ABSTRACT

BRILL, NANCY LEE. Effects of grower management practices and field characteristics on insect damage to sweetpotato (*Ipomoea batatas* (L. Lam.) roots. (Under the direction of Jonathan R. Schultheis).

On-farm research studies were conducted with North Carolina sweetpotato growers to determine relationships between grower management practices and field characteristics with insect damage to sweetpotato roots. Injury by wireworm, *Diabrotica* spp., and *Systena* spp. (WDS) complex, sweetpotato flea beetle, white grubs, and whitefringed beetle was categorized by the incidence of roots injured by those species and the severity of injury on damaged roots. Severity was determined by measuring the length of sweetpotato flea beetle tunneling, the number of WDS holes and the diameter of WDS holes. The incidence of the overall insect damage, or injury by any species, was also obtained. Field locations for these projects served as replications.

<u>Questionnaire</u>

In 2002 and 2003, sixteen sweetpotato growers provided twenty-six field locations where roots were sampled, graded, and assessed for insect damage. Growers responded to a questionnaire about these field locations. The cultural practices, tillage practices, and pesticides used by growers, as well as the weeds, soil drainage class, and rainfall amounts in those fields, were related to the insect damage on the sampled roots.

Approximately 25% of North Carolina's planted sweetpotato acreage was represented by the project conducted in 2002 and 2003. Whitefringed beetle and white grubs caused the least amount of insect damage, 3.0% and 4.6%, respectively. Sweetpotato flea beetle damage averaged 18%, while the most damage, 29%, was caused by WDS. The cultural practices, pesticides used, and tillage practices varied

considerably among the 26 field locations used for the questionnaire, indicating that, due to the high amount (average of 43%) of overall insect damage, current management practices used by sweetpotato growers are ineffective for controlling injury to sweetpotato roots by soil-borne insects.

Growers who rotated sweetpotato crops with cotton, delayed the planting and harvest time, subsoiled their fields, and cultivated more than 3 times during the growing season had higher amounts of insect damaged roots from their fields. Overall insect damage on roots from fields in which chlorpyrifos was used was high, about 30%, even though that amount was less than the incidence of damaged roots from fields where chlorpyrifos was not applied (75%). If growers used herbicides they had less WDS damaged roots, although the use of the EPTC herbicide resulted in more grub and whitefringed beetle damage. Roots from poorly drained soils had more WDS damage than roots from well drained soils. Rainfall was positively correlated to the amount of sweetpotato flea beetle damaged roots.

Time of planting and harvest study.

In 2003 and 2004, six sweetpotato growers provided thirteen field locations where sweetpotatoes were planted early (on or before 28 May) and late (after 16 June). Roots were sampled in each of the fields at approximately 90, 105, and 120 days after each planting time, graded, and scored for insect damage. Yield was also obtained.

An early planting and early harvest resulted in the least amount of sweetpotato flea beetle and grub damage, 16% and 1.7%, respectively, although grub damage was also low (1.7%) with a late planting and late harvest time. However, if growers planted late, sweetpotato flea beetle and overall insect damage was high (approximately 45 to

50%) regardless of when roots were harvested. The diameter of WDS holes was larger on roots harvested later in the growing season. The highest yield of number one grade roots, 21 t/ha, was obtained with a late harvest (120 DAP). These results suggest that growers will need to balance decisions between potential losses in yield, or more insect damaged roots, depending on the time that sweetpotatoes are planted and harvested.

EFFECTS OF GROWER MANAGEMENT PRACTICES AND FIELD CHARACTERISTICS ON INSECT DAMAGE TO SWEETPOTATO (*Ipomoea batatas* (L.) Lam.) ROOTS

by
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For Sharon

PERSONAL BIOGRAPHY

Nancy L. Brill was born in New Jersey, but lived in New York and Massachusetts during her childhood. She later returned to her home state as a teenager, where she attended high school and then Cook College of Rutgers University. After earning a Bachelor of Science degree in Natural Resource Management with Honors, she decided to attend graduate school in order to develop a career in agriculture. Her passion for farming began at a young age with a desire to work outside. Having no background in agriculture, she began working at a local farm market as a cashier in high school. Eventually she worked in the greenhouses and then later had her ideal job of working in the fields. Aspirations of furthering her career in agriculture led her to North Carolina State University. While attending graduate school, she had a beautiful baby girl who is an inspiration to fulfilling Nancy's personal dream of owning her own farm someday.

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Jones Farms
McPherson Farm
Millstream Farms
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Chapter 1

Introduction

North Carolina ranks first in the United States in sweetpotato production accounting for about 40% of national production and generating $79 million annually in farm gate value (NCDA & CS, 2003). 'Beauregard' is the principal sweetpotato cultivar grown by North Carolina growers because of its high yields, preference in commercial markets, and early harvest date (Schultheis et al., 1999), and it is also the primary cultivar grown in the United States (M. Cannon and Z. Pesic-VanEsbroeck, personal communication). Despite these advantages, 'Beauregard', released by the Louisiana Agricultural Experiment Station in 1987, is susceptible to damage by most soil insects (Rolston et al., 1987; Sorensen and Holmes, 2002). Each year growers lose a portion of their sweetpotatoes to insect damage and incur significant costs managing insects and weeds (Adams and Riley, 1997; Bridges and Bauman, 1992).

Economically important insect species that affect the quality of sweetpotato roots in North Carolina include wireworm (*Conoderus falli, C. vespertinus, C. amplicollis, C. lividus, C. bellus, Melanotus communis, and Glyphonyx* spp.) /*Diabrotica balteata, Diabrotica undecimpunctata* / *Systena blanda* complex, or WDS, sweetpotato flea beetle larvae (*Chaetocnema confinis*), white grubs (*Strigoderma arboricola*, *Cotinis nitida*, *Popillia japonica*), and whitefringed beetle larvae (*Graphognathus* spp.) (Baker and Sorensen, 1994). Larvae of the soil-borne insects feed on and damage the developing sweetpotato storage roots. Because they live in the soil, it is especially challenging to sample and control the larval stages. Recommendations for controlling insect damage include using soil applied insecticides to control larvae and foliar applied insecticides to control adults, avoiding fields known to have a history of infestation, and rotating crops (USDA 1999; Wilson et al. 1989)

In a 1996 survey of North Carolina sweetpotato growers, 66% of respondents used insecticides to manage insects, particularly wireworms, white grubs, whitefringed beetle larvae, and flea beetle larvae and adults (Toth et al. 1997). Integrated Pest Management (IPM) was considered a good pest control practice by 93% of respondents even though only 56% claimed they practiced IPM mostly by walking fields to scout for insects or using sweetpotato weevil pheromone traps. A few respondents listed the use of soil seed baits and light traps as well as keeping records of scouting information to monitor the need and timing of foliar insecticide applications. The majority of growers used chemical control (Toth et al. 1997). Although synthetic insecticides are the principle tools used by North Carolina sweetpotato growers to manage insect damage to sweetpotatoes, they are often ineffective.

In addition to the problem of ineffective or unreliable control using currently registered products, new chemical product registrations are difficult to obtain because sweetpotato is considered a minor crop. A key insecticide, chlorpyrifos, is currently used extensively by sweetpotato growers and is targeted by the Food Quality Protection Act (FQPA) of 1996 as high priority for restricted or cancellation in the near future (Curtis Consulting, 2003). Insect damage to sweetpotato roots reduces root quality and causes significant economic loss because insecticides for sweetpotatoes are limited and often ineffective.

Besides the use of chemicals, few growers practice IPM because a program is not well developed for the sweetpotato industry. One example of IPM development was the creation of an action threshold for the Oriental beetle, which caused severe economic losses to sweetpotato growers in southern Maryland (Myers et al., 1997). However, there is little development of action thresholds for soil borne insects that damage sweetpotatoes. This research was part of the on-going development of an IPM program in the sweetpotato industry. Objectives of this research were: 1.) to gather information on cultural practices used by North Carolina growers in sweetpotato production through the use of a questionnaire, 2.) to obtain information about growers' sweetpotato fields, 3.) to evaluate insect damage on roots sampled from the surveyed fields, 4) to determine effects of planting date and harvest date on yield and insect damage to roots, and 5.) to determine the marketability or non-marketability of different amounts and severity of insect damage caused by the sweetpotato flea beetle and WDS complex.

Chapter 2 is a description of the questionnaire as well as the on-farm methods used to harvest roots from each growers' field. Chapter 2 also reports the incidence of fields in which certain mangement practices were used and summarizes the incidence of roots damaged by different insects. Chapter 3 is a more in-depth analysis of the questionnaire. Correlations were made between insect damage and the management practices of growers or the conditions in growers' fields from which roots were sampled for insect damage assessment. Chapter 4 describes the methods and reports the results for an experiment involving the effects of planting and harvest time on yield and insect damage to sweetpotato roots.

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Chapter 2

Questionnaire of Sweetpotato Grower Practices, Field Characteristics and Injury to Roots by Soil Insects

ABSTRACT

Sixteen sweetpotato growers responded to a questionnaire conducted in 2002 and 2003 to gather information on cultural practices and 26 field sites in North Carolina. Roots were sampled from those 26 fields and examined for insect damage. Specific information was obtained regarding crop rotations, row spacing, planting dates, subsoiling, bedding, cultivating, pesticide use, soils, weeds, and surrounding vegetation. Management practices and field conditions varied among growers. Insect damage ranged from 7.2% to 100%.

INTRODUCTION

Growers, processors, researchers, and extension personnel collaborated during 2001 to identify knowledge gaps in sweetpotato production and determined that more information and research are needed in order to understand interactions between weeds, insects, and other production factors that cause insect damage to roots (Curtis Consulting, 2003). On-farm surveys and research are practical approaches to address these issues. Surveys and questionnaires are valuable methods for identifying potentially important relationships involving pest problems and production practices that can help define hypotheses that can subsequently be tested experimentally. Such surveys are also valuable in raising grower awareness of specific production or pest management issues as well as their interest in obtaining information related to this issue.

On-farm scientific projects connect to the needs of farmers and also allow farmers to plan and participate in the projects (Ehrenfeld, 1993). In Kansas, a survey was used to show that farmers are supportive of on-farm research, whether it was conducted by themselves or in cooperation with others, and that the Extension Service can ultimately help coordinate efforts and/or share results (Norman et al., 1997). The primary objective of our questionnaire was to develop a project that actively included county agents, researchers and growers in characterizing some of the factors likely to be related to sweetpotato root damage caused by insects.

MATERIALS AND METHODS

A questionnaire was conducted in 2002 and 2003 to gather information on cultural practices and field sites designated for sweetpotato production by North Carolina growers. Sixteen growers located in seven counties in North Carolina provided information specific to a total of 26 fields from which roots were harvested. Specific goals of the survey and field sampling included:

1.) Identify pesticides used and the number of applications, rate, and dates of application.
2.) Identify cultural practices used by NC sweetpotato growers such as: crops planted in each field during the previous two years, row spacing, planting date, subsoiling, depth of subsoiling, timing of bedding, re-shaping of beds, the number of cultivations, and the timing of cultivations.
3.) Characterize sweetpotato field production in terms of: surrounding vegetation, soil series, soil texture, and soil drainage class.
4.) Identify the density and diversity of weeds in sweetpotato production fields.

Questionnaire. Each grower was asked to respond to the following questions in 2002 and/or 2003.

1.) What is the number of acres of sweetpotatoes planted in the field sampled?
2.) What other crops are grown next to your sweetpotato fields? Name crops and direction from sweetpotato field (North, South, East, West) (Table 1; Appendix B).
3.) What crops were grown in this same field in 2000/2001 and 2001/2002 (include winter cover crops)?

4.) How much rainfall did you receive on your farm in 2002/2003?

5.) Did you irrigate?

6.) When did you plant the sweetpotato field in 2002/2003?

7.) What was the row spacing of your beds in 2002/2003?

8.) What type of beds did you use for growing sweetpotato slips? (e.g. plastic greenhouses/enclosed structures, field beds, etc.)

9.) Did you subsoil your sweetpotato fields in 2002/2003? If so, how deep?

10.) How many days/weeks prior to transplanting did you bed your fields?

11.) Did you rework your beds prior to transplanting? If so, how many times?

12.) How many times did you cultivate during the growing season?

13.) When did you cultivate during the growing season?

14.) List all herbicides and all insecticides applied as well as their rate of application and dates, or number of applications.

Establishment of field sites and measurement of weeds. In 2002, twelve growers provided information on a total of 15 field locations. Ten sites were established randomly within each field, with the exception of a few sites that were specifically chosen because they were weedy or varied in topography. Each site was two rows by 15.2 m (50 ft.). Twenty-five randomly selected roots were harvested from each site for a total of 250 roots harvested from each field location. Global Positioning System (GPS) waypoints were taken from the center of each site with a Garmin “etrex Venture” (Part Number 190-00203-00 Rev. C, Garmin International Inc., Olathe, Kansas) unit so that soil series, texture and drainage could be obtained from the Soil Survey Geographic (SSURGO) Database of the Natural Resource Conservation Service (NRCS).

Weed populations and species present in the sites were obtained in 2002 by counting each weed species within a 3.05 m (10 ft) radius in every direction from the center of each sample site; such an area extended past the rows from which roots were harvested. One exception to counting weeds in 2002 was with location 15, which had an extremely high population of yellow nutsedge. Because of the high population, nutsedge plants were counted within a 32.0 cm^2 (1.05 ft^2) metal frame randomly placed in each site. Three such counts were made in each site for location 15. An average of the three counts was made to obtain a number of nutsedge plants within one 32 cm^2 area, which was then multiplied by the total area of the site to obtain a total number of nutsedge plants per site for location 15.

In 2003, eight growers provided a total of 11 field locations. Ten sample sites were designated within each field as described above. Growers were asked to provide fields with high pigweed (*Amaranthus dubius*) and yellow nutsedge (*Cyperus esculentus*) infestations. Fields were selected such that five fields contained yellow nutsedge and six fields contained pigweed. Within each field, five sites were weed-free and five sites were chosen based on high weed populations (approximately one weed per square foot). Twenty-five roots were harvested from 4.57 m (15 ft) of row in each site for a total of 250 roots harvested from each field location. A GPS reading was obtained from the middle of each site in each field (10 total) so that soil information such as series, drainage, and texture could be obtained through SSURGO.

In 2003, every pigweed was counted within the site but nutsedge populations were measured by counting the nutsedge plants within a 30.5 cm^2 (1 ft^2) metal frame randomly placed within the site. Two such counts were made in each site. An average of the two counts was made to obtain a number of nutsedge plants within one square-foot area, which was then multiplied by the total area of the site to obtain a total number of nutsedge plants per site. Weeds were counted differently in 2003 in order to avoid counting weeds outside of the area from which roots were sampled, which occurred in 2002 as described above. All weed counts were conducted in late July and August of both years.

When the actual numbers of yellow nutsedge plants at location 15 and the five locations in 2003 were calculated based on the area sampled in 2003, they were much higher than the numbers of yellow nutsedge plants in the other locations. Therefore, numbers of nutsedge plants were transformed to $\log_n$ prior to subjecting the data to linear regression analysis (PROC REG). The logged values are reported in Table 1.

Twenty-five number one grade roots (USDA, 1981) were harvested from each of 10 sites per field (total of 250 roots per field) in both years using a one-row digger or hand dug. In 2002, each of the 10 harvest sites per field consisted of two rows, each 15.2 m (50 ft) long; in 2003, each harvest site within a field consisted of one row 4.57 m (15 ft) long. A total of 6500 roots were obtained and evaluated for insect damage over the years. Roots were placed in labeled paper bags and stored in wooden crates. The roots were cured and held under normal storage conditions until they were scored for insect damage.

Categorization of insect damage on sweetpotato roots. Sweetpotato roots were scored for damage by wireworm, *Diabrotica* spp., and *Systena* spp. (WDS) complex, which included the following species: *Conoderus falli, C. vespertinus, C. amplicollis, C. lividus, C. bellus, Melanotus communis,* and *Glyphonyx* spp. *Diabrotica balteata, Diabrotica* *undecimpunctata*, and *Systena blanda*. Roots were also scored for damage by the naturally occurring populations of sweetpotato flea beetle larvae (*Chaetocnema confinis*), white grubs (*Strigoderma arboricola*, *Cotinis nitida*, *Popillia japonica*), and whitefringed beetle larvae (*Graphognathus* spp.). Classifying damage by *Diabrotica* spp., *Systena* spp. and wireworms into a single category designated as WDS complex has been done in previous studies because damage by those species is difficult to differentiate (Day, 1978; Jones et al. 1979). Day (1978) tested insecticides and methods of application to control wireworm, white grub, and several beetle larvae and found that as the incidence of roots with injury increased, the severity of injury to individual roots also increased. The author also noted that it would have been possible to find greater differences between treatments if the scars on each root were counted, thus suggesting that an additional method for scoring insect damage on roots would have benefited the study. Therefore, in these studies, root damage was rated in two ways: 1) The number and incidence of roots damaged by white grubs, flea beetle, whitefringed beetle, WDS and overall insect damage in samples of 25 roots per site. 2) The severity of damage by flea beetle and WDS.

The number of roots with injury by sweetpotato flea beetle, WDS, white grubs, or whitefringed beetle was divided by the total number of roots sampled at each site (n = 25) to obtain an overall incidence of roots damaged by insects. Severity was measured in two ways: 1) The number of WDS holes was counted, totaled and divided by the number of roots with WDS damage to obtain an average number of holes per root damaged by WDS. 2) Sweetpotato flea beetle feeding scars on each damaged root were measured in centimeters, and the lengths for each root were totaled and divided by the number of roots with sweetpotato flea beetle damage to obtain an average sweetpotato flea beetle feeding scar length.

Measurement and identification of insect damage on sweetpotato roots. In 2003 and 2004 the diameter of WDS holes was also measured. A template ruler of circles ranging from 1.59 mm to 47.6 mm was used to measure the diameter (Part Number 977-110, Staedtler, INC., Chatsworth, California. In cases where the WDS holes were not perfectly circular, smaller increments of diameter measurements were taken with the smallest circles on the ruler and those numbers were added to obtain a total diameter of the irregular holes. The flea beetle tunneling was measured in centimeters with string or rulers made from index cards to allow for flexibility in measuring the scars that were not in straight lines.

Visual guides were used to differentiate the insect damage (Sorensen and Holmes, 2002). White grubs damaged roots by causing wide, tunnel-like gouges on the surface of the roots (Zehnder, 1998; Figure 1). Whitefringed beetles also damaged roots by creating tunnels, but the cavities were not as deep or wide as white grub damage. Sweetpotato flea beetle damage consisted of narrow, smooth tunnels close to the surface of the skin and often not in a straight line (Figure 2), while the tunneling caused by whitefringed beetle was wider and had smooth grooves on the edges of the cavities (Figure 3). Sweetpotato flea beetle and whitefringed beetle damage was differentiated from mechanical damage caused by the harvester, which created a straight line with no grooves on the surface of the roots.

WDS damage was distinguished from water lesions or lenticels, which were often raised bumps on roots as opposed to holes incurred from damage by the WDS complex of species. In many instances, roots with very deep WDS holes were connected to shallow, smooth cavities just under the skin (Figure 4a), which is most likely a result of early season damage by *Systena* sp. (Hofmaster and Savage 1978). Those shallow cavities were not included when measuring the diameter of holes. More typical WDS damage encountered on roots during the assessment for insect damage is shown in Figure 4b. The scoring of insect damage was completed about mid-March in 2002 and 2003 and early November in 2004.

Extension Agents coordinated with researchers to assist with harvesting and obtaining growers' contact information, consent for on-farm projects, and answers to the survey questionnaire. In addition to the field locations, growers provided the sweetpotato plants, fertilizers, pesticides and all management practices that required their own equipment and employees. Growers and extension agents were present and assisted during many of the harvests to aid in the collection of samples and data. The design of the project was not completely random because the subsampling areas, or sites, were chosen specifically for weediness or other factors like variation in topography, e.g. changes in slope of the land. The field characteristics, grower practices and incidence of damaged roots are presented below.

QUESTIONNAIRE RESULTS

Cultural Practices. Each grower and field location had its own unique characteristics and combination of production practices (Table 2). However, there were several common production practices across field locations. For example, various combinations of cotton, tobacco or soybeans comprised the primary crop rotations in 2000, 2001, and 2002. Other crops included in some rotations were watermelon, corn, greens, sweetpotato, pumpkins, and cowpeas. The sweetpotato field for one grower was never planted with a crop in previous years so the crop rotation was designated as “no crop planted.”

Planting dates ranged from 12 May until the end of July (Table 2). The optimum time for harvesting ‘Beauregard’ is reported to be 100 to 110 days after transplanting under non-stressful growing conditions (Schultheis et al, 1999), however, only 10 of the 26 fields were harvested at or before 110 days after transplanting and one field was harvested 147 days after transplanting. The average number of days roots were in the field was 119 (SE 15.7 days). A total of three fields were irrigated in 2002; no fields were irrigated in 2003.

