Management of orchard floor vegetation is directly related to subsequent peach [Prunus persica (L.) Batsch] tree growth and yield (Arnold and Aldrich, 1980; Belding et al., 2004; Buckelew, 2009; Foy et al., 1994; Liverani et al., 1992; Majek et al., 1993; Meagher and Meyer, 1990; Welker and Glenn, 1989). Unwanted vegetation competes with trees for water and nutrients and can also serve as an alternate host for pathogens and insect pests, including hemipteran insects that damage and distort fruit, generally referred to as catfacing insects (Meagher et al., 1987; Meagher and Meyer, 1990; Mitchem, 2005).

Orchard floor management strategies for peach production include establishing a cover crop or a permanent sod in the row middles to prevent erosion, maintain soil structure, and facilitate equipment movement during wet weather, with a vegetation-free strip in the tree row maintained with herbicides to maximize tree growth and productivity (Foy et al., 1994; Layne and Tan, 1988; Layne et al., 1994; Mitchem, 2005). Growth of young peach trees increases when grown in vegetation-free soil compared with trees grown with groundcover (Liverani et al., 1992; Meyer et al., 1992; Parker and Meyer, 1996). In peach orchards with vegetation in the row middles, growth increases as the width of the vegetation-free area in the tree row increases (Buckelew, 2009; Welker and Glenn, 1988; Welker and Glenn, 1989). A 3.0- to 3.6-m wide vegetation-free strip in the tree row is a common orchard floor management system in the southeastern United States (Mitchem, 2005).

Supplemental irrigation of peach orchards is recommended in many locations with erratic precipitation and is especially encouraged on sandy soils. For drier climates or years, supplemental irrigation increases peach tree growth, fruit yield per tree, fruit size, and number of fruit buds per tree (due to greater shoot length) over nonirrigated trees (Buckelew, 2009; Layne and Tan, 1988; Layne et al., 1994; Reeder et al., 1979). The greatest number of fruit buds per tree increases crop potential after a spring freeze. Water stress during the final fruit swell period (3–4 weeks preceding maturity) reduces fruit size and quality (Lockwood and Coston, 2005), and therefore economic returns. Drip irrigation from April or May through harvest in Georgia on Faceville and Greenville sandy loam soil was as effective at maximizing total yield and fruit diameter as irrigating all season (Horton et al., 1981). In Oklahoma on a Teller sandy loam soil there was no increase in either fruit yield or fruit size when irrigated from budbreak through harvest compared with only irrigating during the swel period (Huslig et al., 1993).

Significant insect damage to peach fruit in North Carolina is caused by a hemipteran complex which includes the tarnished plant bug, Lygus lineolaris (Palisot de Beauvois), and stink bugs in the genera Acrosternum, Euschistus, Nezara, and Thyanta (Killian and Meyer, 1984; Meyer and Ritchie, 1983) and is referred to as catfacing insect damage. These insects distort fruit shape with irregular and variable-sized necrotic skin spots and are managed using four to six early-season applications of broad-spectrum insecticides. However, even vigorous chemical applications in the southeastern United States will only provide partial control unless combined with an orchard floor vegetation management program (Meagher et al., 1987; Meyer, 1984). Vegetation management within and between rows can reduce the number of insecticide applications needed (Atanassov et al., 2002; Killian and Meyer, 1984). Insecticide-resistant populations of L. lineolaris have been reported (Snodgrass, 1996), thereby providing further support for integrated pest management strategies. Consumers are increasingly aware of and concerned about the amount of pesticide used in fruit production and their perceived effects on the environment (Fiore, 1999). Reducing the amount of insecticide necessary to control catfacing insects would decrease inputs, minimize applicator risk, and reduce the potential for insecticide-resistant pest populations while possibly providing a marketing advantage for the product.

The objective of this study was to measure the effects of vegetation-free strip width and irrigation on peach tree growth, fruit yield, harvest maturity, size, and incidence of catfacing damage in a young (fourth to eighth leaf) peach orchard on a light sandy soil.

**Materials and Methods**

The experiment was conducted from 2009 to 2013 at the Sandhills Research Station in Jackson Springs, NC (35.21°N, 79.63°W; average annual precipitation 117 cm). Soil was a Candor sand (sandy, kaolinitic, thermic...
Grossarenic Kandiults) with a pH of 5.8 and humic matter of 0.6%. The orchard consisted of ‘Contender’ peach trees grafted onto ‘Guardian’ rootstock. One-year whips were planted on 3 Feb. 2006 at a spacing of 5.5 m within the row and 6.0 m between rows. Trees were pruned each spring to an open center form (Lockwood and Myers, 2005).

