ABSTRACT

BAUMLER, REBECCA ELIZABETH. Effects of Crop Rotation on Wireworm (Coleoptera: Elateridae) Populations in North Carolina Sweetpotato Fields. (Under the direction of George G. Kennedy.)

Studies were conducted to determine the wireworm (Coleoptera: Elateridae) species present in the Coastal Plain agricultural region of North Carolina, effects of crop rotations on the abundance of wireworms, and effects of both crop rotations and wireworm abundance on damage to harvested sweetpotato roots. Wireworm larvae were sampled in the soil using oat baits. Adult wireworms were sampled using yellow sticky traps. In 2005 and 2006, 2,857 total oat baits and 521 total sticky traps were retrieved from insecticide-free portions of 60 total sweet potato fields located throughout the Coastal Plain. Two thousand one hundred twenty-four total larvae and 3,482 total adults were obtained, belonging to eight species. The proportions of total wireworm larvae and adults captured represented by each species, respectively, were: *Conoderus amplicollis* (0.051, 0.002), *C. bellus* (0.043, 0.022), *C. falli* (0.046, 0.020), *C. lividus* (0.047, 0.033), *C. scissus* (0.057, 0.056), *C. vespertinus* (0.627, 0.629), *Glyphonyx* sp. (0.049, 0.176), and *Melanotus communis* (0.066, 0.010).

Three studies were conducted to determine the effect of preceding crop on the abundance of overwintering wireworms present in fields which may damage any subsequent crop planted. Treatments were defined by the previous year's crop and were chosen to reflect common crop rotations in the region. A small-plot study was conducted wherein baiting was conducted in spring and early summer with the following treatments: corn, cotton, fallow, soybean, sweet potato, and tobacco. The second was an overwintering study, and involved baiting commercial fields in late fall and early spring. Treatments were: corn, cotton, peanut, soybean, sweetpotato, and tobacco. In the third study, a commercial field survey, baiting was conducted in commercial fields in late spring and early summer. Treatments were: corn, cotton, cucurbit, peanut, soybean, sweetpotato, and tobacco. In the small-plot study, *M. communis* was the predominant species, and was found in significantly higher numbers following soybean and corn. Mean total numbers of wireworms per bait (all species) were highest following soybean. In the overwintering study, *C. lividus* was the predominant species, and mean total numbers of wireworms were highest following corn and soybean. In the commercial field survey, *C. vespertinus* was the predominant species, and mean total numbers of wireworms per bait were highest following corn.

The small-plot study and commercial field survey continued into early autumn. Sweetpotatoes were planted in each field used in these studies, and data were analyzed to examine wireworm populations in sweetpotato through the growing season, whether wireworm abundance differed during the growing season or by previous crop, and whether wireworm damage to sweetpotato was related to wireworm abundance during a particular time period or previous crop. The most abundant wireworm species across these studies was *C. vespertinus*. *C. vespertinus* larvae were smaller and more abundant after 15 July than earlier in the season, indicating an early-summer generation turnover, and that adults oviposit in sweet potato. *C. vespertinus* larval abundance was not affected by previous crop. Incidence of wireworm damage to sweet potato was positively correlated with late-season abundance of *C. vespertinus*.

Effects of Crop Rotation on Wireworm (Coleoptera: Elateridae) Populations in North Carolina Sweetpotato Fields

by
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BIOGRAPHY

Rebecca Baumler was born August 20, 1979 in Louisville, Kentucky. The first child of George and Mary Beth Baumler, she grew up in the rural outskirts of Jefferson County, and graduated from Assumption High School in 1997.

Rebecca attended the University of Kentucky in Lexington, and received her B.S. in Plant and Soil Science in 2003. Thereafter, she began working as a technician for Dr. Daniel A. Potter at the University of Kentucky, conducting and assisting with research projects in turf and ornamental entomology. During this time, she decided to pursue a graduate degree in entomology. In 2005, Rebecca moved to Raleigh, North Carolina to begin her master's research under the direction of Dr. George G. Kennedy investigating the wireworms present in sweetpotato and the effects of crop rotation on their populations.

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INTRODUCTION

Sweetpotato, *Ipomoea batatas* (L.), is an economically important crop in the southeastern United States. Four states (Alabama, Louisiana, Mississippi, and North Carolina) produce 175 million lbs of sweetpotatoes annually, totaling 80% of the nation's sweetpotato production (IPM Centers 2003, Curtis and Haley 2006). Soil-inhabiting insect pests are a major concern for growers, and management strategies for these pests have included routine prophylactic applications of Food Quality Protection Act (FQPA)-targeted insecticides. In 2001 and 2002, a series of workshops was conducted to address the need for updated pest management strategies in sweetpotato (IPM Centers 2003). These workshops gave rise to the Southern Sweetpotato IPM Project (hereinafter Project), a research initiative funded by a USDA, Cooperative State Research, Education and Extension Service grant. The goals of the Project included the identification of factors that contribute to damage by root-feeding insects and by post-harvest disease pathogens, the evaluation of management tactics for these insects and pathogens, and the development of a risk-assessment tool that would aid growers in production and management decisions (Curtis and Haley 2006).

The Project's organizers conducted a survey of growers in the major sweetpotato states of Alabama (AL), Louisiana (LA), Mississippi (MS), and North Carolina (NC) in 2005 to determine the chief concerns facing the sweetpotato industry. Growers were asked questions about production practices and management decisions for their 2004 sweetpotato crop. Of the respondents, 65% and 76% indicated that insect damage was causing them to leave portions of their crop in the field, and to cull the crop on the packing line, respectively (Curtis and Haley 2006). ‘Beauregard’, a sweetpotato variety which is more susceptible to insect damage than other varieties (Thompson, et al. 1999), was most commonly planted, accounting for 88.5% of sweetpotato acreage in 2004. Cropping history was ranked by 77% of respondents as one of the five most important field selection factors, and 95% reported that they rotate crops. Among the most highly ranked reasons for using this practice was reduction of insect damage to roots (Curtis and Haley 2006). The studies described herein were conducted as part of the Project, and focus on the cultural practice of crop rotation as it relates to wireworm populations in North Carolina.

North Carolina is the largest sweetpotato-producing state, with 40-46% of the total US harvested acreage from 2003-2007 (USDA NASS 2008). The crop is worth over $100 million to the state’s economy (NCDA 2006). There are over 300 sweetpotato growers in NC; most of these are located in Johnston, Nash, Edgecombe, Sampson, Wilson, and Columbus counties, in the Coastal Plain region (IPM Centers 2005).

Wireworms, the larvae of click beetles, feed on the roots and seeds of many important crops and are important in agriculture throughout much of the world, including North America. Wireworms are the most economically damaging insect pest of sweetpotato in NC, causing unsightly holes on the roots, which render them unmarketable. Wireworms are subterranean during the immature life stages, and many overwinter as larvae in the soil. Their life cycles and the numbers of years spent underground vary among species (Thomas 1940). Historically, wireworms have been difficult to manage because they are subterranean and occur irregularly in both space and time. Soil-applied insecticides have been the most effective tool to manage wireworms in sweetpotato and other crops; however, these chemicals do not consistently prevent damage to sweetpotato, and the registrations for many insecticides commonly used for wireworm control have either been cancelled or are at risk of being cancelled in the United States under the Environmental Protection Agency FQPA of 1996. Effective chemical alternatives that control mid- and late season damage to root, corm, and tuber crops are scarce. Consequently, alternative approaches to wireworm management are needed. A better understanding of the biology and behavior of wireworms and their relationship to host plants is essential as a foundation for developing new pest management tactics to prevent economic damage by wireworms.

Several species of wireworms have been associated with certain crops or crop rotations (Thomas 1940). Because many wireworm species overwinter in the soil as larvae, it is believed that previous crop can play a role in wireworm abundance (Shirck and Lanchester 1936, Lane 1941, Nash and Rawlins 1941, Shirck 1945, Gibson et al. 1958, Belcher 1989, Seal 1990). Research in both the northwestern and midwestern USA has demonstrated that crop rotation can be useful for avoiding wireworm damage; however, many of the crops and most of the wireworm species included in these studies are not present in the southeastern USA (Gui, 1935; Lane, 1941; Shirck, 1945; Gibson et al, 1958; Belcher, 1989). Because geographical differences exist in both cropping patterns and the wireworm species present, it is important to understand the effects of crop rotations on wireworm populations with regard to distinct cropping regions.

For many crops, the risk of wireworm damage is greatest after planting, when the overwintered larvae may feed on germinating seeds, seedlings, or roots of young plants, which can delay plant development or cause death (Thomas 1940). For this reason, the studies described in Chapter 1 focus on those wireworms present in the soil from autumn (following harvest of the previous crop) to early summer (following planting of the current crop) in order to describe the relationship between previous crop and early-season wireworm populations that may render damage to a variety of newly-planted crops. In the case of sweetpotatoes, the risk of damage occurs over several months, from the beginning of storage root development in early summer until harvest in the fall. Accordingly, the studies described in Chapter 2 examine wireworm populations in sweetpotato fields throughout the growing season, as well as wireworm damage to the harvested crop.

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EARLY-SEASON WIREWORM (COLEOPTERA: ELATERIDAE) SPECIES COMPOSITION AND THE INFLUENCE OF PRECEDING CROP ON WIREWORM ABUNDANCE IN THE COASTAL PLAIN OF NORTH CAROLINA

ABSTRACT Three studies were conducted to determine the species composition of wireworms (Coleoptera: Elateridae) in the coastal plain of North Carolina and the effect of preceding crop on wireworm species abundance. In all three studies, relative samples of wireworm populations were taken from the soil using oat baits. Treatments were defined by the previous year's crop and were chosen to reflect common crop rotations in the region. A small-plot study was conducted with the following treatments: corn, cotton, fallow, soybean, sweetpotato, and tobacco. The second was an overwintering study and involved baiting commercial fields in late fall and early spring to sample overwintering wireworm populations. Treatments were: corn, cotton, peanut, soybean, sweetpotato, or tobacco. In the third study, a commercial field survey, baiting was conducted in commercial fields in late spring and early summer. Treatments were: corn, cotton, cucurbit, peanut, soybean, sweetpotato, or tobacco. Overall, eight wireworm species were recovered from the baits: *Conoderus amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. scissus*, *C. vespertinus*, *Glyphonyx* sp., and *Melanotus communis*. In the small-plot study, *M. communis* was the predominant species, and was found in significantly higher numbers following soybean and corn. Mean total numbers of wireworms per bait (all species) were highest following soybean. In the overwintering study, *C. lividus* was the predominant species, and mean total numbers of wireworms were highest following corn and soybean. In the commercial field survey, *C. vespertinus* was the predominant species, and mean total numbers of wireworms per bait were highest following corn in the commercial field survey.

Keywords: wireworm, crop rotation, *Conoderus* spp., *Melanotus communis*

Introduction

WIREWORMS, THE LARVAE of click beetles, feed on the roots and seeds of many important crops and are a significant pest in agriculture throughout North America and much of the world. Many of the wireworm species of concern overwinter in the soil as larvae for one or more years and are present at planting. Thereafter, they may feed on germinating seeds and the roots of seedlings and transplants, causing stunting or death of the plants (Thomas 1940). Historically, wireworms have been difficult to manage because they are subterranean and occur irregularly in both space and time. Soil-applied insecticides have been the most effective management tool; however, the registrations for many insecticides commonly used for wireworm control have either been cancelled or are at risk of being cancelled in the United States under the Environmental Protection Agency Food Quality Protection Act of 1996. Consequently, alternative approaches to wireworm management are needed. A better understanding of the biology and behavior of wireworms and their relationship to host plants is important as a foundation for developing new pest management tactics.

Certain wireworm species are associated with and may prefer particular crops. Because many wireworm species overwinter as larvae, the crop history of a field is known to influence the abundance of wireworms. Therefore, any crop planted into a field that is heavily infested with wireworms is at an increased risk of damage, even if it may not be not the preferred food of the wireworm species (Eagerton 1914, Bryson 1930, Shirck and Lanchester 1936, Nash and Rawlins 1941, Norris 1957, Hawkins et al. 1958, Rabb 1963, Doane et al 1975, Belcher 1989, Seal et al. 1992). Research in both the northwestern and midwestern USA has demonstrated that crop rotation can be useful for avoiding wireworm damage; however, many of the crops and most of the wireworm species included in these studies are not present in the southeastern USA (Gui, 1935; Lane, 1941; Shirck, 1945; Gibson et al, 1958; Belcher, 1989). Because geographical differences exist in both cropping patterns and the wireworm species present, it is important to understand the effects of crop rotations on wireworm populations in distinct cropping regions.

Herein we report the results of a series of field studies to determine the species composition of overwintering wireworm larvae in the coastal plain of North Carolina and the effect of commonly grown crops on their abundance. Knowledge of the relationship of previous crops to wireworm populations is essential in identifying crop rotations that minimize risk of early-season wireworm damage to seeds and newly transplanted crops.

Materials and Methods

Baiting procedure. Wireworm baits consisted of approximately 78 g of dry, steam-crimped oats (Purina Mills, St. Louis, MO). Baits were soaked in water overnight, then drained and placed in the ground at a depth extending from 2.54 – 12.7 cm below the soil surface using a bulb planter 6 cm in diameter. Each bait was then covered with soil, and a wire flag marked its location. Baits were left in the field for approximately 14 d and recovered using a golf course cup cutter 10.16 cm in diameter and 15.24 cm deep, which removed the bait plus approximately 948 cm^3 of the surrounding soil. Each bait including the surrounding soil was individually placed into a plastic bag and stored at 5° C until processed. Occasionally, a bait was destroyed by rodents or birds, however this was rare. Samples were visually examined by spreading the soil and remnants of the bait over a flat surface. Wireworms recovered from samples were placed in vials of 75% ethanol and identified to species under a light microscope using the keys of Rabb (1963), Riley and Keaster (1979), and Seal (1990). Baiting in each study was carried out continuously throughout the duration of the study. When a bait was removed, another was placed in the same plot.

Small-plot crop rotation study. A small-plot experiment was conducted at the Cunningham Research Station in Kinston, NC from 2003 to 2006. In the spring of 2003, two fields were planted to sweetpotatoes, which received no insecticide treatments. In 2004, Field 1 was planted in a randomized complete block design with four replicates of each of the six following treatments: corn, cotton, fallow, soybean, sweetpotato, and tobacco. With the exception of fallow, these represent crops commonly grown in the coastal plain of NC. Plots were 10 m wide (eight rows) and 12 m long. Each crop was managed according to North Carolina State Extension Service recommended production practices, including weed and insect control (NC CES 2007; Table 1.1). After harvest, these plots were delineated and maintained. Each plot was baited for wireworms continuously with two baits per plot from 4 April – 19 July 2005. All plots in Field 1 were planted to sweetpotato on 14 June 2005. After the sweetpotatoes were planted, the baits were placed directly in the plant rows.

The same experiment was carried out in Field 2, except that all plots were planted to sweetpotato in 2004, the rotation crops were planted in 2005, and wireworm baiting took place in 2006 from 28 Feb – 30 March, and from 2 June – 19 July. Field 2 was planted to sweetpotatoes on 2 June 2006.

Overwintering study. In a separate study, baiting was conducted in the late fall of 2005 and early spring of 2006 in 30 commercial fields located in Edgecombe, Nash, and Wilson Counties. Five fields each had been planted to the following crops during the 2005 growing season: corn, cotton, peanut, soybean, sweetpotato, or tobacco. These crops had received normal production practices as determined by the growers. Six baits were placed in each field during each 14-d baiting cycle. Each bait was covered with a 1 m^2 sheet of black plastic to heat the soil directly underneath. Baiting commenced 28 October after harvest and continued to 16 December 2005 (fall period). A second period of baiting ran from 2 March – 13 April 2006 (spring period). While there were five fields for each crop in both baiting periods, the same 30 fields were not all used in the fall and spring because some of the fall-baited fields were not available in the spring. In those cases (n = 4), the fields were replaced by fields that had been planted to the same crops in the preceding year.

Commercial field survey. An additional two-year survey of wireworm populations in commercial fields to be planted to sweetpotato was conducted to determine the wireworm species composition and effects of the preceding year's crop on early season wireworm abundance. These fields were located in Columbus, Cumberland, Duplin, Edgecombe, Johnston, Nash, Sampson, Wayne, and Wilson Counties. All fields had received normal production practices as determined by the growers during the previous year. Before sweetpotatoes were planted in each field, 16 rows (1 m wide x 91 m long) in each field, were marked. These rows received no insecticides, but otherwise received all normal production practices. These rows were divided into six plots, each 16 m x 15 m. Baiting was conducted in 2005 in 27 sweetpotato fields that had been planted to the following crops in 2004: corn (three fields), cotton (five), cucurbit (two), peanut (four), soybean (six), sweetpotato (two), or tobacco (five); and in 2006 in 13 fields that had been planted to the following crops in 2005: cotton (six fields), or soybean (seven fields). Wireworm baits were maintained in each plot continuously from 1 April – 19 July 2005 and from 9 June – 19 July 2006. Since the fields used in this study were managed by different growers, planting dates varied from site to site. In many of these fields, baiting commenced before sweetpotatoes were planted.

Data analysis. Wireworm species identifications in each study were recorded to determine species composition. Data for each species were summed across all sample dates within a study prior to analysis. Data from each study were subjected to ANOVA to examine the effects of previous crop on the abundance of each wireworm species. The data from the small-plot crop rotation study were analyzed as a randomized complete block design. The other experiments were analyzed as completely randomized designs. Mean separations were based on Fisher's Protected LSD, where treatment means were significantly different at $\alpha < .05$.

Results of statistical analyses are presented only for those species captured frequently enough to meet the ANOVA assumption of homogeneity of variance. Transformations (square root or log10) were used whenever appropriate, based on inspection of residuals, to increase homogeneity of variance (PROC GLM, SAS Institute 1999). Means and standard errors are presented for the remaining species.

Results

Small-plot crop rotation study. A total of 406 baits were placed, and 391 of these were retrieved. There were 116 wireworms recovered (Figure 1.1 A). The total numbers of individuals of each species and the proportion of total wireworms captured represented by each species were: 2 *Conoderus amplicollis* (0.02), 4 *C. bellus* (0.03), 17 *C. falli* (0.15), 2 *C. lividus* (0.02), 8 *C. vespertinus* (0.07), 23 *Glyphonyx* sp. (0.20), 59 *Melanotus communis* (0.51), and 1 other (unknown sp.; 0.01).

Only total wireworms (all species) and *M. communis* were sufficiently abundant to justify ANOVA. Mean numbers of total wireworms and *M. communis* per bait were not significantly different by year ($F_{1,6} = 0.88$, $p = 0.3842$; $F_{1,6} = 0.32$, $p = 0.5894$; respectively; Table 1.2) and there were no interactions between year and previous crop.

