on 2 September, 2014, and “C” and “D” on 22 September, 2014. Cured leaf weights were obtained for yield comparisons.

Insecticide treatments were applied to threshold plots after infestation exceeded the ET for either tobacco budworms or hornworms. Scheduled treatments were predetermined using the maximum label rate allowed within the season, with at least one treatment each targeting

budworms and hornworms. Scheduled hornworm treatments were applied as close to harvest as the labeled pre-harvest interval allowed. All foliar treatments targeting budworms were applied using a CO₂ powered backpack sprayer fitted with a T2 solid-cone nozzle with a 140 liters/ha (37 gals/ha) spray volume at 52 psi. Hornworm treatments were made with the same backpack sprayer but with a T3 solid-cone nozzle at 280 liters/ha (74 gals/ha) and 65 psi.

Statistical analyses.

Data were analyzed in SAS v9.3 (SAS Institute, Cary NC). Budworm larvae, hornworm larvae, and parasitized hornworm observations are reported as the proportion of plants infested with at least one budworm, the number of observed hornworms per plant, and the proportion of parasitized larvae, respectively. All insect observation data were log transformed and subjected to repeated measures analysis of variance (ANOVA) via the MIXED procedure. Pesticide residue and yield data were subjected to ANOVA via the MIXED procedure, and degrees of freedom were calculated using the Satterthwaite adjustment if needed to correct for heteroskedasticity (2013 data, Rocky Mount yield 2014, and Rocky Mount chlorantraniliprole 2014). Degrees of freedom were calculated using the Satterthwaite adjustment for all budworm analyses and for Rocky Mount parasitized hornworm analysis in 2013 and for Kinston budworm analysis in 2014. Sites within a year were analyzed separately and explanatory variables included treatment, date, and the interaction of treatment and date; replication nested within treatment was considered random. Means were separated via pairwise comparisons using the Tukey-Kramer adjustment.

Results

Insect observations, 2013.

Budworm infestation at Rocky Mount differed significantly between treatments ($F=2.94$; $df=8,162$; $P=0.0043$), week ($F=67.80$; $df=5,162$; $P<0.0001$), and the interaction of treatment by week ($F=2.05$; $df=40,162$; $P=0.0010$). All plots at Rocky Mount receiving foliar treatments were treated at least once for budworms (Table 3.2), which resulted in lower pest densities relative to the control, but some materials were more efficacious than others. Foliar treatments targeting hornworms were necessary in less than half of the Blackhawk and Belt treatments, and no other plots exceeded ET (Table 3.3). Post-insecticidal application, hornworm density in those plots was reduced below the ET and the control treatment. Hornworms densities differed between treatments ($F=3.99$; $df=8,27$; $P=0.0031$) and week ($F=10.34$; $df=1,27$; $P=0.0034$). Rates of hornworm parasitism differed between treatments ($F=7.49$; $df=8,54$; $P<0.0001$) (Tables 3.2, 3.3).

Budworm infestations at Kinston differed significantly between treatments ($F=9.63$; $df=6,21$; $P<0.0001$), week ($F=34.44$; $df=4,84$; $P<0.0001$), and the interaction of treatment by week ($F=7.67$; $df=24,84$; $P<0.0001$) (Table 3.4). All plots at Kinston received one or fewer foliar chemical applications to control budworms (Table 3.4); Plots at Kinston did not reach ET for budworms until plants were flowering. IPM guidelines do not recommend treatment when plants are close to topping, but treatments were applied to measure efficacy. Tobacco budworm populations did not exceed threshold in flubendiamide (Belt) plots at Kinston during 2013, and no treatments were made so that in the event that chemical applications were necessary to control hornworms, threshold based applications could be made and the resultant residue data could still

be collected. Hornworm pressure was particularly low at Kinston and no plots exceeded ET during our study in 2013.

Pesticide residues, 2013.

Leaf samples from each priming at Rocky Mounty were analyzed for flubendiamide residues. Residues did not differ among primings ($F=1.75$; $df=2,18$; $P=0.2013$), but increased with higher application frequency and rate ($F=15.69$; $df=1,18$; $P=0.0009$) (Table 3.5).

Insect observations, 2014.