The spacing between rows ranged from 96.5 to 121.9 cm (38 to 48 inches), with 102 cm (40 inches) as the most frequent spacing (Table 2). Sweetpotato slips for all sweetpotato field locations were obtained from field beds in the spring of 2002 and 2003, except location 15, where slips were obtained from greenhouses. In location 1, the grower reported using both greenhouses and field beds for planting stock. One grower used black plastic and high tunnel greenhouses to cover his field beds.

The production fields were subsoiled in the spring of 2002 and 2003 in 58% of the fields. The depth of subsoiling ranged from 15.2 cm (six inches) to 61.0 cm (24 inches). The time before transplanting that fields were bedded ranged from two days to 30 days and 54% of the fields were bedded at least two weeks prior to transplanting. Beds were reworked one time in 46% of the fields prior to transplanting.

All growers reported that cultivation began one to two weeks after transplanting (Table 2). Three cultivations were made 46% of the time, which was the most frequent number of times fields were cultivated during the growing season. The frequency of the three cultivations ranged from weekly to once every two to three weeks. Fields that were cultivated four, five, or six times were done weekly or no more than two weeks between cultivation. Fields that were cultivated two times were spread two to three weeks apart. Additional methods of weed control reported by growers included hand weeding and mowing.

Field Conditions. Soil texture and drainage varied within field sites and between field locations (Table 3). The primary textures were loamy sand and sandy loam. The most common soil drainage class was well drained. Although growers were asked to report rainfall amounts during the May to October growing season, not all growers recorded the amount of rainfall on their farms. As a result, rainfall is reported according to measurements obtained by the State Climate Office of North Carolina at the weather station closest to the field from which roots were harvested.

Relative to other weeds, yellow nutsedge was the most dense in growers' fields in 2002 and 2003 according to the actual numbers. Pigweed was present at the next highest density in both 2002 and 2003 (Table 1). All other weed species were less frequently found among sites in 2002 and at much lower populations than pigweed or yellow nutsedge. The density of other weeds was less in 2003 compared to 2002 because the establishment of sample sites within fields in 2003 was based on the presence of pigweed and yellow nutsedge in order to avoid areas with other weeds, if possible.

Pesticide Use. Eighty four percent of the growers reported the use of chlorpyrifos, but application times varied (Table 2; Appendix A). Some growers applied chlorpyrifos several weeks before transplanting sweetpotatoes, while others applied chlorpyrifos only a few days before transplanting. All growers who used chlorpyrifos applied it only one time. The most commonly used insecticides were chlorpyrifos, a preplant chemical used to control sweetpotato flea beetle and wireworm larvae; endosulfan, used to control adult, foliar-feeding insects; and phosmet which is a foliar spray used to control sweetpotato flea beetle and wireworm adults and other adult, foliar-feeding insects (Table 4). Imidacloprid, applied in transplant water to control flea beetles, was used at only one location, which had 38% total insect damage, but only 12% damage by sweetpotato flea beetle. The most common insecticides used by growers in sweetpotato fields throughout the growing season were chlorpyrifos, endosulfan and phosmet.

The most common herbicides used were clomazone and EPTC to control annual grasses and broadleaf weeds (Table 3; Appendix A). Other herbicides used to a less extent were fluazifop, glyphosate, napropamide, sethoxydim, and s-metolachlor. Herbicide use was not reported for six field locations. In one location, hand weeding was used two to three times during July and August and at another location hand weeding was done two times during the growing season (data not shown). Two field locations had no herbicides applied to the fields.

Insect Damage. The total insect damage at each of the 26 field locations ranged from 7.2% to 100% (Table 5). The field in location 14 was an organic sweetpotato production site (98.8% damaged roots) while the field in location 10 was a transitional production site (i.e., converting from conventional to organic production; 36.9% damage to roots). All other locations used various conventional production practices to grow sweetpotatoes.

White grub and whitefringed beetle damaged the fewest roots, 4.6% and 3.0% respectively, for both years. The mean incidence of whitefringed beetle damage was higher than white grubs in 2002 largely because one location had 48% damage (Table 6). In 2002, the other locations had zero or less than 10% whitefringed beetle damage and none was detected at any locations in 2003. Whitefringed beetle larval populations can be localized in the field and result in “hot spots” that cause severe damage to roots (Zehnder, 1997), which may have occurred in the location in 2002 and explain the higher incidence of damage and severity.

Damage to roots by sweetpotato flea beetle for both years averaged 18% with a mean severity of 5.9 cm per damaged root. The incidence of WDS damage averaged 29% and severity averaged 3.6 holes per root. The overall total incidence of damage, i.e. the incidence of roots with damage by any species or groups of species, averaged 43%.

Conclusions. The information collected from this survey provided details about conditions within sweetpotato fields as well as current practices used to manage fields provided by selected growers who account for approximately 25% of North Carolina’s planted sweetpotato acreage. The data on the amount and severity of insect damage to roots harvested from the on-farm sample sites provides information that is not currently available to growers, researchers and other personnel involved in the sweetpotato industry. Such information gives an indication of the extent of insect damage to the sweetpotato crop in North Carolina (Table 5). The project served as a source of ideas for researchers to design some specific on-farm research studies and to make decisions as to what are realistic expectations for sampling and scoring roots for similar projects in the future. For example, the appropriate size of an area from which roots are harvested and the number of growers and field locations that one person can manage for conducting on-farm research was determined, as well as methods for scoring each category of insect damage.

This on-farm extension questionnaire was a preliminary study for a much larger study funded by a Risk Avoidance and Mitigation Program (RAMP) grant from the USDA that will develop a risk index or advisory software program for sweetpotato growers. The risk index for sweetpotato would be similar to the Southern Corn Rootworm Advisory developed for peanut in 2001 (Herbert et al. 2004). The peanut index uses information on five factors: soil texture, soil drainage class, planting date, cultivar resistance, and field history of rootworm damage in order to determine whether or not a grower's field was at "low," "moderate," or "high" risk from Southern Corn Rootworm damage to peanut. If such a system were developed for soil-borne insects that damage sweetpotato roots, it should result in more efficient use of pesticides and reduce production costs to growers, thereby offering effective pest management strategies to sweetpotato growers in the United States, considering that results of this survey indicate current control measures are not satisfactory.

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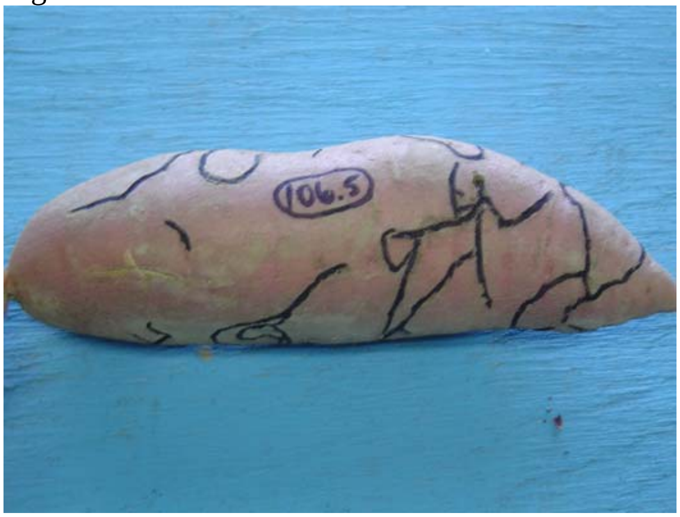
Figure 1.

White grub (*Strigoderma arboricola, Cotinis nitida, Popillia japonica*) damage on a sweetpotato root.

Figure 2.



Sweetpotato flea beetle (*Chaetocnema confinis*) damage on a sweetpotato root. The damage on this root is outlined in black marker and totaled 106.5 cm.

Figure 3.

Whitefringed beetle (*Graphagnathus* spp.) damage on a sweetpotato root.

Figure 4a.

Large WDS (*Melanotus communis, Conoderus vespertinus, C. falli, C. amplicollis, C. lividus, C. bellus,* and *Glyphonyx spp.*)/ *Diabrotica balteata, Diabrotica undecimpunctata*/*Systena blanda*) damage on a sweetpotato root. Note the shallow, smooth cavities just under the skin that are around the opening of the hole. Such cavities were not included in the analysis.

Figure 4b.

WDS (*Melanotus communis*, *Conoderus vespertinus*, *C. falli*, *C. amplicollis*, *C. lividus*, *C. bellus*, and *Glyphonyx spp.*)/ *Diabrotica balteata*, *Diabrotica undecimpunctata*/*Systena blanda*) damage on a sweetpotato root with a hole diameter of about 1.59 mm.

Table 1. Common names and density of each weed identified at 26 field locations (260 on-farm sites) in North Carolina, 2002 and 2003.

		Density of weeds[z]		
Common name	No. of site occurrences	2002	2003	Total
Pigweed	124	956.2	861	1817
Yellow nutsedge[y]	61	27.4	83.1	111
Cocklebur	13	6.3	1	7.3
Sicklepod	20	29.6	3	32.6
Florida pussley	21	28.4	1	29.4
Tropical croton	25	8.5	18	26.5
Large crabgrass	41	32.9	2	34.9
Common lambsquarters	8	0.3	6	6.3
Ground cherry	5	0.5	3	3.5
Eastern black nightshade	4	0	4	4.0
Smartweed	7	2.3	28	30.3
Common ragweed	13	19.6	3	22.6
Morningglory (*Ipomoea spp*.)	5	1.5	0	1.5
Fall panicum	1	0.2	0	0.2
Trumpetcreeper	3	0.5	0	0.5
Prickly sida	8	1.7	0	1.7
Common bermudagrass	1	0.5	0	0.5

Table 1 (continued)

Horsenettle	1	2.0	0	2.0
Annual sedge	4	0	10.5	10.5

[z] The density for each sample site in 2002 was the number of weeds in the area of a circle (with the radius equal to 10 ft.). The density for each sample site in 2003 was the number of plants in an area 15 feet long by one row wide (row spacing varied for each grower, so an average of 3.47 feet was used in calculations). Therefore, the number of weeds counted in 2002 was divided by 6.02 so the area was equivalent to 2003.
[y] The values for yellow nutsedge, which was counted in ten sample sites in 2002 and in 25 sample sites in 2003, were transformed to lon_n; the number of yellow nutsedge plants from those sites are reported as the log_n transformation in this table.

Table 2a. Cultural management practices employed by sweetpotato growers in 2002 and 2003.

Location (2002)	Planting Date	Length of time in field[z]	Rotation 2 yrs. before sweetpotato	Rotation 1 yr. before sweetpotato	Row spacing[z]
1	6/18/02	100	soybeans	tobacco	44
2	5/17/02	125	soybeans	soybeans	44
3	6/7/02-6/14/02	~123	tobacco	tobacco	46
4	mid-June/02	~135	watermelon	tobacco	48
5	6/20/02	129	cotton	cotton	42
6	5/28/02	132	cotton	cotton	40
7	6/17/02	133	soybeans	soybeans	40
8	mid-June/02	~ 110	corn	soybeans	42
9	6/5/02	124	cotton	cotton	40
10	all of July/02	64-94	greens	greens	42
11	5/17/02	129	unknown	tobacco	38
12	6/7/02	134	tobacco	cotton	38
13	6/3/02	147	cotton	cotton	42
14	5/31/02	125	sweetpotato	cowpeas	42
15	6/1/02	141	field	sweetpotato	38

Location (2003)	Planting Date[z]	Length of time in field[y]	Rotation 2 yrs. before sweetpotato	Rotation 1 yr. before sweetpotato	Row spacing[y]
16	6/10/03	127	tobacco	cotton	42
17	6/27/03	107	soybeans	corn	48
18	5/12/03	134	cotton	cotton	40
19	6/11/03	105	cotton	cotton	40
20	6/21/03	104	sweetpotato	cotton	40
21	6/5/03	112	tobacco	pumpkins	40
22	6/24/03	104	tobacco	pumpkins	44
23	6/11/03	105	cotton	cotton	40
24	6/20/03	105	cotton	cotton	40
25	5/16/03	117	watermelon	soybeans	40
26	6/11/03	105	cotton	cotton	40

[z] "Length of time in field" is reported as number of days. "Row spacing" is reported in inches (1 inch = 2.54 cm).

Table 2b. Cultural management practices employed by sweetpotato growers in 2002 and 2003.

Location (2002)	Subsoil	Depth of subsoiling[z]	Time of bedding[y]	Beds reworked	Number of cultivations	Time of cultivations[x]
1	no	n/a	21-28	no	3	once every 10-12 days
2	no	n/a	7	no	6	weekly
3	no	n/a	30	yes	5	weekly
4	no	n/a	14-21	no	4	once every 1-2 weeks
5	no	n/a	5	yes	3	weekly
6	yes	8-10	25-30	yes	4	weekly
7	no	n/a	10	no	3	every 10 days
8	yes	8	30	yes	3	weekly
9	yes	10-12	30	no	3-4	once every 10 -14 days
10	yes	24	14	yes	3	once every days
11	no	n/a	30	yes	3	once every 1.5 weeks
12	yes	18	7	no	5-6	weekly
13	no	n/a	21	yes	3	once every 2-3 weeks
14	yes	14-16	10	yes	4	weekly
15	yes	18	6-7	no	5-6	weekly
Location (2003)	**Subsoil**	**Depth of subsoiling[z]**	**Time of bedding[y]**	**Beds reworked**	**Number of cultivations**	**Time of cultivations[x]**
16	no	n/a	14-21	yes	3	every 10 days to 3 weeks
17	yes	16	7-14	yes	2	once every 2 weeks
18	yes	12	21	no	2-3	weekly
19	yes	12	21	no	2-3	weekly
20	yes	6	7	no	3	once every 9-10 days
21	yes	10	2	no	2	once every 3 weeks
22	no	n/a	14	yes	3	weekly
23	yes	12	21	no	2-3	weekly
24	yes	10-12	21-28	no	3	weekly
25	no	n/a	14	no	4	once every 1-2 weeks
26	yes	15	14	yes	3	once every 1-2 weeks

[z] "Time of Bedding" is reported as number of days.
[y] "Depth of subsoiling" is reported in inches (1 inch = 2.54 cm).
[x] "Time of cultivations" refers to the frequency of the "Number of cultivations" after transplanting.

Table 3. Characterization of North Carolina sweetpotato grower's 26 field locations in 2002 and 2003.

Location (2002)	Soil Series	Texture[z]	Drainage[y]	Rainfall (inches)[x]
1	Norfolk, Gritney, Grantham	ls, sl vfsl	W, MW P	17.3
2	Norfolk, Dothan, Rains	ls, ls fsl	W P	17.3
3	Norfolk, Goldsboro	ls, sl	W, MW	23.0
4	Goldsboro, Lynchburg	fsl, fsl	MW, SP	6.4
5	Norfolk, Lynchburg	ls, sl	W, SP	15.8
6	Norfolk, Rains	ls, sl	W, P	15.8
7	Dragston, Kenansville	ls, ls	SP, W	7.4
8	Woodington, Norfolk	ls, ls	P, W	15.8
9	Wagram, Orangeburg Marvyn, Johns	ls, ls ls, fsl	W, W W, SP	15.8
10	Norfolk, Orangeburg, Rains	ls, ls sl	W, W P	15.8
11	Norfolk	ls	W	16.0
12	Wagram, Norfolk	ls, ls	W	15.8
13	Norfolk, Goldsboro	lfs, fsl	W, MW	6.4
14	Blanton	s	MW	15.8
15	Wagram	ls	W	15.8
Location (2003)	**Soil Series**	**Texture[z]**	**Drainage[y]**	**Rainfall (inches)[x]**
16	Norfolk	ls	W	33.4
17	Rains, Stallings	sl, ls	P, SP	33.4
18	Norfolk	ls	W	25.2
19	Norfolk	ls	W	25.2
20	Norfolk	ls	W	48.8
22	Norfolk	ls	W	15.4
22	Norfolk	ls	W	24.6
23	Wagram	ls	W	25.2
24	Marvyn	ls	W	25.2
25	Autryville	ls	W	22.9
26	Autryville	ls	W	22.9

Table 3 (continued)

[z] Soil texture varied at the ten sample sites and is listed with respect to the corresponding soil series. All variations are reported in the table; ls=loamy sand, sl=sandy loam, vfsl=very fine sandy loam, fsl=fine sandy loam, lfs=loamy fine sand, s=sand.
[y] Drainage is listed with respect to corresponding soil texture. W=well drained, MW=moderately well drained, SP=somewhat poorly drained, P=poorly drained.
[x] Rainfall is reported from the closest weather station to the field from which roots were harvested for the May to October growing season; 1 inch = 2.54 cm.

Table 4. Insecticide regimes used to control soil borne insects in 25 field locations in North Carolina, 2002 and 2003.

Pesticide regime	Number of fields regime was used
1. Organic[z]	1
2. Transitional[z]	1
3. Baythroid	2
4. chlorpyrifos	3
5. chlorpyrifos, endosulfan, imidacloprid	2
6. chlorpyrifos, endosulfan, phosmet	13
7. chlorpyrifos, carbaryl, endosulfan	1
8. chlorpyrifos, carbaryl, endosulfan, phosmet	1
9. chlorpyrifos, carbaryl, endosulfan, imidacloprid, phosmet	1

[z] Beneficial grub-stake nematodes were applied to the field at an amount of 7 packages per 15 acres. One package contained 25 million nematodes.

Table 5. Overall incidence of insect damage by all species or groups of species from ten sites (1 to 10) at 26 field locations (1 to 26) in North Carolina in 2002 and 2003.[z]

Site/Field No.	1	2	3	4	5	6	7	8	9	10	Avg.[y]
2002											
1	8	0	4	4	4	12	24	4	4	8	**7.20**
2	8	12	32	16	8	4	16	8	8	2	**13.2**
3	36	8	2	4	13	2	4	4	0	32	**14.1**
4	24	12	12	16	12	8	16	20	33	4	**15.7**
5	8	32	24	28	28	4	16	8	29	24	**30.9**
6	52	4	36	52	4	8	8	25	28	24	**27.7**
7	57	12	32	8	24	8	36	36	64	36	**31.3**
8	2	28	32	12	6	64	28	28	16	32	**32.0**
9	28	48	48	48	24	21	32	44	4	24	**32.1**
10	48	6	44	52	32	44	25	32	2	12	**36.9**
11	24	56	61	2	24	32	36	36	36	52	**37.7**
12	64	92	84	29	64	56	64	21	64	96	**63.4**
13	8	8	96	92	88	88	100	88	56	96	**86.4**
14	100	100	100	100	100	92	100	100	100	96	**98.8**
15	100	100	100	100	100	100	100	100	100	100	**100**
2003											
16	32	24	12	16	24	40	60	44	44	80	**37.6**
17	17	32	76	32	88	84	56	83	52	24	**54.4**
18	100	80	92	96	92	100	83	96	92	96	**92.7**
19	36	32	28	20	16	12	20	36	0	36	**23.6**
20	84	84	24	16	16	56	36	8	40	32	**39.6**
21	12	4	12	20	16	32	72	40	21	24	**25.3**
22	24	16	28	0	12	16	44	0	36	0	**17.6**
23	44	20	36	20	24	32	48	52	48	8	**33.2**
24	72	96	96	88	88	100	100	96	96	88	**92.0**
25	60	42	24	24	48	44	40	64	76	32	**45.4**
26	44	20	48	52	44	0	28	8	36	48	**32.8**

[z] Twenty-five roots were harvested from each of the ten sample sites (1 to 10) and the average amount of damage is reported for the 25 roots.
[y] An overall average is reported for each field number (location). Average insect damage for the 26 field locations is 43.1%.

Table 6. Insect damage to sweetpotato roots by sweetpotato flea beetle, WDS complex, white grubs, whitefringed beetle and all species (Total) at 26 field locations for North Carolina growers in 2002 and 2003.