Means and standard errors by year for *C. amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. vespertinus*, and *Glyphonyx* sp. are reported in Table 1.2.

Previous crop significantly affected the mean number of total wireworms and *M. communis* per bait ($F_{5, 30} = 3.09$, p = 0.0230; $F_{5, 30} = 2.64$, p = 0.0429, respectively; Fig. 1.2). Total wireworms were most abundant in plots previously planted to soybean, least abundant in plots previously planted to sweetpotato, and of intermediate abundance in plots previously planted to corn, fallow, tobacco, and cotton. The greatest numbers of *M. communis* per bait were captured following soybean and corn, and the least following tobacco and sweetpotato. Intermediate numbers were caught in baits following cotton and fallow. Means and standard errors by previous crop for *C. amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. vespertinus*, and *Glyphonyx* sp. are reported in Table 1.3.

Overwintering Study. A total of 1,080 baits were placed in 30 commercial fields during the periods ‘fall’ and ‘spring’, and 1,032 of these were retrieved. There were 192 wireworms recovered (Fig. 1.1 B). The total numbers of individuals of each species and proportion of total wireworms captured represented by each species were: 1 *Conoderus falli* (0.01), 73 *C. lividus* (0.38), 7 *C. scissus* (0.04), 53 *C. vespertinus* (0.28), 39 *Glyphonyx* sp. (0.20), 14 *M. communis* (0.07), and 5 others (unknown spp.; 0.03).

Only total wireworms, *C. lividus*, *C. vespertinus*, and *Glyphonyx* sp. were sufficiently abundant to justify ANOVA. Mean numbers of total wireworms and *C. lividus* per bait were greater during the spring than the fall period ($F_{1, 20} = 15.55$, p = 0.0008; $F_{1, 20} = 10.53$, p = 0.0041; Table 1.4). There were no significant differences in wireworm abundance by baiting period for *C. vespertinus* ($F_{1, 20} = 2.82$, p = 0.1089;

Table 1.4) or *Glyphonyx* sp. ($F_{1, 20} = 0.79$, $p = 0.3845$; Table 1.4). There were no interactions between baiting period and previous crop. Means and standard errors for *C. falli*, *C. scissus*, and *M. communis* by baiting period are reported in Table 1.4.

Mean numbers of total wireworms per bait differed significantly by previous crop ($F_{5, 20} = 8.89$, $p < 0.0001$; Fig. 1.3). More total wireworms were caught following corn and soybean than any other crop, and fewer were caught following sweetpotato and peanut than any other crop. Intermediate numbers were caught following tobacco and cotton. The abundances of *C. lividus*, *C. vespertinus*, and *Glyphonyx* sp. each differed significantly depending on previous crop ($F_{5, 20} = 7.61$, $p = 0.0001$; $F_{5, 20} = 4.72$, $p = 0.0029$; and $F_{5, 20} = 3.83$, $p = 0.0088$; respectively; Fig. 1.3). The highest mean numbers of *C. lividus* per bait were caught following corn and the lowest were caught following sweetpotato and peanut. Intermediate numbers were caught following tobacco, soybean, and cotton. The mean numbers of *C. vespertinus* per bait were greater following cotton and soybean than following any of the other crops. The greatest numbers of *Glyphonyx* sp. per bait were captured following soybean and none were captured following cotton, peanut, and sweetpotato. Intermediate numbers were caught following corn and tobacco. Means and standard errors for *C. falli*, *C. scissus*, and *M. communis* are reported in Table 1.5.

Commercial Field Survey. A total of 594 baits were placed in 40 fields during 1 April – 19 July 2005 and 9 June – 19 July 2006, and 585 of these were retrieved. There were 235 wireworms recovered (Fig. 1.1 C). The total numbers of larvae of each species and proportion of total wireworms captured represented by each species were: 1

Conoderus amplicollis (< 0.01), 18 *C. bellus* (0.08), 1 *C. falli* (< 0.01), 6 *C. lividus* (0.03), 2 *C. scissus* (0.01), 173 *C. vespertinus* (0.74), 15 *Glyphonyx* sp. (0.06), 14 *M. communis* (0.06), and 5 others (unknown spp.; 0.02).

Only total wireworms and *C. vespertinus* were sufficiently abundant to justify ANOVA. Mean numbers of total wireworms per bait were higher in 2005 than in 2006 ($F_{1,34} = 8.44$, $p = 0.0064$; Table 1.6). Mean numbers of *C. vespertinus* were not significantly different by year ($F_{1,34} = 1.99$, $p = 0.1671$). There were no interactions between year and previous crop. Means and standard errors for *C. amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. scissus*, *Glyphonyx* sp., and *M. communis* by year are reported in Table 1.6.

Mean numbers of total wireworms per bait were higher in fields previously planted to corn than to any of the other crops used in this study ($F_{6,34} = 3.38$, $p = 0.0100$; Fig. 1.4). Mean numbers of *C. vespertinus* per bait did not differ significantly by previous crop ($F_{6,34} = 1.80$, $p = 0.1276$; Fig. 1.4). Means and standard errors for *C. amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. scissus*, *Glyphonyx* sp, and *M. communis* by previous crop are reported in Table 1.7.

Discussion

Differences in the length of the larval stage exist among the eight wireworm species captured during these studies. *C. bellus*, *C. falli*, and *C. vespertinus* spend one year or less in the larval stage (Eagerton 1914, Jewett 1945, Norris 1957, Rabb 1963, Day et al. 1971), while *C. amplicollis*, *C. lividus*, and *C. scissus* remain in the soil as larvae for one to two years (Cockerham and Deen 1936, Jewett 1948, Seal et al. 1992). *M. communis* is believed to have a larval stage of 6 years in Iowa, but we were unable to find any information regarding life history from lower latitudes, and it is likely that the life cycle of this species is shorter in NC, where the winters are shorter and milder than those of IA (Fenton 1926, Thomas 1930). We were unable to locate any published information on the length of the larval stage of *Glyphonyx* sp. Because adult *Glyphonyx* sp. trapped in the same fields used in this study were identified as *G. bimarginatus* (unpublished data), and because the larvae we collected matched the description of *G. bimarginatus* larvae by Cheshire and Jones (1988), we believe the larvae to be of this species. For those wireworm species known or suspected to remain in the soil for more than one year, it may be necessary to examine crop rotations extending back further than the previous season, or to monitor wireworm adults in rotation crops in order to determine host-plant/oviposition site preferences for each species.

In all of our studies, the mean total number of wireworms per bait was significantly different with respect to the previous crop. Means were consistently among the highest following corn and lowest following sweetpotato and, when present, peanut (Figs. 1.2, 1.3, 1.4). The reasons for these differences are not certain, but there may be several influential factors. Corn was the only grass included in these studies, and is planted up to one month earlier than the other common rotation crops in eastern NC. It may be that the structure of the corn canopy at the time adults are present provides a more attractive oviposition site for adult female wireworms than the relatively bare soil of the other rotations, or simply that corn or grass crops are more suitable for the survival and development of wireworms than other plants, leading to a larger population in the soil after the corn crop.

Variations in common growing practices throughout the season among the rotation crops used in these studies may also play a role in determining subsequent differences in wireworm abundance. At the start of the growing season, fields may be cultivated to varying degrees depending on the crop to be planted. Tillage has been shown to reduce wireworm populations, presumably by both mechanical injury and exposure to predators (Salt and Hollick 1949, Hawkins et al. 1958, Seal et al. 1992). For several of the rotation crops in this study, conventional tillage is commonly used, which may reduce the baseline population of wireworm in a field prior to planting. Tobacco and sweetpotato are grown on raised beds. These fields are typically disked prior to bedding in the spring, and may be rebedded after planting. This additional soil disturbance may further reduce wireworm populations within these crops. Conservation tillage has been increasingly common in corn, cotton, and soybean (USDA Crop Profiles 2007), which may allow for the survival of more overwintered wireworms. In addition to tillage, soil insecticides applied before or during planting, or applied as seed treatments may reduce overwintering wireworm populations. However, recent research indicates that insecticide exposure may incapacitate wireworms and temporarily prevent feeding without causing mortality (van Herk and Vernon 2007). Whether or not wireworm populations are reduced at the start of the previous season's crop via cultivation or chemicals, they may increase as wireworm oviposition and egg hatch take place during the summer. Pre-plant and at-plant application of soil insecticides may not be effective against the survival and development of wireworm species in which oviposition and egg hatch occurs during the summer. For the crops studied here, none but sweetpotato, peanut, and cucurbit commonly receive soil-applied insecticides after planting. Attempts to reduce oviposition through the use of foliar-applied insecticides have not proven to be effective in reducing wireworm damage to storage roots in sweetpotato (Abney et al., unpublished data). Finally, in the cases of peanut and sweetpotato, harvesting techniques require soil disturbance, which may reduce wireworm populations in fall, while the other rotations here are not commonly cultivated after harvest.

Low numbers of larvae captured overall prevented an analysis of species composition by previous crop in each of our studies. However, there were large differences in species composition between the studies (Fig. 1.1). *M. communis* made up 51% of the total wireworms caught in the small-plot crop rotation study, and < 8% in the others. *C. lividus* made up 39% of the wireworms caught in the overwintering study, but was rarely caught in the other studies. Finally, in the commercial field survey, *C. vespertinus* made up 74% of the total wireworms caught. The species compositions in these tests cannot be compared statistically, but the differences among the tests themselves may help to explain their differences and provide insight for further investigation.

M. communis is a common corn-infesting wireworm in the Midwest, but studies of the effects of crop rotation that included corn did not report on this species (Fenton 1926, Riley and Keaster 1979, Belcher 1989). Our small-plot crop rotation study was conducted at Cunningham Research Station, where corn, soybean, and small grains have been frequent rotation crops for many years. It is likely that the Cunningham Research Station possesses a larger population of *M. communis* than the other areas where sampling took place. Indeed, *M. communis* makes up at least half of the total wireworms caught in nearly every treatment of the small-plot test (Fig. 1.2), but was most abundant following corn and soybean. In both the overwintering study and commercial field survey, mean numbers of *M. communis* per bait were again most abundant following corn, although differences were not significant (Tables 1.4, 1.5). The species composition in the small plot crop rotation study and the means from the commercial field survey are consistent with the hypothesis that *M. communis* occurs more commonly following corn, especially in areas where corn is frequently grown. If the length of the larval stage of *M. communis* in the Southeast were known, rotation studies could be designed to more accurately describe the occurrence of this species in relation to corn and other rotation crops.

The overwintering study and commercial field survey were both conducted in commercial fields throughout the NC Coastal Plain. The major difference between these studies is the time of year that they were conducted. The overwintering study took place in the late fall, winter, and early spring. Other than time of baiting, there is no apparent reason why *C. lividus* was captured more frequently in the overwintering study than in the other studies (Fig. 1.1). It is possible that *C. lividus* is more active in the colder months than the other species.

The commercial field survey was conducted during the period when many of the crops grown in the Coastal Plain of NC are planted and early-season wireworms can be a problem. *C. vespertinus* was overwhelmingly the most prevalent species (Fig. 1.1). Although *C. vespertinus* larvae were more abundant following cotton and soybean than other crops in the overwintering study, there were no significant differences among treatments for this species in any of the other tests (Fig. 1.3). However, in the commercial field survey, *C. vespertinus* was most abundant following corn (Table 1.5). The lack of consistent differences for this species suggest that further work is required before robust conclusions regarding effects of rotation crops on abundance can be made. Given that *C. vespertinus* has a one-year life cycle and oviposition occurs primarily in June and July (Rabb 1963), any such effect would have to reflect the size of the ovipositing adult population resulting from oviposition in the previous year's crop in the same or nearby fields.

In summary, eight wireworm species were recovered in three studies over two years in the coastal plain of North Carolina. These species have different life and seasonal histories. *C. vespertinus* is the most abundant and widespread species in the region and its early-season abundance appears to be minimally affected, if at all, by the previous crop. Because *C. vespertinus* is univoltine, this could indicate that adult females do not have ovipositional preferences for any of the crops used in these studies, or that the production practices used in preferred crops make them less favorable for *C. vespertinus* larvae. *M. communis* was found to be more abundant following corn. The length of the larval stage of *M. communis* in NC is uncertain, but corn may provide a superior habitat for oviposition and survival of *M. communis* than the other crops included in our study. Total wireworms (all species) were consistently more abundant following corn than other rotation crops.

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Table 1.1. Production practices used on rotation crops in the small-plot crop rotation study.

Year	Crop	Date	Operation	Compound	Rate
2004	Corn	3/26	Fertilize	10-20-20	300 lb/ac
		3/30	Plant		
			Insecticide	Lorsban® 15G	13.5 lb/ac
		4/1	Herbicide	Lasso® 4L	2 qt/ac
			Herbicide	Atrazine 4L	1 qt/ac
			Fertilize	30%	52 gal/ac
		5/11	Herbicide	Permit® 75WGD	1 oz/ac
		6/15	Herbicide	Evik® 80DF	1.5 lb/ac
	Cotton	3/26	Fertilize	10-20-20	300 lb/ac
		5/11	Plant		
			Insecticide	Temik®	5 lb/ac
		7/1	Growth reg.	Pix	8 oz/ac
		7/14	Growth reg.	Pix	16 oz/ac
	Soybean	5/12	Plant		
		6/1	Herbicide	Roundup® 5.5SL	1 qt/ac
		8/9	Insecticide	Larvin® 3.2F	1 pt/ac
	Sweetpotato	4/21	Herbicide	Eptam® EC	3.5 pt/ac
		4/23	Fumigant	Telone® II	9 gal/ac
		4/24	Herbicide	Command® 3 ME	1.33 pt/ac
			Insecticide	Lorsban® 4EC	2 qt/ac
		6/9	Plant		
		6/16	Fertilize	0-15-38-.25B	400 lb/ac
		7/6	Fertilize	34-0-0	150 lb/ac
		7/28	Insecticide	Imidan® 70 WSB	1.33 lb/ac
		8/11	Insecticide	Thiodan 3EC	1 qt/ac
		8/27	Insecticide	Imidan® 70WSB	1.33 lb/ac
	Tobacco	3/24	Herbicide	Tillam® 6E	2 qt/ac
			Herbicide	Command® 3ME	1.33 pt/ac
			Insecticide	Lorsban® 4E	2 qt/ac
		3/26	Fumigant	C-17	10.5 gal/ac
		5/7	Plant		
			Fertilize	8-8-24	475 lb/ac
		5/20	Fertilize	15-0-14	200 lb/ac
			Cultivate		
		5/26	Cultivate		
		6/1	Cultivate		
		6/15	Insecticide	Orthene® 97	.75 lb/ac
		6/25	Growth reg.	Fair 85	2 gal/ac
		6/29	Growth reg.	Fair 85	2.5 gal/ac

Table 1.1 (continued)

Year	Crop	Date	Operation	Compound	Rate
2004	Tobacco	7/3	Growth reg.	Fair 85	1.33 gal/ac
		7/21	Insecticide	Orthene® 97	.75 lb/ac
2005	Corn	4/7	Plant	DKC 6621	25,300 seed/ac
			Fertilize	30% Nit.	170 N/ac 52 gal/ac
			Fertilize	10-34-0	3.2N-11P-0 3 gal/ac
			Fertilize	24-sulfur	7.92 N/ac 3 gal/ac
		4/12	Herbicide	Lasso® 4L	2 qt/ac
			Herbicide	Atrizine 4L	1 qt/ac
		4/18	Fertilize	0-0-60	100 lbs/ac
		5/11	Cultivate		
		6/13	Herbicide	Evik® 80DF	1.5 lbs/ac
			Surfactant		1 pt/ac
	Cotton	5/17	Plant	FM991RR	
		6/10	Replanted	Skips	
		8/1	Growth reg.	Pix	12 oz/ac
	Soybean	4/18	Plant	Group VII	
		5/17	Herbicide	Roundup® original	1 qt/ ac
		5/24	Insecticide	Sevin®	1.25 lbs/ac
	Sweetpotato	4/28	Herbicide	Eptam® 7EC	3.5 pt/ac
			Herbicide	Command® 3E	1.33 pt/ac
			Insecticide	Lorsban®	2 qt/ac
		4/29	Nematicide	Telone® II	7.5 gal/ac
		6/14	Plant		
		6/23	Fertilize	0-15-38-.25B	400 lb/ac
		7/5	Cultivate		
		7/12	Fertilize	15.5-0-0	325 lbs/ac
		7/20	Cultivate		
		8/1	Herbicide	Roundup®	50% wick-bar
		8/3	Insecticide	Imidan®	1.3 lb/ac
		8/10	Herbicide	Select®	8 oz/ac
		8/20	Insecticide	Thionex®	1 qt/ac
		8/24	Herbicide	Roundup®	50% wick-bar
		9/13	Insecticide	Imidan®	1.3 lb/ac
		9/27	Harvest		
	Tobacco	3/10	Herbicide	Tillam®	2 qt/ac
			Herbicide	Command®	1.33 pt/ac
			Insecticide	Lorsban®	2 qt/ac
			Fumigant	Telone® C-17	10.5 gal/ac
		4/22	Plant		

Table 1.1 (continued).

Year	Crop	Date	Operation	Compound	Rate
2005	Tobacco	4/22	Fertilize	8-8-24	475 lb/ac
			Insecticide	Orthene® 97	0.75 lb/ac
		5/4	Fertilize	15-0-14	150lb/ac
		5/17	Cultivate		
		5/26	Cultivate		
		6/6	Insecticide	Orthene® 97	0.75 lb/ac
		6/15	Growth reg.	Fair 85®	1.5 gal/ac
		6/22	Growth reg.	Fair 85®	2 gal/ac
		6/23	Topping		
		7/1	Growth reg.	Fair 30	1.3 gal/ac
		7/29	Insecticide	Orthene® 97	0.75 lb/ac
		8/3	Insecticide	Tracer®	2 oz/ac

Table 1.2. Abundance* of seven wireworm species captured in oat baits in a small-plot study conducted during 4 April – 19 July 2005 and 28 Feb – 30 March and 2 June – 19 July 2006.

Wireworm species	Year	
	2005	2006
Total wireworms	0.38 ± 0.08a	0.25 ± 0.05a
M. communis	0.15 ± 0.06a	0.16 ± 0.04a
C. amplicollis	0 ± 0	0.01 ± 0.01
C. bellus	0.02 ± 0.01	0 ± 0
C. falli	0.05 ± 0.02	0.04 ± 0.01
C. lividus	0.01 ± 0.01	0 ± 0
C. vespertinus	0.03 ± 0.02	0.02 ± 0.01
Glyphonyx sp.	0.10 ± 0.04	0.03 ± 0.01

* Data are means of wireworms per bait ± SEM over all fields regardless of the crop grown during the previous season.