The average number of insecticide applications per treatment and average application rates differed between treatments (Table 3.11), but in general, budworm and hornworm pressure was low requiring one or fewer foliar applications, on average, to reduce pest density below ET (Tables 3.6, 3.7, 3.8). Budworm infestations varied significantly between treatments ($F=15.59$; $df=5,18$; $P<0.0001$), week ($F=12.66$; $df=5,90$; $P<0.0001$), and the interaction of treatment by week ($F=3.72$; $df=25,90$; $P<0.0001$) at Rocky Mount. Hornworm infestation differed significantly by treatment ($F=14.64$; $df=5,18$; $P<0.0001$), week ($F=51.34$; $df=4,72$; $P<0.0001$), and the interaction of treatment by week ($F=9.67$; $df=20,72$; $P<0.0001$). Hornworm parasitism rates significantly differed by treatment ($F=15.93$; $df=5,18$; $P<0.0001$), and the interaction of treatment by week ($F=3.61$; $df=20,72$; $P<0.0001$) but not week ($F=1.60$; $df=4,72$; $P=0.18$) (Tables 3.6, 3.7, 3.8).

An unusually prolonged moth flight during a time of rapid plant growth resulted in heavy budworm pressure at Kinston in 2014. As a result, an average of two applications of both

“Threshold” treatments were necessary to lower budworms below the ET (Table 3.9). Budworm infestation at Kinston differed by treatment ($F=32.71$; $df=5,18$; $P<0.0001$), week ($F=427.97$; $df=5,90$; $P<0.0001$), and the interaction of treatment by week ($F=16.74$; $df=25,90$; $P<0.0001$). The single, high-rate spray for budworms in the “schedule chlorantraniliprole” (Coragen) treatment was insufficient to lower infestation below ET. Hornworm pressure was low at Kinston and only two “threshold” plots were treated during the study (Table 3.10). Hornworm infestation was significantly different between treatments ($F=2.91$; $df=5,18$; $P=0.0426$) and week ($F=5.88$; $df=3,54$; $P=0.0015$), but not for the interaction of treatment by week ($F=1.68$; $df=15,54$; $P=0.0833$). Hornworm parasitism rates at Kinston were too low to analyze (Tables 3.9, 3.10).

Yield and pesticide residue, 2014.

Yield differed among treatments ($F=3.95$; $df=5,18$; $P=0.0135$) and yield per priming decreased over multiple primings ($F=95.34$; $df=3,53$; $P<0.0001$) at Rocky Mount. Yields from the first two primings were similar, but were greater than from both subsequent primings. The control treatment yielded less than “threshold chlorantraniliprole,” but there were no other differences among treatments. At Kinston, yield did not differ between treatments ($F=2.50$; $df=5,18$; $P=0.0694$), but decreased over multiple primings ($F=488.27$; $df=2,36$; $P<0.0001$) (Table 3.12).

Pesticide residues for 2014 experiments were analyzed from the first priming only, when residues were likely to be highest (Vann et al. 2008). Flubendiamide residues differed between treatments and the control at Rocky Mount ($F=5.93$; $df=2,9$; $P=0.0227$). Flubendiamide applied at threshold produced similar residue levels as the scheduled application treatment and the

control but the scheduled treatment was higher than the control. Chlorantraniliprole residues differed between treatments and the control ($F=8.89$; $df=2,9$; $P=0.0074$). Residues in the scheduled treatment were similar to the threshold treatment, and both were higher than the control (Figure 3.1).

Kinston flubendiamide residues differed among treatments and the control ($F=34.20$; $df=2,9$; $P<0.0001$). Threshold and scheduled treatments were similar, and both were higher than the control. Threshold chlorantraniliprole treatments had higher residues than the control, and scheduled treatments had higher residues than both threshold and control treatments ($F=45.54$; $df=2,9$; $P<0.0001$) (Figure 3.1).

Discussion

Tobacco growers report making an average of over three foliar insecticide applications during the growing season, including preventative treatments (Slone, Chapter 1; Appendices C and D). ETs for key tobacco pests were developed over 40 years ago (Mistic 1972, Reagan 1976) and they may need revision to accommodate modern production practices and their influence on pest population dynamics (Castle and Naranjo 2009). If pest-specific, yield-loss relationships can be established in tobacco, they may provide the information necessary to adjust ETs based on the cost of insecticidal management and the crop value in a given year (Chasen et al. 2015). Nonetheless, our results suggest that even these potentially dated ETs may allow growers to reduce insecticide applications without impacting yield.

For both sites in 2013, less than one insecticide application, of any material, was sufficient to control tobacco budworms, and on average, less than one application was necessary for hornworms due to low hornworm pressure. The timing of insecticide application in tobacco can have a dramatic effect on efficacy (Mcfadden 1968, Johnson 1979, Semtner 1984). Budworms are generally protected from pesticides by their feeding niche within the tender leaves in the bud (Lampert 1987). Newest growth is also not exposed to previous insecticide applications, so preventive treatments relying on pesticide persistence for control are not advised.