The experimental design was a factorial randomized complete block with six replications and two factors, vegetation-free strip width (0, 0.6, 1.2, 2.4, 3.0, and 3.6 m) with or without microsprinkler irrigation. Details of the treatments were described by Bucklew (2009). Each plot contained four trees, the two center trees being record trees. Vegetation-free strips were chemically maintained using Chateau® (fumioxamiz at 213.3 g·ha⁻¹ a.i.; Valen BioSciences Corp., Libertyville, IL) for preemergent weed control and Gramoxone Inteon® (paraquat at 0.67 to 1.0 kg·ha⁻¹ a.i., with non-ionic surfactant at 0.25% v/v; Syngenta Crop Protection, LLC, Greensboro, NC) as a postemergent burn-down. Row middles were allowed to populate with native weedy species and were maintained by mowing to a height of 10–13 cm tall. Insects were managed per the Southeastern Peach, Nectarine and Plum Pest Management Insects were managed per the Southeastern Peach, Nectarine and Plum Pest Management Guide (Horton et al., 2013) using Imidan® (phosmet at 3.36 kg·ha⁻¹; Gowan, Yuma, AZ), Asana® (fenvalerate at 0.28 kg·ha⁻¹; Syngenta Crop Protection, LLC), and permethrin (0.56 kg·ha⁻¹; Helena Chemical, Collierville, TN), all of which help control catfacing insects as well as other peach pests such as plum curculio and oriental fruit moth. All trees were fertilized uniformly with two applications of fertilizers, 30–40 d of full bloom by hand so that remaining fruit were no closer than 15 cm apart. Fruit were harvested over three or four dates each year. Fruit from each record tree were weighed for total yield and percentage

### Table 1. Monthly weather data for the Sandhills Research Station, Jackson Springs, NC.*

| Yr       | 2009 | 2010 | 2011 | 2012 | 2013 |
|----------|------|------|------|------|------|
| Temperature min (°C) | 4.9  | 5.2  | 5.4  | 10.1 | 2.1  |
| Temperature max (°C) | 15.6 | 16.9 | 16.7 | 22.0 | 13.7 |
| Precipitation (cm)  | 10.2 | 12.1 | 11.3 | 15.9 | 8.3  |
| Irrigation (cm)     | —    | 0    | 0    | 0    | 0    |

### Table 2. Effect of vegetation-free strip width and irrigation on trunk cross-sectional area (cm²), years 4–8.*

| Strip width (m) | 2009 | 2010 | 2011 | 2012 | 2013 |
|----------------|------|------|------|------|------|
| 0              | 22.8 d<sup>+</sup> | 32.8 d | 39.2 d | 47.0 d | 64.9 c |
| 0.6            | 38.7 c | 49.6 c | 57.6 c | 66.3 c | 85.8 b |
| 1.2            | 45.7 bc | 57.8 bc | 66.4 bc | 72.8 bc | 91.7 b |
| 2.4            | 54.1 ab | 62.9 b | 72.6 b | 81.9 ab | 102.7 ab |
| 3.0            | 50.0 b | 63.8 b | 73.5 ab | 82.4 ab | 99.5 ab |
| 3.6            | 62.6 a | 75.7 a | 88.0 a | 96.3 a | 115.5 a |
| P value         | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

### Table 3. Effect of vegetation-free strip width and irrigation on peach yield (kg), years 4–8.*

| Strip width (m) | 2009 | 2010 | 2011 | 2012 | 2013 |
|----------------|------|------|------|------|------|
| 0              | 9.6 e<sup>+</sup> | 16.1 d | 21.7 d | 28.1 d | 24.3 d | 99.8 d |
| 0.6            | 18.5 cd | 22.8 c | 29.6 c | 38.3 c | 25.8 cd | 134.9 c |
| 1.2            | 17.1 d | 29.5 b | 34.6 bc | 40.5 c | 29.8 bc | 151.4 c |
| 2.4            | 23.3 ab | 31.8 b | 39.8 b | 49.1 ab | 31.6 b | 175.7 b |
| 3.0            | 21.6 bc | 33.1 b | 39.9 b | 44.3 bc | 37.0 a | 175.9 b |
| P value         | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Irrigation      | 22.7 a | 32.7 a | 37.8 a | 43.5 a | 32.7 a | 169.4 a |
| Nonirrigated    | 16.2 b | 26.1 b | 33.0 b | 41.3 a | 30.0 a | 146.6 b |
| P value         | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| P value for strip x irrigation interaction | 0.0759 | 0.5165 | 0.4302 | 0.4898 | 0.6707 |

*Main effect means are pooled across other main effects and 6 reps.