Only total wireworms and *M. communis* were sufficiently abundant to justify ANOVA. Values within a row followed by the same letter are not significantly different.

Table 1.3. Abundance* of six wireworm species captured in oats baits during 4 April – 19 July 2005 and 28 Feb – 30 March and 2 June – 19 July 2006 in small plots previously planted to six rotations during 2004 and 2005, respectively.

Wireworm species	Previous crop					
	Corn	Cotton	Fallow	Soybean	Sweetpotato	Tobacco
C. amplicollis	0 ± 0	0 ± 0	0.01 ± 0.01	0 ± 0	0.01 ± 0.01	0 ± 0
C. bellus	0 ± 0	0.02 ± 0.02	0.02 ± 0.02	0.02 ± 0.02	0 ± 0	0.02 ± 0.02
C. falli	0.05 ± 0.02	0 ± 0	0.11 ± 0.04	0.03 ± 0.02	0.01 ± 0.01	0.08 ± 0.03
C. lividus	0 ± 0	0 ± 0	0 ± 0	0.04 ± 0.04	0 ± 0	0 ± 0
C. vespertinus	0.02 ± 0.02	0.03 ± 0.02	0 ± 0	0.08 ± 0.06	0 ± 0	0.02 ± 0.02
Glyphonyx sp.	0.04 ± 0.02	0.04 ± 0.03	0.03 ± 0.02	0.15 ± 0.09	0.03 ± 0.02	0.10 ± 0.06

* Data are means of wireworms per bait ± SEM over both years of the study. Data did not meet homogeneity of variance assumption of ANOVA.

Table 1.4. Abundance* of six wireworm species captured in oat baits in commercial fields during the fall and spring baiting periods.

Wireworm species	Baiting period	
	Fall (28 Oct – 16 Dec 2005)	Spring (2 Mar – 13 Apr 2006)
Total wireworms	0.12 ± 0.03b	0.25 ± 0.04a
C. lividus	0.03 ± 0.01b	0.11 ± 0.03a
C. vespertinus	0.03 ± 0.01a	0.07 ± 0.02a
Glyphonyx sp.	0.03 ± 0.01a	0.04 ± 0.02a
C. falli	0.00 ± 0.00	0 ± 0
C. scissus	0.01 ± 0.01	0 ± 0
M. communis	0.01 ± 0.00	0.02 ± 0.01

* Data are means of wireworms per bait ± SEM analyzed over all fields, regardless of the crop grown during the previous season.
Only total wireworms, *C. lividus*, *C. vespertinus*, and *Glyphonyx* sp. were sufficiently abundant to justify ANOVA. Values within a row followed by the same letter are not significantly different.

Table 1.5. Abundance* of three wireworm species captured in oat baits during the fall period (28 October – 16 December 2005) and spring period (2 March – 13 April 2006) in commercial fields previously planted to six rotation crops.

Previous crop	*C. falli*	*C. scissus*	*M. communis*
Corn	0 ± 0	0.04 ± 0.03	0.04 ± 0.02
Cotton	0 ± 0	0 ± 0	0 ± 0
Peanut	0 ± 0	0 ± 0	0.01 ± 0.01
Soybean	0 ± 0	0 ± 0	0.01 ± 0.01
Sweetpotato	0 ± 0	0 ± 0	0.01 ± 0.01
Tobacco	0.01 ± 0.01	0 ± 0	0.02 ± 0.01

* Data are means of wireworms per bait ± SEM over both baiting periods of the study. Data did not meet homogeneity of variance assumption of ANOVA.

Table 1.6. Abundance* of eight wireworm species captured in oat baits in commercial fields during 1 April – 19 July 2005 and 9 June – 19 July 2006.

Wireworm species	Year	
	2005	2006
Total wireworms	0.56 ± 0.15a	0.23 ± 0.11b
C. vespertinus	0.39 ± 0.14a	0.20 ± 0.10a
C. amplicollis	0.00 ± 0.00	0 ± 0
C. bellus	0.06 ± 0.02	0 ± 0
C. falli	0.00 ± 0.00	0 ± 0
C. lividus	0.01 ± 0.01	0.01 ± 0.01
C. scissus	0.01 ± 0.01	0 ± 0
Glyphonyx sp.	0.06 ± 0.04	0.01 ± 0.01
M. communis	0.03 ± 0.01	0.01 ± 0.01

* Data are means of wireworms per bait ± SEM over all fields, regardless of the crop grown during the previous season.
Only total wireworms and *C. vespertinus* were sufficiently abundant to justify ANOVA.
Values within a row followed by different letters are significantly different.

Table 1.7. Abundance* of seven wireworm species captured in oat baits during 1 April – 19 July 2005 and 9 June – 19 July 2006 in commercial fields previously planted to seven rotation crops.

Wireworm species	Previous rotation						
	Corn (3)	Cotton (5)	Curcubit (2)	Peanut (4)	Soybean (6)	Sweetpotato (2)	Tobacco (5)
C. amplicollis	0 ± 0	0.00 ± 0.00	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
C. bellus	0.14 ± 0.10	0.04 ± 0.03	0 ± 0	0 ± 0	0.03 ± 0.02	0 ± 0	0.03 ± 0.02
C. falli	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.01 ± 0.01
C. lividus	0 ± 0	0.02 ± 0.01	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.03 ± 0.02
C. scissus	0 ± 0	0.00 ± 0.00	0.08 ± 0.08	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Glyphonyx sp.	0.03 ± 0.03	0.09 ± 0.07	0 ± 0	0.04 ± 0.04	0.02 ± 0.01	0 ± 0	0 ± 0
M. communis	0.10 ± 0.10	0.03 ± 0.02	0 ± 0	0.04 ± 0.04	0.01 ± 0.01	0 ± 0	0.01 ± 0.01

* Data are means of wireworms per bait ± SEM over both years of the study.
Average of number of replicates indicated in parentheses, 645 total baits.
Data did not meet homogeneity of variance assumption of ANOVA.

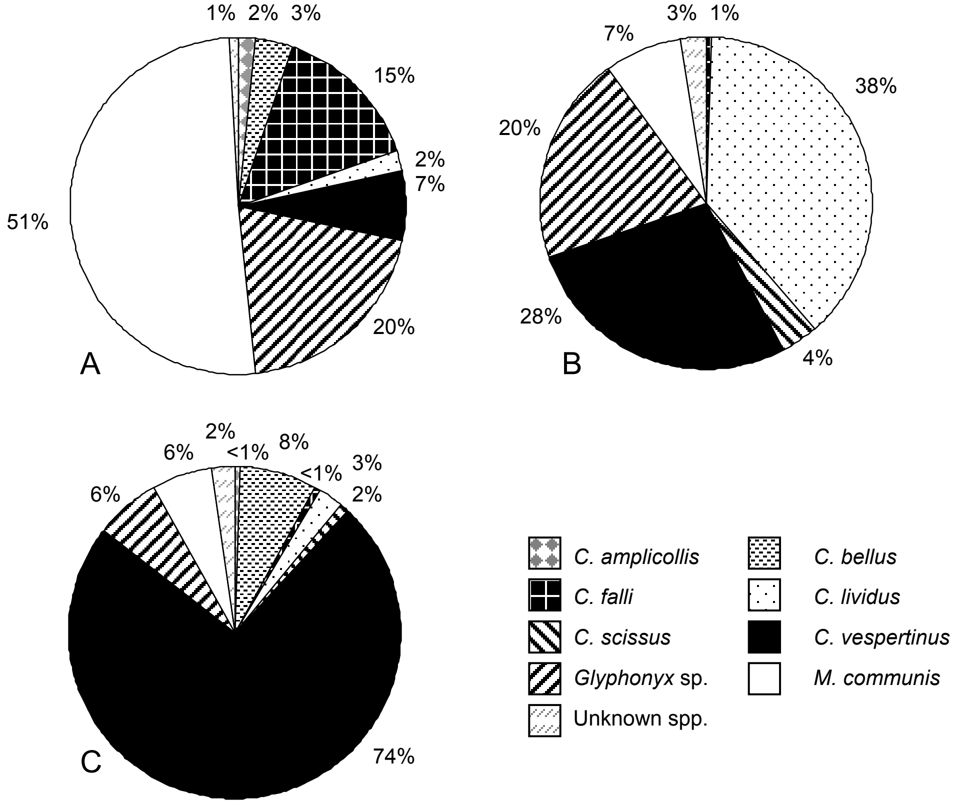

Figure 1.1. Species composition of wireworms captured in oat baits across previous crops.

A: Small-plot crop rotation study (4 April – 19 July 2005; 28 Feb – 30 March, 2 June – 19 July 2006; n = 116)
B: Overwintering study in commercial fields (28 October – 16 December 2005, 2 March – 13 April 2006; n = 192)
C: Commercial field survey (1 April – 19 July 2005 and 9 June – 19 July 2006; n = 235)

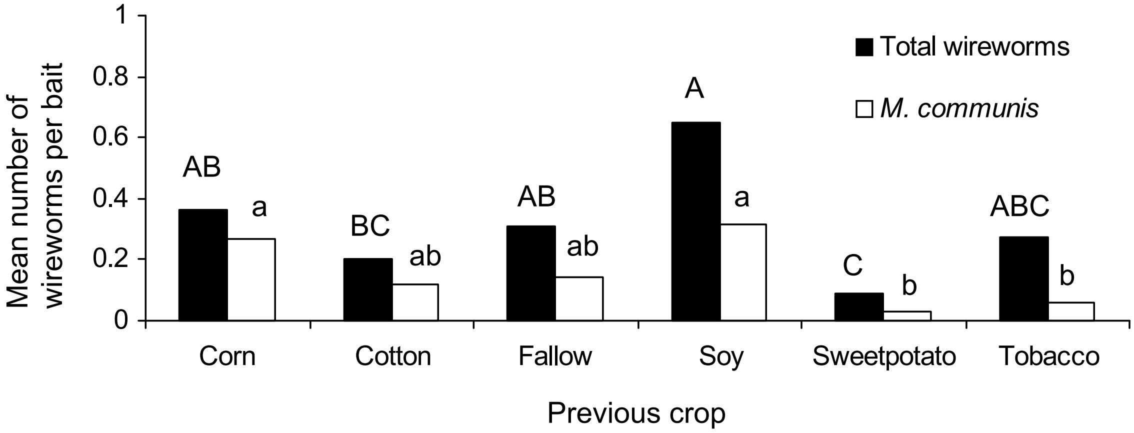

Figure 1.2. Abundance of *M. communis* and total wireworms (all species) captured in oat baits during 4 April – 19 July 2005 and 28 Feb – 30 March and 2 June – 19 July 2006 in small plots previously planted to six rotations.

Letters that are the same for different crops indicate that the means are not significantly different, within a species at α = 0.05.

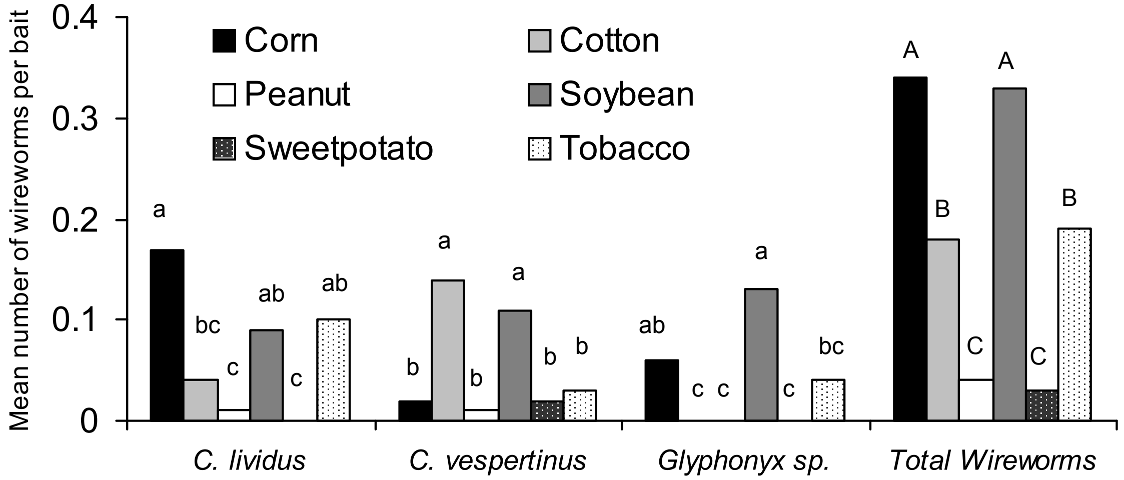

Figure 1.3. Abundance of wireworms captured in oat baits during 28 October – 16 December 2005 and 2 March – 13 April 2006 in commercial fields planted to crops commonly grown in the coastal plain of NC.

Letters that are the same for different crops indicate that the means are not significantly different, within a species at α = 0.05.

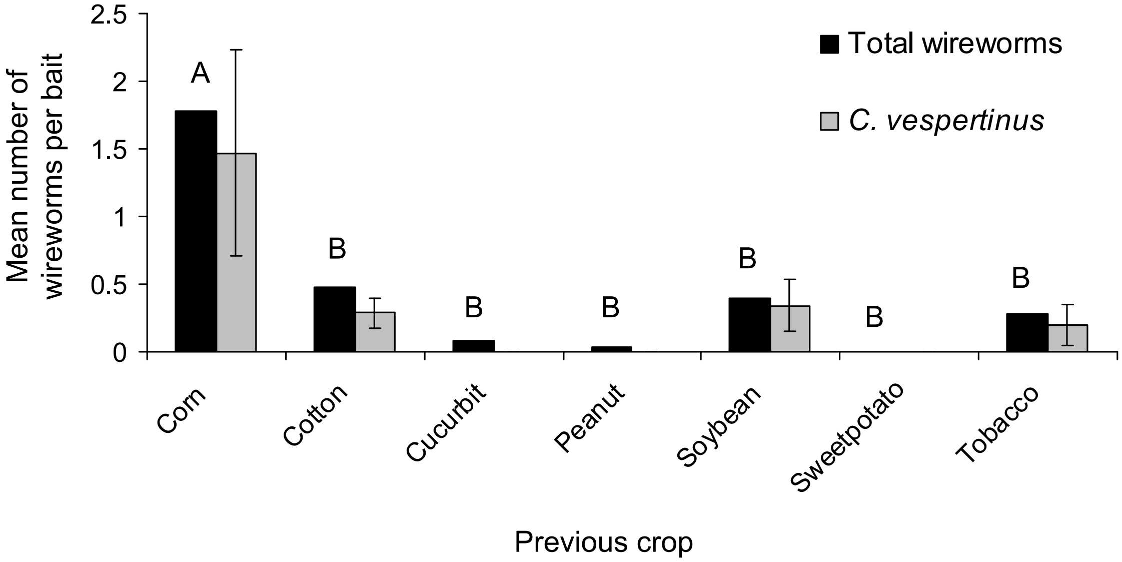

Figure 1.4. Abundance of total wireworms (all species) and of *C. vespertinus* captured in oat baits during 1 April – 19 July 2005 and 9 June – 19 July 2006 in commercial fields planted to seven crops during the 2004 and 2005 growing seasons, respectively.

Letters that are the same for total wireworms indicate no significant difference at α = 0.05. Mean numbers of *C. vespertinus* per bait did not differ significantly among rotations. Error bars for *C. vespertinus* represent standard error.

SEASONAL POPULATION CHANGES IN WIREWORM SPECIES (COLEOPTERA: ELATERIDAE) AND SUBSEQUENT DAMAGE TO NORTH CAROLINA SWEETPOTATO

ABSTRACT Studies were conducted to determine the effects of previous crop on wireworm species abundance in sweetpotato throughout the growing season in NC, and on damage to sweetpotato storage roots at harvest. Species composition and seasonal biology of wireworms present in sweetpotato were also examined. Wireworm larvae were sampled using oat baits, and adults were sampled using sticky traps. Eight species of larval wireworms were identified: *Conoderus amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. scissus*, *C. vespertinus*, *Glyphonyx* sp., and *Melanotus communis*. Adults of the same species were captured, but all *Glyphonyx* adults were identified as *G. bimarginatus*. The most abundant wireworm species was *C. vespertinus*, comprising over 65% of the larvae and over 63% of the adults captured. *C. vespertinus* larvae were smaller and more abundant after 15 July than earlier in the season, indicating an early-summer generation turnover, and that adults oviposit in fields planted to sweetpotato. *C. vespertinus* larval abundance was not affected by previous crop. Incidence of wireworm damage to sweetpotato was positively correlated with late-season abundance of *C. vespertinus*.

Keywords: wireworm, *Conoderus vespertinus*, crop rotation, sweetpotato

Introduction

NORTH CAROLINA PRODUCES over three million kg of sweetpotatoes annually, worth over $100 million to the state's economy (NCDA & CS 2006). Wireworms are the most economically damaging insect pest of sweetpotato in NC, causing unsightly holes on the roots, which render them unmarketable. Wireworms are subterranean during the immature life stages, and many overwinter as larvae in the soil. Their life cycles and the numbers of years spent underground vary among species (Thomas 1940). Soil-applied insecticides are currently the most effective tool to manage wireworms in sweetpotato; however these chemicals do not consistently prevent damage. Identifying the wireworm species present in sweetpotato and understanding their biology are the first steps toward developing improved pest management strategies to prevent economic damage by wireworms.

Several species of wireworms have been associated with certain crops or crop rotations (Thomas 1940). Because many wireworm species overwinter in the soil as larvae, it is believed that previous crop can play a role in wireworm abundance (Shirck and Lanchester 1936, Lane 1941, Nash and Rawlins 1941, Shirck 1945, Gibson et al. 1958, Belcher 1989, Seal 1990). Previous work in our laboratory indicated that crops commonly grown in rotation with sweetpotato in the NC coastal plain may impact overwintered populations of certain wireworm species. *C. vespertinus* was the most abundant species in the region and was not consistently affected by previous rotation crop, while *M. communis* was more abundant following corn and soybean than other rotations (Baumler, unpublished). For many crops, the risk of wireworm damage is greatest shortly after planting, when the overwintered larvae may feed on germinating seeds or roots of young plants, which can delay plant development or cause death (Thomas 1940). For sweetpotato, the risk of damage occurs over several months, from the beginning of storage root development in early summer until harvest in the fall. The studies described herein examine wireworm populations in sweetpotato fields throughout the growing season, as well as wireworm damage to the harvested crop. Objectives were: to determine whether previous crop affects wireworm abundance in sweetpotato fields throughout the growing season, to determine whether incidence of wireworm-damaged roots at harvest is related to previous crop and to wireworm abundance, and to describe the overall species composition and seasonal changes in wireworm populations in sweetpotato fields.