Fewer insecticide applications will also likely translate to a reduction in end of season pesticide residues. Residue analysis from 2013 suggests that slightly higher rates and increased frequency of application can result in greater pesticides residues on cured leaf.

Chlorantraniliprole residues were lower in threshold plots compared to scheduled plots at Kinston in 2014 (Figure 3.1). Threshold plots received a lower rate of insecticide but the same number of applications as the scheduled treatment. No other differences were detected between threshold and scheduled treatment pesticide residues in 2014. The scheduled chlorantraniliprole application at Rocky Mount produced lower residues than the same treatment at Kinston, which would suggest that environmental conditions affected pesticide residue. Residues are often higher on the lower stalk tobacco leaves as those leaves are the first harvested and pesticides are somewhat protected from environmental degradation by the upper leaves (Vann et al. 2008).

Differences in insecticide applications in the 2014 experiments did not compromise yield (Tables 3.11, 3.12). Using the maximum labelled rate or either insecticide did not improve budworm or hornworm control, and our results suggest that fewer than two insecticidal applications may be necessary on average to provide season long control of lepidopteran pests.

The variability we observed in pest pressure among years resulted in some pests never reaching ET, resulting in one or fewer insecticidal applications for the entire season. Treating for caterpillar pests at ET may reduce the average number of sprays and may lower residues on cured leaf.

Overall, our results demonstrate that current ETs can be used to reduce foliar insecticide applications in tobacco targeting budworms and hornworms, applications made at the lowest labeled rate are sufficient to reduce population densities below ET, and pesticide residues may be reduced when the number of insecticide applications and application rates are reduced. All of these practices have the potential to provide meaningful cost savings for growers, but these results need to be replicated in farm-scale production systems to quantify these potential benefits. Economic validation of IPM practices may help align grower practices with IPM recommendations.

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TABLES

Table 3.1 Insecticide active ingredient, application rate and method, and year studied

Treatment (A.I.; rate per ha)	Application Method	Year
Admire Pro only (imidacloprid; 0.72 ml/ha)	Greenhouse tray drench	2013
Belt (flubendiamide; 23.9 ml/ha)	Foliar	2013
Belt (flubendiamide; 35.9 ml/ha)	Foliar	2013
Besiege (chlorantraniliprole & lambda-cyhalothrin; 107.7 ml/ha)	Foliar	2013
Blackhawk (spinosad; 18.0 ml/ha)	Foliar	2013
Blackhawk (spinosad; 23.9 ml/ha)	Foliar	2013
Coragen (chlorantraniliprole; 59.8 ml/ha)	Foliar	2013
Prevathon (chlorantraniliprole; 239.4 ml/ha)	Transplant Water(TPW)	2013
Prevathon (chlorantraniliprole; 239.4 ml/ha)	TPW, Foliar	2013
Untreated Control (UTC)	n/a	2014
Admire Pro only (imidacloprid; 0.72 ml/ha)	Greenhouse tray drench	2104
Belt (flubendiamide; 23.9 ml/ha)	Foliar	2014
Belt (flubendiamide; 35.9 ml/ha)	Foliar	2014
Coragen (chlorantraniliprole; 59.8 ml/ha)	Foliar	2014
Coragen (chlorantraniliprole; 89.8 ml/ha)	Foliar	2014

Table 3.2 Mean tobacco budworm applications and infestation, Rocky Mount 2013

Treatment	Application method	Rate ml/ha	Mean TBW-applications per plot	Proportion TBW infested plants ¹				
				11 June	17 June	24 June ²	2 July ²	11 July
Untreated	--	--	0	0.00 a	0.02 a	0.07 a	0.53 a	0.64 a
Prevathon	TPW	239.4 ml/ha	0	0.00 a	0.00 a	0.07 a	0.57 a	0.65 a
Prevathon	TPW + foliar	239.4 ml/ha	1	0.01 a	0.01 a	0.08 a	0.35 a	0.10 b
Belt	Foliar	35.9 ml/ha	1.25	0.01 a	0.00 a	0.05 a	0.29 a	0.17 b
Belt	Foliar	23.9 ml/ha	1	0.02 a	0.02 a	0.04 a	0.57 a	0.11 b
Besiege	Foliar	107.7 ml/ha	1	0.01 a	0.01 a	0.08 a	0.33 a	0.24 ab
Blackhawk	Foliar	18.0 ml/ha	1	0.01 a	0.03 a	0.08 a	0.31 a	0.34 ab
Blackhawk	Foliar	23.9 ml/ha	1	0.02 a	0.01 a	0.08 a	0.38 a	0.17 b
Coragen	Foliar	59.8 ml/ha	1	0.01 a	0.01 a	0.10 a	0.31 a	0.18 b

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

² Date of foliar TBW-targeting treatment applications.

