Influence of Soil Temperature, Rainfall, and Planting and Harvest Dates on *Chaetocnema confinis* (Coleoptera: Chrysomelidae) Damage to Sweetpotato Roots

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ABSTRACT A study was carried out in 10 counties of North Carolina from 2004 to 2006 to determine the effect of planting and harvest times on flea beetle, *Chaetocnema confinis* Crotch (Coleoptera: Chrysomelidae), damage to sweetpotato, *Ipomoea batatas* (L.), storage roots. Planting and harvesting of sweetpotatoes later in the season resulted in less damage than early planting and harvesting. Regression analysis was done to study the relationship of weather parameters with the flea beetle damage. Weather parameters included air temperature (Celsius), soil temperature at 5- and 10-cm depth (Celsius), rainfall (millimeters), and soil moisture (volume:volume) at 0–10-, 10–40-, and 40–100-cm depth. The best regression model included mean soil temperature at 10-cm depth, total rainfall, and number of adults caught on yellow sticky traps as independent variables (all between 1 August and harvest date of each field). Soil temperature and adult catches on yellow sticky traps of *C. confinis* were positively related to damage, whereas rainfall was negatively correlated. The model explained 45% of the total variation in the flea beetle damage. Soil temperature alone accounted for 32% of the total variation in flea beetle damage followed by rainfall (9%) and adult catches (4%). When the time interval was limited to 30 d before harvest, soil temperature was still the best explanatory variable accounting for 23% of the total variation in flea beetle damage followed by rainfall (7%) and adult catches (4%). Understanding the effects of planting/harvesting and weather factors on flea beetle damage will be useful in predicting the time when the sweetpotato crop is at greater risk from high levels of damage by *C. confinis*.

KEY WORDS sweetpotato, *Chaetocnema confinis*, planting date, harvest date, soil temperature

Sweetpotato, *Ipomoea batatas* (L.), is one of the world's most important food crops, especially in developing countries (Woolfe 1992). North Carolina ranks first in the United States in sweetpotato production, accounting for ≈40% of national production and generating $79 million annually in farm gate value (NCDA & CS 2006). Throughout the world, production of sweetpotatoes is severely limited by several insect pests (Schalk et al. 1991, Talekar 1991, Lawrence et al. 1997, Jackson et al. 2002). Economically important insect species that affect the quality of sweetpotato roots in North Carolina include wireworm (primarily *Conoderus vespertinus* F., and *Melanotus communis* Gyllenhal; Baumler and G.G.K., unpublished), spotted cucumber beetle (*Diabrotica undecimpunctata howardi* Barber), banded cucumber beetle (*Diabrotica balteata* LeConte), palestriped flea beetle (*Systena blanda* Melsheimer), sweetpotato flea beetle (*Chaetocnema confinis* Crotch), Japanese beetle (*Popillia japonica* Newman), and whitefringed beetle larvae (*Graphognathus leucoloma* Boheman) (Sorensen and Baker 1994), although wireworms and sweetpotato flea beetle account for the majority of insect damaged roots in commercial sweetpotato fields (M.R.A. and G.G.K., unpublished).

C. confinis has long been recognized as a pest of sweetpotato roots (Cuthbert and Reid 1965). The adults pass the winter under plant debris in the field, field margins, and adjacent areas. They emerge in spring and may feed on weeds and less desirable vegetation until crop plants become available. Adults feed on the foliage leaving narrow channels or grooves in the upper surfaces of leaves. Larvae make small winding tunnels just under the skin of roots. These tunnels eventually darken and split open leaving shallow scars. This type of damage usually is restricted to fibrous roots, but larvae may injure the fleshy marketable portion of roots during heavy infestations (Sorensen and Holmes 2002).

Flea beetle damage to sweetpotato reduces the quality of harvested storage roots and causes significant economic loss. It is especially challenging to sample and control the larval stages of flea beetle. Recommendations for controlling flea beetle damage include using soil and foliar applied insecticides, growing resistant varieties, destroying plant residues and

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keeping fields free of weeds (Chalfant et al. 1990). However, the use of chemicals can be expensive and unreliable, and may cause environmental and safety concerns. Effective, practical, low-input, environmentally benign integrated pest management (IPM) alternatives to chemical pest control are not available (Schalk et al. 1993, Lawrence et al. 1997).