	Sweetpotato Flea Beetle		**WDS**		**White Grub**	**Whitefringed Beetle**	**Total**
Location	Percent damage[z]	Severity of damage[y]	Percent damage	Severity of damage	Percent damage	Percent damage	Percent damage
2002							
1	2.8	5.8	4	2.1	0.4	0	7.2
2	3.6	4.9	3.6	1.4	6	0	13.2
3	0.8	2.8	11.6	3.8	2	0.8	14.1
4	1.2	4.5	10.9	1.6	4.4	0	15.7
5	4	4.7	24.5	2.8	4	0.8	30.9
6	12.4	6.6	8.8	2.6	2.8	9.2	27.7
7	2.1	5.1	28.3	3.5	3.2	0	31.3
8	14	5.6	18.4	2.2	2.4	4.8	32
9	29.7	5.3	5.6	1.8	0.4	0.8	32.1
10	2.8	5	34.1	2.7	0.8	0.4	36.9
11	11.7	5.2	28.9	2.32	4	0	37.7
12	6.8	4.8	59	4	8	1.6	63.4
13	17.2	4.9	44.8	3.9	19.6	48.4	86.4
14	20	5.2	98	12.6	10.4	0	98.8

Table 6 (continued)

15	4.4	2.4	100	26	44.8	10	100
2003							
16	96	3.9	31	2.8	0.8	0	37.6
17	24	5.8	39	2.2	1.6	0	54.4
18	89	20	31	1.9	0.4	0	92.7
19	22	6.5	2.4	0.8	0	0	23.6
20	31	6.3	12	2.3	0.8	0	39.6
21	4.4	6.9	20	2.3	3.6	0	25.3
22	1.2	0.2	16	0.97	0.4	0	17.6
23	24	5.4	12	1.3	0	0	33.2
24	82	17.5	82	3.5	0	0	92
25	42	4.7	4.4	0.82	0	0	45.4
26	18.4	4.3	14.4	0.63	0	0	32.8

[z] Percent damage is calculated as the amount of roots damaged by a particular species or group of species divided by the total number of roots for that location. The average of the ten sample sites within each location is reported. A total of 250 roots were harvested from each location.

[y] Severity of damage is calculated as the average length of flea beetle tunnels (reported in centimeters), the average number of WDS holes, and the average number of grub or whitefringed beetle lesions per total number of roots damaged by the particular species or group of species.

Chapter 3

Effects of Cultural Practices and Site Selection on Insect Damage to Sweetpotato Roots

ABSTRACT

A total of 6,500 ‘Beauregard’ sweetpotato roots were sampled from 26 fields in North Carolina in 2002 and 2003 in order to identify relationships between insect damage to roots and field characteristics and production practices. Injury by wireworm/*Diabrotica* spp./*Systena* spp. (WDS) complex, sweetpotato flea beetle (*Chaetocnema confinis*), white grubs (*Popillia japonica*, *Strigoderma arboricola*, and *Cotinis nitida*), and whitefringed beetle (*Graphagnathus* spp.) was characterized as the incidence of roots injured by each species/group of species and the severity of injury to damaged roots. Sweetpotato flea beetle damage increased approximately 26%, and overall insect damage increased 30%, when cotton was planted in fields either one or two years before sweetpotatoes, compared to tobacco or soybeans planted one or two years before sweetpotatoes. One grower that did not use herbicides in two fields sustained 36% more WDS damage to roots, however, when the herbicide EPTC was used in fields, grub damage increased 9% and whitefringed beetle damage increased 2.6%. When chlorpyrifos was not used, overall insect damage increased 36%. Poorly drained soils resulted in 19% more WDS damage. The average number of WDS holes increased by 4.3 and grub damage increased 7.4% when fields were cultivated more than three times. If fields were subsoiled, a 17% increase in sweetpotato flea beetle damage and a 21% increase in overall insect damage occurred. Sweetpotato flea beetle damage was positively correlated with rainfall (P = 0.07; R^2 = 0.13). Grub damage was higher on roots from fields with pigweed than from fields with yellow nutsedge populations. In general, planting early and harvesting early resulted in less insect damage to roots, however,

sweetpotato flea beetle damage decreased as harvest date increased ($P = 0.1$). The influence that factors such as crop rotations, pesticides, soil drainage, tillage practices, weeds, and planting and harvest dates has on insect damage to sweetpotato roots are important considerations for production decisions and future research projects.

INTRODUCTION

Surveys or questionnaires are useful research tools for gathering specific information typically not available through public resources. Previous research has used surveys to determine the effect that cultural practices have on herbicide resistance, economics of production, insect damage, and plant diseases. A survey conducted in Saskatchewan, Canada found differences in herbicide resistance in wild oat populations depending on whether or not producers employed weed sanitation (Legere et al. 2000). A survey of cotton producers in south Georgia, United States, determined that the most efficient fields, in terms of generating revenue, were those that utilized genetically modified cotton varieties with conservation tillage practices as opposed to conventional tillage practices (Ward et al. 2002).

Results of a survey in Korea to assess rice damage due to the smaller leaf miner (*Hydrellia griseola* F.) showed that the higher incidence of rice damage occurred when rice was transplanted early at a high altitude and fertilized at a high rate (Choi et al. 1983). Wheat growers in Canada were asked to provide information on the history of fields in which wheat heads were inspected for fusarium head blight (Teich and Nelson 1984). The frequency of fusarium head blight on wheat was influenced by factors such as crop rotation, soil fertility and weed density. The severity of fusarium head blight was lower where wheat was not planted after maize, where nitrogen and phosphorous fertilization were adequate and where weed density was low. In South Nyanza, Kenya, one survey confirmed that the sweetpotato weevil (*Cylas* spp.) was the most damaging insect pest for that region while another survey prioritized factors such as crop rotation, planting dates, harvest techniques, and planting methods for future research projects that would focus on the effect of those cultural practices on weevil damage to sweetpotato roots (Smit and Matengo 1995).

Sweetpotato crop surveys were conducted in North Carolina to determine pesticide use and other pest management practices used for sweetpotato production in 1991 and 1996 (Toth et al. 1991, 1997). Neither of those surveys associated production practices or pesticide use with insect damage to sweetpotato roots. A survey in Georgia estimated that the cost of controlling soil insects combined with the loss of the sweetpotato crop due to insect injury totaled $530,000 for the 1,072 acres planted to sweetpotato in Georgia in 1997 (Adams and Riley 1997). In 2002 and 2003, a questionnaire was conducted to gather information on the cultural management practices utilized by North Carolina sweetpotato growers on specific fields. Information within those fields on weed species, weed populations, soil drainage and soil type was also obtained. The objective of this study was to detect correlations between insect damage to sweetpotato roots and growers' cultural practices, field management, insect management, weed management, and site characteristics, such as rainfall and drainage.

MATERIALS AND METHODS

Grower participation. In 2002 and 2003, sixteen growers responded to a questionnaire to report the cultural practices used in 26 sweetpotato fields from which root samples were obtained. A total of 40,000 to 43,000 acres of sweetpotatoes were planted in North Carolina in 2002 and 2003 (NCDA & CS 2003). 'Beauregard' sweetpotato fields planted by the growers who participated in the survey in 2002 and 2003 represented approximately 25% of the total acreage of sweetpotatoes planted by North Carolina growers both years (Table 4; Appendix B).

On-farm site selection. Ten sites were established within each field to sample roots (total of 260 sites over two years). Each site was 15.2 m (50 ft) long in 2002 and 4.6 m (15 ft) long in 2003 by two rows wide. Twenty-five roots were harvested from each site for a total of 250 roots from each of the 26 field locations (6,500 total roots). During 2002 the weed species at each site were identified and each plant counted within a 3.1 m (10-foot) radius of the center of each site. In 2003, sites were established in areas where only pigweed or yellow nutsedge was prevalent because those two weeds had the highest density in growers' fields in 2002 (see Table 1 in Chapter 2). Furthermore, these weeds are the most important weed pests in sweetpotato fields (Toth et al 1991, 1997; Semidey et al. 1987). In cases where yellow nutsedge was too numerous to count within each site, populations were determined by counting yellow nutsedge within three, 32 cm^2 areas per site in 2002 and two, 30.5 cm^2 areas per site in 2003. The weed counts were averaged and then multiplied by the area of the sites in order to obtain a total yellow nutsedge population for each site. In other sites in both years, yellow nutsedge plants were counted individually where the population was low. A GPS reading was taken at each site both years to obtain soil information such as series, texture and drainage through the Soil Survey Geographic (SSURGO) Database of the Natural Resource Conservation Service (NRCS).

Root acquisition, damage assessment and statistical analysis. Number one grade roots (USDA 1981) were harvested at every location in both years with a one-row mechanical harvester. Roots were placed in labeled paper bags, which were then placed in wooden crates, cured and kept at recommended storage conditions (Boyette et al. 1997) so the roots could be examined later for insect damage (Chapter 2). Damage was categorized as wireworm (*Melanotus communis, Conoderus vespertinus, C. falli, C. amplicollis, C. lividus, C. bellus* and *Glyhphonyx* spp.)/ *Diabrotica balteata, Diabrotica undecimpunctata*/*Systena blanda* complex (WDS), sweetpotato flea beetle larvae (*Chaetocnema confinis*), white grubs (*Strigoderma arboricola, Cotinis nitida, Popillia japonica*), and whitefringed beetle larvae (*Graphognathus* spp.).

This experiment was not a completely random design because each field location had areas of subsampling, or sites, that were chosen for specific purposes, usually for an abundance or lack of weeds. Analysis of variance (PROC GLM) was used to statistically analyze the relationship between insect damage and the following factors, which are discussed in detail below: crop rotations (crops planted one and two years before sweetpotatoes), subsoiling, time of bedding, reworking of beds, cultivations, herbicides, EPTC herbicide, foliar insecticides, chlorpyrifos insecticide, chlorpyrifos application timing and soil drainage. Multiple comparisons were conducted for crop rotations and time of bedding. The values of Fisher's Protected LSD are reported in cases where the overall F-test was significant for the multiple comparisons. Simple linear regression (PROC REG) was used to statistically analyze the relationship between insect damage and the following factors, which are described in detail in the sections below: rainfall, pigweed and nutsedge populations, and planting dates and the duration of roots in the field.

In some instances, surveys were not fully completed by the growers. As a result, only fields with complete information provided by the growers were used in the analyses and fields that did not have complete information were excluded from statistical analyses. The code and output for this paper was generated using SAS Version 8.02, Cary, North Carolina (Appendix B).

Cultural practices.

One-year crop rotation. The growers who participated were asked to report the crop rotations they used one year before planting sweetpotatoes. An analysis was performed to determine differences in insect damage in fields with cotton, tobacco or soybeans as one-year crop rotations since those crops were the most commonly used for rotation and provided a reasonable sample number for comparison. Twelve fields were planted with cotton, four fields were planted with soybeans and four fields were planted with tobacco prior to the sweetpotato crop. Other crop rotations were employed in only one or two fields and therefore, were not used in the analysis.

Two-year crop rotation. As was the case with crops planted one year before sweetpotatoes, cotton, soybean and tobacco were the crops most utilized two years prior to planting sweetpotatoes. Thus, an analysis was performed to determine differences in insect damage in fields with cotton, tobacco or soybeans as two-year crop rotations. Nine fields were planted with cotton, four fields were planted with soybeans and five fields were planted with tobacco. As with one year crop rotations, other crop rotations consisted of only one or two samples and therefore, were not used in the analysis.

Planting dates and duration of roots in the field. The 26 field locations were grouped into categories of early, mid and late planting dates. Five fields were planted and designated as "early", between 12 May and 31 May, twelve field locations designated as a "mid-season" planting date, between 1 June and 15 June, and eight field locations were designated as a "late" planting, between 15 June and 31 July. These dates coincided with the transplanting data achieved with commercial sweetpotato plantings in North Carolina in 2002 and 2003 in which about 35% of planting was completed by the end of May, 60% by mid-June and the remaining 40% thereafter (North Carolina Dept. of Agriculture, 2005).

Field Management.

Subsoil. An analysis was performed to determine differences in insect damage between fields that were subsoiled compared to fields that were not subsoiled. Fifteen fields were subsoiled in the year that sweetpotatoes were planted and 11 fields were not subsoiled.

Time of Bedding. An analysis was performed to determine if there were differences in insect damage with various times that field beds were made prior to planting sweetpotato transplants. Three categories were chosen for the analysis: 1) beds were made three or more weeks before planting in ten fields, 2) beds were made between one to three weeks before planting in nine fields, and 3) beds were made less than or equal to one week before planting in seven fields.

Reworking of Field Beds. Another analysis was conducted to determine differences in insect damage depending on whether or not the field beds were re-worked prior to planting. Beds were re-worked in 12 fields while beds were not re-worked in 14 fields.

Cultivations. An analysis was performed to determine differences in insect damage between 18 fields with less than or equal to three cultivations compared to eight fields with more than three cultivations (a total of 26 fields).

Weed management/Presence of weeds in sweetpotato fields.

Herbicides. Because weeds may influence the presence of insects that affect sweetpotato roots, an analysis was performed to determine the difference in insect damage in fields in which herbicides were used compared to fields in which herbicides were not used. Growers reported the use or non-use of herbicides in 20 of the 26 field locations. Herbicides were applied in eighteen of the 20 field locations, while herbicides were not applied in two field locations (they were organically grown fields).

EPTC herbicide. EPTC was singled out from other herbicides for separate analysis because it is incorporated at the same time as chlorpyrifos insecticide, which is unlike other herbicide applications for the sweetpotato crop. Growers reported whether or not EPTC was used for 20 of the 26 field locations. EPTC was applied to six of the 20 fields, while EPTC was not applied to 14 fields. An analysis was conducted to determine the differences in insect damage between the 14 fields that had EPTC compared to the six fields that did not have EPTC.

Weeds. Weeds can serve as host plants for insects that injure sweetpotato roots (Zehnder 1998). Pigweed and yellow nutsedge were selected for determining differences in insect damage with weed populations because those two weed species had the highest density in sweetpotato fields in 2002 and 2003 (Table 1 from Chapter 2) and pigweed is an important weed in sweetpotato (Semidey et al, 1987). Other weed species' densities were low and therefore, not included in the analysis (Tables 5-11; Appendix B). The density of pigweed and yellow nutsedge populations for 2002 was adjusted to the area of the sites in 2003 since the plots from which root samples were harvested differed between years.

Insect management.

Foliar insecticides. Foliar insecticides are targeted against the adult stage of soil insects to prevent egg laying. An analysis that included 25 fields was performed to determine the difference in insect damage in fields in which foliar insecticides were used compared to fields in which foliar insecticides were not used. Foliar insecticides were applied in 21 of the 25 field locations, while foliar insecticides were not applied in four field locations.

Chlorpyrifos insecticide. Growers reported whether or not chlorpyrifos was used in 25 field locations. Of the 25 fields, chlorpyrifos was applied to 21 fields while chlorpyrifos was not applied to four fields. Two out of the four fields in which chlorpyrifos was not applied were fields using organic production methods. Other factors, such as crop rotations, planting dates, rainfall, number of field cultivations, and soil drainage varied among the 25 fields. An analysis was performed to determine whether the insect damage was different in fields in which chlorpyrifos was used compared to fields in which chlorpyrifos was not used, i.e. the 21 fields were compared to the four fields.

Timing of chlorpyrifos insecticide application. A more specific analysis was conducted to determine the effect of timings of chlorpyrifos applications on insect damage. Of the 21 field locations in which chlorpyrifos was applied, growers provided the precise time of chlorpyrifos application for 16 fields. The timing of chlorpyrifos application was grouped into two categories in which eight of the 16 fields had one application one to seven days before planting, and eight of the 16 fields had one application two or more weeks before planting. An analysis was performed to determine whether the insect damage was different between the two chlorpyrifos application timings.

Site characteristics.

Soil Drainage. The effect that soil drainage had on the incidence of insect damage to sweetpotato roots was also investigated. The insect damage to roots from sites with "poorly drained" locations was compared to the insect damage to roots from sites with "well drained" locations. The six field locations were chosen because many of the cultural practices were similar and the primary variation was that subplots varied in soil drainage class. A "poorly drained" soil is one in which "water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods" (Soil Survey Division Staff 1993). A "well drained" soil is one in which "water is removed from the soil readily but not rapidly" (Soil Survey Division Staff 1993).

Three field locations with 15 sites that had a "poorly drained" drainage class were chosen for statistical analysis because they had similar crop rotations, planting dates, harvests, and cultivations. The crop rotations one year before planting sweetpotatoes were soybeans, tobacco and corn and the crop rotations two years before planting sweetpotatoes were soybeans (2 fields) and corn. The planting dates were mid-June, 18 June, and 27 June, the harvest dates were 110, 100 and 107 days after planting and all 15 field locations had three cultivations.

Three field locations with 15 sites that had a "well drained" drainage class were chosen for statistical analysis because they also had similar crop rotations, planting dates, harvests, and cultivations. The crop rotations one year and two years before planting sweetpotatoes were cotton for the three field locations. The planting dates were 11 June and the harvests were 105 days after planting and all field locations had three cultivations.

Rainfall. Rainfall data for the sweetpotato growing season (May to October) was obtained from the weather station closest to the field from which roots were harvested. The State Climate Office of North Carolina provided the rainfall data (<http://www.nc-climate.ncsu.edu/>). The rainfall from the weather stations was representative of the fields selected for the on-farm studies in each year. An analysis was conducted to determine the influence of rainfall on insect damage to roots. Rainfall was also averaged across locations within each year to obtain an average amount of rainfall per field location for 2002 and 2003, which was compared to the average amount of flea beetle damage in each year.

RESULTS AND DISCUSSION

Eighty percent of roots damaged by sweetpotato flea beetle had tunnel tracks on the surface of the root between 1.8 inches (4.50 cm) and 2.3 inches (5.80 cm). A strong relationship between sweetpotato flea beetle severity (based on tunnel track length) and the incidence of roots damaged by flea beetle ($P = 0.0002$; $R^2 = 0.5$; df = 1,22; F = 19.05) existed, indicating that the amount of tunneling on roots increased as a greater incidence of roots damaged by flea beetle increased (Figure 1).

There was a positive correlation ($P < 0.0001$; $R^2 = 0.5$; df = 1,22; F = 25.36) between incidence of roots damaged by WDS and severity indicating that the average number of holes on damaged roots increased as the incidence of damaged roots increased (Figure 2). Eighty seven percent of WDS severity (number of holes per root) was between 1.4 and 6.6 holes per root (data not shown).

Crop rotations, tillage practices, pesticides, or the presence of weeds in fields did not influence the incidence of whitefringed beetle damage. The lack of statistically significant responses to these factors most likely resulted from the fact that no whitefringed beetle damage was detected on roots in 2003 and very little was detected in 2002, with the exception of a few locations averaging 5.1% damaged roots. It is common for whitefringed beetle damage to be distributed unevenly in the field (Zehnder 1998). We found this to be the case in these studies.

Cultural practices.

One-year crop rotations**.** The total incidence of roots damaged by all insect species was affected by one-year crop rotations of cotton, tobacco, and soybeans ($P = 0.07$; df = 2, 153; F = 3.09). Sweetpotato roots had 49% total insect damage with a crop rotation of cotton, and roots had 19% total insect damage with a crop rotation of tobacco (*P* = 0.03 Fisher's Protected LSD). There were no differences in insect damage to sweetpotato roots from fields with tobacco and soybean crop rotations or cotton and soybean crop rotations one year before sweetpotatoes were planted. Fields with soybean crop rotations had a mean of 30% insect damage.

Injury from sweetpotato flea beetle and WDS increased when cotton was planted one year prior to sweetpotato, relative to planting soybean or tobacco crops one year before sweetpotato. Although crop rotations are an important management tool employed by growers in order to avoid insect damage, there is little information on the influence that crop rotations of cotton, soybeans or tobacco have on insect damage to sweetpotato roots.

<u>Two-year crop rotations</u>**.** The incidence of flea beetle damage was affected by two year crop rotations of cotton, soybeans and tobacco (*P* = 0.07; df = 2,135; F = 3.15). When cotton was planted two years before sweetpotatoes were planted, it affected the incidence of roots damaged by sweetpotato flea beetle compared with tobacco planted two years before sweetpotatoes were planted (*P* = 0.04 Fisher's Protected LSD). Flea beetle damage was 28% more with a cotton rotation than with tobacco. A difference in the incidence of roots damaged by flea beetle occurred when cotton and soybean crop rotations were compared (*P* = 0.09 Fisher's Protected LSD). Thirty-three percent of sweetpotato roots were damaged by flea beetle with a cotton rotation compared to 8% flea beetle damage with a soybean rotation.

<u>Planting dates and duration of roots in the field</u>**.** No relationships existed between insect damage and harvest date with an early planting. The following occurred when

plantings were established mid-season and the days to harvest increased: the incidence of WDS increased (P = 0.09; R^2 = 0.26; Figure 3); and the severity of flea beetle damage decreased (P = 0.04; R^2 = 0.37; df = 1,10; F = 5.77). The following relationships approached significance when plantings were established mid-season and the number of days roots were in the field increased: the incidence of flea beetle damage decreased (P = 0.11; R^2 = 0.23; Figure 3) and overall insect damage increased (P = 0.11, R^2 = 0.23; df = 1, 10; F = 2.99). When plantings were made late in the season, the incidence of white grub damage approached significance and increased (P = 0.11; R^2 = 0.39; Figure 4). The following occurred as the days to harvest increased irrespective of the planting date: incidence of WDS damage increased (P = 0.09; R^2 = 0.12; Figure 5); the incidence of white grub damage approached significance and increased (P = 0.1; R^2 = 0.11; df = 1, 24; F = 2.86; y = 274.23 + 38.895x); and the incidence of flea beetle damage approached significance and decreased (P = 0.11; R^2 = 0.1; Figure 5).