Table 3.3 Mean hornworm applications and infestation, Rocky Mount 2013

Product	Application method	Rate ml/ha	Mean HW-applications per plot	Proportion HW infested plants ¹			
				31 July ²	9 Aug	Total HW	Total PHW
Untreated	--	--	0	0.08 a	0.08 a	0.08 a	0.05 a
Prevathon	TPW	239.4 ml/ha	0	0.06 a	0.02 a	0.04 ab	0.00 c
Prevathon	TPW + foliar	239.4 ml/ha	0	0.01 a	0.00 a	0.00 b	0.00 c
Belt	Foliar	35.9 ml/ha	0.25	0.05 a	0.00 a	0.02 ab	0.00 c
Belt	Foliar	23.9 ml/ha	0	0.01 a	0.00 a	0.00 b	0.00 c
Besiege	Foliar	107.7 ml/ha	0	0.01 a	0.00 a	0.01 b	0.00 c
Blackhawk	Foliar	18.0 ml/ha	0.25	0.09 a	0.01 a	0.05 ab	0.01 bc
Blackhawk	Foliar	23.9 ml/ha	0.5	0.10 a	0.02 a	0.06 ab	0.03 ab
Coragen	Foliar	59.8 ml/ha	0	0.00 a	0.00 a	0.00b	0.00 c

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

² Date of foliar HW-targeting treatment applications.

Table 3.4 Mean tobacco budworm applications and infestation, Kinston 2013

Product	Application method	Rate ml/ha	Mean TBW-applications per Plot	Proportion TBW infested plants ¹				
				30 Apr	5 June	13 June	20 June ²	27 June
Untreated	--	--	0	0.10 a	0.02 a	0.05 a	0.17 a	0.32 a
Prevathon	TPW	239.4 ml/ha	0	0.03 a	0.02 a	0.02 a	0.04 b	0.17 b
Prevathon	TPW + foliar	239.4 ml/ha	0.25	0.01 a	0.01 a	0.01 a	0.07 ab	0.11 bc
Besiege	Foliar	107.7 ml/ha	1	0.04 a	0.02 a	0.05 a	0.14 ab	0.01 c
Blackhawk	Foliar	18.0 ml/ha	1	0.04 a	0.03 a	0.04 a	0.16 a	0.00 c
Blackhawk	Foliar	23.9 ml/ha	0.75	0.04 a	0.01 a	0.01 a	0.10 ab	0.04 c
Coragen	Foliar	59.8 ml/ha	0.75	0.08 a	0.03 a	0.02 a	0.15 ab	0.02 c

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

² Date of foliar TBW-targeting treatment applications.

Table 3.5 Pesticide residues and application frequency, Rocky Mount 2013

Treatment	Average applications/plot	Flubendiamide residues (ppm)			
		“A” priming	“B” priming	“C” priming	Average ¹
Belt (3.0 fl oz)	1.5	9.40	12.6	7.27	9.74 a
Belt (2.0 fl oz)	1.0	2.47	4.61	2.57	3.22 b

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

Table 3.6 Mean tobacco budworm applications and infestation, Rocky Mount 2014

Product	Mean TBW applications per plot	Mean ml/ha applied	Proportion TBW infested plants ¹					
			17 June ²	25 June ²	1 July ²	9 July	14 July	22 July
No insecticide	0	0	0.01 a	0.07 ab	0.12 a	0.13 ab	0.06 a	0.02 a
Admire Pro only (no foliar)	0	0	0.02 a	0.16 a	0.15 a	0.16 a	0.06 a	0.01 a
Threshold Coragen (5.0 fl oz)	0.5	29.9	0.02 a	0.07 ab	0.08 ab	0.05 bc	0.03 a	0.04 a
Schedule Coragen (7.5 fl oz)	1	89.8	0.02 a	0.01 b	0.01 b	0.03 bc	0.02 a	0.02 a
Threshold Belt (2.0 fl oz)	0.75	18.0	0.03 a	0.13 a	0.06 ab	0.06 bc	0.02 a	0.02 a
Schedule Belt (3.0 fl oz)	2	71.8	0.04 a	0.01 b	0.00 b	0.01 c	0.01 a	0.01 a

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

² Date of foliar TBW-targeting treatment applications.