Cultural control is an attractive approach that fits well into sweetpotato IPM programs. Studies have been done to examine the effect of planting and harvest dates on yield parameters in sweetpotato, but very few assessed insect damage to roots (Martin 1987, 1988; Noda et al. 1997). Zehnder (1997) showed reduction in whitefringed beetle damage to sweetpotato roots by early planting and early harvest, but no other soil-borne insect damage to roots was reviewed in that study.

Little information has been published concerning the relationship of flea beetles and root damage to sweetpotatoes and the climatic conditions that enhance injury to roots. Generally, flea beetles are favored by stable warm spring weather and hampered by alternating periods of warm and cold temperatures with intermittent rains (Kuepper 2003). High rainfall is reported to have a negative effect on flea beetle *Longitarsus jacobaeae* Waterhouse because the beetle density seems to be lower at higher rainfall sites (Gourlay et al. 2006). Information about sweetpotato flea beetle damage and factors affecting it is lacking. The objectives of the research described herein were to determine the effect of planting and harvest dates on the incidence of damage to sweetpotato roots caused by *C. confinis* and to determine the existence and nature of relationships between site characteristics, such as rainfall, temperature, and soil moisture and *C. confinis* damage to storage roots.

Materials and Methods

Field Sites. The studies were conducted in commercial sweetpotato fields in 10 coastal plain counties of North Carolina over 3 yr. In 2004 and 2005, 30 field sites were selected for the study; in 2006 18 sites were selected. The fields were planted with the variety Beauregard. In each field, a block of sweetpotatoes 16 rows wide by 90 m long was not treated with insecticides. Each untreated block was divided into six 16-row plots, each 15 m long. Data were collected from the middle three rows.

Planting. Sweetpotato planting began in early May and continued until mid-July. In 2004, planting dates ranged from Julian date 127–193, whereas in 2005 they ranged from Julian date 139–183. In 2006, they ranged from Julian date 139–174.

Harvesting. Sweetpotato harvest began in August and continued through mid-October. In 2004 and 2005, harvest dates ranged from Julian dates 231–282 and 238–293, respectively. In 2006 harvest dates ranged from Julian date 237–291. The number of days between planting and harvest (i.e., plant age) ranged from 89 to 130, from 88 to 130, and from 90 to 133 d in 2004, 2005, and 2006, respectively.

Weather Data. Weather data from field sites were provided by ZedX, Inc. (Bellefonte, PA). Parameters included air temperature (Celsius), soil temperature at 5- and 10-cm depth (Celsius), rainfall (millimeters), and soil moisture (volume:volume) at 0–10, 10–40, and 40–100 cm. Data were collected every hour and averaged to get daily means. For analysis, daily mean temperature and soil moisture were further averaged for a particular time interval, whereas the rainfall was summed for same time period.

Insect Sampling. The population of *C. confinis* adults was monitored by yellow sticky traps (23 by 26 cm) (Great Lakes IPM, Vestaburg, MI). Two traps were placed ≈60 m apart within a single row in the middle three rows of each untreated block. They were fastened to bamboo stakes and maintained at a height of ≈5 cm above the plant canopy. Traps were changed every 10–14 d. All *C. confinis* adults per trap were counted in the laboratory by using a dissecting microscope. Traps were removed from the field 20–25 d before harvest. Voucher specimens are held in the Department of Entomology, North Carolina State University, Raleigh, NC.

Damage Assessment. Root damage was assessed by randomly collecting 25 storage roots from one of the three middle rows in each of the six plots in each field. In total, 150 storage roots were sampled from each field. Sweetpotatoes were dug using a one-row, tractor-drawn sweetpotato plow. Roots from each plot were hand harvested, placed into individually labeled paper bags, and transported to the laboratory where they were washed and examined individually. Flea beetle damage was characterized by the presence of very narrow winding channels (1–2 mm wide) on the root surface, which are characteristic of feeding by *C. confinis* larvae. The proportion of roots with damage was calculated by dividing the number of roots with at least one feeding scar by the total number of roots evaluated per plot.