The roots that were in the field longest, 147 days, had the most whitefringed beetle damage. Similarly, roots with the second highest incidences of damage by whitefringed beetle, also had second longest lengths of time that roots were left in the field (141 days and 132 days after planting). Zehnder (1997) found that the incidence of feeding damage by whitefringed beetle increased as root diameter increased, supporting our results that the length of time roots are left in the field has an effect on the incidence of damage to roots.

Field Management.

Subsoiling. Subsoiling affected the severity and incidence of flea beetle damage to roots (*P* = 0.01; df = 1,216; F = 6.96 for severity; *P* = 0.06; df = 1,216; F = 3.91 for incidence). When fields were subsoiled, flea beetle damage increased by 1.7 inches (4.19 cm) and the incidence of damage increased by 17% compared to fields not subsoiled (Table 1). The incidence of roots damaged by WDS and white grubs also tended to be greater in subsoiled fields and the effect of subsoiling on total insect damage to roots was significant (*P* = 0.05; df = 1,216; F = 4.24). When fields were subsoiled, overall insect damage on roots increased by 21% (Table 1). The reason(s) for these results are unclear.

Time of bedding. There was no difference between the amount and severity of flea beetle, WDS, white grubs, whitefringed beetle and overall insect damage on roots from fields in which beds were made less than or equal to one week before planting, between one to three weeks before planting, or three or more weeks before planting (Table 1).

Reworking of field beds. There was no difference between the amount and severity of flea beetle, WDS, white grubs, whitefringed beetle and overall insect damage on roots from fields in which beds were reworked before planting compared to roots from fields in which beds were not reworked before planting (Table 1).

Cultivations. There was a difference in the severity of WDS damage between fields with less than or equal to three cultivations and more than three cultivations (*P* = 0.05; df = 1, 216; F = 4.37). Fields with more than three cultivations had an average of 6.4 WDS holes per roots, while fields with less than or equal to three cultivations had an average of 2.1 WDS holes per root. The incidence of roots damaged by white grubs was also affected by cultivation (*P* = 0.06; df = 1, 216; F = 4.03). Fields with less than or equal to three cultivations had 2.4% grub damage while fields with more than three cultivations had 9.8% grub damage. Cultivation can modify the soil temperature and moisture, and influence the behavior of soil insects (Wright 1999), which may be the reason why there was more grub damage with more cultivation.

Weed management.

Herbicides. The fields in which herbicides were used had 30% of roots damaged by WDS, however, 66% of sweetpotato roots had WDS damage in fields receiving no herbicide (*P* = 0.06; df = 37,162; F = 1.51). Clomazone, which controls grasses and some broadleaf weeds, was used by a majority of growers (Table 3; Appendix B), and since grass is a host plant for wireworms (Metcalf and Flint 1962), it is possible that more WDS damage occurred in fields where clomazone was not used. There were no differences between the use and non-use of herbicides for the incidence or severity of roots damaged by the other insect species evaluated.

EPTC herbicide. The use or non-use of EPTC influenced white grub and whitefringed beetle damage on roots. Roots had 11% grub damage when EPTC was used compared to only 2% grub damage when EPTC was not used (*P* = 0.07; df = 1,162; F = 3.61). The incidence of whitefringed beetle damage was also influenced by the use of EPTC in fields (*P* = 0.02; df = 1,162; F = 6.19). Roots had 2.7% whitefringed beetle damage when EPTC was used on roots, but roots had only 0.1% whitefringed beetle damage when EPTC was not used in fields. The reason(s) for these results are unknown. Other weed control factors such as tillage may also influence insect damage to sweetpotato roots.

Weeds. A positive correlation approached significance between the number of nutsedge plants and the severity of WDS damage to roots (Figure 6a). There was a positive correlation between the number of yellow nutsedge plants and the incidence of grub damage to roots (Figure 6b). There were no significant relationships between the number of pigweed plants and any insect damage to roots.

When fields with nutsedge and pigweed populations were compared, there was a difference in the incidence of grub damage (P = 0.08; df = 1, 18; F = 3.47). Sweetpotato roots had 1.2% grub damage in fields with pigweed compared to 0.1% grub damage in fields with nutsedge.

In 2003, growers used mowing as a weed management tool for pigweed in three of the six field locations that had pigweed populations. The incidence of WDS damaged roots and incidence of overall insect damage was greater when pigweed was not mowed (P = 0.0014; df = 1,8; F = 22.74 for WDS; P = 0.03; df = 1,8; F = 6.78 for total damage). When pigweed was not mowed, 34% of roots were damaged by WDS and roots had 62% overall insect damage compared to 11% of roots damaged by WDS and 30% overall insect damage when pigweed was mowed. Growers did not report whether or not they used mowing as a weed management tool in 2002.

Insect management.

Foliar Insecticides. There was no difference between the amount and severity of sweetpotato flea beetle, WDS, white grubs, whitefringed beetle and overall insect damage on roots from fields treated with or without foliar insecticides. In another study, foliar insecticides, such as endosulfan, carbaryl, and parathion, failed to produce damage-free sweetpotato roots (Chalfant et al. 1979). In fact, a high incidence (more than 50%) of the roots were damaged by sweetpotato flea beetle when foliar sprays were used, which was not different than the incidence of infestation on roots from the nontreated check plots. Foliar insecticide sprays were apparently ineffective in controlling the sweetpotato flea beetle; foliar sprays used to control other insects that damage sweetpotato roots were not discussed in that study.

Chlorpyrifos. The influence that chlorpyrifos had on the incidence of insect damage to sweetpotato roots is important to consider since 85% of the sweetpotato growers we surveyed reported using the pesticide (Table 2. Appendix A). Chlorpyrifos affected the amount and severity of WDS damage to roots ($P < 0.0001$; df = 1, 207; F = 27.55 for incidence; $P = 0.0003$; df = 1,207; F = 18.59 for severity), white grub damage ($P = 0.006$; df = 1,207; F = 9.35), and total insect damage ($P = 0.01$; df = 1,207; F = 6.92). Fields in which chlorpyrifos was not used had 73%, 16%, and 75% WDS, white grub, and total insect damage, respectively, while fields in which chlorpyrifos was used had 20%, 2.0%, and 38% WDS, white grub, and total insect damage, respectively. Chlorpyrifos has been reported to be an effective management tool used to control soil insects that damage sweetpotatoes (Chalfant et al. 1990). Although our data indicated that insect damage to sweetpotatoes was less if chlorpyrifos was used than if it was not used, considerable insect damage (38%) still occurred in sweetpotato fields treated with chlorpyrifos.

Timing of chlorpyrifos application. No differences were observed between insect damage by any species in fields where chlorpyrifos was applied within one week or two or more weeks before planting. Even though chlorpyrifos incorporated before planting has been shown to effectively control wireworms in Georgia (Chalfant et al. 1987), there was a substantial amount of overall insect damage to roots (38%) regardless of when growers applied chlorpyrifos to sweetpotato fields in our study.

Site Characteristics.

Soil Drainage. The incidence of roots damaged by WDS was affected by soil drainage (P = 0.08; df = 1,4; F = 5.33). Poorly drained locations had 21% WDS damaged roots compared to well-drained locations with 2.4% WDS damaged roots. The poorly drained soils most likely had a higher incidence of wireworm damage because the greatest populations of wireworms are usually found in poorly drained areas and/or water spots in the field (Ratcliffe et al. 2004). The incidence and severity of flea beetle, white grubs and overall insect damage, as well as the severity of WDS, was not influenced by soil drainage.

Rainfall. Rainfall varied between years, so the correlation between the amount of rainfall and insect damage was examined. The incidences of WDS, white grub and whitefringed beetle damage were not significantly influenced by rainfall. The incidence of flea beetle damage was significantly influenced by rainfall (P = 0.07; Figure 7). Flea beetle damage increased as rainfall increased (R^2= 0.13). These results suggest that a wet growing season would result in more flea beetle damage. The average rainfall per location across the 15 field locations in 2002 was 37 cm (14.7 inches), while the average rainfall per location for the 11 field locations in 2003 was 65 cm (27.5 inches). The amount of flea beetle damage in 2002 was an average of 8.9% compared to 31% in 2003.

Conclusions. In general, the severity of sweetpotato flea beetle and WDS damage increased as the incidence of roots damaged by those insects or groups of insects increased. Cotton planted in fields either one or two years before sweetpotatoes were planted resulted in more sweetpotato flea beetle damage. Planting and harvesting early resulted in less insect damage, although sweetpotato flea beetle damage decreased as the growing season progressed. When fields were subsoiled, roots exhibited more insect damage compared to fields that were not subsoiled. Fields cultivated less than or equal to three times had roots with less grub damage and fewer WDS holes compared with fields cultivated more frequently. More WDS damaged roots existed where nutsedge was located and if herbicides were not used compared to when nutsedge was absent and if herbicides were used. However, the use of EPTC herbicide in fields resulted in more grub and whitefringed beetle damaged roots. Roots from fields with pigweed populations had more grub damage than roots from fields with yellow nutsedge populations. Preplant application of chlorpyrifos reduced the incidence and severity of insect damaged roots but the timing of the preplant application was not important. Soils that were poorly drained had more WDS damaged roots. Higher amounts of rainfall, approximately 65 cm, during the growing season resulted in more sweetpotato flea beetle damage than fields with less than half that amount of rainfall. These results suggest that cultural practices (crop rotations and planting/harvesting dates), tillage practices (subsoiling and the number of cultivations), herbicides, and characteristics within growers' fields (soil drainage and rainfall) are some of the more important influences on the incidence of insect damage to sweetpotato roots and may need to be considered in future research projects.

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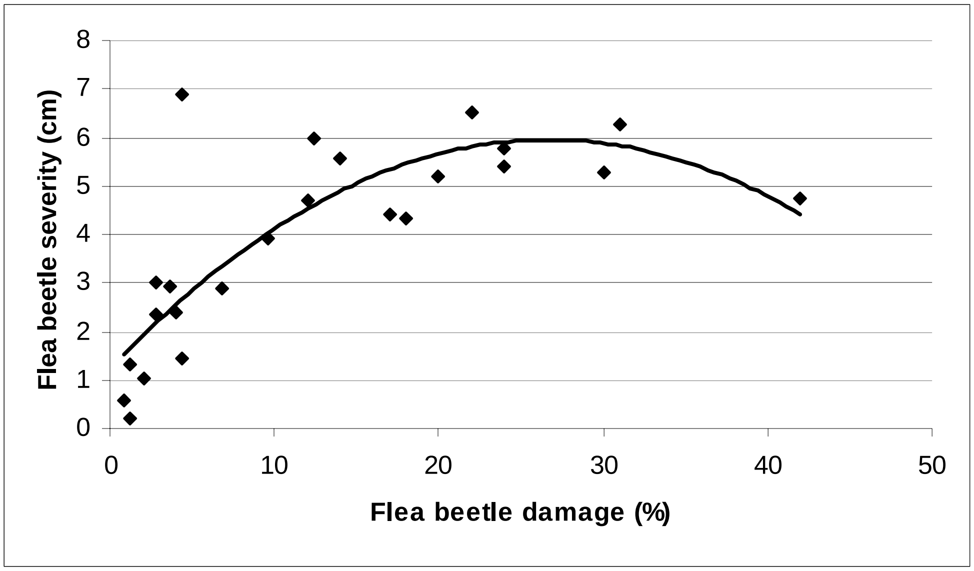
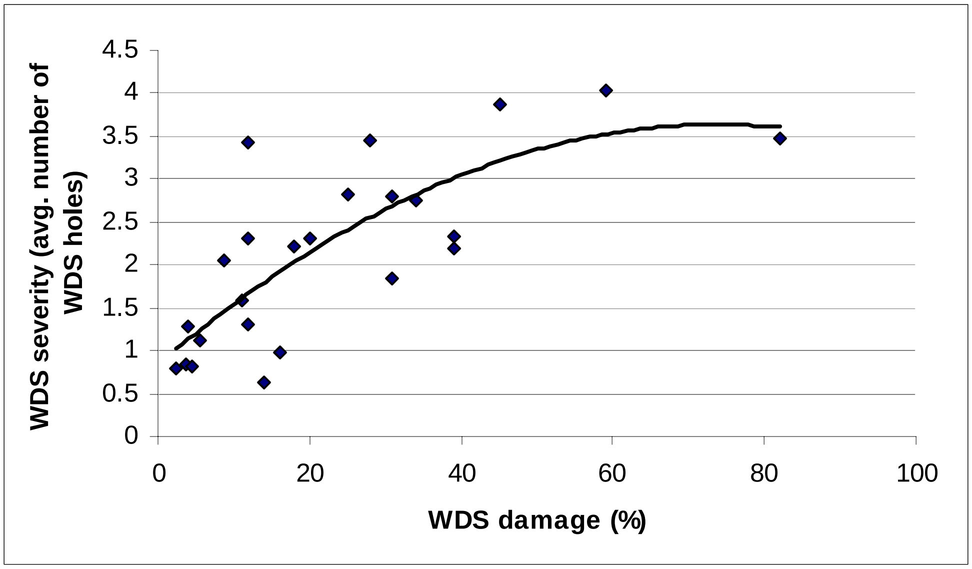
Figure 1.



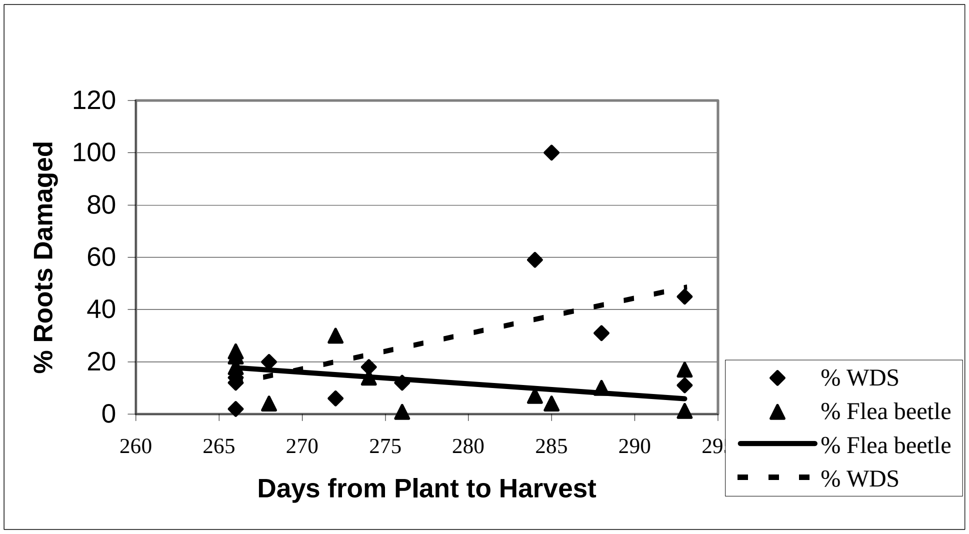
Sweetpotato flea beetle severity as influenced by the incidence of flea beetle damage for 24 field locations in 2002 and 2003 (P = 0.0002; R^2 = 0.464; $y = - 0.00431x^2 + 0.06917x – 0.05799$; df = 1,22; residual MSE = 0.13733).

Figure 2.



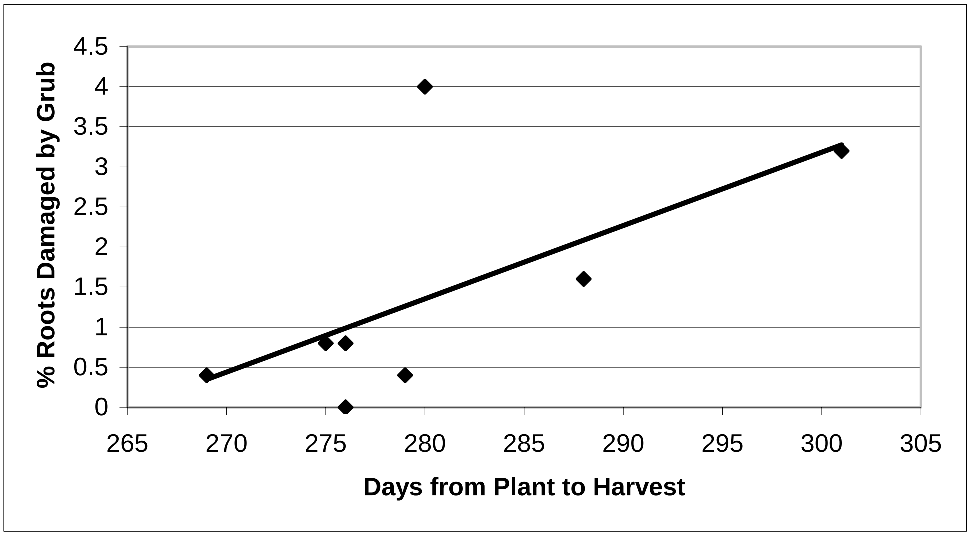
WDS severity as influenced by the amount of WDS damage for 24 field locations in 2002 and 2003 (P = < 0.0001; R^2 = 0.5355; y = $0.02392x^2 + 0.02761x + 0.03514$; df = 1,22; residual MSE = 13.33258).

Figure 3.



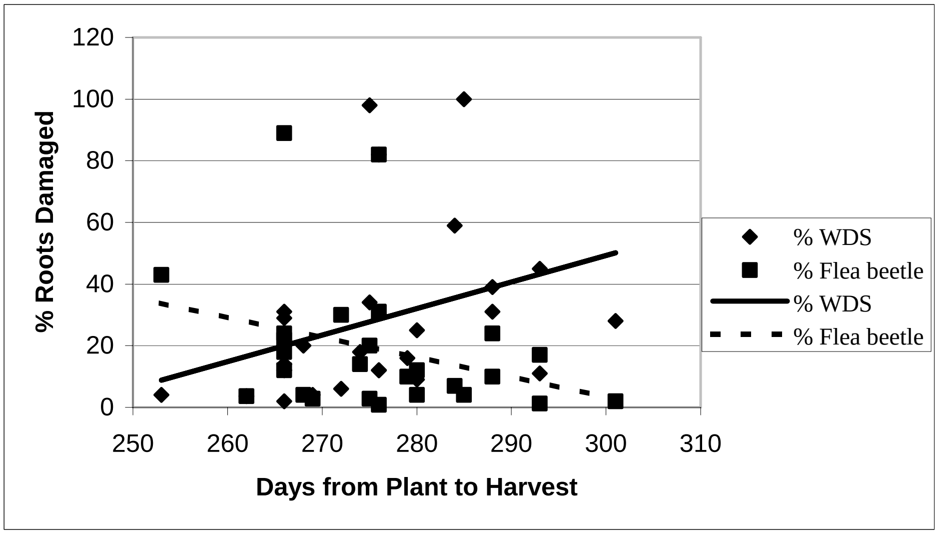
Incidence of WDS and flea beetle damage as influenced by the length of time roots were in the field when growers planted mid-season (*P* = 0.0898, R^2 = 0.2607, y = 272.33217 + 19.07201x, df = 1,10, residual MSE = 318.3 for WDS; *P* = 0.1129, R^2 = 0.232, y = 284.23610 – 52.52188x; df = 1,10, residual MSE = 283.23 for flea beetle).

Figure 4.



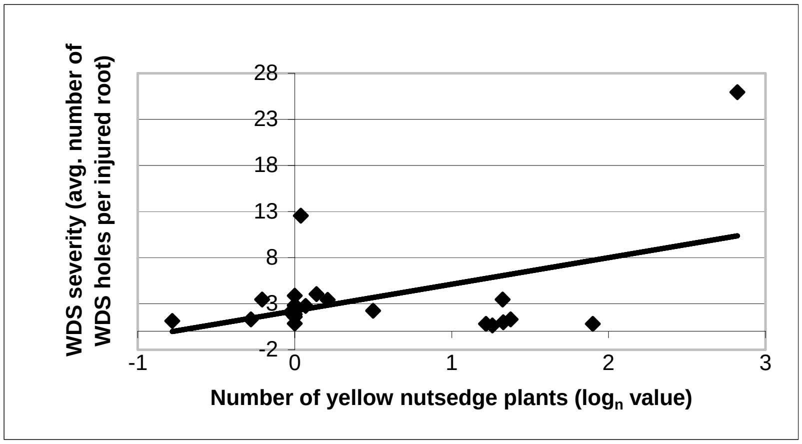
Incidence of white grub damage as influenced by the length of time roots were in the field when planting occurred late at 26 field locations in 2002 and 2003 (P = 0.11, R^2 = 0.3879, y = 274.56522 + 423.91304x, df = 1,6, residual MSE = 264.5).

Figure 5.