Table 3.7 Mean hornworm applications and infestation, Rocky Mount 2014

Product	Mean HW applications per plot	Mean ml/ha applied	Proportion HW infested plants ¹				
			7 Aug ²	15 Aug ²	22 Aug	27 Aug	4 Sept
No insecticide	0	0	0.54 a	0.50 a	0.30 a	0.05 a	0.02 a
Admire Pro only (no foliar)	0	0	0.35 ab	0.42 a	0.13 a	0.03 a	0.02 a
Threshold Coragen (5.0 fl oz)	1	59.8	0.18 bc	0.00 b	0.00 b	0.00 a	0.00 a
Schedule Coragen (7.5 fl oz)	1	89.8	0.14 bc	0.13 b	0.01 b	0.00 a	0.00 a
Threshold Belt (2.0 fl oz)	0.75	118.0	0.04 c	0.02 b	0.00 b	0.00 a	0.01 a
Schedule Belt (3.0 fl oz)	1	35.9	0.00 c	0.00 b	0.00 b	0.00 a	0.00 a

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

² Date of foliar HW-targeting treatment applications; not included on graph July 30, 2014 spray date for Belt (Threshold).

Table 3.8 Mean hornworm parasitism, Rocky Mount 2014

Treatment	Proportion HW parasitism¹				
	7 Aug	15 Aug	22 Aug	27 Aug	4 Sept
No insecticide	0.14 a	0.20 a	0.32 a	0.35 a	0.10 a
Admire Pro only (no foliar)	0.10 a	0.14 ab	0.21 a	0.17 b	0.04 ab
Threshold Coragen (5.0 fl oz)	0.074 a	0.005 b	0.00 b	0.00 c	0.00 b
Schedule Coragen (7.5 fl oz)	0.04 a	0.056 ab	0.00 b	0.00 c	0.00 b
Threshold Belt (2.0 fl oz)	0.01 a	0.023 b	0.00 b	0.017 bc	0.0057 ab
Schedule Belt (3.0 fl oz)	0.00 a	0.00 b	0.00 b	0.00 c	0.00 b

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

Table 3.9 Mean tobacco budworm applications and infestation, Kinston 2014

Product	Mean TBW applications per plot	Mean ml/ha applied	Proportion TBW infested plants ¹			
			18 June ²	24 June ²	2 July	7 July
No insecticide	0	0	0.64 a	0.77 a	0.43 ab	0.28 a
Admire Pro only (no foliar)	0	0	0.69 a	0.78 a	0.53 a	0.29 a
Threshold Coragen (5.0 fl oz)	2	119.7	0.66 a	0.19 b	0.03 c	0.01 b
Schedule Coragen (7.5 fl oz)	1	89.8	0.68 a	0.19 b	25 b	0.27 a
Threshold Belt (2.0 fl oz)	2	47.9	0.75 a	0.28 b	0.05 c	0.08 b
Schedule Belt (3.0 fl oz)	2	71.8	0.68 a	0.31 b	0.05 c	0.03 b

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

² Date of foliar TBW-targeting treatment applications.

Table 3.10 Mean hornworm applications and infestation, Kinston 2014

Product	Mean HW applications per plot	Mean ml/ha applied	Proportion HW infested plants ¹			
			29 July ²	8 Aug ²	14 Aug	20 Aug
No insecticide	0	0	0.07 a	0.11 a	0.16 a	0.02 a
Admire Pro only (no foliar)	0	0	0.08 a	0.17 a	0.13 a	0.03 a
Threshold Coragen (5.0 fl oz)	0	0	0.01 a	0.01 a	0.00 a	0.00 a
Schedule Coragen (7.5 fl oz)	1	89.8	0.09 a	0.04 a	0.09 a	0.01 a
Threshold Belt (2.0 fl oz)	0.5	12.0	0.10 a	0.05 a	0.03 a	0.00 a
Schedule Belt (3.0 fl oz)	1	35.9	0.07 a	0.00 a	0.00 a	0.00 a

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha=0.05$).

² Date of foliar HW-targeting treatment applications.

Table 3.11 Foliar insecticide applications on average per plot, 2014

Treatment	UCPRS (Rocky Mount)		LCPRS (Kinston)	
	Average applications	Average ml/ha applied	Average applications	Average ml/ha applied
No insecticide	0	0	0	0
Admire Pro only (no foliar)	0	0	0	0
Threshold Coragen (5.0 fl oz)	1.5	89.8	2	119.7
Schedule Coragen (7.5 fl oz)	2	179.5	2	179.5
Threshold Belt (2.0 fl oz)	1.5	35.9	2.5	59.8
Schedule Belt (3.0 fl oz)	3	107.7	3	107.7