Materials and Methods

Baiting Procedure. Wireworm baits consisted of approximately 78 g of dry, steam-crimped oats (Purina Mills, St. Louis, MO). Baits were soaked in water overnight, then drained and placed in the ground in portions of sweetpotato fields left untreated by insecticides at a depth below the soil surface extending from 2.54 cm at the top of the bait to 12.7 cm at the bottom of the bait surface using a bulb planter 6 cm in diameter. Each bait was then covered with soil and marked with a wire flag. Baits were left in the field for approximately 14 d and recovered using a golf course cup cutter 10.16 cm in diameter and 15.24 cm deep, which removed the bait plus approx. 948 cm^3 of the surrounding soil. Baiting was carried out continuously throughout the duration of each study. When a bait was removed, another was placed in the same plot. Each bait including the surrounding soil was individually placed into a plastic bag and stored at 5° C until processed. Occasionally, a bait was destroyed by rodents or birds, however this was rare. Samples were visually examined by spreading the soil and remnants of the bait over a flat surface. Wireworms recovered from samples were placed in vials of 75% ethanol and identified to species under a light microscope using the keys of Rabb (1963), Riley and Keaster (1979), and Seal (1990).

Adult trapping. Wireworm adults were monitored with yellow corn rootworm traps (Great Lakes IPM Inc., Vestaburg, MI 48891). Two traps were placed in the same portion of each field in which larval baiting was conducted. Each trap was secured approx. 0.2 m off the ground, or just above the leaf canopy, to a bamboo stake in the center of a row. Traps were replaced every 12-16 d. Beetles were removed from traps, cleaned of adhesive with Histoclear™ (National Diagnostics Inc., Atlanta, GA 30336), and identified to species under a light microscope using the keys of van Zwaluwenburg (1922), Van Dyke (1932), Smith and Enns (1977), Smith and Enns (1978), Smith and Balsbaugh (1984). The number of beetles of each species was recorded for each trap.

Small-plot crop rotation study. A small-plot experiment was conducted over four years at the Cunningham Research Station in Kinston, NC to examine the effects of previous crop on seasonal wireworm abundance within sweetpotato fields and damage to sweetpotato storage roots at harvest. In the spring of 2003, two fields were planted to sweetpotato, which received no insecticide treatments. In 2004, Field 1 was planted in a randomized complete block design with four replicates of each of the six following treatments: corn, cotton, fallow, soybean, sweetpotato, and tobacco. Plots were 10 m wide (eight rows) by 12 m. Each crop was managed according to North Carolina State Extension Service recommended production practices, including weed and insect control (NC CES 2007; Table 1.1). After harvest, the location of each plot was clearly marked. Each plot was baited for wireworms continuously with two baits per plot from 20 April to 13 September 2005. All plots in Field 1 were planted to sweetpotato on 14 June 2005. After planting, the baits were placed directly in the two center rows of each plot.

The same experiment was repeated in Field 2, except that all plots were planted to sweetpotato in 2004, the rotation crops were planted in 2005 (Table 1.1), and wireworm baiting took place in 2006 from 17 March to 11 September. For both repetitions of the study, baits collected before 20 July were designated to be from the early baiting period, and those collected from July 20 to harvest were designated to be from the late baiting period.

Field 2 was planted to sweetpotato on 2 June 2006. Sweetpotatoes in Field 1were harvested on 27 September 2005 and sweetpotatoes in Field 2 were harvested on 18 September 2006. Twenty-five roots from each plot were harvested and examined for damage. The number of holes symptomatic of wireworm damage was recorded for each sweetpotato.

Wireworm abundance. The data from the small-plot crop rotation study were analyzed as a randomized complete block design. Mean separations were based on Fisher's Protected LSD, at $\alpha < 0.05$. Transformations (square root or log 10) were used whenever appropriate, based on inspection of residuals, to increase homogeneity of variance. Only results from those species captured frequently enough to meet the ANOVA requirement for homogeneity of variance are presented. Species compositions during the early (prior to 20 July) and late (20 July to harvest) baiting periods were determined. Data were subjected to analysis of variance to determine whether mean numbers of each wireworm species per bait differed by previous crop, year, or baiting period (PROC GLM, SAS Institute 1999).

Damage. Damage incidence was defined as the mean proportion of harvested roots per plot with wireworm damage. Damage severity was defined as the mean number of wireworm feeding holes per root per plot. Both damage incidence and severity data were subjected to regression analyses against mean numbers of larvae per bait caught in the same plot during the early and late baiting periods to determine whether relative larval abundance during different periods was related to wireworm damage to sweetpotato (PROC REG, SAS Institute 1999). A separate analysis of variance was conducted to determine if damage incidence and severity differed by year or previous crop (PROC GLM, SAS Institute 1999).

Commercial field survey. A two-year survey of wireworm populations in 49 commercial sweetpotato fields was conducted to determine the wireworm species composition and effects of the preceding year's crop on wireworm abundance. These fields were located in Columbus, Cumberland, Duplin, Edgecombe, Johnston, Nash, Sampson, Wayne, and Wilson Counties. All fields received normal production practices as determined by the growers during the previous year. Before sweetpotatoes were planted in each field, 16 rows (1 m wide x 91 m long) in each field, were marked. These rows received no insecticides, but otherwise received all normal production practices. These rows were divided into six plots, each 16 m x 15 m. Larval baiting was conducted from 15 April to 8 September 2005 in 29 fields and from 9 June to 22 September 2006 in 20 fields. Because the fields used in this study were managed by different growers, planting dates varied from site to site.

During the early baiting period (15 April to 19 July) in 2005, 27 commercial sweetpotato fields were sampled for wireworm larvae using oat baits. Of these fields, three were planted to corn during 2004, five to cotton, two to cucurbit (one to squash, one to watermelon), four to peanut, six to soybean, two to sweetpotato, and five to tobacco. All of the same field sites were sampled during the late period in 2005; however, two fields planted to tobacco during 2004 were added to the study and were sampled during the late period. During the early baiting period in 2006, 16 commercial sweetpotato fields were sampled for wireworm larvae using oat baits. Nine of these were planted to cotton, and seven to soybean during 2005. All of the same field sites were sampled during the late period in 2006; however, three fields planted to cotton and one planted to tobacco in 2005 were added to the study and were also sampled during the late period. Harvest dates varied by field and ranged from 26 August to 20 October 2005, and from 25 August to 26 October 2006. Twenty-five roots from each plot were harvested (150 per field) and examined for damage. The number of wireworm holes was recorded for each sweetpotato.

Wireworm abundance. The commercial field survey was analyzed as a completely randomized design. Analyses were conducted as in the small-plot crop rotation study.

Damage. Damage data were analyzed as in the small-plot crop rotation study. However, in addition to data from the commercial field survey, the data used for determining differences in damage incidence and severity by year or previous crop included damage data from 35 sweetpotato fields in 2004, in which larval baiting was not conducted. Four of these fields were planted to corn in 2003, six to cotton, three to cucurbit, three to peanut, ten to soybean, one to sweetpotato, seven to tobacco, and one field that had been left fallow in 2003. The data also included nine additional sweetpotato fields for 2006, in which larval baiting was not conducted. Four of these fields had been planted to cotton and five to soybean in 2005.

Species composition and temporal pattern of abundance. Larval baiting and adult trapping were conducted in insecticide-free portions of 35 sweetpotato fields from 20 April to 20 September 2005, and in insecticide-free portions of 25 sweetpotato fields from 17 March to 22 September 2006. Study locations included the on-farm sites and small-plot test described above plus additional locations in one commercial field and ten research station fields.

All larvae and adults were categorized by the interval of time during which they were caught in the field. Because larvae were captured alive, each larva was considered to have been collected on the date that the bait was removed from the field. In contrast, because adult beetles collected on sticky traps were typically dead when the traps were collected, each adult was considered to have been collected on the midpoint of the interval that the trap was in the field. There were at least 40 bait samples or 20 sticky traps included in each monitoring interval. Mean numbers of individuals of each species per bait or trap in each field were subjected to analysis of variance by interval to determine whether numbers of wireworm larvae or adults vary significantly over time (PROC GLM, SAS Institute 1999).

***C. vespertinus* head capsule width.** Head capsules of *C. vespertinus* larvae were measured to the nearest 0.1 mm and categorized by the interval of time during which they were caught. At least 25 individuals were caught during each interval. Head capsule widths were subjected to analysis of variance by interval to determine if there was a significant change in larval size that would indicate a generation turnover (PROC GLM, SAS Institute 1999).

Results

Small-plot crop rotation study. In 2005, 62 and 121 wireworm larvae were recovered from 168 and 238 baits during the early and late baiting periods, respectively. In 2006, 54 and 232 wireworms were recovered from 223 and 201 baits during the early and late baiting periods, respectively (Table 2.1). In the early baiting periods of both 2005 and 2006, *M. communis* comprised the largest proportion of total wireworms, while in the late periods of both years, *C. vespertinus* made up the largest proportion. *C. amplicollis* made up a small proportion of the total wireworms captured in 2005 and the early period of the 2006 season, but became more abundant in the late period of 2006. *C.*

falli and *Glyphonyx* sp. were caught during the early and late baiting periods in both years. *C. bellus*, *C. lividus*, and *C. scissus* tended to be proportionately less abundant or less consistently present in the bait captures.

Wireworm abundance.

Total wireworms. Mean numbers of total wireworms per bait did not differ significantly by previous crop ($F_{5, 30} = 1.78$, $p = 0.1479$; Table 2.2) or by year ($F_{1, 6} = 4.70$, $p = 0.0733$) but were greater during the late baiting period than the early period ($F_{1, 36} = 37.99$, $p < 0.0001$; years pooled; Table 2.3). There were no interactions between previous crop, year, and baiting period for total wireworms.

C. amplicollis. Mean numbers of *C. amplicollis* per bait did not differ significantly by previous crop ($F_{5, 30} = 0.79$, $p = 0.5862$; Table 2.2). Mean numbers of *C. amplicollis* larvae per bait were greater in the late baiting period of 2006 than in any other period, resulting in a significant interaction between baiting period and year for this species ($F_{1, 36} = 29.66$, $p < 0.0001$). When each year was analyzed separately, mean numbers of *C. amplicollis* per bait were significantly greater in the late period than the early period of 2006 ($F_{1, 18} = 36.84$, $p < 0.0001$; Table 2.3) but did not differ significantly between periods in 2005 ($F_{1, 18} = 1.80$, $p = 0.1964$).

C. vespertinus. Mean numbers of *C. vespertinus* per bait did not differ significantly by previous crop ($F_{5, 30} = 0.41$, $p = 0.8353$; Table 2.2) or year ($F_{1, 6} = 0.55$, $p = 0.4871$), but were greater during the late baiting period than the early period ($F_{1, 36} = 52.22$, $p < 0.0001$ (years pooled); Table 2.3). There were no interactions between previous crop, year, and baiting period for *C. vespertinus*.

M. communis. Mean numbers of *M. communis* per bait were significantly different by previous crop ($F_{5, 30} = 2.77$, $p = 0.0357$; Fig. 2.1) and were most abundant in plots previously planted to corn and soybean, least abundant in plots previously planted to sweetpotato and tobacco, and were of intermediate abundance in plots previously planted to cotton or left fallow. Mean numbers of *M. communis* larvae per bait were not significantly different by year ($F_{1, 6} = 0.02$, $p = 0.8802$), but were significantly greater during the early baiting period than the late period ($F_{1, 36} = 26.08$, $p < 0.0001$; Table 2.3). There were no interactions between previous crop, year, and baiting period for *M. communis*.

Other spp. *C. bellus*, *C. falli*, *C. lividus*, *C. scissus*, and *Glyphonyx* sp. were not sufficiently abundant to justify statistical analyses. Means and standard errors for each of these species following the six rotations and during the early and late baiting periods are reported in Tables 2.2 and 2.3, respectively.

Damage. Incidence of wireworm damage to sweetpotatoes at harvest differed significantly by previous crop ($F_{5, 30} = 2.55$, $p = 0.0485$; Fig. 2.2) and by year ($F_{1,6} = 7.81$, $p = 0.0314$; Fig. 2.3), but there was no interaction between previous crop and year. Damage incidence was greater in 2006 than in 2005. The highest incidences of damage occurred following fallow and soybean, the lowest following corn and cotton, and intermediate damage incidence occurred following sweetpotato and tobacco. Severity of wireworm damage to sweetpotatoes at harvest did not differ significantly by previous crop ($F_{5,30} = 2.16$, $p = 0.0853$; Fig. 2.2) or by year ($F_{1, 6} = 5.13$, $p = 0.0641$; Fig. 2.3), and there was no interaction between previous crop and year.

There were no significant relationships between damage incidence at harvest and mean numbers of either total wireworms per bait ($F_{1, 46} = 0.00$, $p = 0.9717$; Fig. 2.4 A) or *M. communis* per bait ($F_{1, 46} = 0.35$, $p = 0.5571$; Fig. 2.4 C) during the early baiting period. There were also no significant relationships between damage severity at harvest and mean numbers of total wireworms per bait ($F_{1, 46} = 0.10$, $p = 0.7551$; Fig. 2.4 B) or *M. communis* ($F_{1, 46} = 0.45$, $p = 0.5054$; Fig. 2.4 D) during the early baiting period.

There were significant relationships between damage incidence at harvest and late-period mean numbers of both total wireworms per bait ($F_{1, 46} = 8.26$, $p = 0.0061$; Fig 2.5 A) and *C. amplicollis* per bait ($F_{1, 46} = 5.21$, $p = 0.0271$; Fig. 2.5 C). These regressions explained 15% and 10% of the variance in damage incidence, respectively. There was no significant relationship between damage incidence and late-period mean numbers per bait of *C. vespertinus* ($F_{1, 46} = 3.02$, $p = 0.0888$; Fig. 2.5 E). There was a significant relationship between damage severity at harvest and late-period mean numbers of total wireworms per bait ($F_{1, 46} = 5.14$, $p = 0.0281$; Fig. 2.5 B). This regression explained 10% of the variance in damage severity. There were no significant relationships between damage severity and late-period mean numbers of either *C. amplicollis* ($F_{1, 46} = 2.62$, $p = 0.1124$; Fig. 2.5 D) or *C. vespertinus* ($F_{1, 46} = 2.32$, $p = 0.1345$; Fig. 2.5 F).

Commercial field survey. During 2005, 193 and 448 wireworms were recovered from 323 and 551 baits during the early and late baiting periods, respectively (Table 2.4). *C. scissus* made up a small proportion of the total wireworms captured early in 2005, but became more abundant late. During 2006, 42 and 410 wireworms were recovered from

120 and 448 baits during the early and late baiting periods, respectively (Table 2.4). *C. vespertinus* made up the largest proportion of total wireworm caught in baits in both years and in both baiting periods.

Wireworm abundance.

Total wireworms. Mean numbers of total wireworms per bait were significantly different by previous crop ($F_{6, 40} = 2.89$, $p = 0.0198$; Fig. 2.6). Total wireworm abundance was greatest in fields previously planted to corn and least in fields previously planted to cucurbit and sweetpotato (Fig. 2.6). Mean total numbers of wireworms per bait were not significantly different by year ($F_{1, 48} = 0.61$, $p = 0.4371$), but were significantly greater during the late baiting period than the early ($F_{1, 34} = 37.72$, $p < 0.0001$; Table 2.5). There were no interactions between previous crop, year, and baiting period for total wireworms.

C. vespertinus. Mean numbers of *C. vespertinus* per bait were similar regardless previous crop ($F_{6, 40} = 2.09$, $p = 0.0758$; Table 2.6) or by year ($F_{1, 50} = 0.01$, $p = 0.9070$), but were significantly greater during the late baiting period than the early ($F_{1, 34} = 34.03$, $p < 0.0001$; Table 2.5). There were no interactions between previous crop, year, and baiting period for *C. vespertinus*.

Other spp. Means and standard errors for *C. amplicollis*, *C falli*, *C. lividus*, *C. scissus*, *Glyphonyx* sp., and *M. communis* by previous crop and baiting period are reported in Tables 2.6 and 2.5, respectively.

Damage. Incidence of wireworm damage to sweetpotatoes at harvest did not differ significantly by year ($F_{2,75} = 1.47$, $p = 0.2370$; Table 2.7) or by previous crop ($F_{7,75}$

= 0.94, p = 0.4802; Table 2.8), and there was no interaction between year and previous crop. Severity of wireworm damage to sweetpotatoes at harvest did not differ significantly by year ($F_{2, 75}$ = 1.87, p = 0.1611; Table 2.7) or by previous crop ($F_{7, 75}$ = 0.86, p = 0.5443; Table 2.8), and there was no interaction between year and previous crop.

There were significant relationships between damage incidence at harvest and early-period mean numbers per bait of both total wireworms ($F_{1, 41}$ = 9.76, p = 0.0033; Fig. 2.7 A) and *C. vespertinus* ($F_{1, 41}$ = 7.21, p = 0.0104; Fig. 2.7 C). These regressions explained 19% and 15% of the variance in damage incidence, respectively. There were also significant relationships between damage severity at harvest and early-period mean numbers per bait of both total wireworms ($F_{1, 41}$ = 4.18, p = 0.0472; Fig. 2.7 B) and *C. vespertinus* ($F_{1, 41}$ = 4.18, p = 0.0473; Fig. 2.7 D). Each of these regressions explained 9% of the variance in damage severity.

There were significant relationships between damage incidence at harvest and late-period mean numbers per bait of total wireworms ($F_{1, 47}$ = 11.71, p = 0.0013; Fig. 2.8 A) and *C. vespertinus* ($F_{1, 47}$ = 7.55, p = 0.0085; Fig. 2.8 C). These regressions explained 20% and 14% of the variance in damage incidence, respectively. There were no significant relationships between damage severity at harvest and late-period mean numbers per bait of either total wireworms ($F_{1, 47}$ = 1.20, p = 0.2790; Fig 2.8 B) or *C. vespertinus* ($F_{1, 47}$ = 0.31, p = 0.5822; Fig. 2.8 D).

Species composition and temporal pattern of abundance.

Larvae. During 2005 and 2006, 1,550 and 1,307 baits were retrieved and 1,058 and 1,066 total wireworms were recovered, respectively (Table 2.9). Eight species of wireworm larvae were identified, which accounted for 99% of all larvae collected. In both years, *C. vespertinus* was the most abundant species collected in baits, and the numbers of *C. vespertinus* larvae per bait were significantly different by the time interval in which they were captured (2005: $F_{7, 111} = 10.03$, $p < 0.0001$; 2006: $F_{8, 103} = 10.80$, $p < 0.0001$; Fig. 2.9). In 2005, the greatest numbers of *C. vespertinus* larvae were caught from 1 August through 30 September. In 2006, the greatest numbers of larvae were caught from 16 August through 30 September.