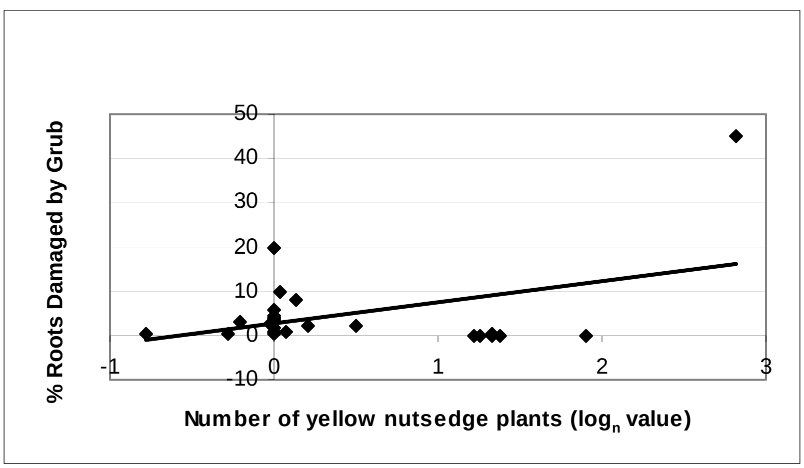
Incidence of WDS and sweetpotato flea beetle damage as influenced by the length of time roots were in the field regardless of planting time ($P = 0.09$, $R^2 = 0.1168$, y = 272.14749 + 13.57925x, df = 1,24, residual MSE = 354.8 for WDS; $P = 0.11$, $R^2 = 0.1032$, y = 278.93259 – 15.63743x, df = 1,24, residual MSE = 313.4 for flea beetle).

Figure 6a.



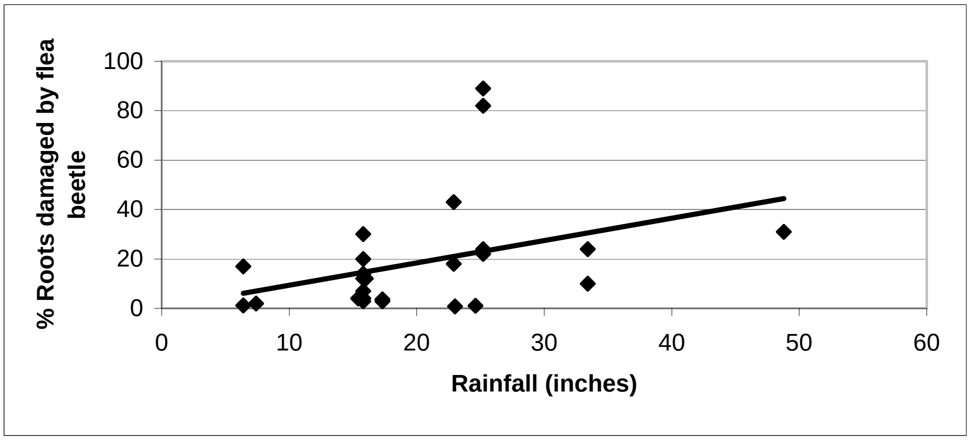
The severity of WDS damage as influenced by the number of yellow nutsedge plants in 26 field locations in 2002 and 2003. The log_n values are reported for the number of yellow nutsedge plants (P = 0.02; R^2 = 0.21; y = 0.16839 + 0.07270x; df = 1,24; residual MSE = 3.47).

Figure 6b.



The incidence of white grub damage as influenced by the number of yellow nutsedge plants in 26 field locations in 2002 and 2003. The logged values of the number of yellow nutsedge plants are reported (P = 0.03, R^2 = 0.1736; y = 0.24879 + 3.66618x, df = 1,24; residual MSE = 2.87).

Figure 7.



The incidence of sweetpotato flea beetle damage as influenced by rainfall at 26 field locations in 2002 and 2003 (P = 0.0686; R^2 = 0.1316; y = 17.39747 + 14.56066; df = 1,24; residual MSE = 271.69040).

Table 1. Incidence and severity of insect damage on sweetpotato roots as influenced by cultural practice or weed presence in 2002 and 2003.

Cultural practice or weed presence[z]	No. of plots	**Flea beetle** %	**Flea beetle** Severity	**WDS** %	**WDS** Severity	**White grub** %	**Total** %
Herbicides							
Yes	170	19	5.3	27	3.5	4.6	41
No	90	11	4.1	66	7.6	5.6	68
	NS	NS	NS	*	NS	NS	NS
Eptam							
Yes	60	11	3.7	38	6.4	11	48
No	200	21	5.9	28	2.8	2.2	41
	NS	NS	NS	NS	NS	*	NS
Foliar							
Yes	190	20	5.3	25	3.3	5.0	42
No	70	15	4.9	47	4.9	3.8	56
	NS	NS	NS	NS	NS	NS	NS
Subsoil							
Yes	150	26	6.8	34	4.4	5.1	52
No	110	8.8	2.6	19	2.2	4.1	31
	NS	*	**	NS	NS	NS	**
Rework							
Yes	120	11	3.8	31	3.2	4.1	42
No	140	25	6.0	25	3.6	5.1	44
	NS	NS	NS	NS	NS	NS	NS
Pigweed Density							
Present	122	15	4.7	28	3.7	5.6	44
Absent	138	20	5.2	27	3.6	5.1	43
	NS	NS	NS	NS	NS	NS	NS
Nutsedge Density							
Present	46	16	4.1	38	5.2	3.4	50
Absent	214	19	5.0	25	2.5	3.2	40
	NS	NS	NS	NS	NS	NS	NS
Total weed Density							
Present	185	19	5.3	28	3.5	4.5	44
Absent	75	21	5.4	24	2.1	3.7	40
	NS	NS	NS	NS	NS	NS	NS

Table 1 (continued)

Time of Bedding							
≤ 1 week	70	10	4.0	34	5.8	9.9	43
> 1 < 3 weeks	90	14	3.3	31	3.1	2.4	41
≥ 3 weeks	100	29	7.2	21	2.1	3.0	45
	NS	NS	NS	NS	NS	NS	NS

[z] NS, *, **, Nonsignificant or significant for associated LS Mean value at P < 0.10, or 0.05, respectively.

Chapter 4

Effects of Time of Planting and Harvesting on Yield and the Incidence of Insect Damage to ‘Beauregard’ Sweetpotato Roots

ABSTRACT

The objective of this research was to evaluate the effects of planting date and harvest date on yield and the incidence and severity of insect damage to ‘Beauregard’ sweetpotato roots. On-farm research was conducted in 2003 and 2004 in 13 growers’ fields in North Carolina, with each field as a replicate. The experiment was a split plot, randomized complete block design. Each grower’s field had an early and late planting date, approximately 30 days apart, which were the whole plot factors. Roots were harvested in each field at approximately 90, 105, and 120 days after each planting date and were the split plot factors. Roots were scored for the incidence and/or severity of damage caused by sweetpotato flea beetles (*Chaetocnema confinis*), wireworm/*Diabrotica* spp./*Systena* spp. (WDS) complex, and white grubs. When sweetpotatoes were planted early, the incidence of flea beetle damaged roots increased 33% as the harvest time increased from 90 to 120 days after planting (DAP) in the first year. However, when sweetpotatoes were established at the later planting time, damage to roots was similar across harvest times and the incidence of damaged roots was 15% greater than in the early planted and early harvested plots. In the second year, an early planting resulted in less WDS damage as roots had fewer and smaller holes per root than a later planting time. Second year results showed that grub damage was 1.7% with an early planting and early harvest, which was an average of 6.4% lower than the incidence of grub damage on roots when sweetpotatees were planted early and harvested 120 DAP, or planted late and harvested 90 DAP. The severity of damage, or length of sweetpotato flea beetle tunnels, number of WDS holes, and diameter of WDS holes, increased as the incidence of damage increased ($P < 0.0001$). The highest yield of number one grade roots was obtained with early plantings and late harvests. Our results suggest that

growers need to plant and harvest early in order to reduce insect damage to sweetpotato roots. However, growers will likely encounter a potential loss in yield of number one grade roots if sweetpotatoes are planted early and harvested early.

INTRODUCTION

Beauregard became the predominant commercial sweetpotato cultivar grown and sold in the United States after its release in 1987 (Rolston et al. 1987; Schultheis and Jester 2002). North Carolina, Mississippi, and Louisiana, account for about 85% of all sweetpotato acreage in the United States (USDA 2004). Approximately 80% of sweetpotato seed sales in North Carolina consist of the Beauregard cultivar, while 99.9% and 100% of sweetpotato seed sales in Mississippi and Louisiana, respectively, are 'Beauregard' (M. Cannon, Z. Pesic van Esbroeck, personal communication).

Although Beauregard is the primary cultivar grown and is valued for its disease resistance, high yields and culinary attributes, it is susceptible to insect damage. Several sweetpotatoe cultivars, such as 'Jewel' or 'Centennial,' are resistant to insects, but 'Beauregard' is not resistant to flea beetle, WDS or whitefringed beetle (Cuthbert and Jones 1978, Jones et al. 1987, Schalk et al. 1991, 1992). Insect pests developed into an important economic concern as 'Beauregard' became a popular cultivar. For example, a survey in Georgia estimated that the cost of controlling soil insects combined with the loss of the sweetpotato crop due to insect injury totaled $530,000 for the 1,072 acres planted to sweetpotato in Georgia in 1997 (Adams and Riley 1997). Because Beuregard is the cultivar most grown in the United States' and is not resistant to several soil insects, insect control related to growers' cultural practices is an important consideration.

'Beauregard' has been included in a limited number of cultural management research studies because it is a relatively new cultivar. In particular, there are limited studies involving soil insects that affect the Beauregard cultivar. For example, in Japan, the starch properties of sweetpotatoes were examined in response to different planting and harvesting dates (Noda et al. 1997). The planting and harvest dates coincided with the United States growing season for sweetpotatoes, but the study did not use the Beauregard cultivar and it did not assess insect damage to the roots. Studies were conducted in Puerto Rico on the morphology, growth, and yield of sweetpotato clones in response to planting dates with year-round production, but insect damage was not examined nor was ‘Beauregard’ tested (Martin 1987, 1988). Another study in Papua New Guinea examined the effect of time of planting on yield of sweetpotatoes (King 1985). Higher yields were correlated with low rainfall, although high levels of damage by the sweetpotato weevil, which was associated with low rainfall or irrigation, reduced yield. A similar study was done in the Solomon Islands on the effect that the time of planting had on yields of sweetpotatoes (Gollifer 1980). Yields were highest during periods of high rainfall and low yields were associated with low rainfall. With the exception of the sweetpotato weevil, insect damage on roots was not evaluated for either study in Papau New Guinea or the Solomon Islands.

A research project that evaluated the population dynamics of whitefringed beetle led to the suggestion that an early planting and early harvest may reduce whitefringed beetle damage to sweetpotato roots (Zehnder 1997), but no other soil-borne insect damage to roots was reviewed in that study. Several studies have been conducted to assess insect damage to sweetpotato roots in response to different chemical insect controls (Chalfant et al. 1979, 1987, 1992, 1993; Day, 1978; Hofmaster and Savage 1978; Johnson et al. 1974). In many of those studies, ‘Beauregard’ was not evaluated. Our objectives were to examine the effects of the time of planting and harvesting on the incidence of damage to ‘Beauregard’ sweetpotato roots caused by various soil insect species and determine the effects on yield.

MATERIALS AND METHODS

Study sites. Five growers provided five field locations in 2003 and six growers provided eight field locations in 2004. Plots were established in each field location to conduct on-farm research experiments for this project. Each field location was treated as a replication, so there were five replications in 2003 and eight replications in 2004. Growers who participated in these studies were from major sweetpotato producing counties in North Carolina, including Nash, Wilson, Sampson, and Johnston (North Carolina Department of Agriculture and Consumer Services, 2003).

Treatments in these studies included two planting times approximately 30 days apart. The "early" date was typically mid to late-May and a "late" planting date was mid to late-June (Table 1). In each replication, both early and late plantings were established within the same field location or in fields that were within 0.5 km of each other and separated by a nonpaved road and/or a row of trees. Two exceptions were that paved roads separated the early and late plantings by 6.4 km for one field location in 2003 and by 3.5 km for one field location in 2004. Roots were harvested at approximately 90, 105, and 120 days after each of the two planting dates resulting in a total of 6 harvest times (treatments) for each replicate (Table 1). Harvest plots (6 total) were established in each field replicate. Each plot consisted of four subplots that were each two rows wide and 9.1 m long in 2003. The subplots were two rows wide and 4.6 m long in 2004 and separated by 6.1 m alleys in both years. In 2003 and 2004, 20 U.S. grade number one roots (North Carolina Department of Agriculture 1979) were collected randomly from each subplot for a total of 80 roots sampled from each plot. The sampled roots were assessed for insect damage. Roots were scored for insect damage as discussed in Chapter 2.

Soil information/Yield. Global Positioning System (GPS) waypoints were taken at each field location in both years with a Garmin "etrex Venture" unit (Olathe, Kansas) so that soil information could be obtained from the Soil Survey Geographic (SSURGO) Database of the Natural Resource Conservation Service (NRCS). The yield of No. 1 roots (diameter of 4.4 cm ≤ 8.9 cm and length of 7.6 cm ≤ 22.9 cm), canner roots (diameter of 2.5 cm ≤ 4.4 cm), and jumbo roots (diameter > 8.9 cm) was obtained in both years (North Carolina Department of Agriculture 1979). All roots in each subplot were harvested and weighed, including the roots that were randomly sampled for insect damage assessment, in order to calculate the yield. Yield was acquired for the five field locations in 2003. In 2004, yield was obtained for seven field locations. Roots were cured and stored in paper bags under normal storage conditions and were scored for insect damage within five months of harvest in 2003 and within five weeks of harvest in 2004.

Marketability. In 2004, five leading sweetpotato packers and shippers in North Carolina were asked to rate a set of 26 sweetpotato roots that represented a wide range of insect damage in order to determine which damaged roots were marketable. WDS damage on those roots ranged from small pinholes less than 1.6 mm in diameter to large holes that were 6.8 mm in diameter. Sweetpotato flea beetle tunneling on those roots ranged from 2.5 to 84.5 cm in length. Roots with grub or whitefringed beetle damage were not included in the survey because roots with such damage are not marketable (North Carolina sweetpotato growers, personal communication).

Statistical analysis. The experiment was a split plot, randomized complete block design, with the two planting times as whole-plot factors and the three harvest times as split-plot factors. Field locations were used as replications, or blocks. Insect damage and sweetpotato yield were across planting and harvest times using analysis of variance (PROC GLM) and mean separations (LSMEANS) using a 0.1 P-value for level of significance for insect damage and a 0.05 P-value level of significance for yield. The incidence of WDS and sweetpotato flea beetle damage was compared to the severity of WDS and sweetpotato flea beetle damage using simple linear regression (PROC REG). The initial calculation of the incidence of insect damage included all damage, whether marketable or unmarketable. A second analysis adjusted the incidences of insect damage by sweetpotato flea beetle, WDS, and overall insect damage by designating roots as damaged by sweetpotato flea beetle or WDS only if the damage was unmarketable.

Several field locations had no grub damage; those locations were excluded from statistical analysis (Table 2). The severity of white grub damage to sweetpotato roots was not assessed in this study because any amount of white grub damage results in an unmarketable root. Data relating yield to the time of planting and harvesting were averaged across both years. However, if differences between years existed for particular sweetpotato grades, yield data were reported according to each year. Yield was compared to harvest time using simple linear regression (PROC REG). The code and output for the data was generated using SAS software (SAS Institute, 2001). SAS codes can be found in Appendix B.

RESULTS

Cultural practices and pesticide information. Data relating insect damage to time of planting and harvesting were analyzed separately for each year because the crop rotations, pesticides used, tillage practices and soil type varied among the field locations in each year (Table 3). In 2003, the crop planted one and two years before sweetpotatoes was mostly cotton. In 2004, the crops planted one year before sweetpotatoes were tobacco for three locations, cotton for two locations, and soybeans for three locations. The crops planted two years before sweetpotatoes in 2004 were cucumbers, cotton, and sweetpotatoes (one field location), tobacco (four locations) and one grower did not know what crop was planted so it was reported as “unknown.”

There were several soil series in the field locations in both years (Table 3). However, a Norfolk series was present at all field locations in both years except three field locations in 2004. All field locations in 2003 had a texture of loamy sand, which was classified as well and/or moderately well drained (Soil Survey Division Staff, 1993). The soil texture in 2004 was mostly loamy sand, sandy loam or sand and the drainage was classified as poorly drained, moderately well drained, well drained, and well/somewhat extensively well drained.

Chlorpyrifos was used at all locations, except one in 2004 (Table 3). Chlorpyrifos was applied at the time that fields were bedded for every location in both years. The tillage practices also varied among locations as well as the row spacing.

Marketability survey. The respondents of the survey rated the marketability of insect-damaged roots dependening on whether the roots could be shipped for retail (i.e. grocery stores), food services (i.e. restaurants), wholesale, or processing for canning. Most of the sweetpotato flea beetle or WDS damage was rated as marketable if roots were to be sold for wholesale and processing, while the same amount and severity of damage was rated as unmarketable if roots were to be sold for retail or food services. Therefore, the determination of marketable or unmarketable insect damage was based on whether roots would be sold for retail or food services, thus providing more conservative ratings of damage. The specific rating of marketability was derived from what the majority of the five respondents answered.

Shippers and packers were conservative about the level of WDS damage on roots sold for retail since very little insect damage on roots is tolerated in grocery stores. The majority of WDS damage was rated as unmarketable. WDS damaged roots were rated as marketable if roots had a total amount of WDS damage equal to or less than 3.4 mm in diameter, or if roots had two WDS holes, each approximately 1.7 mm in diameter. Those roots were not considered to be damaged roots for the calculation of the incidence of unmarketable WDS damage. Any roots with WDS damage more than that amount was considered unmarketable. Roots that had sweetpotato flea beetle damage scars less than 38.5 cm in total length were rated as marketable and those roots were not considered to be damaged roots for the calculation of the incidence of unmarketable flea beetle damage.

When sweetpotato flea beetle damage to roots was calculated only for unmarketability, the incidence of sweetpotato flea beetle damage decreased substantially in both years (Table 4 and 5). This indicates that even though a considerable amount of roots were injured by sweetpotato flea beetle (an average of 38% in 2003 and 40% in 2004), most sweetpotato flea beetle damaged roots were marketable (only 3.1% in 2003 and 1.8% in 2004 were unmarketable). However, the incidences of unmarketable WDS damaged roots did not decrease as much as the incidences of unmarketable flea beetle damaged roots. Roots injured by WDS averaged 19% in 2003 and 22% in 2004. After calculating for unmarketability, WDS damaged roots averaged 8.6% in 2003 and 20% in 2004. The incidences of unmarketable roots due to WDS, flea beetle, and overall insect damage are important calculations in this study because those values excluded marketable insect damage and therefore, consider only damage that affected the market value of sweetpotato roots was examined.

Insect damage for 2003. Whitefringed beetle damage was not detected in any field locations in 2003, so it was not included in the analysis.

Sweetpotato flea beetle. The severity of sweetpotato flea beetle damage was positively correlated to the incidence of flea beetle damage in 2003 ($P < 0.0001$; $R^2 = 0.6139$; df = 1,118). An interaction between planting and harvest time occurred with the incidence of sweetpotato flea beetle damage ($P = 0.05$; $R^2 = 0.85$; df = 13,16) (Table 4). When sweetpotatoes were planted early, the incidence of sweetpotato flea beetle damage increased 33% as harvest time increased 90 to 120 DAP. When sweetpotatoes were established at the later planting time, damage to roots was similar: 45%, 49%, and 42%, with a harvest time of 90, 105 and 120 DAP, respectively (Figure 1).

The incidences of unmarketable roots due to sweetpotato flea beetle and the severity of sweetpotato flea beetle damage were similar, regardless of treatment in 2003 (Table 4). However, a trend occurred where sweetpotato flea beetle severity generally increased as harvest time was delayed.

WDS. The severity of WDS damage was positively correlated to the incidence of WDS damage in 2003 ($P < 0.0001$; $R^2 = 0.5553$; df = 1,118). There were no differences at the $P = 0.10$ level in the incidence of WDS damage, unmarketable roots due to WDS damage, number of WDS holes, or the diameter of WDS holes for the different treatments in 2003 (Table 4).

White grubs. There were no differences in the incidence of grub damage for different planting and harvest times and the interaction between planting and harvest times in 2003 (Table 2).

Overall insect damage. An interaction between planting and harvest time existed with the incidence of overall insect damage ($P = 0.07$; $R^2 = 0.872$; df = 13, 16) (Table 4). When sweetpotatoes were planted early, overall insect damage increased 29% as the harvest time increased from 90 to 120 DAP. As was the case with sweetpotato flea beetle damage, the greatest incidence increase occurred between 105 and 120 DAP. When sweetpotatoes were established at a later planting date, overall insect damage to roots was similar, 51%, 50% and 48% when roots were harvested at 90, 105 and 120 DAP, respectively (Figure 2). There were no differences in unmarketable roots due to overall insect damage with different planting and harvest times and there was no interaction between planting and harvest time in 2003.