Table 3.12 Mean yield (g) per plant, 2014

Treatment	Rocky Mount					Kinston			
	Priming ²					Priming ²			
	(A) a	(B) a	(C) b	(D) c	Average yield ¹	(A) a	(B) b	(C) c	Average Yield ¹
No insecticide	47.5	52.3	35.4	24.1	39.9 a	33.6	11.5	6.96	17.3 a
Admire Pro only (no foliar)	48.7	53.2	35.3	26.1	40.8 ab	33.2	7.81	7.20	16.1 a
Threshold Coragen (5.0 fl oz)	54.6	59.9	49.6	41.5	51.4 b	47.5	24.7	15.0	29.1 a
Schedule Coragen (7.5 fl oz)	56.1	56.8	48.5	34.5	49.0 ab	43.2	19.3	14.0	25.5 a
Threshold Belt (2.0 fl oz)	49.7	50.4	44.1	35.8	45.0 ab	43.2	17.6	15.2	25.3 a
Schedule Belt (3.0 fl oz)	43.2	47.7	40.5	29.8	40.3 ab	48.5	21.8	16.4	28.9 a

¹ Values within a column followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

² Priming position values within a row followed by the same lowercase letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

FIGURES

Figure 3.1 Pesticide residues (ppm), Kinston (A) and Rocky Mount (B) 2014. Values within chemical treatment followed by the same letter are not significantly different via pairwise comparisons with Tukey-Kramer adjustment ($\alpha = 0.05$).

APPENDICES

APPENDIX A

2015 Tobacco Integrated Pest Management Survey

The purpose of this survey is to collect grower options on integrated pest management (IPM) practices and recommendations in flue cured tobacco. Participation in this survey is voluntary, and all responses are anonymous. If you would like more information about this survey or about IPM, please contact Hannah Burrack (ph: 919.513.4344, hjburrac@ncsu.edu). Thank you for your participation!

How old are you?

☐ 18-25 ☐ 26-35 ☐ 36-45 ☐ 46-55 ☐ 56-65 ☐ 66+

Ethnicity:

☐ White ☐ Hispanic/Latino ☐ Asian ☐ Black/ African American
☐ Native American ☐ Other/Decline to respond

Gender:

☐ Male ☐ Female ☐ Decline to respond

How many years have you grown tobacco?

☐ 1-5 ☐ 6-10 ☐ 11-20 ☐ 21+ (specify)

Which county is the majority of the land you farm located? If you are not located in North Carolina, please also specify your state. _____

How many acres total (all crops) do you farm?

_____ Acres

How many acres of tobacco (on average) do you grow each year?

_____ Acres

How do you determine when to apply insecticides to tobacco?

- ☐ When Plants reach a certain age/size
- ☐ Based on farm/field history
- ☐ Scouting reports
- ☐ Other. Please specify: _____

If you scout for insects in tobacco, which practices do you use? Check all that apply.

- ☐ I inspect plants throughout my fields weekly. If so, how many plants? _____
- ☐ I inspect plants throughout my fields less than once per week.
If so, how frequently? _____ If so, how many plants? _____
- ☐ I scout "hot spots" or areas of damage when I see them
- ☐ I drive my fields regularly. If so, how frequently? _____
- ☐ I pay a crop consultant to scout my fields. If so, how frequently? _____
- ☐ I do not scout for insects
- ☐ Other. Please specify: _____

If you do not scout for insects, why not? Check all that apply.

- ☐ Too expensive
- ☐ Too time consuming
- ☐ Happy with insect control without scouting
- ☐ Other. Please specify: _____

Do you have sufficient equipment to apply all pesticide needs in a timely manner to all fields? (Rather, are your fields centrally located such that you can apply all insecticides in 3-4 days?)

- ☐ Yes
- ☐ No
- ☐ Somewhat. Please specify:_____

How do you currently access IPM information resources? Check all that apply.

- ☐ Print resources (GAP notebook, Tobacco field guide, etc)
- ☐ Internet/ Extension Webpages
- ☐ Handheld device/ phone
- ☐ Word of mouth/ other growers
- ☐ County agents
- ☐ Crop consultants
- ☐ Pesticide dealers
- ☐ Other. Please specify:_____

Do you plan on continuing to grow tobacco for at least the next 5 years?

- ☐ Yes
- ☐ No
- ☐ Undecided. Please specify:_____

Is there anything else you would like to share about your insect management practices or about insect management recommendations?

Thank you for your time!

APPENDIX B

2016 Tobacco Integrated Pest Management Survey

The purpose of this survey is to collect grower opinions on integrated pest management (IPM) practices and recommendations in flue cured tobacco. Participation in this survey is voluntary, and all responses are anonymous. If you would like more information about this survey or about IPM, please contact Hannah Burrack (ph: 919.513.4344, hjburrac@ncsu.edu). Thank you for your participation!