Data Analysis. Damage data from the six plots in each field were averaged and considered as one replicate for analysis. Simple linear regression analysis was done to examine the effect of planting and harvest dates on the percentage of sampled roots damaged by flea beetle in 2004, 2005, and 2006. Fields with no damage were omitted during analysis because our interest was in how the various dependent variables were related to the incidence of damaged roots in fields infested by *C. confinis.* Stepwise linear regression (PROC REG, SAS Institute 2005) was used to determine the relationship between the weather parameters and *C. confinis* adults and damage. Correlation analysis (PROC CORR, SAS Institute 2005) was done before stepwise regression to determine whether all the variables were independent. We found that planting and harvest dates, mean soil temperature at 5- and 10-cm depth, and the soil moisture variables and rainfall were highly correlated to each other. Planting and harvest dates were highly correlated with soil temperature. Highly correlated independent variables were not included in the same stepwise regression analysis, but were tested with noncorrelated independent variables in separate analyses to determine which variable provided the best explanatory power. Based on these analyses, soil temperature at 10-cm depth and rainfall were included in a final stepwise regression analysis. Data on root damage were arcsine transformed based on inspection of residuals (PROC PLOT, SAS Institute 2005), to stabilize variance before stepwise regression. Separate analysis was done for two time intervals to determine the best relationship between weather parameters (mean soil temperature at 10-cm depth and total rainfall), *C. confinis* adults, and damage. The first analysis included the mean soil temperature at 10 cm, total rainfall, and number of *C. confinis* adults caught per sticky trap after 31 July (Julian date = 212) until the traps were removed before harvest. This was done because in the majority of fields adult catches peaked on or after 1 August. Because only larval stages feed on the roots and *C. confinis* has a generation time of 30 d (Griffin 1999), we assumed that only the larvae that gave rise to these adults and the offspring of these adults could have been present after the storage roots began to expand and thus had the potential to cause damage. The second analysis examined the same relationships for the 30-d period immediately before harvest.

Results

Planting. Planting date was negatively correlated with the incidence of damage to storage roots by *C. confinis* larvae in 2005 ($F = 10.95$; df = 1, 28; $P = 0.0026$; $R^2 = 0.28$). No significant relationship was observed between planting date and damage in 2004 and 2006 (Fig. 1).

Harvesting. Harvest date was negatively correlated with the incidence of *C. confinis* damage in 2005 ($F = 19.97$; df = 1, 28; $P = 0.0001$; $R^2 = 0.41$) and 2006 ($F = 8.86$; df = 1, 15; $P = 0.0094$; $R^2 = 0.37$). However, in 2004, there was no significant relationship between harvest date and *C. confinis* damage ($F = 3.75$; df = 1, 21; $P = 0.0634$; $R^2 = 0.15$) (Fig. 2). Plant age at harvest was negatively correlated with the incidence of *C. confinis* damage in 2005 ($F = 5.86$; df = 1, 28; $P = 0.0221$; $R^2 = 0.17$) and 2006 ($F = 9.08$; df = 1, 15; $P = 0.0087$; $R^2 = 0.37$). No significant relationship was observed between age at harvest and *C. confinis* damage in 2004 (Fig. 3).

Weather Parameters. Forty-five percent of the total variation in the incidence of damage to storage roots by *C. confinis* was explained by the regression model that included mean soil temperature at 10-cm depth, total rainfall, and adults per trap from 1 August to harvest ($F = 13.78$; df = 3, 50; $P = <0.001$) as independent variables in the following equation (Table 1):

$$\text{Root damage (arcsine)} = 0.074\,(\text{ST}) - 0.601(\text{RF}) + 0.002(\text{A}) - 1.476$$

where ST is mean soil temperature (Celsius) at 10-cm depth, RF is total rainfall (millimeters), and A is adults per trap.