* Treatments were separated by the Tukey-Kramer method for each harvest date at the P ≤ 0.05 level and means within each column within main effects followed by the same letter do not significantly differ.

*Main effect means are pooled across other main effects and 6 reps.

* Treatments were separated by Duncan’s new multiple range test for each harvest date at the P ≤ 0.05 level and means within each column within main effects followed by the same letter do not significantly differ.
The effect of vegetation-free strip width and irrigation on TCSA is shown in Table 2. A 3.6-m vegetation-free strip with irrigation had the greatest TCSA, followed by strips with irrigation and vegetation-free strips with irrigation. Trees in the 3.6-m vegetation-free strip without irrigation had the smallest TCSA. The effect of vegetation-free strip width and irrigation on total yield is shown in Table 3. In all years, yield was greatest from trees with a 3.6-m vegetation-free strip and lowest from trees with a 0-m strip. Trees in the 0.6–3.0 m vegetation-free strips produced intermediate yields; trees with larger vegetation-free strips had greater yields compared with trees with smaller vegetation-free strips. Spring frost/freeze blossom damage resulted in lower yields in 2013 with smaller treatment differences, although the trend was the same as in previous years. In 2009–11 irrigated trees had significantly greater yield, by an average of 6.0 kg/tree. In 2012 and 2013, there were no significant irrigation × strip interactions in the 5 years studied.

Table 4. Effect of vegetation-free strip width and irrigation on percent of total yield harvested at each harvest date, years 4–8. *

| Strip width (m) | 0 | 0.6 | 1.2 | 2.4 | 3.0 | 3.6 |
|-----------------|---|-----|-----|-----|-----|-----|
| 2009 % Fruit harvested on each of three harvest dates each yr | | | | | | |
| First | Second | Third | First | Second | Third | First | Second | Third | First | Second | Third |
| 69.9 | 22.0 | 8.1 | 23.9 | 55.4 | 19.1 | 65.8 | 33.0 | 1.2 | 70.7 | 25.8 | 3.5 |
| 41.8 | 38.7 | 17.2 | 17.7 | 61.5 | 24.5 | 57.6 | 35.6 | 2.4 | 52.8 | 30.4 | 14.3 |
| 39.1 | 35.9 | 27.7 | 19.7 | 57.5 | 41.7 | 60.7 | 41.7 | 1.9 | 58.1 | 31.3 | 13.0 |
| 48.2 | 33.5 | 18.2 | 30.6 | 53.6 | 15.1 | 62.8 | 34.0 | 3.1 | 54.0 | 34.3 | 11.7 |
| 47.4 | 29.9 | 18.4 | 28.5 | 53.6 | 13.3 | 56.7 | 37.4 | 1.6 | 54.0 | 30.7 | 13.5 |
| 42.7 | 34.3 | 28.4 | 28.2 | 53.8 | 22.7 | 47.7 | 50.4 | 6.3 | 39.0 | 41.6 | 21.2 |
| Irrigation | | | | | | | | | | | |
| Irrigated | 57.7 | 29.4 | 9.4 | 28.9 | 57.2 | 10.2 | 60.6 | 33.6 | 2.0 | 49.2 | 34.6 | 13.9 |
| Nonirrigated | 38.6 | 35.3 | 30.5 | 20.6 | 54.8 | 28.8 | 56.5 | 44.0 | 3.5 | 60.3 | 30.0 | 11.8 |
| Interaction | | | | | | | | | | | |
| P value | 0.0051 | 0.0005 | 0.7322 | 0.0015 | 0.9607 | 0.6171 | 0.2585 | 0.4867 | 0.1712 | 0.9264 | 0.9993 | 0.8850 |

*Main effects means are pooled across other main effects and 6 reps.

*Values not reported due to significant interaction.
harvest date increased with greater vegetation-free strip widths. In 2009 and 2012, the 3.6-m vegetation-free strip width treatment had the greatest and the 0-m plot had the lowest percentage of total yield collected at the third harvest. This same trend was also seen in 2011, though not statistically significant ($P = 0.07$).