Age:

☐ 18-25 ☐ 25-35 ☐ 35-45 ☐ 45-55 ☐ 55-65 ☐ 65+

Ethnicity:

☐ White ☐ Hispanic/Latino ☐ Asian ☐ Black/African American ☐ Native American
☐ Other/Decline

Gender:

☐ Male ☐ Female ☐ Decline to respond

How many years have you grown tobacco?

☐ 1-5 ☐ 5-10 ☐ 10-20 ☐ 20+ (please specify: _____)

Which county is the majority of the land you farm located? If not in NC, please specify state. _____

How many acres total (all crops) do you farm?

_____ Acres

How many acres of tobacco (on average) do you grow each year?

_____ Acres

What best describes your farm?

- ☐ I own all the land I farm
- ☐ I own some and rent some of the land I farm
- ☐ I rent all the land I farm
- ☐ Other

Do you plan on continuing to grow tobacco for at least the next 5 years?

- ☐ Yes
- ☐ No
- ☐ Undecided. Please specify: _____

How do you determine when to apply insecticides to tobacco in the field?

- ☐ When plants reach a certain age/size
- ☐ Based on farm/field history
- ☐ When insects are observed in fields
- ☐ Only when insects exceed economic thresholds (ETs)
- ☐ Other. Please specify: _____

If you scout for insects in tobacco, which practices do you use? Check all that apply.

- ☐ I inspect plants throughout my fields weekly. (If so, how many plants? _____)
- ☐ I inspect plants throughout my fields less than once per week.
(If so, how frequently? _____ How many plants? _____)
- ☐ I scout "hot spots" or areas of damage when I see them
- ☐ I drive my fields regularly. (If so, how frequently? _____)
- ☐ I pay a crop consultant to scout my fields. (If so, how frequently? _____)
- ☐ I do not scout for insects
- ☐ Other. Please specify: _____

Please indicate your level of agreement with the following statements:

Scouting is too expensive	<i>Strongly agree</i>	<i>Agree</i>	<i>Neither agree nor disagree</i>	<i>Disagree</i>	<i>Strongly disagree</i>
Scouting is too time consuming	<i>Strongly agree</i>	<i>Agree</i>	<i>Neither agree nor disagree</i>	<i>Disagree</i>	<i>Strongly disagree</i>
I do not need to scout to get acceptable insect control	<i>Strongly agree</i>	<i>Agree</i>	<i>Neither agree nor disagree</i>	<i>Disagree</i>	<i>Strongly disagree</i>
I will have lower yields if I make fewer insecticide applications	<i>Strongly agree</i>	<i>Agree</i>	<i>Neither agree nor disagree</i>	<i>Disagree</i>	<i>Strongly disagree</i>
Integrated pest management (IPM) takes too much effort	<i>Strongly agree</i>	<i>Agree</i>	<i>Neither agree nor disagree</i>	<i>Disagree</i>	<i>Strongly disagree</i>
The advantages of IPM outweigh the disadvantages	<i>Strongly agree</i>	<i>Agree</i>	<i>Neither agree nor disagree</i>	<i>Disagree</i>	<i>Strongly disagree</i>

Please rate your level of knowledge and interest in IPM:

Compared to other growers, my <u>knowledge</u> of IPM is...	<i>Much higher</i>	<i>Higher</i>	<i>About the same</i>	<i>Lower</i>	<i>Much lower</i>
Compared to other growers, my <u>interest</u> in IPM is...	<i>Much higher</i>	<i>Higher</i>	<i>About the same</i>	<i>Lower</i>	<i>Much lower</i>

How many insecticide applications did you make in 2015:

Greenhouse/ At transplant: _____

Pre topping: _____

Post topping: _____

Do you have sufficient equipment to apply pesticides in a timely manner to all fields?
(Rather, are your fields centrally located so that you can apply insecticides to all of them in 3-4 days?)

- ☐ Yes
- ☐ No
- ☐ Somewhat. Please specify: _____

How do you currently access IPM information resources? (*Check all that apply*)

- ☐ Print resources (GAP notebooks, Tobacco field guide, etc.)
- ☐ Internet/Extension Webpages
- ☐ Handheld device/phone
- ☐ Word of mouth/Other growers
- ☐ County agents. *If used, how many times per season?* _____
- ☐ Crop consultants. *If used, how many times per season?* _____
- ☐ Pesticide dealers. *If used, how many times per season?* _____
- ☐ Other. Please specify: _____

Is there anything else you would like to share about your insect management practices or about insect management recommendations?

Thank you for your time!