Soil temperature at 10-cm depth alone accounted for 32% of the total variation, rainfall explained an additional 9%, and the remaining 4% was explained by the number of adults caught on sticky traps. The percentage of flea beetle damage was positively related to soil temperature (10 cm) and adults, but it was negatively related to rainfall. When parameters were considered only for the 30 d before harvest, 34% of the variation in the flea beetle damage was explained by the regression model that included soil temperature at 10-cm depth, rainfall, and adults per trap as independent variables ($F = 8.11$; df = 3, 47; $P = <0.001$) in the following equation (Table 1):

$$\text{Root damage (arcsine)} = 0.046\,(\text{ST}) - 0.660(\text{RF}) + 0.013(\text{A}) - 0.724.$$

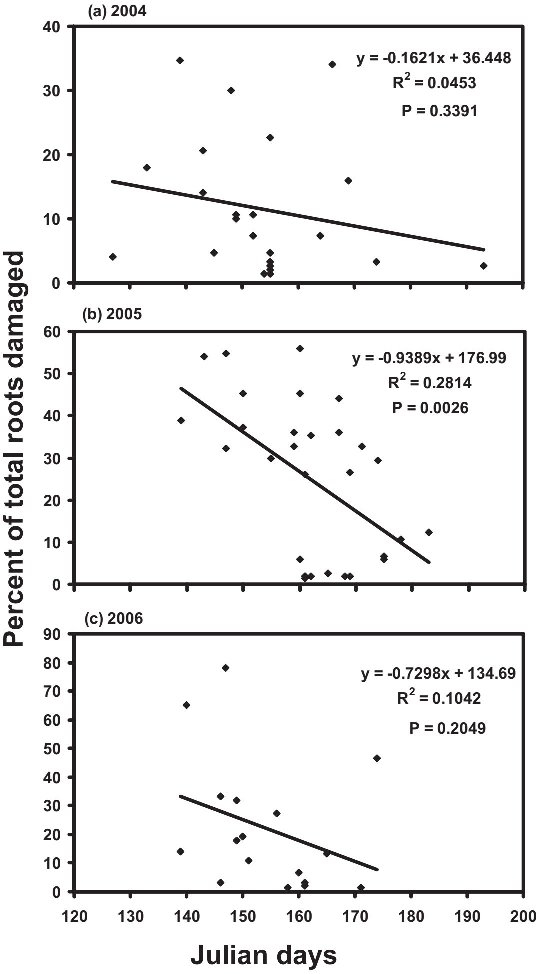

Fig. 1. Relationship between sweetpotato planting date and incidence of *C. confinis* damage during 2004 (a), 2005 (b), and 2006 (c).

Discussion

The present studies indicate that the incidence of damage to storage roots caused by *C. confinis* larvae is affected by planting and harvest dates. We found that