Means and standard errors for *C. amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. scissus*, *Glyphonyx* sp., and *M. communis* are reported in Table 2.10.

Adults. During 2005 and 2006, 2,360 and 1,482 total adult beetles were recovered from 228 and 293 traps, respectively (Table 2.11). Eight species of adult beetles were identified. In both years, *C. vespertinus* was the most abundant species collected on traps, and numbers of *C. vespertinus* adults per trap varied significantly over time (2005: $F_{5, 104} = 39.47$, $p < 0.0001$; 2006: $F_{5, 83} = 44.25$, $p < 0.0001$; Fig. 2.10). In 2005, the most *C. vespertinus* adults were captured from 1 – 15 July, and the fewest after 15 August. In 2006, the most *C. vespertinus* adults were captured from 1 – 31 July, and the fewest after 15 August.

During 2005, mean numbers of *G. bimarginatus* adults captured per trap did not differ significantly over time ($F_{5, 104} = 0.78$, $p = 0.5675$; Fig. 2.11). During 2006, mean numbers of *G. bimarginatus* adults differed significantly over time ($F_{5, 83} = 5.64$, $p = 0.0002$; Fig. 2.11). The greatest numbers of *G. bimarginatus* adults were captured during August.

Means and standard errors for *Conoderus* spp., *C. amplicollis*, *C. bellus*, *C. falli*, *C. lividus*, *C. scissus*, and *Melanotus* spp. adults are reported in Table 2.12.

***C. vespertinus* head capsule width.** In both years of the study, mean head capsule widths of *C. vespertinus* larvae differed significantly over time (2005: $F_{9, 69} = 8.21$, $p < 0.0001$; 2006: $F_{5, 47} = 8.30$, $p < 0.0001$; Fig. 2.12). During 2005, larval head capsule width declined significantly after 15 July. In 2006, baiting began in mid-June, and larvae caught from 16 – 30 June were significantly larger than those caught during July and August.

Discussion

The species composition in the small-plot crop rotation study was very different than that in the commercial field survey. In the early period, *M. communis* comprised over 50% of the wireworms collected in the small-plot study, but less than 6% of those collected in the commercial field survey (years pooled). Likewise, in the late baiting period of 2006, *C. amplicollis* comprised over 30% of the total wireworms collected in the small-plot study, but less than 2% in the commercial field survey. These differences in species composition may in part explain the inconsistency in the effects of previous crop on mean wireworm numbers that we observed between these studies. They may also help to explain why there were differences in damage incidence by previous crop in the small-plot study (Fig. 2.2), but not in the commercial field survey (Table 2.8). Sweetpotatoes planted following soybean had significantly higher incidences of damage than those planted following cotton in the small-plot study, while in the commercial field survey there were no significant differences between these treatments and the trend was reversed. The reasons for the differences in species composition between the small-plot study site, located at the Cunningham Research Station in Kinston, NC, and the other field sites, located throughout the sweetpotato production region in NC, are unknown, but could be related to the mix of crops grown at the research station, which may provide supportive habitat for several species of wireworms within a relatively small area. Another important difference between the small-plot study and the commercial field survey is that the small-plot study was a balanced design, and the commercial field survey was not. The commercial field survey relied on availability of commercial field sites. The lack of significant differences among the treatments in these studies could be due to a lack of statistical power caused by this imbalance.

Among the aims of the studies presented here were to determine the overall wireworm species composition in the NC Coastal Plain, and to illustrate the seasonal activity of those species in relation to sweetpotato. In the small-plot study, *M. communis* was more abundant in the early than the late baiting period in both 2005 and 2006 (Tables 2.1, 2.3). This suggests that mature *M. communis* larvae present prior to the planting of sweetpotato did not remain in the crop to oviposit as adults or that the larvae were less responsive to the oat baits later in the season. In contrast, *C. amplicollis* larvae were significantly more abundant in the late period than the early period in 2006, indicating that this species oviposits in sweetpotato or becomes more responsive to oat baits late in the season. *C. vespertinus* was the only species collected consistently throughout all of our studies. Rabb (1963) described the life history of *C. vespertinus* in tobacco. In the Piedmont region of NC, *C. vespertinus* is univoltine and overwinters as a larva. Larval numbers decrease in late spring when pupation occurs and adult emergence begins. Adults and eggs are present from late spring through early autumn, but the peak adult flight occurs in early summer. Our data correspond well with Rabb's findings in tobacco (Figs. 2.8, 2.9). We found that mean larval numbers of *C. vespertinus* per bait were lowest in early July, when mean numbers of adults per trap were greatest. Mean larval numbers per bait began to drastically increase in early August and leveled off in September. In all of our experimental studies, we found significantly more *C. vespertinus* in the late baiting period (20 July to harvest) than the early period (prior to 20 July). We also found mean larval head capsule width to be largest in late spring, and smallest in mid-summer (Fig. 2.11). These findings are consistent with the early-summer generation turn-over in tobacco described by Rabb (1963). The only inconsistency between our data and Rabb's is that Rabb reported that larval numbers from the current season's eggs begin to increase in mid-June, while we did not observe this until early August. Likewise, Rabb found the fewest *C. vespertinus* larvae in early June, while we found the lowest numbers in early July. We believe that these dissimilarities were caused by a difference in methods, and not by a change in the habits of *C. vespertinus*. Rabb used both sifting and Tullgren funnels to find larvae, and was able to observe first instar larvae, which by our methods were very difficult to detect.

The timing of *C. vespertinus* life stages corresponds with the growth and development of sweetpotatoes. Sweetpotatoes are planted in late May or early June. The onset of root swell begins about a month later, when adult wireworms are in peak flight and presumably, oviposition is at a peak as well. Storage root development continues until harvest in the fall. It follows that because *C. vespertinus* is the most abundant species in sweetpotato, and larval numbers of this species increase during root swell, that they are likely responsible for most of the holes in the roots identified as characteristic wireworm damage. In our commercial field survey, *C. vespertinus* larval numbers during the late portion of the season were positively correlated with incidence of wireworm damage (Fig. 2.8 C).

However, while damage incidence was correlated with mean numbers of total wireworms, and with mean numbers of *C. amplicollis*, or *C. vespertinus* during the early and late baiting periods, none of the correlations were strong (Figs. 2.5 A, C; 2.7 A, C; 2.8 A, C). The highest R^2 value was 0.20, for the regression of damage incidence and mean numbers of total wireworms per bait during the early baiting period of the commercial field survey, a relationship that was not significant in the small-plot crop rotation study (Fig. 2.4 A). Bait samples are relative samples, and while they capture more wireworms than absolute, unbaited samples, the resulting data are not sufficiently robust to consistently predict wireworm damage incidence or severity to sweetpotato.

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Table 2.1. Total numbers and species composition of wireworm larvae collected from 168 oat baits during the early baiting period and 238 oat baits in the late baiting period of 2005, and from 223 oat baits in the early baiting period and 201 oat baits in the late baiting period of 2006, in the small-plot crop rotation study.

Species	2005				2006			
	Early (20 April – 19 July)		Late (20 July – 13 September)		Early (17 March – 19 July)		Late (20 July – 11 September)	
	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total
Total wireworms	62		121		54		232	
M. communis	25	40.3	8	6.6	34	63.0	19	8.2
C. vespertinus	5	8.1	68	56.2	3	5.6	109	47.0
C. amplicollis	0	0.0	3	2.5	2	3.7	77	33.2
C. falli	9	14.5	16	13.2	8	14.8	11	4.7
Glyphonyx sp.	16	25.8	10	8.3	7	13.0	4	1.7
C. bellus	4	6.5	10	8.3	0	0.0	8	3.4
C. lividus	2	3.2	1	0.8	0	0.0	1	0.4
C. scissus	0	0.0	1	0.8	0	0.0	0	0.0
other	1	1.6	4	3.3	0	0.0	3	1.3

Table 2.2. Abundance[1] of seven wireworm species captured in oat baits during 20 April – 13 September 2005 and 17 March – 11 September 2006 in small plots of sweetpotato previously planted to six rotations during 2004 and 2005, respectively.

Previous Rotation	Wireworm species							
	Total wireworms	*C. amplicollis*	*C. vespertinus*	*C. bellus*	*C. falli*	*C. lividus*	*C. scissus*	*Glyphonyx* sp.
Corn	0.65 ± 0.16a	0.12 ± 0.09a	0.16 ± 0.06a	0.03 ± 0.02	0.04 ± 0.01	0 ± 0	0 ± 0	0.03 ± 0.01
Cotton	0.44 ± 0.13a	0.05 ± 0.03a	0.14 ± 0.06a	0.02 ± 0.01	0.03 ± 0.02	0 ± 0	0 ± 0	0.03 ± 0.01
Fallow	0.65 ± 0.15a	0.12 ± 0.08a	0.22 ± 0.07a	0.02 ± 0.01	0.09 ± 0.03	0.01 ± 0.01	0 ± 0	0.02 ± 0.01
Soybean	0.65 ± 0.10a	0.04 ± 0.02a	0.19 ± 0.05a	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.02	0 ± 0	0.13 ± 0.05
Sweetpotato	0.45 ± 0.16a	0.12 ± 0.07a	0.19 ± 0.09a	0.02 ± 0.01	0.04 ± 0.02	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.01
Tobacco	0.55 ± 0.13a	0.11 ± 0.07a	0.15 ± 0.04a	0.03 ± 0.02	0.05 ± 0.01	0 ± 0	0 ± 0	0.05 ± 0.03

[1] Data are means of wireworms per bait ± SEM over both years of the study.
Only total wireworms, C. amplicollis, and C. vespertinus were sufficiently abundant to justify ANOVA. Values within a column followed by the same letter are not significantly different.

Table 2.3. Abundance[1] of seven wireworm species captured in oat baits during the early and late bating periods of 2005 and 2006 in small plots of sweetpotato.

Wireworm species		Baiting period	
		Early (17 Mar – 18 Jul)	Late (19 Jul – 13 Sep)
Total wireworms		0.31 ± 0.05	0.82 ± 0.09*
C. amplicollis	2005	0.00 ± 0.00	0.01 ± 0.01
	2006	0.01 ± 0.01	0.35 ± 0.08*
C. vespertinus		0.02 ± 0.01	0.33 ± 0.04*
M. communis		0.16 ± 0.03	0.03 ± 0.01*
C. bellus		0.01 ± 0.01	0.03 ± 0.01
C. falli		0.04 ± 0.01	0.04 ± 0.01
C. lividus		0.01 ± 0.01	0.00 ± 0.00
Glyphonyx sp.		0.07 ± 0.02	0.03 ± 0.01

[1] Data are means of wireworms per bait ± SEM. Four replicates, 830 total baits.
* Means for early and late baiting periods are significantly different at $p < 0.05$ by Fisher's Protected LSD.

Table 2.4. Total numbers and species composition of wireworm larvae collected in commercial sweetpotato fields from 323 oat baits during the early baiting period and 551 oat baits during the late baiting period of 2005, and from 120 oat baits during the early baiting period and 448 oat baits in the late baiting period of 2006.

Species	2005				2006			
	Early (15 April – 19 July)		Late (20 July – 8 September)		Early (21 June – 19 July)		Late (20 July – 22 September)	
	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total
Total wireworms	193		448		42		410	
C. scissus	2	1.0	50	11.2	0	.	10	2.4
C. vespertinus	135	69.9	351	78.3	38	90.5	353	86.1
C. amplicollis	1	0.5	9	2.0	0	.	1	0.2
C. bellus	18	9.3	14	3.1	0	.	6	1.5
C. falli	1	0.5	8	1.8	0	.	3	0.7
C. lividus	5	2.6	1	0.2	1	2.4	5	1.2
Glyphonyx sp.	14	7.3	10	2.2	1	2.4	3	0.7
M. communis	13	6.7	2	0.4	1	2.4	5	1.2
other	4	2.1	3	0.7	1	2.4	24	5.9

Table 2.5. Abundance[1] of eight wireworm species captured in oat baits during the early and late bating periods of 2005 and 2006 in commercial sweetpotato fields.

Wireworm species	Baiting period	
	Early (15 Apr – 19 Jul)	Late (20 Jul – 22 Sep)
Total wireworms	0.44 ± 0.11	0.96 ± 0.14*
C. vespertinus	0.32 ± 0.10	0.82 ± 0.13*
C. amplicollis	0.00 ± 0.00	0.01 ± 0.01
C. bellus	0.04 ± 0.01	0.02 ± 0.01
C. falli	0.00 ± 0.00	0.01 ± 0.00
C. lividus	0.01 ± 0.00	0.02 ± 0.01
C. scissus	0.00 ± 0.00	0.06 ± 0.02
Glyphonyx sp.	0.04 ± 0.02	0.01 ± 0.01
M. communis	0.02 ± 0.01	0.01 ± 0.00

[1] Data are means of wireworms per bait ± SEM over both years of the study.

* Means for early and late baiting periods are significantly different at $p < 0.05$ by Fisher's Protected LSD.

Table 2.6. Abundance[1] of eight wireworm species captured in oat baits during 15 April – 8 September 2005 and 9 June – 22 September 2006 in commercial sweetpotato fields previously planted to seven rotation crops in 2004 and 2005, respectively.

Previous rotation	Wireworm species							
	C. vespertinus	*C. amplicollis*	*C. bellus*	*C. falli*	*C. lividus*	*C. scissus*	*Glyphonyx* sp.	*M. communis*
Corn	1.60 ± 0.39a	0.06 ± 0.04	0.07 ± 0.05	0 ± 0	0.06 ± 0.06	0.01 ± 0.01	0.03 ± 0.02	0.07 ± 0.05
Cotton	0.55 ± 0.14a	0.01 ± 0.01	0.03 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01	0.05 ± 0.03	0.02 ± 0.01
Cucurbit	0.06 ± 0.06a	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0.13 ± 0.08	0 ± 0	0 ± 0
Peanut	0.30 ± 0.18a	0 ± 0	0 ± 0	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.02	0.02 ± 0.02
Soybean	0.65 ± 0.19a	0.00 ± 0.00	0.02 ± 0.01	0.01 ± 0.00	0.01 ± 0.01	0.07 ± 0.04	0.02 ± 0.01	0.01 ± 0.01
Sweetpotato	0.09 ± 0.06a	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Tobacco	0.55 ± 0.20a	0 ± 0	0.05 ± 0.03	0.01 ± 0.01	0.01 ± 0.01	0 ± 0	0 ± 0	0.01 ± 0.01

[1] Data are means of wireworms per bait ± SEM over both years of the study. Only C. vespertinus were sufficiently abundant to justify ANOVA. Values within a column followed by the same letter are not significantly different.

Table 2.7. Incidence and severity of wireworm damage to sweetpotato roots at harvest in 2004, 2005, and 2006 in the commercial field survey.

Year	Damage incidence (proportion of roots with wireworm damage ± SEM)	Damage severity (mean number of holes per root ± SEM)
2004	0.30 ± 0.04	0.98 ± 0.18
2005	0.42 ± 0.04	1.60 ± 0.26
2006	0.38 ± 0.04	2.22 ± 0.80

Table 2.8. Incidence and severity of wireworm damage to sweetpotato roots in 2005 and 2006 in commercial fields previously planted to seven rotations in 2004 and 2005, respectively.

Previous rotation	Damage incidence (proportion of roots with wireworm damage ± SEM[1])	Damage severity (mean number of holes per root ± SEM[1])
Corn	0.30 ± 0.12	1.32 ± 0.73
Cotton	0.42 ± 0.04	2.36 ± 0.88
Cucurbit	0.52 ± 0.14	2.50 ± 0.92
Peanut	0.34 ± 0.08	1.15 ± 0.39
Soybean	0.31 ± 0.04	1.02 ± 0.20
Sweetpotato	0.25 ± 0.08	0.60 ± 0.26
Tobacco	0.38 ± 0.07	1.44 ± 0.32

[1] Data are averaged over both years of the study.

Table 2.9. Total numbers and species composition of wireworm larvae collected from 1,550 oat baits, from 20 April to 20 September in 35 sweetpotato fields in 2005, and from 1,307 oat baits from 17 March to 22 September in 25 sweetpotato fields in 2006.

Species	2005		2006	
	Number	Percent of total	Number	Percent of total
Total	1058		1066	
C. vespertinus	728	68.8	671	62.9
C. amplicollis	18	1.7	100	9.4
C. bellus	69	6.5	31	2.9
C. falli	35	3.3	71	6.7
C. lividus	28	2.6	9	0.8
C. scissus	59	5.6	66	6.2
Glyphonyx sp.	56	5.3	18	1.7
M. communis	54	5.1	84	7.9
other	11	1.0	16	1.5

Table 2.10. Abundance[1] of seven wireworm species (larvae) during different time intervals from 35 sweetpotato fields in 2005 and 25 sweetpotato fields in 2006.

Interval		*C. amplicollis*	*C. bellus*	*C. falli*	*C. lividus*	*C. scissus*	*Glypho-nyx* sp.	*M. communis*
2005	Apr 1 – May 31 (6)	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.03	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.08 ± 0.05
	Jun 1 – 15 (7)	0.02 ± 0.02	0.02 ± 0.02	0.02 ± 0.02	0.05 ± 0.03	0.02 ± 0.02	0.06 ± 0.04	0.07 ± 0.07
	Jun 16 – 30 (12)	0.00 ± 0.00	0.10 ± 0.03	0.00 ± 0.00	0.03 ± 0.02	0.00 ± 0.00	0.02 ± 0.01	0.05 ± 0.02
	Jul 1 – 15 (23)	0.00 ± 0.00	0.07 ± 0.03	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01	0.05 ± 0.04	0.05 ± 0.04
	Jul 16 – 31 (32)	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.05 ± 0.03	0.02 ± 0.01	0.01 ± 0.01
	Aug 1 – 15 (32)	0.02 ± 0.01	0.04 ± 0.03	0.02 ± 0.01	0.00 ± 0.00	0.05 ± 0.03	0.01 ± 0.01	0.00 ± 0.00
	Aug 16 – 31 (31)	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.07 ± 0.04	0.02 ± 0.01	0.01 ± 0.00
	Sep 1 – 30 (7)	0.03 ± 0.03	0.02 ± 0.02	0.00 ± 0.00	0.12 ± 0.11	0.17 ± 0.09	0.06 ± 0.03	0.02 ± 0.02
2006	Mar 16 – 31 (1)	0.03	0.00	0.10	0.00	0.00	0.06	0.18
	Jun 1 – 15 (2)	0.00 ± 0.00	0.03 ± 0.03	0.16 ± 0.16	0.03 ± 0.03	0.00 ± 0.00	0.01 ± 0.01	0.61 ± 0.51
	Jun 16 – 30 (9)	0.00 ± 0.00	0.00 ± 0.00	0.06 ± 0.06	0.02 ± 0.02	0.08 ± 0.08	0.05 ± 0.03	0.12 ± 0.09
	Jul 1 – 15 (13)	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01
	Jul 16 – 31 (30)	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.02
	Aug 1 – 15 (29)	0.01 ± 0.01	0.00 ± 0.00	0.05 ± 0.03	0.01 ± 0.01	0.04 ± 0.02	0.00 ± 0.00	0.02 ± 0.01

Table 2.10 (continued).