Insect damage for 2004. Whitefringed beetle damage was not detected at any field location in 2004, so it was not included in the analysis.

Sweetpotato flea beetle. The severity of sweetpotato flea beetle damage was positively correlated to the incidence of sweetpotato flea beetle damage in 2004 ($P < 0.0001$; $R^2 = 0.4336$; df = 1,190). Harvest time affected the incidence of sweetpotato flea beetle damage ($P = 0.04$; $R^2 = 0.92$; df = 19,28) (Table 5). The incidence of sweetpotato flea beetle damage was similar when harvest was 90 DAP or 105 DAP. The incidence of sweetpotato flea beetle damage was 11% less when roots were harvested 120 DAP compared to 90 DAP. The reason(s) for the decrease in the incidence of sweetpotato flea beetle damage for the 120 DAP harvest time is unknown. No differences between treatments were measured for the severity of flea beetle damage or unmarketable roots due to flea beetle damage with planting and harvest times and an interaction between planting and harvest times in 2004.

WDS. The severity of WDS damage was positively correlated to the incidence of WDS damage in 2004 ($P < 0.0001$; $R^2 = 0.49$; df = 1,190). The severity of WDS damage was affected by planting time ($P = 0.10$; $R^2 = 0.75$; df = 15,13) (Table 5). The average number of WDS holes on roots damaged by WDS was 3.0 when sweetpotatoes were planted early compared to 4.0 holes with a later planting. The diameter of WDS holes was also influenced by planting time ($P = 0.002$; $R^2 = 0.91$; df = 15,13) and harvest time ($P = 0.03$; $R^2 = 0.91$; df = 15,13). The average diameter of WDS holes on roots damaged by WDS was 11.6 mm when sweetpotatoes were planted early compared to 20.5 mm when sweetpotatoes were planted late. The diameter increased 6.4 mm as harvest time progressed from 90 to 120 DAP. This indicates that the diameter increased the longer the sweetpotatoes were in the field.

There were no significant differences in unmarketable roots due to WDS damage for planting times and the interaction between planting and harvest times at the $P = 0.10$ level. However, the incidence of unmarketable roots due to WDS damage approached significance ($P = 0.11$; $R^2 = 0.90$; df = 19,28) as the harvest time was delayed. There was no difference in the incidence of WDS damage among treatments in 2004.

White grubs. The incidence of white grub damage was influenced by an interaction between planting and harvest time ($P < 0.01$; $R^2 = 0.47$; df = 19,28) (Table 2). When sweetpotatoes were planted early, grub damage increased 7.8% as harvest time increased from 90 to 120

DAP (Figure 3). When sweetpotatoes were planted late, grub damage decreased 5% as the harvest time increased from 90 to 120 DAP. An early planting followed by a late harvest of 120 DAP, as well as a late planting with an early harvest of 90 DAP, resulted in the most grub damage (9.5% and 6.7%, respectively).

Overall insect damage. The time of harvest affected the incidence of overall insect damage (P = 0.09; R^2 = 0.94; df = 19,28) as well as the incidence of unmarketable roots due to overall insect damage (P = 0.09; R^2 = 0.88; df = 19,28). The amount of overall insect damage was not different with a harvest of 90 DAP or 105 DAP (53% and 55%, respectively), although the incidence of overall insect damage was 6.0% less when roots were harvested 120 DAP compared to 90 DAP. These results are similar to what was described earlier with the incidence of flea beetle damage to roots.

When the incidence of overall insect damage was calculated only for unmarketability, damage was 8% more with a harvest time of 120 DAP than a harvest time of 90 DAP. There were no differences in the incidence of overall insect damage or the incidence of unmarketable roots due to overall insect damage with planting date or for the interaction between planting and harvest times in 2004.

Yield. Responses to treatments were similar between years for total yield, so statistical analysis for total yield in 2003 and 2004 were combined. The yield was influenced by harvest time (P = 0.01; R^2 = 0.12; df = 21,194; Figure 4). The highest yield was 12 t/ha, which included all grades and was attained with a late harvest time of 120 DAP. The lowest yield was 8.0 t/ha and was obtained with an early harvest time of 90 DAP.

Responses to treatments were similar between years for yield of number one grade roots, so statistical analysis for yield of number one grade roots in 2003 and 2004 were combined. The yield was influenced by harvest time (*P* = 0.0003; R^2 = 0.76; df = 21,50; Figure 5) and planting time (*P* = 0.02; R^2 = 0.76; df = 21,50). Regardless of planting time the highest yield of number one grade roots was 21 t/ha, and was attained with a late harvest time of 120 DAP. The lowest yield was 13 t/ha and was obtained with an early harvest time of 90 DAP.

Some yield responses to planting and harvest date differed between years for the grades for sweetpotato roots, so a separate analysis was conducted for each year. Yield of canner grade roots were different between years (*P* = 0.05; R^2 = 0.77; df = 21,50). The yield of canner grade roots was influenced by planting time in 2003 (*P* = 0.002; R^2 = 0.86; df = 13,16), such that the highest yield, 15 t/ha, occurred with a late planting and the lowest yield, 9.1 t/ha, occurred with an early planting. In 2004, an interaction between planting time and harvest time of canner grade roots approached significance (*P* = 0.12; R^2 = 0.83; df = 17,24), although the yields were similar (Figure 6). An early planting and harvest times of 90, 105, and 120 DAP resulted in canner yields of 8.0 t/ha, 9.4 t/ha, and 8.2 t/ha, respectively. A late planting and harvest times of 90, 105, and 120 DAP resulted in canner yields of 9.9 t/ha, 8.6 t/ha, and 8.8 t/ha, respectively.

There were no differences between years for the yield of jumbo grade roots, so results were combined for both years. The yield of jumbos averaged across years was influenced by harvest time (*P* = 0.03; R^2 = 0.66; df = 21,50; Figure 7). The yield of jumbos increased as harvest time increased, such that when roots were harvested 90 DAP, jumbos yielded 0.6 t/ha, while jumbos yielded an average of 3.5 t/ha when roots were harvested 120 DAP. When grades were compared, number one roots had a higher yield than canner and jumbo grades in both years regardless of the planting and harvest time ($P < 0.0001$; $R^2 = 0.72$; df = 23,192).

DISCUSSION

In several instances, the incidence and severity of insect damage on sweetpotato roots increased as harvest was delayed. These relationships were found with specific soil insect pests as well as damage caused across all insect species. Examples include an increase in sweetpotato flea beetle damage or injury by all insects when sweepotato plantings were established early and harvested late in 2003. And, in 2004, there was an increase in the diameter of WDS holes on roots when harvest was delayed as well as an increase in damage regardless of insect species when roots were harvested late rather than early.

There were many occasions in which the incidence or severity of specific insect species was not greater as time to harvest increased. However, in most cases, the incidence or severity of damage increased numerically as harvest time was prolonged after planting time. Specifically, in 2003, this trend was observed for the incidence of flea beetle damage (14% increase from 90 to 120 DAP). This was also evident in 2004 as the incidence of WDS damage to roots was 19%, 22%, and 25% at 90, 105, and 120 DAP, respectively. This trend was also illustrated by the incidence of injury to roots caused by all insects in 2003, which was 38%, 42% and 52% for 90, 105 and 120 DAP, respectively.

The lack of statistical significance associated with these trends suggests variation in responses between fields, or replications. As mentioned earlier, cultural management practices varied considerably between field locations. For example, all field locations did not have the same crop rotations. In complementary studies, we found more insect damaged sweetpotato roots when cotton, rather than tobacco, was grown in the field prior to sweetpotatoes (Chapter 2). Some of the variation in insect damage to roots may also be attributed to the influence that the environment has on insect life cycles (Dowdy 1944).

Variations in the data could also be a result of differences in the biology of specific species, e.g. within the WDS complex (Brust 1989, Chalfant et al. 1990), especially since the biology is not well known for several wireworm species that affect sweetpotatoes in North Carolina (G.G. Kennedy, personal communication).

Another important consideration is that not all damage to sweetpotato roots by insects results in an economic loss. Flea beetle damage to roots generally resulted in some cosmetic damage, rather than loss of marketability, while damage to roots by WDS generally resulted in an economic loss. Delaying harvest by 30 days typically resulted in an additional 5 to 8% of the sweetpotato crop not being marketable due to insect damage by any species.

Although insect damage can be avoided in many cases by planting early and harvesting early, yields were higher later in the season. The yield of number one grade roots nearly doubled when roots continued to size for an additional 30 days in the field. Anioke (1996) reported similar results, in which saleable yields were highest with an earlier planting and later harvest, although delayed harvesting increased damage to the roots by the sweetpotato weevil (*Cylas puncticollis*). Harvesting early to avoid insect damage may not be financially practical for growers due to reduced yields. However, irrigating fields may be one management method used to obtain earlier yields, since continuous soil moisture promotes primary sweetpotato root development (Pardales et al. 2000). Tysowsky (1971) observed a slight reduction in sweetpotato flea beetle injury to sweetpotato roots with the use of irrigation. Timely irrigation may increase sweetpotato yields earlier in the growing season and therefore, avoid an increase in the incidence and severity of insect damage to roots. The results of these studies indicate that growers will need to consider the effects that the time of planting and harvest has on both yield and insect damage to sweetpotato roots and find cultural mangement methods that will increase early yields and result in less insect damage.

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Table 1. Early and late planting dates, three harvest dates for each planting date, and length of time (number of days after planting) roots were in the field for 13 field locations in North Carolina, 2003 and 2004.

2003										
Grower	**Planting date**		**Harvest dates** (Days in field)			**Planting date**		**Harvest Dates** (Days in field)		
V	**Early**	4/30	7/29 (90)	8/13 (105)	8/28 (120)	**Late**	5/27	8/26 (91)	9/11 (107)	9/23 (119)
K	**Early**	5/9	8/6 (89)	8/22 (105)	9/4 (118)	**Late**	6/21	9/19 (90)	10/3 (104)	10/22 (123)
J	**Early**	5/15	8/13 (90)	8/28 (105)	9/11 (119)	**Late**	6/19	9/16 (89)	10/2 (105)	10/17 (120)
W	**Early**	5/22	8/19 (89)	9/4 (105)	9/18 (120)	**Late**	6/20	9/18 (90)	10/3 (105)	10/17 (119)
L	**Early**	5/21	8/19 (90)	9/4 (106)	9/18 (120)	**Late**	6/24	9/23 (91)	10/7 (105)	10/22 (120)
2004										
Grower	**Planting date**		**Harvest dates** (Days in field)			**Planting date**		**Harvest Dates** (Days in field)		
J608	**Early**	5/20	8/18 (90)	9/1 (105)	9/16 (120)	**Late**	6/21	9/19 (90)	10/1 (102)	10/18 (119)
HW	**Early**	5/24	8/23 (91)	9/7 (106)	9/20 (119)	**Late**	6/28	9/27 (91)	10/11 (105)	10/27 (121)
Wb	**Early**	5/20	8/20 (92)	9/2 (105)	9/16 (119)	**Late**	6/17	9/15 (90)	9/30 (105)	10/15 (120)
Lb	**Early**	5/21	8/18 (89)	9/2 (104)	9/16 (118)	**Late**	6/21	9/20 (92)	10/4 (106)	10/19 (121)

Table 1 (continued)

Jb	**Early**	5/24	8/23 (91)	9/7 (106)	9/20 (119)	**Late**	6/21	9/20 (91)	10/4 (105)	10/19 (120)
R	**Early**	5/27	8/25 (90)	9/9 (105)	9/24 (120)	**Late**	6/25	9/24 (91)	10/8 (105)	10/22 (119)
HJ	**Early**	5/28	8/25 (89)	9/9 (104)	9/24 (119)	**Late**	6/28	9/27 (91)	10/11 (105)	10/27 (121)
K	**Early**	5/27	8/25 (90)	9/9 (105)	9/24 (120)	**Late**	6/21	9/20 (91)	10/4 (105)	10/19 (120)

Table 2. Incidence of white grub damage as influenced by planting date, harvest date, and the interaction between planting date and harvest date in 2003 and 2004.

		% Roots injured 2003[z]	2004[y]
Planting date			
Early		0.6	5.5
Late		2.3	3.8
P-value		0.67	0.12
F-value		0.33	3.15
Harvest date (days after planting)			
90		0.9 a	4.2 a
105		2.5 a	4.1 a
120		1.0 a	5.6 a
P-value		0.52	0.65
F-value		0.78	0.43
Planting date and harvest date interaction			
Early	90	1.3 a	1.7 a[x]
Early	105	0.6 a	5.2 bc
Early	120	0.0 a	9.5 d
Late	90	0.6 a	6.7 cd
Late	105	4.4 a	3.0 ab
Late	120	2.0 a	1.7 a
P-value		0.39	0.007
F-value		1.22	6.0

[z] Only two replications had white grub damage; df = 7,4

[y] Chlorpyrifos was not applied in two of these fields. All eight locations had white grub damage; df = 19, 28.

[x] Mean separations are significant if letters are different at P = 0.10 level.

Table 3. Cultural practices, soil information, and pesticide use of 13 sweetpotato field locations in North Carolina, 2003 and 2004[z].

2003 Location	Rotation[y] 2001	Rotation 2002	Soil Series	Texture[x]	Drainage[w]	Pesticides Used	Disc/Plow in Spring	Subsoil	Bedding[v]	Number of cultivations	Row space
1	cot (early)	tob (early)	Norfolk, Bonneau (early)	LS	W	EPTC	unknown	no (early)	2 weeks (early)	3	40
	sp (late)	cot (late)	Goldsboro, Bonneau,			Glyphosate		yes (late)	1 week (late)		
						Chlorpyrifos					
			Norfolk (late)	LS	MW, W, W	Phosmet					
						Endosulfan					
2	cot (both)	cot (both)	Bonneau, Norfolk (both)	LS	W	Clomazone	yes/no	no (both)	10 to 30 days	4	44
						s-metolachlor			(both)		
						Fluazifop					
						Chlorpyrifos					
						Endosulfan					
						Carbaryl					
3	cot (both)	cot (both)	Norfolk (both)	LS	W	Clomazone	no/no	yes (both)	~ 3 weeks	4	40
						EPTC			(both)		
						Chlorpyrifos					
						Phosmet					
						Endosulfan					
						Carbaryl					
4	soy (early)	cot (both)	Norfolk, Goldsboro,	LS, LS, S	W-MW-MW	Clomazone	yes/no	no (both)	2 weeks	4	40
	cot (late)		Blanton (early)			s-metolachlor			(both)		
			Norfolk, Wagram (late)	LS	W	Chlorpyrifos					
						Phosmet					
						Endosulfan					

Table 3 (continued)

5	cot (both)	cot (both)	Marvyn, Norfolk (early) Norfolk (late)	LS LS	W W	Clomazone Chlorpyrifos Phosmet Endosulfan	unknown	yes (both)	5 weeks (both)	3	40

2004 Location	Rotation 2002	Rotation 2003	Soil series	Texture	Drainage	Pesticides used	Disc/Plow in Spring	Bedding	Number of cultivations	Row space	Hand pull of weeds
6	tob (both)	cot (both)	Faceville (early) Norfolk (late)	FSL LS	W W	clomazone chlorpyrifos	yes/yes	3 weeks	3	40	yes (both)
7	tob (both)	cot (both)	Blanton (both)	S	MW	s-metolachlor chlorpyrifos bifenthrin	no/no	2 to 3 weeks	4	40	yes (both)
8	sp (early) cot (late)	tob (both)	Norfolk (early) Toisnot (late)	LS L	W P	EPTC sethoxydim chlorpyrifos endosulfan phosmet bifenthrin	yes/yes	2 weeks	3	40	yes (early only)
9	tob (both)	soy (both)	Norfolk	SL	W	clomazone s-metolachlor chlorpyrifos endosulfan	yes/yes	2 weeks (early field) 5 weeks (late field)	4	44	yes (both)
10	cot (both)	tob (both)	Blanton (both)	S	W-SE	clomazone s-metolachlor chlorpyrifos bifenthrin	yes/no	2 weeks	3	44	yes (both)
11	unknown (both)	soy (both)	Norfolk (both)	LS	W	clomazone s-metolachlor endosulfan	yes/no	same day	3	46	no (both)

Table 3
(continued)

12	cucs (both)	tob (both)	Norfolk (both)	SL	W	bifenthrin clomazone s-metolachlor chlorpyrifos endosulfan	yes/no	same day	3	46	no (both)
13	Tob (both)	soy (both)	Dothan (both)	LS	W	Bifenthrin clomazone s-metolachlor chlorpyrifos endosulfan carbaryl	yes/yes	2 to 3 weeks	4	44	no (both)

[z] Throughout the table, information pertaining to the field that was planted early is referred to as “early,” and information pertaining to the field that was planted late is referred to as “late;” and if information was the same for both the early-planted and late-planted field than it is designated as “both.”
[y] cot = cotton; sp = sweetpotato; tob = tobacco; soy = soybean; cucs = cucumbers
[x]Texture is defined as: LS = loamy sand, S = sand, FSL = fine sandy loam, SL = sandy loam
[w]Drainage classes are defined as: W= Well drained, W-SE = somewhat excessively well drained, MW = moderately well drained, P = poorly drained
[v] The time that fields were bedded before transplanting is referred to as “bedding.

Table 4. Incidence and severity of insect damage as influenced by planting date, harvest date, and the interaction between planting and harvest date for 5 field locations in 2003 (number one grade roots only).

		Flea beetle			WDS				Injury by all insects	
		% roots injured[z]	Adjusted[y]	Severity[x]	% roots injured[z]	Adjusted[y]	Severity[x]	Diameter	% roots injured[z]	Adjusted[y]
Planting date										
Early		30	0.7	8.4	16	4.2	1.9	2.8	38	4.9
Late		45	3.5	11	22	13	3	6.2	49	15
P-value		0.03	0.41	0.3	0.53	0.37	0.46	0.23	0.06	0.39
F-value		10.97	0.86	1.59	0.47	1	0.7	2.24	7.01	0.94
Harvest date (days after planting)										
90		31 a	0.5 a	8.9 a	17 a	7.6 a	2.4 a	3.7 a	38 a	7.9 a
105		37 a	1.4 a	8.6 a	20 a	9.8 a	2.6 a	4.7 a	42 a	11 a
120		45 a	4.4 a	12 a	20 a	8.4 a	2.3 a	4.5 a	52 a	12 a
P-value		0.15	0.22	0.26	0.6	0.82	0.77	0.9	0.16	0.45
F-value		2.11	1.64	1.58	0.52	0.2	0.27	0.11	2.08	0.84
Planting date and harvest date (interaction)										
Early	90	16 a	0.0 a	6.5 a	14 a	4.0 a	2.2 a	2.9 a	25 a	4.0 a
Early	105	25 ab	0.0 a	7.0 a	15 a	1.8 a	1.6 a	2.1 a	33 ab	2.3 a
Early	120	49 c	2.0 a	10 a	19 a	6.8 a	2.0 a	3.3 a	56 c	8.5 a
Late	90	45 c	1.0 a	10 a	20 a	11 a	2.5 a	4.3 a	51 c	12 a
Late	105	49 c	2.8 a	9.2 a	25 a	18 a	3.9 a	8.1 a	50 c	19 a
Late	120	42 bc	6.7 a	14 a	21 a	10 a	2.7 a	6.2 a	48 bc	15 a

Table 4
(continued)

P-value	0.05	0.71	0.88	0.61	0.2	0.43	0.81	0.07	0.2
F-value	3.65	0.35	0.13	0.5	1.76	0.95	0.22	3.22	1.78

[z] Of all harvested roots.

[y] Adjusted values are the incidence of roots with damage that is considered to be unmarketable.

[x] Flea beetle severity was measure in centimeters; WDS severity was measured as the number of WDS holes per WDS-damaged roots.
Diameter was measured as the average diameter of WDS holes per WDS-damaged roots.
Replications were included in the analysis of severity for WDS if there were more than, or equal to, five roots that sustained WDS damage.
Replications were included in the analysis of severity for flea beetle damage if there were more than, or equal to, ten roots that had flea beetle damage.

Table 5. Incidence and severity of insect damage as influenced by planting date, harvest date, and the interaction between planting and harvest date for 8 field locations in 2004 (number one grade roots only).