There were differences in maturity on the first harvest date due to irrigation; in 2012, fruit in nonirrigated plots ripened earlier than fruit grown in irrigated plots. In 2011 and 2013, there was no significant difference between irrigated and nonirrigated plots for maturity at the first harvest. In 2011, irrigated treatments had a smaller percentage of total yield collected on the second harvest date compared with nonirrigated treatments while in 2012 irrigated treatments had a greater percentage of total yield collected on the second harvest date compared with nonirrigated treatments. Nonirrigated treatments had a greater percentage of total harvest collected on the third harvest date than irrigated treatments in 2009 and 2010, with no significant differences due to irrigation in years 2011–13.

There were significant irrigation $\times$ strip width interactions for maturity at the first harvest in two of the 5 years studied (Fig. 1) and at the second harvest in one of the 5 years studied. Trees in the nonirrigated 1.2- and 2.4-m vegetation-free strips had percentages of total yield at the first harvest that differed from the expected trend based on the other treatments. There were no significant strip $\times$ irrigation interactions for percentage of total yield collected on the third harvest date in the 5 years studied.

The effect of vegetation-free strip width and irrigation on average peach weight is shown in Table 5. In 2009 and 2010 fruit grown in the 3.0- and 3.6-m vegetation-free strips had the greatest average weight followed by fruit from the 1.2- and 2.4-m vegetation-free strips. Fruit grown in the 0-m strip were among the lowest weights in three out of 5 years. In years 2009–11, fruit were larger in irrigated vs. nonirrigated plots, with an average increase of 19%, while in 2012 fruit were larger in nonirrigated plots than in irrigated plots, by 8%. There was a slight ($P = 0.0496$) irrigation $\times$ strip width interaction in 2013.

The effect of vegetation-free strip width and irrigation on average peach diameter is shown in Table 6. Increasing vegetation-free strip width increased fruit diameter in 2009, 2010, and 2013. In all years, fruit grown in the 0-m strip had the smallest diameter, although not significantly so in 2011 and 2012. Irrigation increased fruit diameter in years 2009–11, with an average increase of 7%, and appeared to slightly decrease diameter in 2012 and 2013, by an average of 1%, though the irrigation was only diameter in 2012 and 2013, by an average of 1%, though the irrigation was only diameter in years 2009–11, with an average increase of 7%, and appeared to slightly decrease diameter in 2012 and 2013, by an average of 1%, though the irrigation was only
Table 7. Effect of vegetation-free strip width and irrigation on percent catfacing damage in ‘Contender’ peach, years 4–6.

| Strip width (m) | 2009 | 2010 | 2011 | Catfacing (%) |
|----------------|------|------|------|---------------|
| 0              | 14.5 a  | 6.9  | 5.3 a  |               |
| 0.6            | 9.8 ab | 6.4  | 2.7 b  |               |
| 1.2            | 11.5 ab| 4.9  | 2.9 b  |               |
| 2.4            | 7.5 bc | 4.8  | 3.2 b  |               |
| 3.0            | 5.5 c  | 6.4  | 2.2 b  |               |
| 3.6            | 5.4 e  | 5.2  | 1.7 b  |               |
| Irrigation     |       |      |      |               |
| Irrigated      | 8.6   | 5.9  | 3.7 a  |               |
| Nonirrigated   | 9.4   | 5.6  | 2.3 b  |               |
| P value        | 0.5539 | 0.5699 | 0.0145 |
| P value for strip × irrigation interaction | 0.0500 | 0.3881 | 0.5700 |

*Main effects are pooled across other main effects and 4 reps.

Results show that fruit grown with wider vegetation-free strip widths may ripen over a longer period than fruit grown with narrower vegetation-free strip widths. The first and last harvest dates differed by only 7–9 d each year. Although the difference in harvest maturity between 0-m and 3.6-m vegetation-free strip widths varied, with treatment compared with 9% without). Our results indicate that benefits can be seen with a vegetation-free strip under the tree (eliminating all weeds, not just winter annuals) as narrow as 0.6 m, potentially reducing the amount of insecticide that will need to be sprayed each year. These differences were observed in an orchard where a commercial pest management program was in place. The use of a vegetation-free strip in the tree row will certainly not eliminate the need for insecticide sprays but will make them more effective.

Although the orchard used in the present study was on a commercial pest management schedule, there was still a reduction in catfacing damage by increasing vegetation-free strip widths. Using 2009 data, if we assume an average yield of 20,000 kg ha⁻¹ and an expected price of US$24 per 23 kg (M.L. Parker, personal communication), an average 9% increase in saleable yield would produce an additional 1800 kg of fruit worth US$1878 per hectare annually. This increase in saleable yield would more than offset the cost of herbicides necessary to maintain the vegetation-free strip in addition to the yield and fruit size benefits.