Interval		*C. ampli-collis*	*C. bellus*	*C. falli*	*C. lividus*	*C. scissus*	*Glypho-nyx* sp.	*M. comm.-unis*
2006	Aug 16 – 31 (24)	0.07 ± 0.04	0.06 ± 0.02	0.04 ± 0.02	0.01 ± 0.01	0.05 ± 0.03	0.00 ± 0.00	0.01 ± 0.01
2006	Sep 1 – 15 (21)	0.06 ± 0.04	0.04 ± 0.01	0.03 ± 0.02	0.02 ± 0.02	0.09 ± 0.06	0.01 ± 0.01	0.01 ± 0.01
	Sep 16 – 30 (7)	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.02	0.02 ± 0.02	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.02

[1] Data are means of wireworms per bait ± SEM. Average of number of replicates indicated in parentheses, 1,550 total baits in 2005, 1,307 total baits in 2006.

Table 2.11. Total numbers and species composition of wireworm adults collected from 228 traps, from 21 June to 20 September in 32 sweetpotato fields in 2005 and from 293 traps, from 15 June to 30 September in 26 sweetpotato fields in 2006.

Species	2005		2006	
	Number	Percent of total	Number	Percent of total
Total	2,360		1,482	
C. vespertinus	1693	71.7	725	48.9
Conoderus spp.	136	5.8	49	3.3
C. amplicollis	3	0.1	3	0.2
C. bellus	43	1.8	43	2.9
C. falli	24	1.0	52	3.5
C. lividus	53	2.2	74	5.0
C. scissus	154	6.5	60	4.0
G. bimarginatus	234	9.9	442	29.8
Melanotus spp.	15	0.6	24	1.6
Other	5	0.2	10	0.7

Table 2.12. Abundance[1] of seven wireworm species (adults) captured on traps during different time intervals in 32 sweetpotato fields in 2005 and 26 sweetpotato fields in 2006.

Interval		*Conoderus* spp.	*C. amplicollis*	*C. bellus*	*C. falli*	*C. lividus*	*C. scissus*	*Melanotus* spp.
2005	16 – 30 Jun (18)	1.39 ± 1.13	0.01 ± 0.01	0.63 ± 0.36	0.24 ± 0.13	0.25 ± 0.10	1.50 ± 0.47	0 ± 0
	1 – 15 Jul (25)	0.72 ± 0.40	0 ± 0	0.13 ± 0.04	0.16 ± 0.14	0.27 ± 0.13	1.11 ± 0.73	0.01 ± 0.01
	16 – 31 Jul (31)	0.66 ± 0.41	0.03 ± 0.02	0.08 ± 0.05	0.05 ± 0.03	0.15 ± 0.05	0.31 ± 0.16	0.03 ± 0.02
	1 – 15 Aug (32)	0.09 ± 0.06	0 ± 0	0.03 ± 0.02	0.08 ± 0.07	0.13 ± 0.06	0.10 ± 0.08	0.15 ± 0.07
	16 – 31 Aug (27)	0.06 ± 0.04	0 ± 0	0.02 ± 0.02	0 ± 0	0.13 ± 0.05	0.15 ± 0.11	0.04 ± 0.03
	1 – 30 Sep (9)	0 ± 0	0 ± 0	0.17 ± 0.12	0 ± 0	0 ± 0	0 ± 0	0.06 ± 0.06
2006	1 – 30 Jun (10)	0.15 ± 0.08	0.03 ± 0.03	0.20 ± 0.15	0.35 ± 0.17	0.05 ± 0.05	0.40 ± 0.19	0.10 ± 0.10
	1 – 15 Jul (14)	0.47 ± 0.17	0.04 ± 0.04	0.42 ± 0.20	0.32 ± 0.21	0.07 ± 0.07	0.58 ± 0.32	0.02 ± 0.02
	16 – 31 Jul (24)	0.25 ± 0.08	0 ± 0	0.25 ± 0.11	0.15 ± 0.09	0.40 ± 0.15	0.27 ± 0.15	0.06 ± 0.03
	1 – 15 Aug (25)	0.12 ± 0.04	0.02 ± 0.02	0.12 ± 0.07	0.26 ± 0.10	0.51 ± 0.20	0.21 ± 0.07	0.10 ± 0.06
	16 – 31 Aug (24)	0.09 ± 0.05	0 ± 0	0.02 ± 0.02	0.30 ± 0.14	0.25 ± 0.10	0.07 ± 0.05	0.06 ± 0.04
	1 – 30 Sep (17)	0.01 ± 0.01	0 ± 0	0 ± 0	0.01 ± 0.01	0.06 ± 0.06	0.01 ± 0.01	0.01 ± 0.01

[1] Data are means of adults per trap ± SEM. Average of number of replicates indicated in parentheses. 228 total traps in 2005, 293 total traps in 2006.

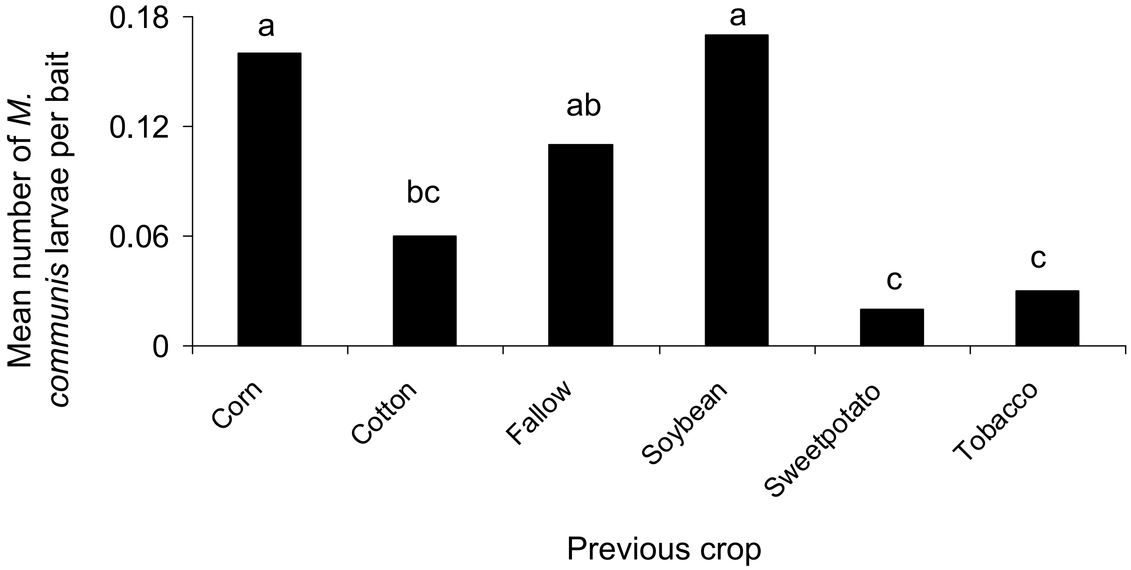


Figure 2.1. Abundance of *M. communis* larvae captured during 20 April – 13 September 2005 and 17 March – 11 September 2006 in small plots of sweetpotato previously planted to six rotations in 2004 and 2005, respectively.

Bars with the same letter are not significantly different.

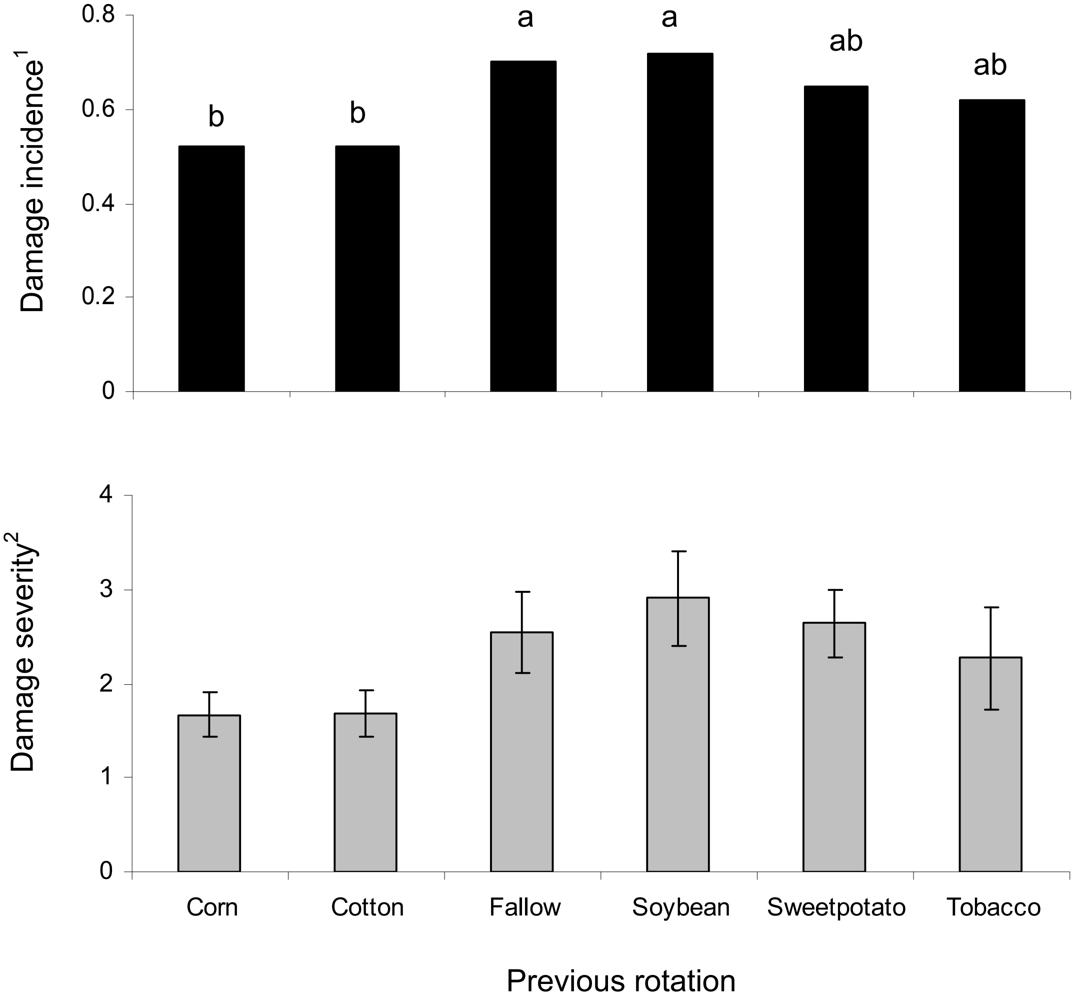


Figure 2.2. Incidence and severity of wireworm damage to sweetpotato roots harvested in 2005 and 2006 from small plots previously planted to six rotations in 2004 and 2005, respectively.

[1] Proportion of total roots with wireworm damage. Means with the same letter above are not significantly different.
[2] Mean number of holes per root.
Values are averaged over both years of the study.

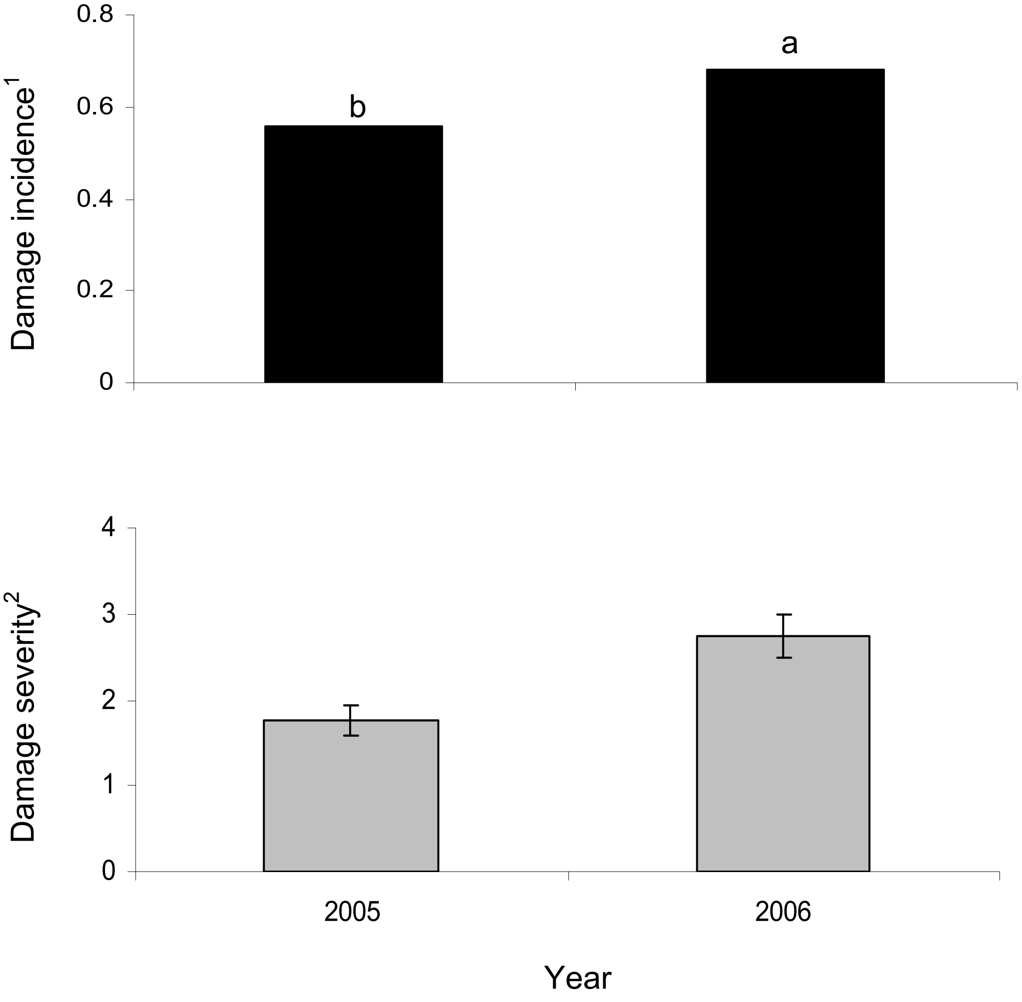


Figure 2.3. Damage incidence and severity to sweetpotatoes at harvest in 2005 and 2006 in the small-plot crop rotation study.

[1] Proportion of roots with wireworm damage.
[2] Mean number of holes per root.

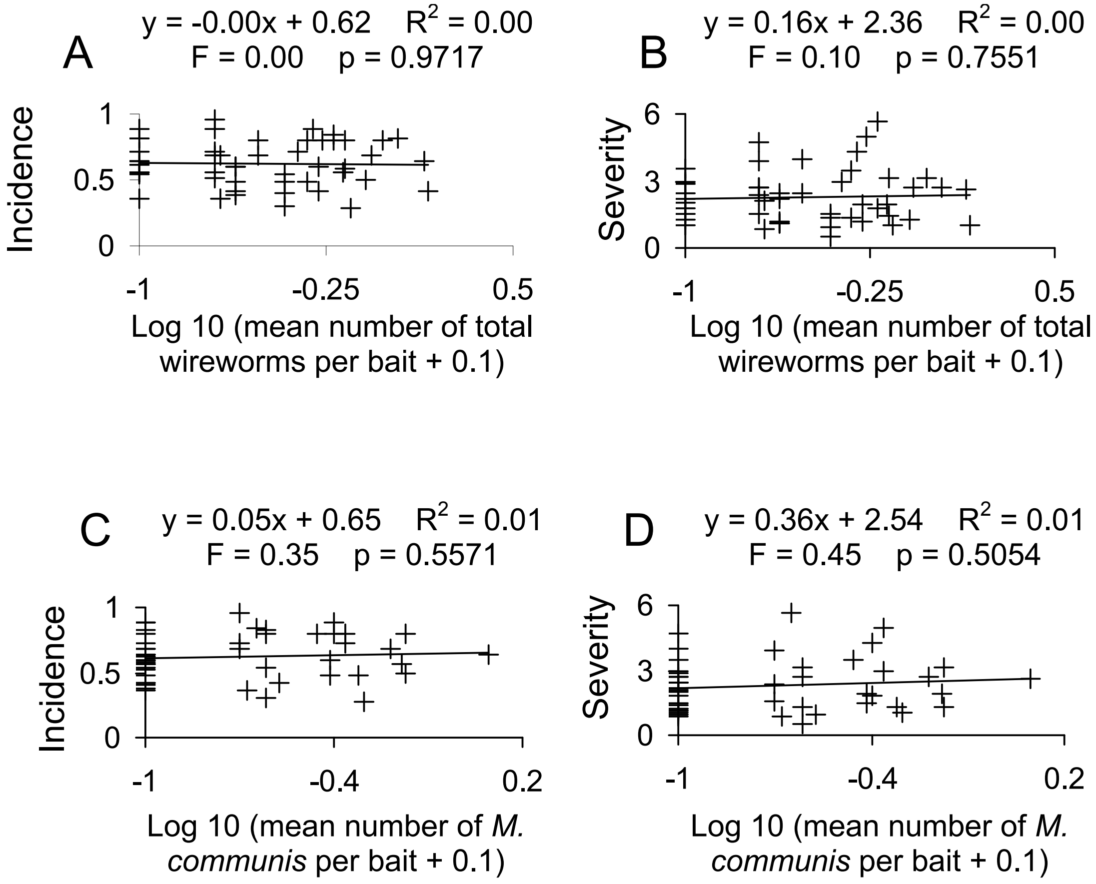
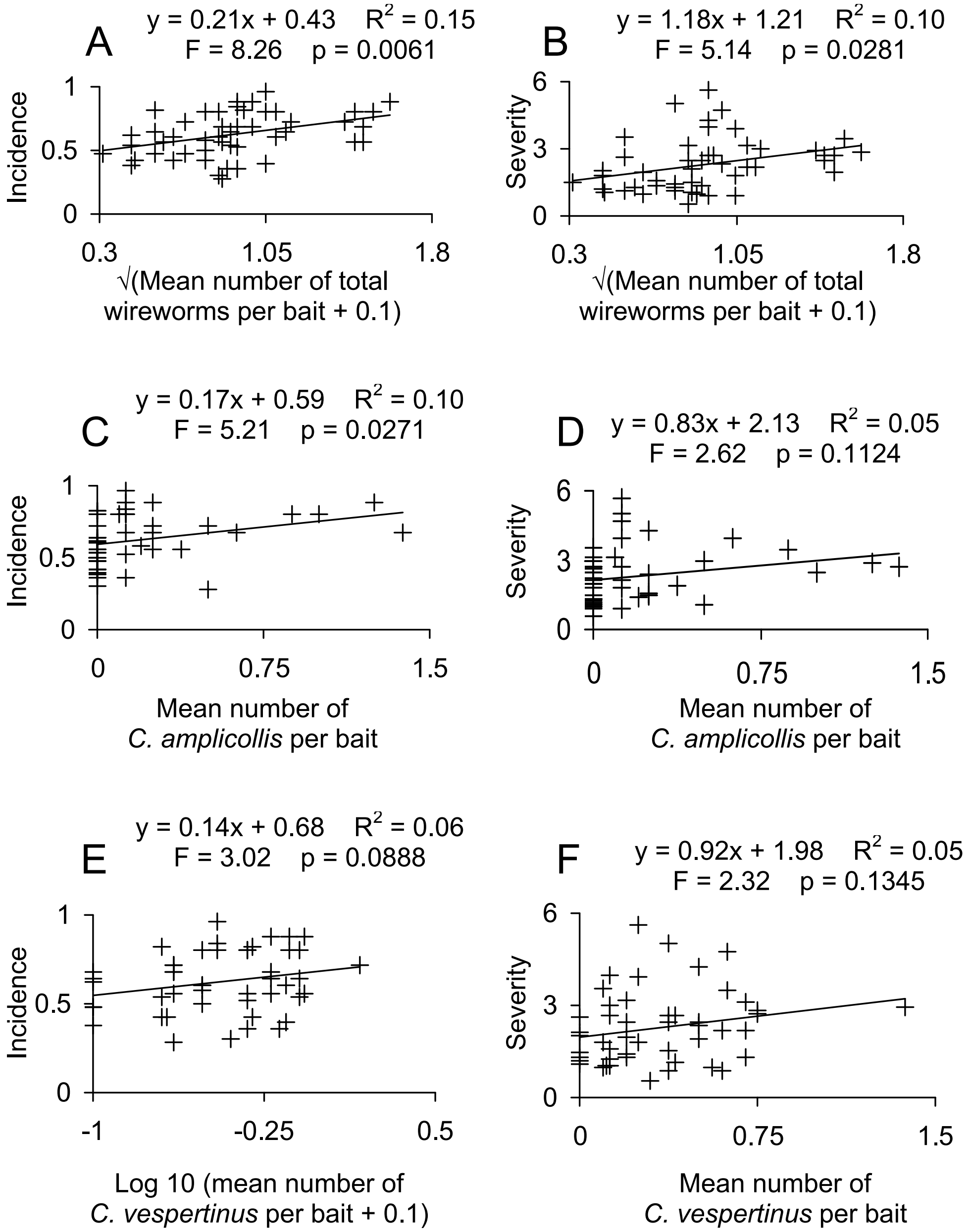