APPENDIX C

2015 Survey summary:

989 surveys were collected from a total of 1932 GAP registrants. Over 93% of responding growers reported Caucasian ethnicity and over 95% reported being male. The average acreage farmed was 877 total acres and 141 tobacco acres per grower.

Over 82% reported the intention to continue growing tobacco for at least five more years, and over 90% reported having the necessary equipment to conduct chemical applications in all fields within several days.

When asked how growers determine when to apply pesticides:

Based on plant age or size, **17.9% agreed**; Based on farm and field history, **12.8% agreed**; Based on scouting reports, **91.1% agreed**; and for methods non-mentioned, **4.5% agreed**.

When asked about scouting practices specifically, growers selected all that applied of the following:

For growers who report scouting weekly, an average of 57 plants were inspected. Growers who report scouting less than weekly scout on average once every two weeks and inspect on average 39 plants. Of the growers who report driving fields, 63% do so daily or weekly. Only 1.75% reported they do not scout at all, and nearly 88% of those that don't scout feel as

though they are happy with their insect control without scouting. Just over 8% of growers report the use of a crop consultant, but it was not specified if those are hired professionals or a family members.

When asked for sources of IPM information, growers selected all that applied of the following:

APPENDIX D

2016 Survey summary:

508 surveys were collected from a total of 1619 GAP registrants. An additional 189 growers attended two meetings where we did not collect surveys. Over 97% of responding growers reported Caucasian ethnicity and over 96% reported being male. The average acreage farmed was 2175 total acres and 331 tobacco acres per grower.

Over 79% reported the intention to continue growing tobacco for at least five more years, and over 87% reported having the necessary equipment to conduct chemical applications in all fields within several days.

When asked how growers determine when to apply pesticides:

Based on plant age or size, **10.2% agreed**; Based on farm and field history, **7.8% agreed**; Based on scouting reports, **50.9% agreed**; Based on economic thresholds, **50.7% agreed**; and for methods non-mentioned, **4.8% agreed**.

When asked about scouting practices specifically, growers selected all that applied of the following:

For growers who report scouting weekly, an average of 63 plants were inspected. Growers who report scouting less than weekly scout on average once every two weeks and inspect on average 52 plants. Of the growers who report driving fields, 52% do

so daily or weekly. Only 0.2% reported they do not scout at all and 7% of growers report the use of a crop consultant, but it was not specified if those are hired professionals or a family members.

When asked about the ownership of the land being farmed for tobacco, growers reported:

Nearly 3% own the land they farm, while 7% only rent, and nearly 87% say they both rent and own some of the land. Another 3% reported other arrangements that were not specified.

When asked how many insecticidal applications were made at different points during the growing season, growers reported the following:

Greenhouse: 375 respondents; average of 1.25 applications

0 times: 12% **1-2 times:** 81% **3-4 times:** 5% **5+ times:** 2%

Pre-topping: 414 respondents; average of 1.52 applications

0 times: 3% **1-2 times:** 88% **3-4 times:** 8% **5+ times:** 1%

Post-topping: 389 respondents; average of 1.64 applications

0 times: 7% **1-2 times:** 80% **3-4 times:** 12% **5+ times:** 1%

Growers were asked about the level of agreement with the following statements:

Scouting is too expensive:

Agree: 8% **Neutral:** 28% **Disagree:** 64%

Scouting is too time consuming:

Agree: 13% **Neutral:** 19% **Disagree:** 68%

Scouting is not necessary to get adequate control:

Agree: 9% **Neutral:** 11% **Disagree:** 80%

Lower yields due to fewer insecticide applications:

Agree: 24% **Neutral:** 28% **Disagree:** 48%

IPM takes too much effort:

Agree: 7% **Neutral:** 28% **Disagree:** 65%

IPM advantages outweigh disadvantages:

Agree: 68% **Neutral:** 23% **Disagree:** 9%

Growers were asked to rate themselves relative to other growers for the following:

My IPM knowledge is:

Higher: 21% Similar: 76% Lower: 3%

My IPM interest is:

Higher: 26% Similar: 72% Lower: 2%

When asked for sources of IPM information, growers selected all that applied of the following:

When asked how many how many times growers contacted the following persons during the growing season, they reported the following:

Extension agents: 57 respondents; average of 3.2 times

1-4 times: 81% 5-8 times: 12% 9+ times: 7%

Crop consultants: 21 respondents; average of 4.5 times

1-4 times: 72% 5-8 times: 14% 9+ times: 14%

Pesticide dealers: 51 respondents; average of 3.5 times

1-4 times: 74% 5-8 times: 20% 9+ times: 6%