		Flea beetle			**WDS**				**Injury by all insects**	
		% roots injured[z]	Adjusted[y]	Severity[x]	% roots injured[z]	Adjusted[y]	Severity[x]	Diameter	% roots injured[z]	Adjusted[y]
Planting date										
Early		43	2.4	10.6	23	21	3	12	56	25
Late		38	1.1	9.4	21	20	4	21	47	24
P-value		0.44	0.27	0.59	0.81	0.95	0.1	0.002	0.35	0.87
F-value		0.67	1.41	0.32	0.06	0	4.73	53.7	1	0.03
Harvest date (days after planting)										
90		40 ab	0.9 a	9.3 a	19 a	16 a	3.3 a	12	53 a	20 a
105		45 a	2.3 a	9.9 a	22 a	20 a	3.5 a	17	55 a	25 ab
120		34 b	2.0 a	11 a	25 a	24 a	3.5 a	18	47 b	28 b
P-value		0.04	0.41	0.13	0.21	0.11	0.77	0.03	0.09	0.09
F-value		3.76	0.91	2.32	1.65	2.42	0.26	4.65	2.61	2.62
Planting date and harvest date (interaction)										
Early	90	43 a	1.4 a	9.5 a	19 a	16 a	2.9 a	8.8 a	56 a	16 a
Early	105	48 a	3.0 a	11 a	24 a	22 a	3.1 a	14 a	61 a	28 a
Early	120	36 a	2.8 a	11 a	25 a	24 a	2.9 a	13 a	51 a	30 a
Late	90	41 a	0.5 a	9.0 a	18 a	17 a	3.8 a	16 a	50 a	23 a
Late	105	41 a	1.6 a	9.0 a	19 a	18 a	4.0 a	21 a	48 a	22 a
Late	120	33 a	1.3 a	11 a	25 a	25 a	4.1 a	24 a	43 a	26 a
P-value		0.88	0.95	0.93	0.66	0.76	0.76	0.26	0.65	0.22
F-value		0.12	0.05	0.07	0.42	0.27	0.28	1.5	0.43	1.61

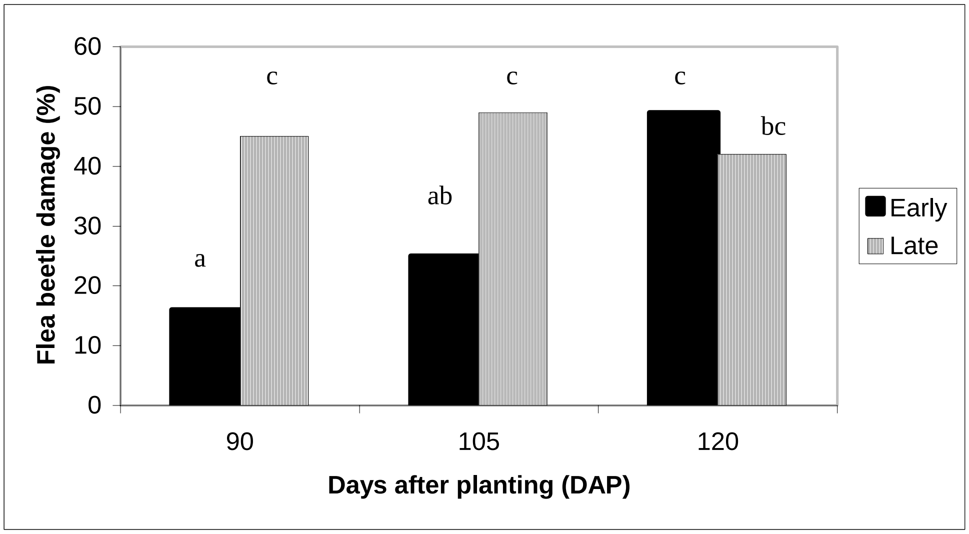
Table 5 (continued)

[z] Of all harvested roots.

[y] Adjusted values are the incidence of roots with damage that is considered to be non-marketable.

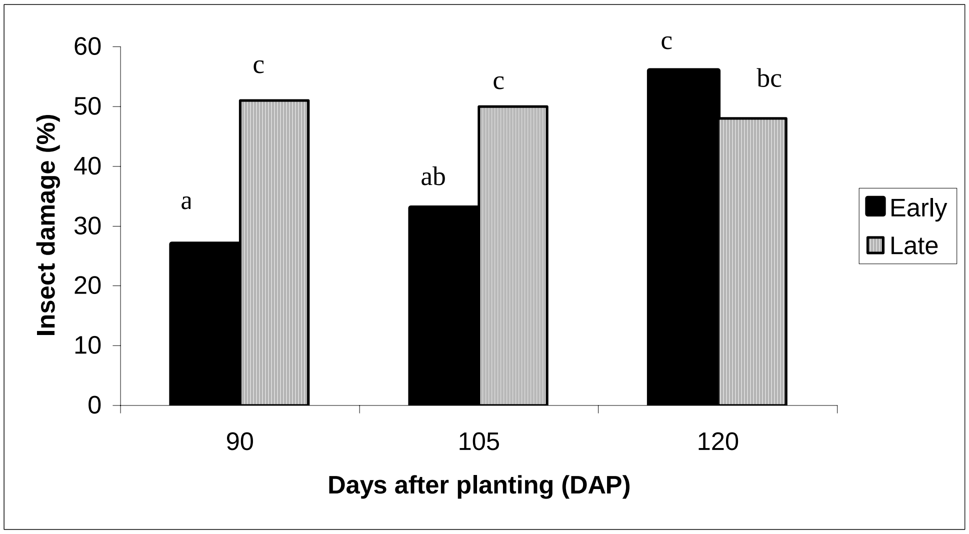
[x] Flea beetle severity was measure in centimeters; WDS severity was measured as the number of WDS holes per damaged roots. Harvested areas (6 total in each replication) were used in the analysis of severity if there were more than, or equal to, 5 roots in each area damaged by WDS And more than, or equal to, 10 roots in each area damaged by flea beetle.

Figure 1.



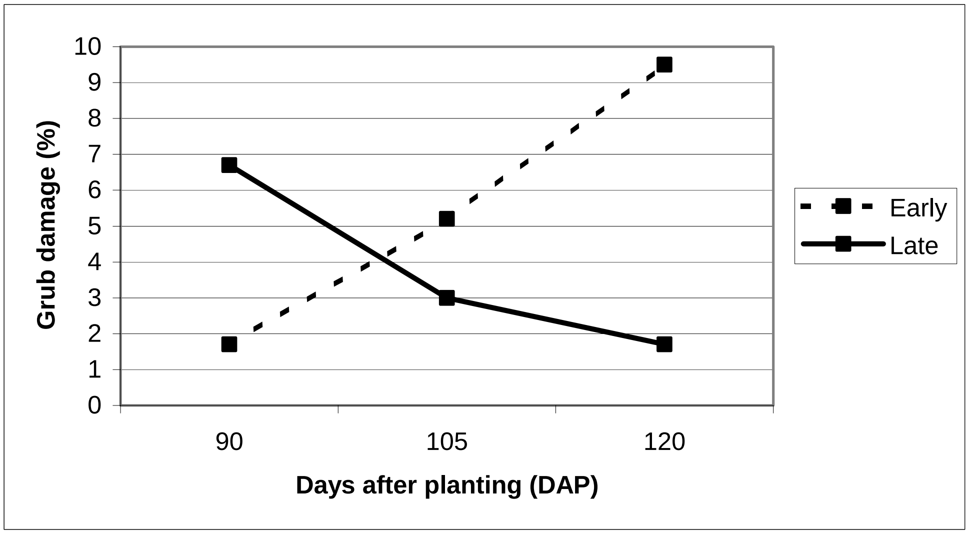
The influence of the interaction between planting time (early and late) and harvest time (90, 105, 120 DAP) on the incidence of flea beetle damage to sweetpotatoes in 2003 (P = 0.05; R^2 = 0.85; df = 13,16).

Figure 2.



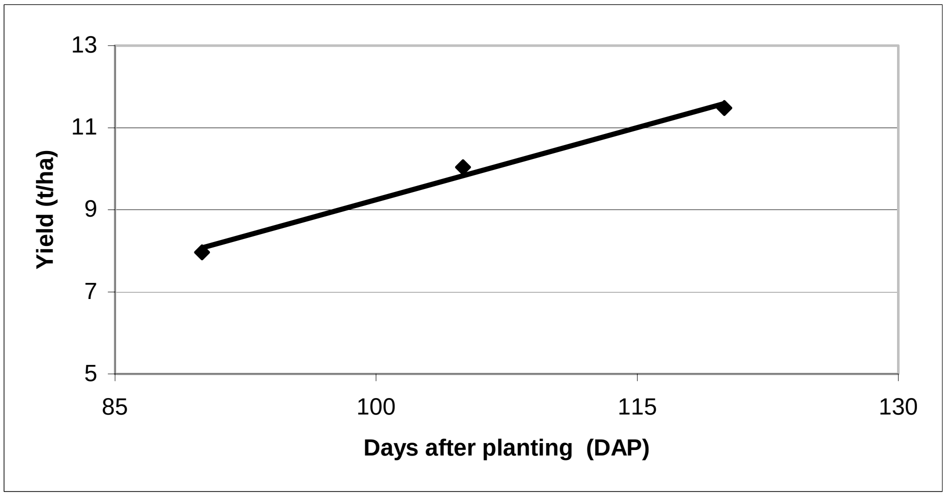
The influence of the interaction between planting time (early and late) and harvest time (90, 105, and 120 DAP) on the incidence of overall insect damage to sweetpotatoes in 2003 (P = 0.07; R^2 = 0.87; df = 13,16).

Figure 3.



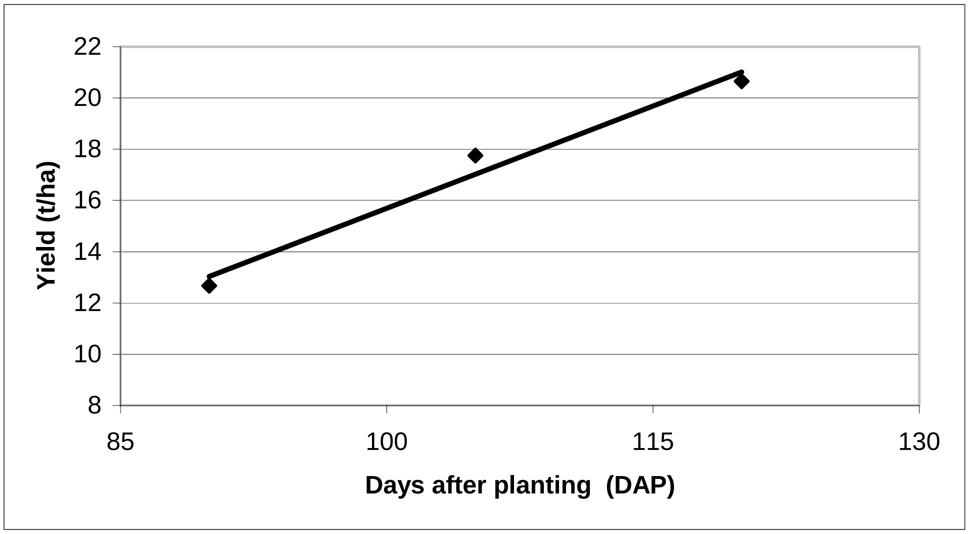
The influence of the interaction between planting time (early and late) and harvest time (90, 105 and 120 DAP) on the incidence of white grub damage to sweetpotatoes in 2004 ($P < 0.01$; $R^2 = 0.47$; df = 19,28); y = - 21.8333 + 0.26x, $R^2 = 0.995$, df = 1,1 for the early planting time and y = 21.3 – 0.167x, $R^2 = 0.93$, df = 1,1 for the late planting time).

Figure 4.



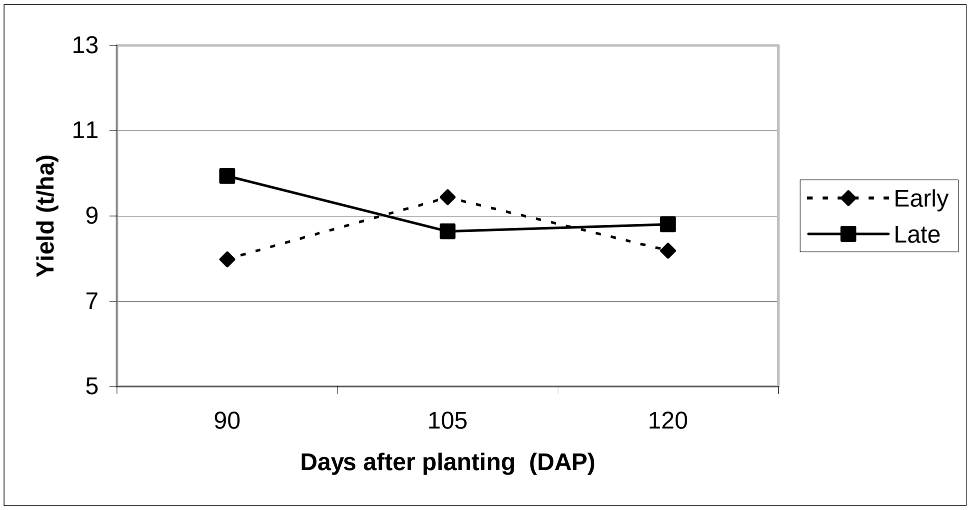
The influence of harvest time (90, 105, and 120 DAP) on the total yield of roots harvested in 2003 and 2004 (P = 0.08; y = -0.251267 + 0.11749x; R^2 = 0.99; df = 1,1). Yield was averaged for each harvest time across all locations for both years.

Figure 5.



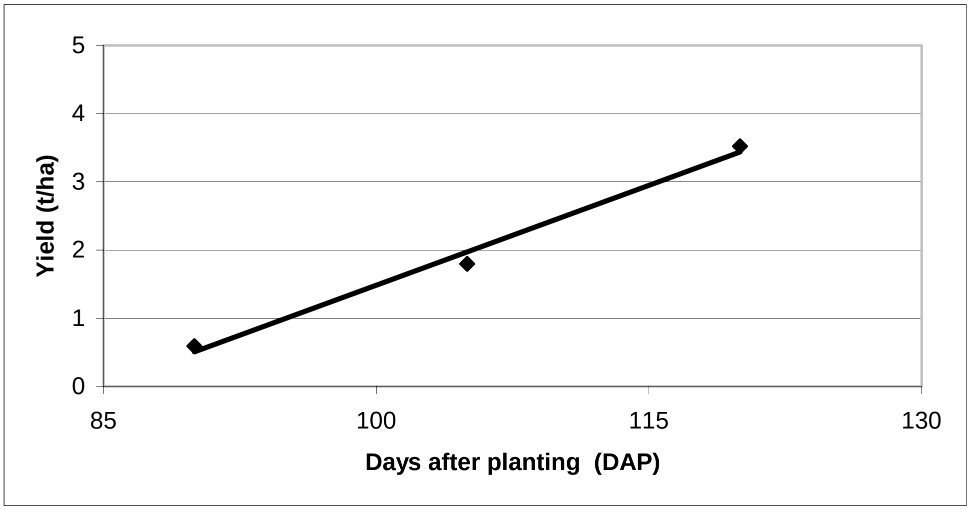
The influence of harvest time (90, 105, and 120 DAP) on the yield of number one grade roots harvested in both years (P = 0.11; y = -10.90423 + 0.26598x; R^2 = 0.98; df = 1,1). Yield of number one grade roots was averaged for each harvest time across all locations in 2003 and 2004.

Figure 6.



The influence of the interaction between planting time (early and late) and harvest time (90, 105, and 120 DAP) on yield of canner grade roots in 2004 (for the interaction P = 0.12; for the early planting time P = 0.92, R^2 = 0.02, df = 1,1 y = 7.808 + 0.00693x; for the late planting time P = 0.41, R^2 = 0.64, df = 1,1, y = 13.0911 – 0.038x). Yield of canner grade roots was averaged for each planting and harvest time across all locations in 2004.

Figure 7.



The influence of harvest time (90, 105, and 120 DAP) on the yield of jumbo grade roots harvested in 2003 and 2004 (*P* = < 0.0001; R^2 = 0.20; df = 1, 70; y = -8.7975 + 0.104x). Yield of jumbo grade roots was averaged for each harvest time across all locations in 2003 and 2004.

Appendices

Appendix A

Tables and Figures

Table 1. Appendix A. Surrounding vegetation in each direction of 26 sweetpotato field locations in 2002 and 2003 in North Carolina.

Location Number	North	South	East	West
1	hardwood	paved	hardwood/ cotton	soybean
2	residential	paved	hardwood	residential
3	soybeans	soybeans	hardwood	paved
4	hardwood	weed line	hardwood	soybeans
5	paved	hardwood	sweetpotato	pond
6	cotton	hardwood	cotton	weeds
7	hardwood	hardwood	hardwood	paved
8	sweetpotato	weeds	paved	building
9	residential	residential	paved	soybeans
10	paved	sweetpotato	weeds	hardwood
11	weeds	hardwood	residential	hardwood
12	paved	soybean	tobacco/weed line	cotton/weeds
13	hardwood	hardwood	weeds	pond/hardwood
14	sweetpotato	hardwood	hardwood	hardwood
15	sweetpotato	weeds	sorghum	residential
16	sweetpotato	tobacco	paved	hardwood
17	hardwood	residential	sweetpotato	sweetpotato
18	sweetpotato	fallow	sweetpotato	soybean/cotton
19	hardwood	paved	hardwood	ditch/soybean
20	hardwood	tobacco	cucumber	fallow
21	hardwood	ditch/paved	residential	residential
22	hardwood	sweetpotato	sweetpotato	hardwood
23	hardwood	ditch/paved	hardwood	ditch/soybean
24	hardwood	corn	hardwood	hardwood
25	hardwood	ditch/paved	ditch/paved	hardwood
26	soybeans	hardwood	hardwood	sweetpotato

Surrounding vegetation of North Carolina growers’ fields in 26 locations, 2002 and 2003. The “hardwood” category of “Surrounding Vegetation” includes conifers and deciduous trees and “paved” indicates that the area next to the field was a paved road. A category with a slash separating two different descriptions, e.g. “ditch/soybean,” indicates that both a ditch and a soybean field described the surrounding vegetation.

Table 2. Appendix A. Insecticide information for 22 sweetpotato growers in North Carolina in 2002 and 2003.

Location 2002	Chlorpyrifos	Timing of chlorpyrifos application	Carbaryl	Endosulfan	Imidacloprid	Phosmet	Rates (per acre)
1	✓	17 days preplant	✓ [z]	✓ [z]		✓ [z]	10 lb, 2 qt, 2 lb, 1 lb
2	✓	3 weeks preplant	✓ 3	✓ 2			2 qt, 1 qt, 1 qt
3	✓	4 days preplant		✓ 1		✓ 2	2 qt, 1.3 qt, 2.3 pt
4	✓	Preplant [y]		✓ 1		✓ 1	not reported
5	✓	Preplant [y]		✓ [z]		✓ [z]	2 qt
6	✓	~ 3 weeks preplant		✓ 3		✓ 2	[x]
7		N/a		✓ 2		✓ 2	1.3 pt, 3.25 pt
8	✓	~3 weeks preplant					2 qt
9	✓	~ 4 weeks preplant		✓ 1		✓ 1	2 qt, 1 qt, 1.3 lb
11	✓	1 day preplant	✓ 1	✓ 3	✓ 1	✓ 2	1.6 pt, 1.5 qt, 1qt, 4 oz, 1.3 lb
13	✓	~ 4 weeks preplant		✓ 3		✓ 1	13 lb, 1 qt, 1.3 lb
Location 2003	Chlorpyrifos	Timing of chlorpyrifos application	Carbaryl	Endosulfan	Imidacloprid	Phosmet	Rates (per acre)
16	✓	~ 2 months preplant		✓ 2		✓ 1	13 lb, 1 qt, 1.5 qt
17	✓	1 week preplant					

Table 2 (continued)							
18	✓	at planting		✓1		✓1	1 qt, 1.3 lb
19	✓	at planting		✓1		✓1	1 qt, 1.3 lb
20	✓	~ 3 weeks preplant		✓2		✓2	2 qt, 2/3 qt, 3.25 pt
21	✓	1 week preplant		✓1		✓3	[x]
22	✓	1st cultivation after planting					15-16 lb
23	✓	at planting		✓1		✓1	1 qt, 1.3 lb
24	✓	~ 3 weeks preplant		✓2		✓1	2 qt, 1qt, 1.3 lb
25	✓	2 weeks preplant		✓1	✓1		2 qt, not reported, 7-8 oz
26	✓	2 weeks preplant		✓3	✓1		2 qt, not reported, 7-8 oz

Insecticide use of North Carolina sweetpotato growers in 26 field locations for 2002 and 2003. Rates are given in respective order of listed insecticides. Number of applications is reported next to check mark. Insect damage is a incidence of roots damaged by any species or group of species out of the total number of roots harvested from each location.

[z] Sprayed at 10-day intervals

[y] Grower did not indicate the number of days or weeks prior to planting that chlorpyrifos was applied.