Figure 2.4. Linear regressions for wireworm damage incidence (mean proportion of roots with damage) and wireworm damage severity (mean number of holes per root) as functions of abundance of total wireworm or *M. communis* larvae during the early baiting period (20 April – 19 July 2005 and 17 March – 19 July 2006) in the small-plot crop rotation study.

Log transformations were performed to improve homogeneity of variance.

Figure 2.5. Linear regressions for wireworm damage incidence (mean proportion of roots with damage) and wireworm damage severity (mean number of holes per root) as functions of abundance of total wireworm, *C. amplicollis*, or *C. vespertinus* larvae during the late baiting period (20 July – 13 September 2005 and 20 July – 11 September 2006) in the small-plot crop rotation study.

Square root and log transformations were performed as needed to improve homogeneity of variance.


A
y = 0.21x + 0.43 R2 = 0.15
F = 8.26 p = 0.0061
Incidence
1
0.5
0
0.3
1.05
1.8
√(Mean number of total wireworms per bait + 0.1)
B
y = 1.18x + 1.21 R2 = 0.10
F = 5.14 p = 0.0281
Severity
6
3
0
0.3
1.05
1.8
√(Mean number of total wireworms per bait + 0.1)
C
y = 0.17x + 0.59 R2 = 0.10
F = 5.21 p = 0.0271
Incidence
1
0.5
0
0
0.75
1.5
Mean number of C. amplicollis per bait
D
y = 0.83x + 2.13 R2 = 0.05
F = 2.62 p = 0.1124
Severity
6
3
0
0
0.75
1.5
Mean number of C. amplicollis per bait
E
y = 0.14x + 0.68 R2 = 0.06
F = 3.02 p = 0.0888
Incidence
1
0.5
0
-1
-0.25
0.5
Log 10 (mean number of C. vespertinus per bait + 0.1)
F
y = 0.92x + 1.98 R2 = 0.05
F = 2.32 p = 0.1345
Severity
6
3
0
0
0.75
1.5
Mean number of C. vespertinus per bait

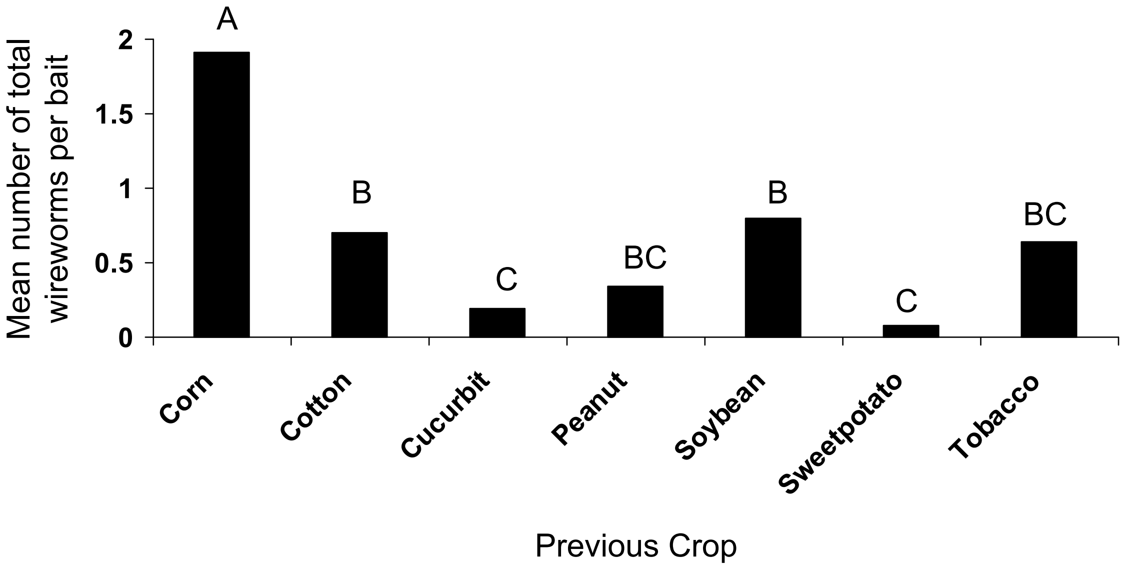


Figure 2.6. Abundance of total wireworms (all species) captured in oat baits during 15 April – 8 September 2005 and 21 June – 22 September 2006 in commercial sweetpotato fields previously planted to seven crops in 2004 and 2005, respectively.

Bars with the same letter above are not significantly different.

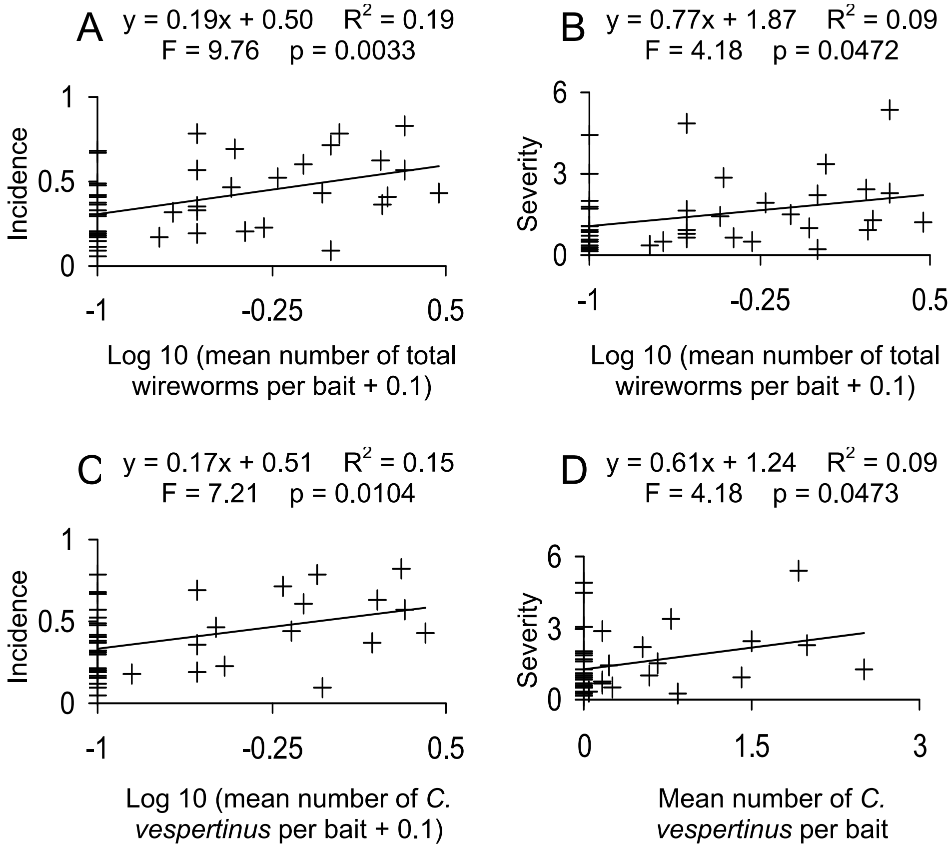


Figure 2.7. Linear regressions for wireworm damage incidence (mean proportion of roots with damage) and wireworm damage severity (mean number of holes per root) as functions of abundance of total wireworm or *C. vespertinus* larvae during the early baiting period (15 April – 19 July 2005 and 21 June – 19 July 2006) in the commercial field survey.

Log transformations were performed as needed to improve homogeneity of variance.

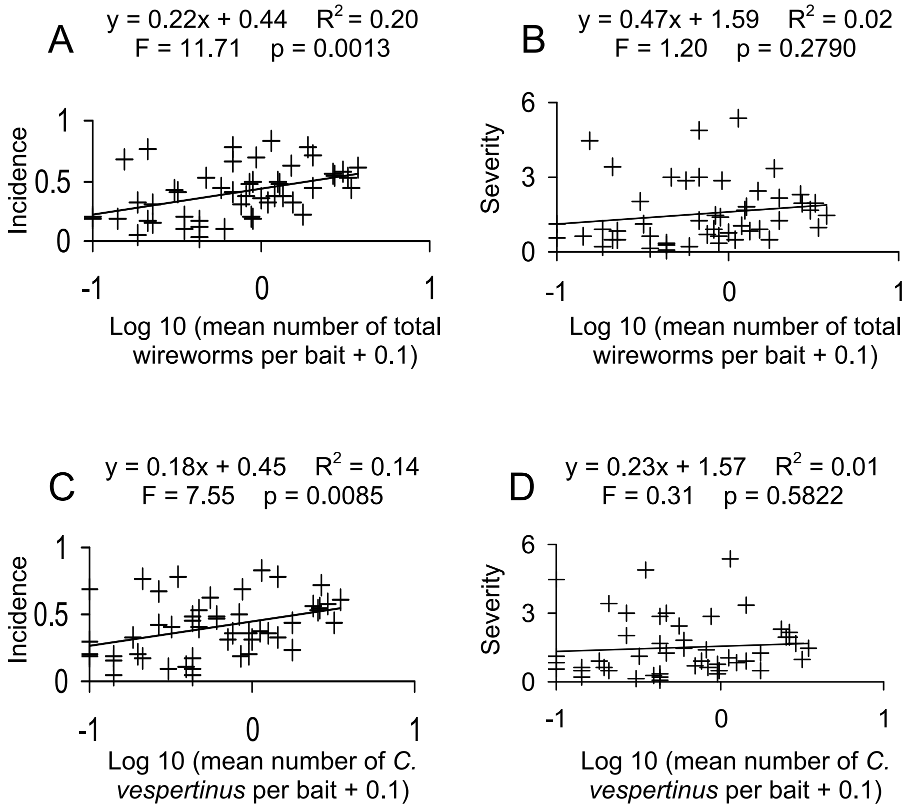


Figure 2.8. Linear regressions for wireworm damage incidence (mean proportion of roots with damage) and wireworm damage severity (mean number of holes per root) as functions of abundance of total wireworm or *C. vespertinus* larvae during the late baiting period (20 July – 8 September 2005 and 20 July – 22 September 2006) in the commercial field survey.

Log transformations were performed to improve homogeneity of variance.

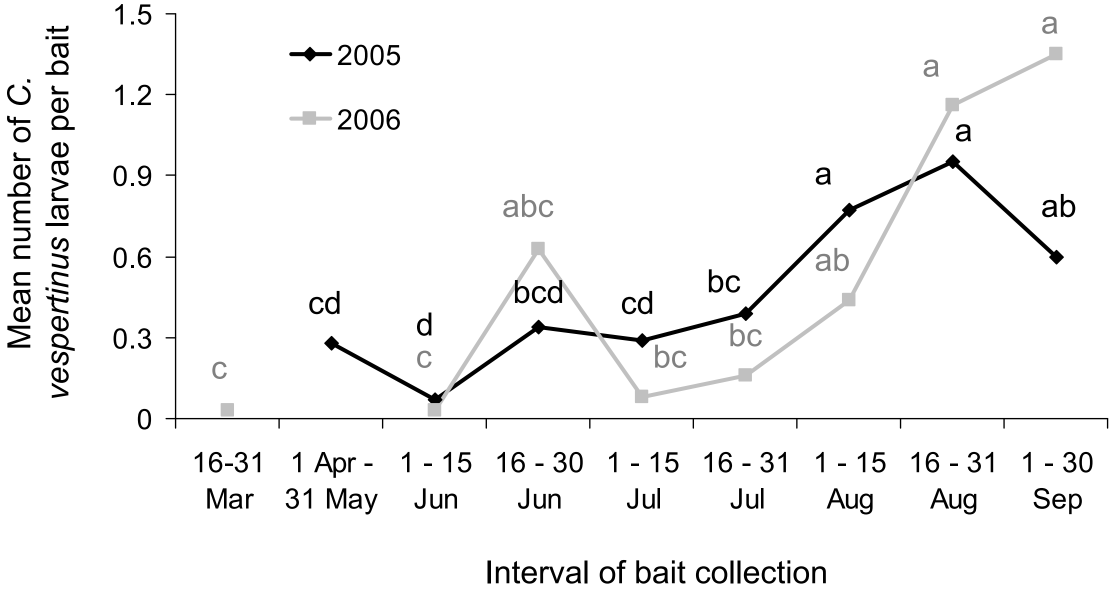


Figure 2.9. Abundance of *C. vespertinus* larvae during different time intervals in 35 sweetpotato fields in 2005 and 25 sweetpotato fields in 2006.

Means separations among sample intervals are within year. Means followed by same letter are not significantly different at $p \leq 0.05$.

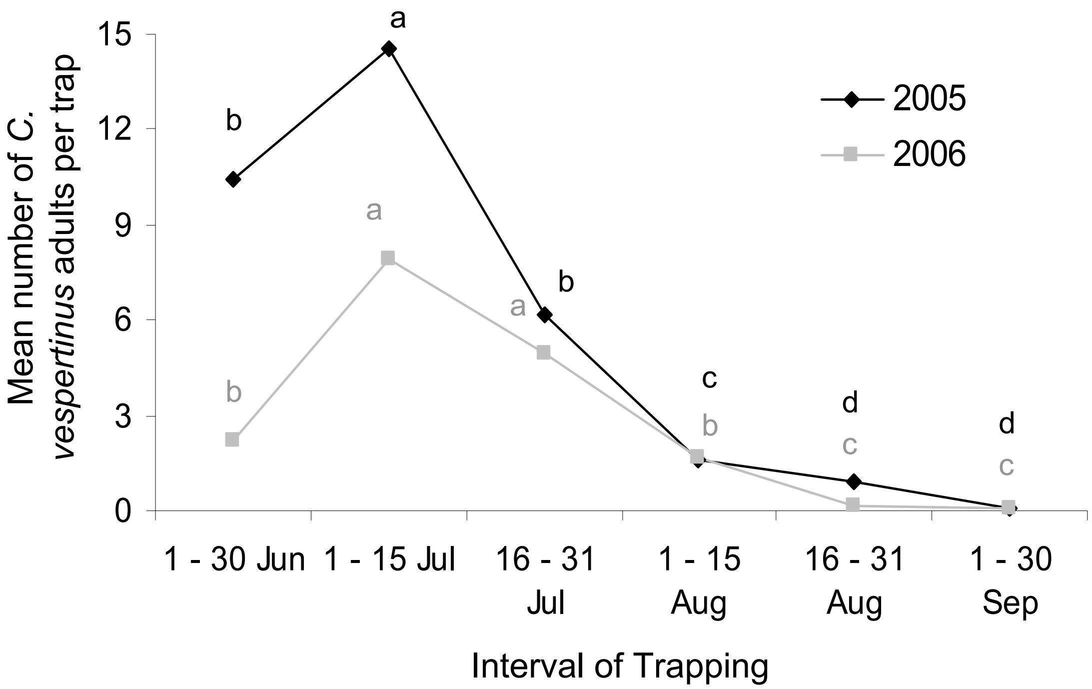


Figure 2.10. Abundance of *C. vespertinus* adults during different time intervals in 32 sweetpotato fields in 2005 and 26 sweetpotato fields in 2006.

Means separations among sample intervals are within year. Means followed by same letter are not significantly different at $p \leq 0.05$.