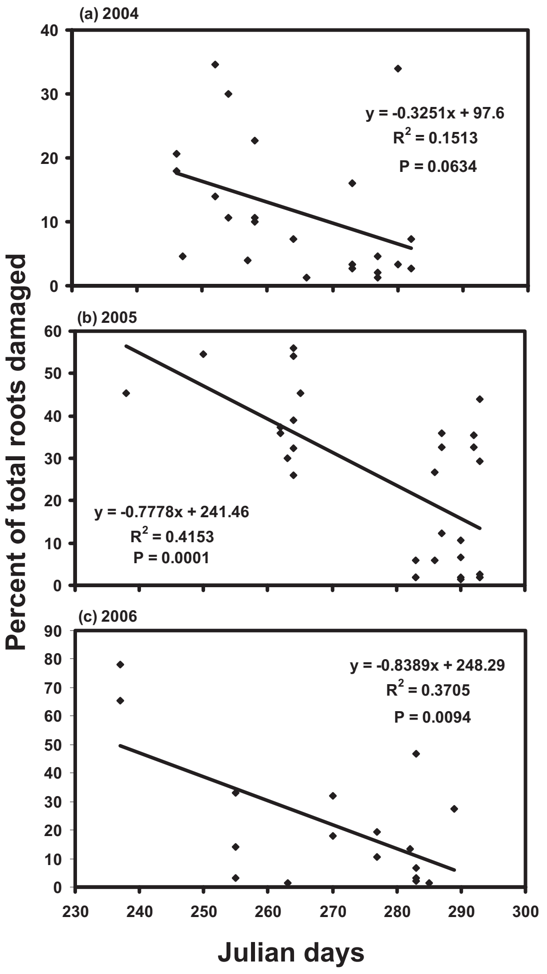

Fig. 2. Relationship between sweetpotato harvest date and incidence of *C. confinis* damage during 2004 (a), 2005 (b), and 2006 (c).

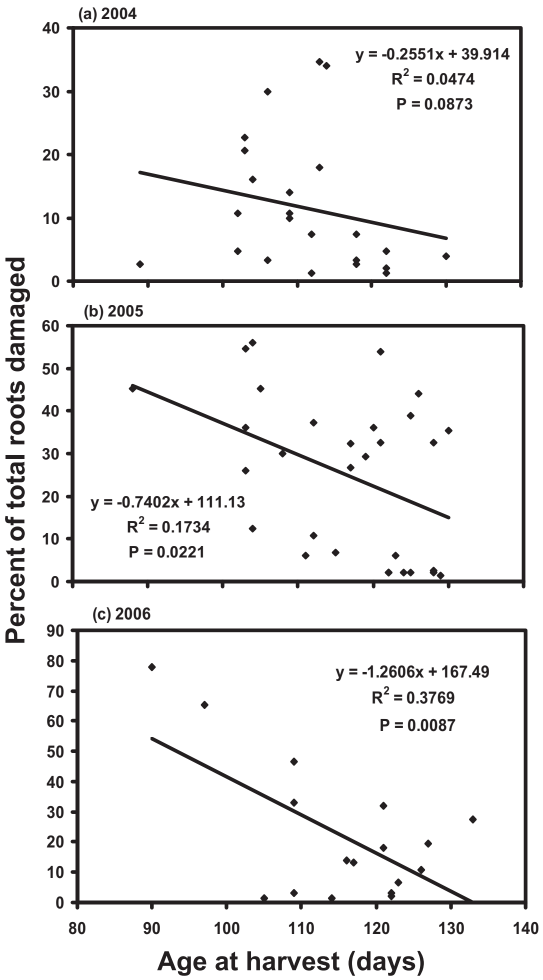

Fig. 3. Relationship between sweetpotato age at harvest and incidence of *C. confinis* damage during 2004 (a), 2005 (b), and 2006 (c).

planting and harvesting of sweetpotato later in the season resulted in less damage than early planting and harvesting. Age at harvest was negatively related to damage. Our findings are consistent with a previous preliminary survey, which suggested that the incidence of damage by *C. confinis* was less in late harvested than early harvested sweetpotato roots (Brill 2005).

Regression analysis revealed that soil temperature was the single most influential factor affecting flea beetle damage. The best regression model (model $R^2 = 0.451$) included mean soil temperature at 10-cm depth, total rainfall, and *C. confinis* adults per trap from 1 August to harvest as independent variables. Soil temperature was positively related to damage and accounted for 32% of the total variation in the flea beetle damage. When the time interval was limited to 30 d, soil temperature was still the best explanatory variable, accounting for 23% of the total variation in damage by *C. confinis* larvae. The model offers a likely explanation for the negative relationships between flea beetle damage and planting and harvest dates. Planting and harvest dates were highly correlated to each other and negatively correlated with mean soil temperature during the period after Julian date 213 or within 30 d before harvest, indicating that as the season progressed, soil became cooler. It is likely that the negative relationships between damage by *C. confinis* and planting and harvest dates are due to a reduction in flea beetle activity as soil temperatures cool combined with the rapid expansion of storage roots late in the season, which obscures surface scars caused by *C. confinis* larvae that fed on the storage roots earlier in the season when the roots were still small. Similar studies by Cagan et al. (2006) involving another flea beetle, *Chaetocnema tibialis* Illiger, infesting *Amaranthus retroflexus* L. and *Amaranthus caudatus* L., showed similar results.