[x] Reported following recommended spray rates

Table 3. Appendix A. Herbicide information and corresponding overall incidence of insect damage for 18 sweetpotato growers in North Carolina in 2002 and 2003.

Location 2002	Fluazifop	Glyphosate	EPTC	Clom-azone	Napro-pamide	Seth-oxydim	s-metola-chlor	Rates (per acre)	Number of applications	Insect damage
1				✓				1.5 pt	1	7.2
2	✓	✓						12 oz, not reported	not reported	13.2
3				✓				1.5 pt	1	14.1
4			✓	✓				not reported	not reported	15.7
5				✓				1.5 pt	1	20.9
8			✓		✓		✓	1 qt, 2 lb, 2/3 lb	not reported	32
11		✓	✓	✓		✓		1.5 pt, 1 pt, 1 pt, 1 pt	1, 1, 1, 1	37.7
12			✓	✓				2.25 to 3.5 pt, 1.5 pt	not reported	63.4
15			✓	✓				2.25 to 3.5 pt, 1.5 pt	not reported	100
Location 2003	Fluazifop	Glyphosate	EPTC	Clom-azone	Napro-pamide	Seth-oxydim	s-metola-chlor	Rates (per acre)	Number of applications	Insect damage
16				✓				1 qt	1	37.6
17				✓				1.5 pt	1	54.4

Table 3 (continued)										
18							✓[z]	¾ pt	1	92.7
19							✓[z]	¾ pt	1	23.6
20		✓	✓					1qt, 1qt	1, 2	39.6
21				✓		✓		1.5 pt, 1.5 pt	1, 2	25.3
22				✓				1.5 pt	1	17.6
23							✓[z]	¾ pt	1	33.2
24				✓				1.8 pt	1	92.0

Herbicide use of North Carolina sweetpotato growers in 26 field locations for 2002 and 2003. Rates and number of applications are given in respective order of listed insecticides. Insect damage is reported as a incidence of roots damaged by any species or group of species out of the total number of roots for each location.

[z] Grower reported applying five days after planting.

Table 4; Appendix A. Sweetpotato acreage of 16 growers in North Carolina in 2002 and 2003.

Grower	Approximate acreage of fields planted with 'Beauregard' by each grower every year^{z}	Approximate acreage of fields planted with 'Beauregard' by each grower in which samples for the on-farm research project were harvested		Incidence of 'Beauregard' acreage represented by each grower for the on-farm research project in both years^{w}
		2002^{y}	2003^{x}	
1.	300	13	n/a	4.33
2.	2,763	16	n/a	0.58
3.	1,000	125	n/a	12.5
4.	800	10	n/a	1.25
5.	400	10	n/a	2.50
6.	525	7.7	9.0	3.18
7.	200	13	n/a	6.50
8.	800	7.54	50	7.19
9.	185	28.5	n/a	15.4
10.	600	10	22	5.33
11.	250	10	n/a	4.00
12.	850	2.5	6.0	10.0
13.	120	n/a	13.6	11.3
14.	125	n/a	2.0	1.60
15.	1600	n/a	6.0	0.38
16.	100	n/a	32	32.0

^{z}Total acreage of 'Beauregard' planted by growers each year (approximate): 10,618
^{y}Total acreage of fields planted with 'Beauregard' from which roots were sampled in 2002 (approximate): 952.54
^{x}Total acreage of fields planted with 'Beauregard' from which roots were sampled in 2003 (approximate): 140.6
^{w}Average incidence of acres in which 'Beauregard' roots were sampled from growers fields in 2002 and 2003 (approximate): 7.3

Table 5. Appendix A. Total number of pigweed at 22 sweetpotato field locations (1-4; 6-23)[z] and ten sample sites within each field (1-10) in 2002 and 2003 in North Carolina. Locations 5, 24, 25, and 26 had no pigweed in all sites and are not included in this table.

Field No./Site	**2**	**11**	**14**	**8**	**10**	**1**	**6**	**9**	**3**	**15**	**12**	**7**	**13**	**4**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
1	0	2	0	0	5	0	0	56	0	7	0	0	0	16	41	17	6	0	15	18	2	0
2	1	10	0	2	10	0	0	3	1	4	0	1	1	19	12	65	0	11	0	0	2	0
3	0	2	0	1	1	0	0	0	2	0	1	0	0	18	64	1	5	0	8	11	0	0
4	5	0	0	4	12	4	0	23	1	1	41	4	0	5	17	54	0	10	0	0	0	0
5	0	1	0	5	18	0	0	0	0	0	3	4	0	6	40	5	9	0	9	15	0	0
6	13	0	0	1	12	3	38	0	0	3	0	3	0	6	32	59	0	17	1	0	0	3
7	12	2	7	0	2	0	0	10	0	3	0	3	1	6	24	98	5	0	20	21	0	0
8	5	0	7	0	22	0	0	2	0	3	0	0	0	7	8	10	0	13	0	0	0	1
9	27	1	6	0	4	0	6	0	0	4	0	0	0	5	15	2	7	1	18	14	0	0
10	3	0	5	5	6	17	0	6	1	4	0	0	0	2	33	3	0	16	1	0	0	2
Average	**6.6**	**1.8**	**2.5**	**1.8**	**9.2**	**2.4**	**4.4**	**10**	**0.5**	**2.9**	**4.5**	**1.5**	**0.2**	**9**	**29**	**31**	**3.2**	**6.8**	**7.2**	**7.9**	**0.4**	**0.6**

Table 6. Appendix A. Total number of large crabgrass at 16 sweetpotato field locations (1-16) and ten sites within each field in 2002 and 2003 in North Carolina. Locations 17-26 had no large crabgrass in all sites and were not included in this table.

Field No./ Site	**2**	**11**	**14**	**8**	**10**	**1**	**5**	**6**	**9**	**3**	**15**	**12**	**7**	**13**	**4**	**16**
1	2	1	5	0	1	0	0	0	1	24	1	0	0	0	0	0
2	1	0	0	0	0	1	0	0	0	24	1	0	0	0	0	0
3	0	0	2	0	0	0	0	0	2	24	0	0	0	0	0	0
4	3	3	2	0	0	0	0	0	0	0	1	0	1	0	0	2
5	2	0	11	0	0	0	0	0	0	0	4	0	0	0	0	0
6	0	0	1	0	0	6	0	0	0	12	3	0	0	0	0	0
7	0	1	4	0	0	0	0	0	1	6	2	0	0	0	0	0
8	0	0	12	0	0	0	0	0	0	0	1	0	0	0	0	0
9	0	0	12	0	0	0	0	0	0	0	2	0	0	1	0	0
10	2	0	12	0	0	1	0	0	0	0	0	0	0	2	0	0
Avg.	**1**	**0.5**	**6.1**	**0**	**0.1**	**0.8**	**0**	**0**	**0.4**	**9**	**1.5**	**0**	**0.1**	**0.3**	**0**	**0.2**

Table 7. Appendix A. Total number of yellow nutsedge at 16 sweetpotato field locations and ten sites (1-10) within each field in 2002 and 2003 in North Carolina. Field locations 2, 11, 5, 13, 4, 16, 17, 18, 20, 21 had no yellow nutsedge in all sites and were not included in this table.

Field No./Site	**14**	**8**	**10**	**1**	**6**	**9**	**3**	**15**	**12**	**7**	**19**	**22**	**23**	**24**	**25**	**26**
1	0	0	0	2	1	0	0	3.7	2	0	0	2.4	2.7	2.6	2.4	2.5
2	3	12	0	3	0	0	0	3.8	26	0	6	2.9	0	2.8	0	0
3	34	0	0	0	0	0	0	3.6	0	0	5	2.6	2.7	2.7	2.5	2.6
4	0	0	0	0	0	0	36	3.7	0	7	0	2.7	0	2.7	0	0
5	20	0	0	0	0	0	40	3.7	0	2	1	2.6	2.6	2.5	2.6	2.7
6	2	0	7	0	0	0	0	3.6	0	0	0	0	0	0	0	0
7	8	0	0	0	2	1	0	3.6	0	0	0	0	2.7	0	2.5	2.4
8	0	0	0	0	0	0	0	3.5	0	0	6	0	0	0	0	0
9	17	0	0	0	0	0	0	3.3	11	0	0	0	2.9	0	2.2	2.4
10	1	0	0	0	1	0	0	3.4	0	0	0	0	0	0	0	0
Average	**8.5**	**1.2**	**0.7**	**0.5**	**0.4**	**0.1**	**7.6**	**3.6**	**3.9**	**0.9**	**1.8**	**1.3**	**1.4**	**1.3**	**1.2**	**1.3**

Table 8. Appendix A. Total number of cocklebur at five sweetpotato field locations and ten sites (1-10) within each field in 2002 and 2003 in North Carolina. Locations 1-5, 7, 8, 10-13, 16-23, 25, 26 had no cocklebur in all sites and were not included in this table.

Field No./Site	**14**	**6**	**9**	**15**	**24**
1	0	9	0	1	0
2	0	3	0	0	0
3	0	4	0	0	1
4	0	7	0	1	0
5	0	0	0	1	0
6	0	0	0	2	0
7	0	0	1	1	0
8	7	0	0	1	0
9	0	0	0	0	0
10	0	0	0	0	0
Average	**0.7**	**2.3**	**0.1**	**0.7**	**0.1**

Table 9. Appendix A. Total number of sicklepod for nine sweetpotato field locations and ten sites (1-10) within each field in 2002 and 2003 in North Carolina. Field locations 1-5, 7, 10, 11, 15, 18-26 had no sicklepod in all sites and were not included in this table.

Field No./Site	**14**	**8**	**6**	**9**	**3**	**12**	**13**	**17**	**16**
1	0	2	0	0	1	7	0	0	0
2	0	0	2	1	0	2	0	0	0
3	0	0	0	4	0	1	0	0	0
4	0	0	0	0	0	77	1	1	0
5	1	0	0	0	0	0	0	0	0
6	0	1	0	0	0	0	0	0	0
7	0	0	0	0	0	0	1	0	0
8	0	3	0	0	0	0	0	0	0
9	0	2	0	11	0	0	0	1	1
10	0	0	0	61	0	0	0	0	0
Average	**0.1**	**0.8**	**0.2**	**7.7**	**0.1**	**8.7**	**0.2**	**0.2**	**0.1**

Table 10. Appendix A. Total number of florida pussley for five sweetpotato field locations (A-AA) and ten sites within each field in 2002 in North Carolina. Field locations 1, 3-6, 8-10, 12, 13, 15-24, and 26 had no florida pussley in all sites and were not included in this table.

Field No./Site	**2**	**11**	**14**	**7**	**25**
1	6	0	7	0	0
2	0	2	3	0	0
3	0	21	0	0	0
4	6	25	31	5	0
5	6	0	6	0	0
6	5	0	0	0	0
7	0	0	0	0	0
8	1	7	0	0	1
9	3	5	14	0	0
10	0	1	14	3	0
Average	**2.7**	**6.1**	**7.5**	**0.8**	**0.1**

Table 11. Appendix A. Total number of tropical croton for seven sweetpotato field locations and ten sites within each field in 2002 in North Carolina. Field locations 3-6, 8-10, 12, 13, 15, 17-23, 25, and 26 had no tropical croton in all sites and were not included in this table.

Field No./Site	2	11	14	1	7	16	24
1	1	0	1	0	0	0	1
2	0	1	2	0	0	2	1
3	1	0	3	0	0	2	1
4	0	0	2	0	3	2	0
5	1	0	1	0	0	1	1
6	0	0	0	1	0	1	0
7	0	0	17	0	0	2	0
8	0	0	0	0	0	0	0
9	0	0	7	0	0	0	0
10	0	0	10	0	0	3	0
Average	**0.3**	**0.1**	**4.3**	**0.1**	**0.3**	**1.3**	**0.4**

Appendix B

SAS Codes

Chapter III

Crop rotations / Field management / Weed management / Insect management

```
%macro allvar(var1);
proc glm data=in.data2;
class &var1 loc subplot ;
model fbprop--total= &var1 loc(&var1) subplot subplot*&var1;
test h=&var1 e=loc(&var1);
lsmeans &var1/ stderr pdiff e=loc(&var1);
run;
quit;
%mend allvar;
%allvar(rotation1yr)
%allvar(rotation2yr)
%allvar(herbicides)
%allvar(foliar)
%allvar(Lorsban)
%allvar(Lorsbanappl)
%allvar(cultivations)
%allvar(drainage)
%allvar(subsoil)
%allvar(bedding)
%allvar(rework)
%allvar(Eptam)
```

Planting dates and duration of roots in the field.

```
proc reg data=a;
model julian=total;
model julian=fbprop;
model julian=wdsprop;
model julian=grubprop;
model julian=fbcm;
model julian=wdsholes;
model julian=grubles;
title "EARLY PD";
proc plot julian*total;
proc plot julian*fbprop;
proc plot julian*wdsprop;
proc plot julian*grubprop;
run;
quit;

proc reg data = a;
model julian=total;
model julian=fbprop;
model julian=wdsprop;
model julian=grubprop;
model julian=fbcm;
model julian=wdsholes;
model julian=grubles;
title "MID PD";
run;
quit;
```

```
proc reg data=a;
model julian=total;
model julian=fbprop;
model julian=wdsprop;
model julian=grubprop;
model julian=fbcm;
model julian=wdsholes;
model julian=grubles;
title "LATE PD";
proc plot julian*total;
proc plot julian*fbprop;
proc plot julian*wdsprop;
proc plot julian*grubprop;
run;
quit;

proc reg data = a;
model julian=total;
model julian=fbprop;
model julian=wdsprop;
model julian=grubprop;
model julian=fbcm;
model julian=wdsholes;
model julian=grubles;
title "DAMAGE REGARDLESS OF PD";
run;
quit;
```

Weeds.

```
proc reg data=a;
model nutsedge = grubprop;
model nutsedge = grubles;
model nutsedge = wfprop;
model nutsedge = wfles;
model nutsedge = total;
model nutsedge = fbprop;
model nutsedge = fblength;
model nutsedge = wdsprop;
model nutsedge = wdsholes;
proc plot data=a;
plot nutsedge*grubprop;
plot nutsedge*grubles;
plot nutsedge*fbprop;
plot nutsedge*fblength;
plot nutsedge*total;
plot nutsedge*wdsprop;
plot nutsedge*wdsholes;
plot nutsedge*wfprop;
plot nutsedge*wfles;
run;
quit;

proc reg data=a;
model pig = grubprop;
```

```
model pig = grubles;
model pig = wfprop;
model pig = wfles;
model pig = total;
model pig = fbprop;
model pig = fblength;
model pig = wdsprop;
model pig = wdsholes;
proc plot data = a;
plot pig*grubprop;
plot pig*grubles;
plot pig*wfprop;
plot pig*wfles;
plot pig*total;
plot pig*fbprop;
plot pig*fblength;
plot pig*wdsprop;
plot pig*wdsholes;
run;
quit;
```

Soil drainage.

```
proc print; run;
proc sort data=a; by loc drain;
proc means data=a noprint; by loc drain;
output out=mn mean=;
var fbprop fblen wdsprop wdshol grubprop grubles total;
data mn; set mn;
proc print data=mn; run;
proc glm data=mn; class loc drain;
model fbprop fblen wdsprop wdshol grubprop grubles total= drain;
means drain;
run;
quit;
```

Rainfall.

```
proc reg data = a;
model rain=total;
model rain=fbprop;
model rain=wdsprop;
model rain=grubprop;
model rain = wfprop;
title "rainfall";
run;
quit;
```

Severity versus Proportion.

```
proc reg data = a;
model fbprop = fbcm;
model wdsholes = wdsprop;
run;
quit;
```

Chapter IV

Analysis of insect damage for 2003.

```
proc print; run;
title "2003 only";
proc sort data=a; by loc pd hd ;
proc means data=a noprint; by loc pd hd  ;
output out=mn mean= ;
var Fbpropdmg fbadj     fblengthdmg WDSpropdmg WDSadj WDSholesdmg
WDSdiam grubpropdmg     grublesiondmg     Total totaladj;
data mn; set mn;
sqwdsho=sqrt(wdsholesdmg); arwdspr = arsin(sqrt(wdspropdmg));
proc print data=mn; run;

proc glm data=mn; class loc pd hd ;
model Fbpropdmg fbadj   fblengthdmg WDSpropdmg WDSadj  arwdspr
      WDSholesdmg WDSdiam sqwdsho
      Total totaladj= loc|pd hd hd*pd ;
test h=loc pd e=loc*pd;

means pd loc*pd pd*hd hd;
output out=p p= pfbpr pfbln pwdspr parwdspr pwdsho psqwdsho ptot
             r= rfbpr rfbln rwdspr rarwdspr rwdsho rsqwdsho rtot;
lsmeans pd hd pd*hd /sterr pdiff e = loc(pd);
run;
proc plot data=p; plot rfbpr*pfbpr rfbln*pfbln rwdspr*pwdspr
rarwdspr*parwdspr
rwdsho*pwdsho rsqwdsho*psqwdsho  rtot*ptot /vref=0;
run;


proc glm data=mn; class loc pd hd ; where loc in ('K','W');
model grubpropdmg grublesiondmg     = loc|pd hd hd*pd
                                       ;
test h=loc pd e=loc*pd;
test h=hd hd*pd e=hd*loc(pd);

means loc*pd pd*hd hd pd;
run;
```

Analysis of insect damage for 2004.

```
proc print; run;
title "2004 only";
proc sort data=a; by loc pd hd ;
proc means data=a noprint; by loc pd hd  ;
output out=mn mean= ;
var Fbpropdmg fbadj     fblengthdmg WDSpropdmg WDSadj WDSholesdmg
WDSdiam grubpropdmg     grublesiondmg     Total totaladj;
data mn; set mn;
sqwdsho=sqrt(wdsholesdmg); arwdspr = arsin(sqrt(wdspropdmg));
proc print data=mn; run;

proc glm data=mn; class loc pd hd ;
```

```
model Fbpropdmg fbadj   fblengthdmg WDSpropdmg WDSadj arwdspr
      WDSholesdmg sqwdsho
      WDSdiam Total totaladj= loc|pd hd hd*pd  ;
test h=loc pd e=loc*pd;

means pd loc*pd pd*hd hd;
output out=p p= pfbpr pfbln pwdspr parwdspr pwdsho psqwdsho ptot
             r= rfbpr rfbln rwdspr rarwdspr rwdsho rsqwdsho rtot;
lsmeans pd hd pd*hd/sterr pdiff e = loc(pd);
run;
proc plot data=p; plot rfbpr*pfbpr rfbln*pfbln rwdspr*pwdspr
rarwdspr*parwdspr
rwdsho*pwdsho rsqwdsho*psqwdsho  rtot*ptot /vref=0;
run;


proc glm data=mn; class loc pd hd ; where loc in
('Lb','Kb','Wb','Jb','R','J608','HJ','HW');
model grubpropdmg grublesiondmg     = loc|pd hd hd*pd
                                       ;
test h=loc pd e=loc*pd;


means loc*pd pd*hd hd pd;
run;
```

Yield.

```
proc print; run;
title "Number One Yield"
var yield;
proc glm data=a; class loc pd hd year ;
model yield= year loc(year) pd|hd year*pd*hd ;
test h=year e=loc(year);
test h=pd hd pd*hd  e=year*pd*hd;
lsmeans  pd pd*hd year year*pd*hd/ stderr pdiff e = year*pd*hd ;
run;
quit;

proc reg data = a;
model yield=hd;
title "proc reg number one";
run;
quit;

proc print; run;
title "Canner Yield"
var = yield;
proc glm data=a; class loc pd hd year;
model yield=year loc(year) pd|hd  year*pd*hd;
test h=year  e=loc(year);
test h=pd hd pd*hd e=year*pd*hd;
lsmeans pd hd pd*hd year year*pd*hd/stderr pdiff e=year*pd*hd;
run;
quit;
```

```
proc reg data = a;
model yield = hd;
title "proc reg canner 2004";
run;
quit;

proc print; run;
title "Jumbo Yield"
var = yield;
proc glm data=a; class loc pd hd year ;
model yield= year loc(year) pd|hd year*pd*hd ;
test h=year  e=loc(year);
test h=pd hd pd*hd e=year*pd*hd;
lsmeans pd hd pd*hd/stderr pdiff e=year*pd*hd;
proc reg data = a;
model yield = hd;
run;
quit;

title "total Yield"
var yield;
proc glm data=a; class loc pd hd year grade;
model yield= year loc(year) pd|hd year*pd*hd grade;
test h=year e=loc(year);
test h=pd hd pd*hd grade e=year*pd*hd;
lsmeans  pd pd*hd year year*pd*hd grade/ stderr pdiff e = year*pd*hd ;
run;
quit;

proc reg data = a;
title "proc reg total";
model yield = hd;
run;
quit;
```