The catfacing data were collected in years 4–6. As the trees age and the canopy diameter increases, a wider vegetation-free strip may be required to minimize catfacing damage and maximize orchard profitability. The interaction between irrigation × strip width needs further exploration to determine the optimum vegetation-free strip width and irrigation for maximum fruit yield and quality. It is also important to note that only one peach variety, ‘Contender’, was used in this study. ‘Contender’ has a very high blossom density, as growers remove fewer fruit buds to delay flowering and therefore have a longer period of catfacing damage by increasing vegetation-free strip widths.

Supplemental irrigation did increase tree growth and greater yield, in agreement with other studies on heavier soils (Lockwood and Myers, 1987). Buckelew (2009) observed newly planted peach, years 4–6. The 0.6-, 1.2- and 2.4-m vegetation-free strips had intermediate catfacing damage. In 2009, the 3.0- and 3.6-m treatments had 9% catfacing damage compared with the 0-m treatment. In 2010, vegetation-free strip widths did not impact incidence of catfacing damage and over all, catfacing damage was less than 7%, but still numerically greater in the 0- and 0.6-m strip treatment. Of the treatments, the 3.0- and 3.6-m vegetation-free strips had intermediate catfacing damage, with irrigated plots having a higher percentage of catfacing damage than nonirrigated plots.

Discussion

This work focused on peach trees in years 4–8, with vegetation-free strip width and irrigation treatments that were initiated at planting, and demonstrates that increasing the vegetation-free strip width under the trees results in greater tree growth and greater yield, in agreement with other studies on younger trees (Arnold and Aldrich, 1980; Belding et al., 2004; Buckelew, 2009; Foy et al., 1994; Liverani et al., 1992; Majek et al., 1993; Welker and Glenn, 1989). In this study, we have shown that to also be the case on light sandy soils and we evaluated the impact of irrigation to overcome any adverse effects of the vegetative competition. In years 4–7 (2009–12, Table 2), across strip width treatments, tree growth in the nonirrigated plots was at least 1 year behind trees grown in irrigated plots. Yields in the eighth year (2013) were lower due to frost/freeze damage (Table 1). Supplemental irrigation did increase tree growth and fruit yield on sandy soil, in agreement with other studies on heavier soils (Layne and Tan, 1988; Layne et al., 1994; Reeder et al., 1979). The earlier fruit ripening and greater average weight and diameter in years of average rainfall (2009–11) further indicate a commercial need and benefit of irrigation for peach on sandy soil, even in an area with relatively high annual rainfall.

Buckelew (2009), observing newly planted and younger trees in the same orchard as this study, reported that peel yields in the third year of a nonirrigated 3.6-m vegetation-free strip could be matched by using irrigation in a vegetation-free strip of 1.2 m. However, in the years observed in the current study, the use of irrigation in vegetation-free strips of 1.2–3.0 m was not sufficient to match the yield produced in a nonirrigated 3.6-m vegetation-free strip. Reducing the vegetation-free area will increase the amount of soil surface covered with vegetation, contributing soil organic matter, maintaining soil structure, and reducing erosion, measures positively related to the agricultural productivity of a site. Reducing the width of the vegetation-free strip will also reduce the amount of herbicide growers need to apply each year, reducing input costs. However, the long-term impact on annual yield, fruit size and weight may make this practice unacceptable, especially in areas where irrigation is not practical due to water scarcity and cost.

Killian and Meyer (1984) reported a reduction in the incidence of catfacing damage on peaches with herbicide control of winter annual weeds in the tree row (2% damage with treatment compared with 14% without) or over the entire orchard floor (4% damage with treatment compared with 9% without). Our results indicate that benefits can be seen with a vegetation-free strip under the tree (eliminating all weeds, not just winter annuals) as narrow as 0.6 m, potentially reducing the amount of insecticide that will need to be sprayed each year. These differences were observed in an orchard where a commercial pest management program was in place. The use of a vegetation-free strip in the tree row will certainly not eliminate the need for insecticide sprays but will make them more effective.

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The catfacing data were collected in years 4–6. As the trees age and the canopy diameter increases, a wider vegetation-free strip may be required to minimize catfacing damage and maximize orchard profitability. The interaction between irrigation × strip width needs further exploration to determine the optimum vegetation-free strip width and irrigation for maximum fruit yield and quality. It is also important to note that only one peach variety, ‘Contender’, was used in this study. ‘Contender’ has a very high blossom density, as growers remove fewer fruit buds to delay flowering and therefore have a longer period of catfacing damage by increasing vegetation-free strip widths.