Temperature also likely affects oviposition and survival of the *C. confinis.* Inoue (2001) reported an increase in the percentage of oviposition from 14 to 73%

Table 1. Regression statistics for incidence of root damage by *C. confinis* related to soil temperature at 10-cm depth, total rainfall, and number of adults per trap

Variable[a,b]	Interval	Parameter	Estimate	SE	F value	P value	Partial R^2	Model R^2
		Intercept	−1.476	0.555	7.06	0.010		
Mean ST (°C)		$\beta 1$	0.074	0.023	10.04	0.002	0.326	
Total RF (mm)	1 Aug. to harvest	β_2	−0.601	0.319	3.55	0.065	0.087	
A		β_3	0.002	0.000	8.01	0.006	0.038	
Full model					13.78	<0.001		0.451
		Intercept	−0.724	0.297	5.92	0.018		
Mean ST (°C)		$\beta 1$	0.046	0.014	10.39	0.002	0.230	
Total RF (mm)	30 d before harvest	β_2	−0.660	0.333	3.93	0.053	0.075	
A		β_3	0.013	0.000	2.53	0.110	0.036	
Full model					8.11	<0.001		0.341

[a] ST, soil temperature at 10-cm depth; RF, RF; A, number of adults per trap.
[b] Dependent variable = arcsine $\sqrt{}$proportion of total roots at harvest damaged by *C. confinis.*

by the flea beetle *Argopistes coccinelliformis* Csiki as the temperature increased from 10 to 30°C. Abdur (2000) reported the optimum range for egg hatch in flea beetle *Psylliodes paralis* Weise was 25–30°C. Also, survival of eggs of the root-feeding flea beetle *Longitarsus bethae* Savini & Escalona was highest (56%) at 32°C and lowest (10%) at 10°C, with the optimum being between 17 and 25°C (Simelane 2007).

Rainfall was the second most influential factor negatively affecting flea beetle damage. It accounted for 8% of the total variation in *C. confinis* damage during the interval from 1 August to harvest and 7% during the 30 d before harvest. The negative effect of rainfall on damage may reflect greater larval feeding on storage roots rather than fibrous roots when the soil is dry (Tysowsky 1971; Sorensen and Holmes 2002). Moist soil retards and dry soil accelerates the emergence of two flea beetles, *Aphthona euphorbiae* Schrank and *L. parvulus* Paykull, on flax (Popov and Firsova 1936).

Adult catches of *C. confinis* were weakly but positively correlated with flea beetle damage and accounted for 4% of the total variation during the interval 1 August to harvest date and also for the 30-d interval before harvest. The relationship between adult catches and damage was weak, not surprisingly, because only larvae cause damage to roots. Survival of adults, eggs and larvae is affected by various mortality factors such as weather, natural enemies, or cultural manipulations, which were not accounted for in our analyses but which can be expected to weaken any relationship between number of adults caught on sticky traps and root damage. The efficiency of the sampling method for adults also may have affected the relationship we observed between adult numbers and damage. It is possible that another more efficient sampling method might have resulted in a stronger relationship.

These studies suggest that late harvesting of sweetpotato results in lower levels of damage by *C. confinis* primarily due to the cooler soil temperatures that prevail later in the season. They also provide support for the commonly held perception of sweetpotato growers that flea beetle damage is worse under dry conditions.

Cultural practices (planting and harvest dates), and site characteristics within growers' fields (soil temperature and rainfall) are some of the more important influences on the incidence of flea beetle damage to sweetpotato roots and may need to be considered in future research projects. Knowledge of the relationships between planting and harvest dates and flea beetle damage may prove useful to growers in assessing the likelihood that individual fields will be at high risk from high levels of damage by *C. confinis.*

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