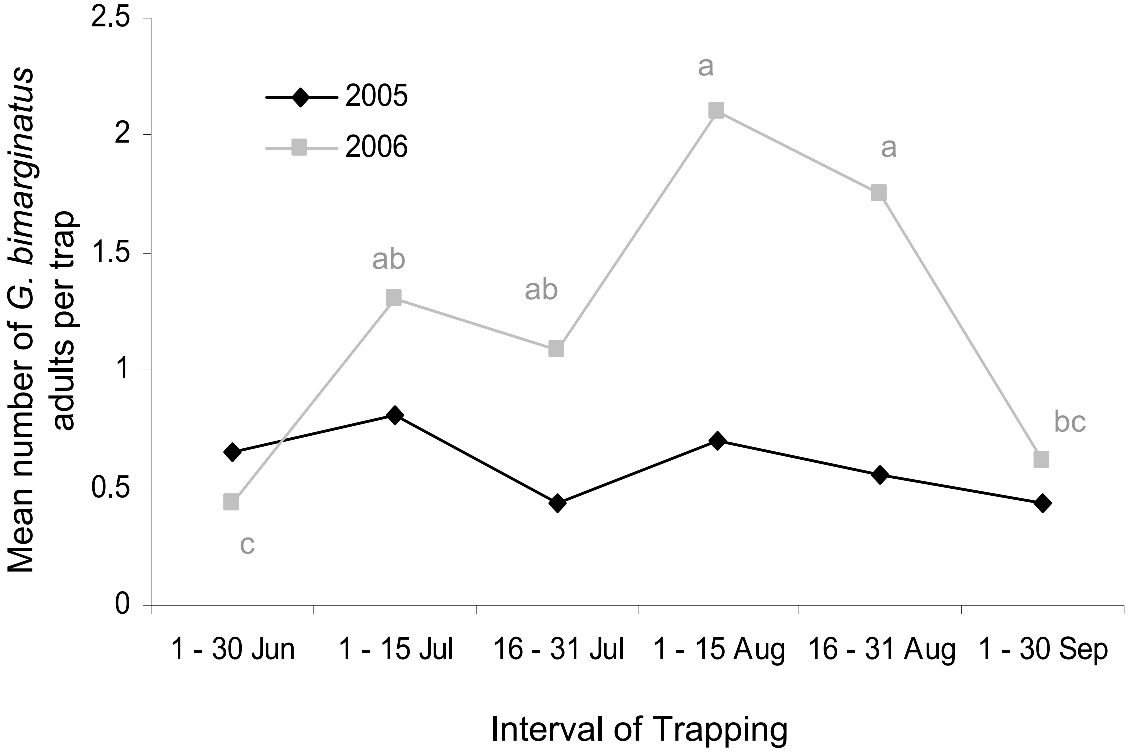


Figure 2.11. Abundance of *G. bimarginatus* adults during different time intervals in 32 sweetpotato fields in 2005 and 26 sweetpotato fields in 2006.

Means separations among sample intervals are within year. Means followed by same letter are not significantly different at $p \leq 0.05$.

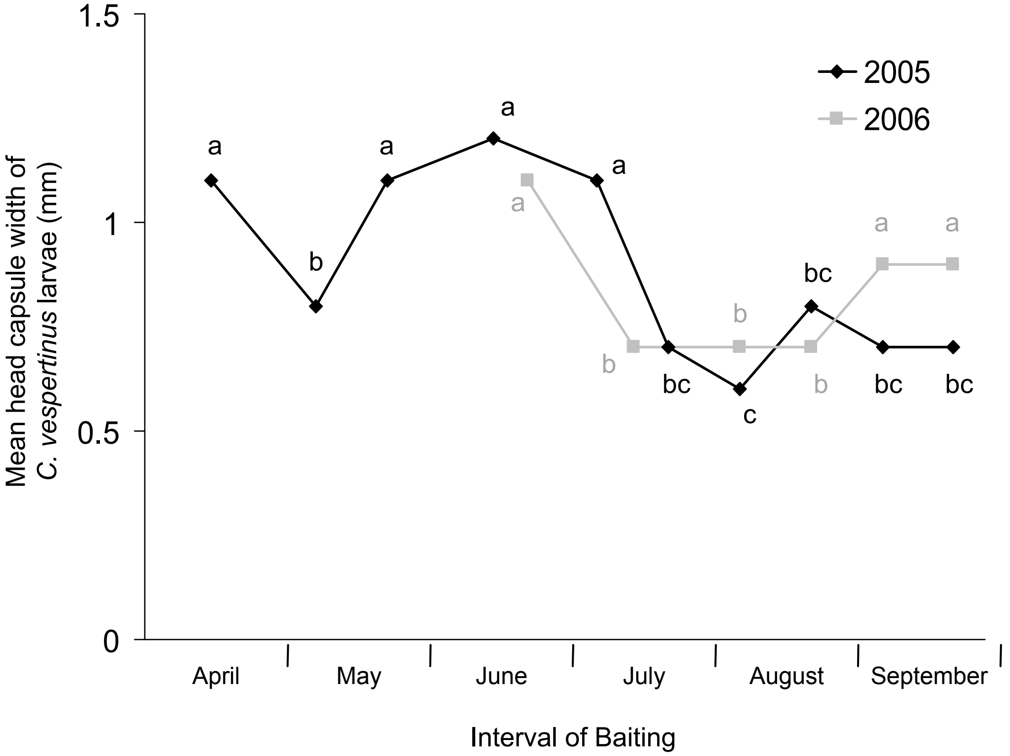


Figure 2.12. Mean head capsule width of *C. vespertinus* larvae* captured during different time intervals in 35 sweetpotato fields in 2005 and 25 sweetpotato fields in 2006.

Means separations among sample intervals are within year. Means followed by same letter are not significantly different at $p \leq 0.05$.

CONCLUSIONS

Wireworm larvae have historically been and continue to be difficult to sample. Absolute samples would be ideal for more accurate estimations of populations, but are too labor- and time-intensive to be practical. Baited samples provide a relative estimate of populations, but bait material preferences of different wireworm species are unknown. Also unknown is whether or not wireworms are less likely to approach baits if there is an abundance of roots from crops and/or weeds present, as is generally the case in sweet potato fields in late summer. While baited samples have limitations, they remain the most efficient means of sampling wireworm populations. Adult beetles may be captured in light traps, in sweep nets, or on sticky traps. The latter were used in our studies because they were practical, relatively inexpensive, and provided the most robust, least biased data set. It would not have been feasible to place light traps in every study field, nor to travel to each field and service each trap daily. Also, *C. vespertinus* adults are not attracted to light traps. Sweep samples in the sweetpotato field provide only information on those wireworm species that are present during the day. Some species, such as *C. vespertinus*, are active at dusk, and may only visit the sweetpotato fields at this time (Eagerton 1914). Sticky traps remained in the field for two weeks, and collected beetles at all hours of the day, in all weather conditions.

Over the two-year period detailed in this thesis, over 3,800 baited soil samples were processed, totaling approximately 8.75 tons of soil from ten NC counties. Over 500 sticky traps were used to sample adult populations at these same locations. Two thousand three hundred sixteen total larvae and 3,842 total adults were captured and identified. Not only was our sampling extensive, but the overall species compositions of larval and adult populations were consistent with one another. For these reasons, we believe that the eight wireworm species present in our samples provide an accurate representation of the wireworms present in NC sweetpotato.

While the wireworm damage to sweetpotato may be caused by all of these species, some were more abundant than others and thus are likely responsible for more of the damage. There were also some differences in wireworm species abundances by previous crop and/or by the season in which they were captured. Life histories have been described for some of the eight species. The following provides a brief summary of the information collected for each species, including what our studies found as well as relevant information from literature.

Conoderus amplicollis (Gyllenhal). This species comprised 5.1% of the total larvae and 0.2% of the total adults captured across all studies in both years. This species is also known as the gulf coast wireworm and was previously called *Heteroderes laurentii* (Guér). Cockerham and Deen (1936) described a one-year life cycle in Alabama, with adult flight and oviposition taking place during spring and summer, and larvae spending one winter in the soil. However, Seal (1990) reported a two- to three-year life cycle as ascertained by ten lab-reared larvae. We cannot be certain about the length of the life cycle in NC. *C. amplicollis* larvae were rare in our studies with one exception. Seventy-seven individuals, comprising 65% of all the *C. amplicollis* larvae captured across all studies in both years, were captured during the late baiting period of

2006 in the small-plot crop rotation study (Table 2.1). The occurrence of these larvae was not affected by the previous year's crop (Table 2.2). If *C. amplicollis* have a one-year life cycle in NC, this indicates that adults moved into the sweetpotato field to oviposit in 2006 and the larvae captured during the late baiting period were their offspring. If *C. amplicollis* has a two- to three-year life cycle in NC, this could indicate either the previous scenario or that the larvae were present in the soil during and/or prior to the early baiting period, but were not attracted to the baits. The presence of *C. amplicollis* larvae in these plots was significantly correlated to damage incidence at harvest. We observed a unique wireworm damage pattern on the sweetpotatoes from the 2006 field of the small-plot crop rotation study. Whereas typical wireworm damage to sweetpotato appears as shallow holes of varying sizes, this damage appeared as a short path (< 1 cm) which ended in a typical shallow feeding hole, as though the wireworm had entered the root at an angle. We believe that this species may be responsible for this unique damage, since we found neither this type of damage nor an abundance of *C. amplicollis* wireworms in any other fields or years.

Conoderus bellus (Say). This species comprised 4.3% of the total larvae and 2.2% of the total adults captured across all studies in both years. Jewett (1945) reported that *C. bellus* larvae hatching from eggs laid in spring and summer undergo metamorphosis by fall and overwinter as adults, indicating a one-year life cycle in Kentucky. Since we did not capture *C. bellus* larvae in the overwintering study, we believe that Jewett’s description of *C. bellus’* life history is applicable in NC. This suggests that *C. bellus* larvae are less of a threat to newly-planted crops in spring than other wireworm species which overwinter as larvae. Adult overwintering also suggests that effects of previous crop on larval *C. bellus* populations would be determined by whether adults emerging from overwintering sites in spring seek certain crop fields for oviposition sites or simply remain in the same area, and/or by harvest and post-harvest practices that may disrupt or destroy adult overwintering sites. In the small-plot crop rotation study, few *C. bellus* larvae were captured, but they were caught in plots previously planted to all six rotations (Table 2.2). In the commercial field survey, *C. bellus* larvae were most abundant in fields previously planted to corn, followed by those previously planted to tobacco, cotton, and soybean (Table 2.6). *C. bellus* larvae were not captured in fields previously planted to cucurbit, peanut, or sweet potato.

Conoderus falli (Lane). This species comprised 4.6% of the total larvae and 2.0% of the total adults captured across all studies in both years. *C. falli* is also known as the southern potato wireworm. Day et al. (1971) reported that in South Carolina, adults are found throughout the year, but most individuals overwinter as larvae. Eggs are laid in spring and early summer, and larvae may reach maturity within two to three months, allowing a second brood of larvae to occur in the same summer (Day et al. 1971). Norris (1957) reported oviposition occurring from spring through fall, and a larval period of approx. 3.5 months to 1 year in Florida. Both of these life history studies support the likelihood that *C. falli* in the southeastern US are capable of having two generations per year. Correspondingly, light traps in Florida over a 5-yr period consistently showed two peak periods of adult flight (Genung 1972). In both 2005 and 2006, we captured the most adults per trap at the onset of trapping, in June (Table 2.12). Following this peak in 2005, there was not another notable increase in adult numbers. However, in 2006, a second peak occurred in late August. Harris (1965) noted that sticky traps were not as effective as black light traps for capturing *C. falli* adults, which could explain our inability to detect a second adult flight period in 2005. Having two generations per year implies that effects of previous crop on the abundance of larval *C. falli* would be most detectable for the first, overwintering generation. Once the overwintering generation reaches maturity, the adults may travel to other fields. In our studies, *C. falli* larvae were rarely captured, and there is not a clear gap between the presence of overwintered and second-generation larvae (Table 2.10). This could indicate that C. falli are simply not an abundant species in sweetpotato, or that oat baits are not an effective means for sampling this species. In either case, the data do not suggest a trend in overwintering larval populations by previous crop (Tables 1.2, 1.4, 1.6).

Conoderus lividus (Degeer). This species comprised 4.7% of the total larvae and 3.3% of the total adults captured across all studies in both years. Jewett (1948) reported that *C. lividus* have a one to two year life cycle in Kentucky. Oviposition occurs in summer, and larvae spend one or two winters in the soil before pupating and emerging as adults in spring and summer. Of the 234 individuals reared, 71% required one year to complete development, and 29% required two years (Jewett 1948). *C. lividus* larvae were rarely captured in baits in both the small-plot crop rotation study and commercial field survey (Tables 2.1, 2.4). Seventy-three individuals, comprising 66% of all the *C. lividus* larvae captured across all studies in both years, were captured during the overwintering study. They were most abundant in fields previously planted to corn, tobacco, and soybean; least abundant in fields previously planted to peanut and cotton (Table 1.5). No individuals were attained from fields previously planted to sweet potato.

Conoderus scissus (Schaeffer). This species comprised 5.7% of the total larvae and 5.6% of the total adults captured across all studies in both years. Seal (1990) reported that in Georgia, *C. scissus* adult emergence and oviposition occur from spring through early fall, and larvae remain in the soil for two to three winters. A two to three year life cycle implies that the crop planted two to three years previously would be more suitable for determining oviposition site preferences of *C. scissus* adult females. However, intermediate crops and/or their production practices would certainly play a role in either encouraging or preventing survival of *C. scissus* larvae. The data we collected do not suggest a tendency for *C. scissus* larvae to occur more commonly immediately following a particular crop. Overall, *C. scissus* larvae were scarce in all studies. However, more *C. scissus* larvae were captured in one commercial sweetpotato field in 2005 than at any other location or time (Table 2.7). This was the only field that had previously been planted to watermelon. The other field previously planted to a cucurbit crop (squash) did not yield *C. scissus* larvae.

Conoderus vespertinus (Fabricius). This species comprised 62.7% of the total larvae and 62.9% of the total adults captured across all studies in both years. *C. vespertinus* is also known as the tobacco wireworm. Rabb (1963) described the life history of *C. vespertinus* in NC. Adult flight and oviposition occur during summer, and larvae spend one winter in the soil before pupating and emerging as adults (Rabb 1963). Effects of previous crop on early-season populations of *C. vespertinus* are uncertain. Larvae were significantly more abundant in fields previously planted to cotton and soybean than to other crops in the overwintering study (Figure 1.3). In all other studies, larval numbers did not vary significantly by previous crop (Tables 2.2, 2.6). *C. vespertinus* larvae were relatively abundant in baited samples in all years, studies, and baiting periods with one exception. Five and three *C. vespertinus* larvae, comprising merely 0.3% and 0.2% respectively, of all *C. vespertinus* larvae captured across all studies in both years, were obtained during the early baiting periods of 2005 and 2006 in the small-plot crop rotation study (Table 2.1). This indicates that there were not a large number of overwintering *C. vespertinus* in these fields. However, significantly more *C. vespertinus* larvae were attained from these sweetpotato fields during the late baiting period. This indicates that adult beetles, which did not originate in the study fields, migrated into the fields to oviposit. Likewise, in the commercial field survey *C. vespertinus* larvae were significantly more abundant during the late baiting period than during the early baiting period (Table 2.5). For sweetpotato, the summer migration of adults and oviposition into the fields is problematic because larval feeding and storage root development occur simultaneously until harvest. In the commercial field survey, abundance of *C. vespertinus* larvae during the late baiting period was significantly correlated to damage incidence at harvest (Figure 2.8 C). The abundance, life cycle, and habits of this species indicate that *C. vespertinus* is the major wireworm affecting sweetpotato in NC.

***Glyphonyx* sp.** (Candeze). This species comprised 4.9% of the total larvae (*Glyphonyx* sp.) and 17.6% of the total adults (*G. bimarginatus*) captured across all studies in both years. Cheshire and Jones (1988) reared field-collected *Glyphonyx* sp. larvae from Georgia to maturity and identified the adults as *G. bimarginatus*. We did not rear field-collected larvae, but identified all adults collected as *G. bimarginatus*. The larvae we collected fit the descriptions of Cheshire and Jones (1988), and so it is likely that they are also *G. bimarginatus*. We were unable to find any literature regarding the life history of this genus or species. Larvae were captured in baits throughout the year (Tables 1.4, 2.10), and adults were present during the span of trapping dates in spring and summer (Fig. 2.10). From these data, it is clear that *Glyphonyx* sp. overwinter as larvae, but it is uncertain if they may also overwinter as adults, eggs, or pupae. In the overwintering study and the small-plot crop rotation study, *Glyphonyx* sp. larvae were most abundant in fields previously planted to soybean (Fig. 1.3, Table 2.2). However, there were no notable differences in *Glyphonyx* sp. larval abundance by previous crop in the commercial field survey (Table 2.6).

Melanotus communis (Gyllenhal). This species comprised 6.6% of the total larvae and 1.0% of the total adults captured across all studies in both years. *M. communis* is also known as the corn wireworm. Fenton (1926) assumed that *M. communis* have a six-year life cycle in Iowa, with adults emerging in late summer, hibernating for one winter, laying eggs the following spring and summer, and subsequent larvae spending five winters in the soil. The length of the life cycle for this species in NC is uncertain. Larvae were captured in baits throughout the year (Tables 1.3, 2.11), and adults were present throughout the trapping periods in spring and summer (Table 2.12). From these data, it is clear that *M. communis* overwinter as larvae, but it is uncertain if they may also overwinter as adults, eggs, or pupae in NC. Eighty-six individuals, comprising 57% of all the *M. communis* larvae captured across all studies in both years, were captured in the small-plot crop rotation study fields at Kinston, NC (Table 2.1). There, larvae were most abundant during the early baiting period (Table 2.3), and in plots previously planted to soybean and corn (Figure 2.1). *M. communis* larvae were captured in low numbers in baits in the overwintering study and the commercial field survey (Tables 1.4, 2.4). However, in both studies they were most abundant in fields previously planted to corn (Tables 1.5, 2.6). Because *M. communis* is believed to have a multi-year life cycle, effects of cropping history should be studied with regard to multi-year rotations.

Due to the difficult nature of wireworm sampling, much of the literature regarding wireworm pest management has considered the group as a whole, and has not treated each individual species as a separate pest. Likewise, in our studies, many species were too scarce to allow statistical analysis, but when all species were pooled, the variance was greatly homogenized and analyses were appropriate. For this reason, we reported on total wireworms (all species) and were able to compare trends between total wireworms and constituent wireworm species. In some cases, it was clear that the trend of the most abundant species was responsible for the trend of the total wireworms. For example, in the commercial field survey, total wireworms were significantly more abundant during the late baiting period than the early, which reflects the same trend for *C. vespertinus*, which made up 80% of the total wireworms in that study (Chapter 2, Tables 8, 9). On the other hand, total wireworms were significantly most abundant in fields previously planted to corn in the commercial field survey, but no significant differences by previous crop were detected for *C. vespertinus*, even though the trend is the same (Chapter 2, Fig. 2, Table 3). Whether or not the additional species behave the same way as *C. vespertinus*, the fact that such differences exist for total wireworms by previous crop is important from a pest management perspective. This information can be used to make recommendations to growers about crop rotations. More work on the life cycles, seasonal histories, and crop associations of the wireworm species of the coastal plain is necessary to continue to improve pest management strategies.

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