ABSTRACT

LANDIS FISK, CONNIE. Effect of Orchard Management Practices on Peach Tree Growth, Yield, and Soil Ecology. (Under the direction of Drs. Michael Parker and Penelope Perkins-Veazie.)

Peach orchard floor vegetation competes with trees for water and nutrients; reducing vegetation in the tree row results in larger trees and greater fruit yields in the early years of the orchard's life. However, orchard floor management affects more than just tree size and fruit yield. Orchard floor management can affect soil ecology and pest behavior and defining these impacts is critical to understanding peach tree short life, a disease complex common to peach replant sites in the southeastern US that results in premature tree death in the spring, three to six years after planting. Research was conducted in a young peach orchard at the Sandhills Research Station in North Carolina in years three through seven after planting to determine the effects of vegetation-free strip widths of 0, 0.6, 1.2, 2.4, 3.0, and 3.6 m in the tree row and irrigation on peach tree growth, fruit yield, and fruit size, on the microbial community in the tree's rhizosphere, and on the incidence of fruit damage from catfacing insects. Trunk cross-sectional area, as a measure of tree growth, increased with increasing vegetation-free strip width; trees grown in the 3.6 m vegetation-free strip had trunk cross-sectional areas 2.3 times greater, on average, than those grown in the 0 m vegetation-free strip. Trunk cross-sectional area also increased with irrigation; trees grown with irrigation had trunk cross-sectional areas 1.2 times greater, on average, than trees grown without irrigation. Yield increased with increasing vegetation-free strip width, from 9.6 kg per tree in the 0 m plot to 27.7 kg per tree in the 3.6 m plot in year three, to 24.3 kg per tree in the 0 m plot and 40.0 kg in the 3.6 m plot in year 7. Yield

increased with irrigation in four out of five years. In two out of five years fruit in irrigated plots matured earlier than fruit in non-irrigated plots. Fruit grown in the 0 m strip matured earliest and had the smallest diameter. Average fruit weight and average fruit diameter increased with irrigation in three out of five years. Vegetation-free strip widths and irrigation had no significant effect on endomycorrhizal colonization of peach roots in years three through four after planting. There were differences in microbial biomass carbon and nitrogen and soil microbial respiration rate between vegetation-free strip widths. Net nitrogen mineralization decreased with greater vegetation-free strip width. In the fourth year after planting, the soil in irrigated plots had higher microbial biomass nitrogen and lower soil microbial respiration rates in the spring. Establishing a vegetation-free strip of as narrow as 0.6 m resulted in less catfacing damage than was seen in 0 m plots. The least catfacing damage was seen at the industry standard vegetation-free strip width of 3.0 or 3.6 m, with or without irrigation. Treatment differences were seen even though the orchard was on a commercial pesticide spray schedule. These are important implications for peach production where the goal is to maximize fruit yield and quality while optimizing the health of trees and soil.

Additionally, the rhizospheres of genetically diverse peach rootstocks were examined to determine effects on the soil microbial community after one year in the field. Soil microbial biomass carbon and nitrogen, soil microbial respiration rate, and net nitrogen mineralization did not differ by rootstock in either fall or spring. 'Controller 5' and 'Viking' had the highest endomycorrhizal root colonization while 'Guardian®' and 'Empyrean® 2' had the lowest.

Effect of Orchard Management Practices on Peach Tree Growth, Yield, and Soil Ecology

by
Connie Landis Fisk

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Horticultural Science

Raleigh, NC

2013

APPROVED BY:

_____
Dr. David Ritchie

_____ _____
Dr. Shuijin Hu Dr. Sara Spayd

_____ _____
Dr. Michael Parker Dr. Penelope Perkins-Veazie
Chair of Advisory Committee Vice-Chair of Advisory Committee

BIOGRAPHY

Connie Landis Fisk was born in a small town in Central Oregon to parents who worked in one of the many lumber mills that the town's economy was based on. She and her two sisters were raised in town but loved to spend time "in the country" with their grandparents. As the oldest grandchild, Connie learned to drive and operate farm equipment to help her grandfather hay in the summer. Her love of animals and being outdoors led her to a position working part-time for the Bureau of Land Management through high school.

As a teen parent, many expected Connie to drop out of school and find a job in Central Oregon but after graduating from high school a semester early she immediately enrolled in classes at Southern Oregon State College. That fall she transferred to Oregon State University (OSU) as a Natural Resources major. A required human nutrition course at OSU led her to switch majors and she graduated in December 1999 with a BS in Nutrition & Food Management with minors in Chemistry and Food Technology.

An internship Connie's senior year in college with a fruit and vegetable processor committed to sustainable agriculture and exceptional quality helped her realize that what she wanted to do with her career was investigate fruit quality and work with growers to determine what can be done in the field to improve and extend it. She went to work in the food industry working in the quality assurance labs of two different companies before returning to OSU to pursue a master's degree to qualify her for a career in research and extension. She completed her MS degree in 2006 in the dual majors of Food Science &

Technology and Horticulture with a project investigating the postharvest quality and storability of hardy kiwifruit (*Actinidia arguta* 'Ananasnaya').

Connie's next position was as the Extension Associate for muscadine grapes at North Carolina State University. Having grown up in Central Oregon, Connie had never seen a muscadine, but knowing their similarities to kiwifruit and that she would get to work with both growers and processors utilizing her broad experience and education, she was excited to accept the challenge. Later that year Connie was invited by James Sprunt Community College to develop and teach a course in viticulture where she discovered a passion for teaching. That prompted her to continue her education as a PhD student at NCSU. While at NCSU, Connie had the opportunity to study tropical plant pathology with a trip to visit growers in Costa Rica, was inducted into Gamma Sigma Delta (the Honor Society of Agriculture), and completed the Certificate of Accomplishment in Teaching.

While still a student at NCSU, Connie accepted a teaching position at Sheridan College in Sheridan, WY where she developed and taught a variety of courses in the classroom and online and advised students in the Sustainable Food Systems AS and Agriculture: Food Science AAS degree programs.

Upon completion of her degree Connie will pursue an academic career with research, extension, and teaching responsibilities focused on fruit production.

ACKNOWLEDGMENTS

I would not be where I am today without the example, support, and patience of many. I would also not be where I am today if so many others hadn't told me that I'd never make it – I do like a challenge.

First, I would like to continue to thank Dr. Mina McDaniel, who encouraged me to not give up on my dream to attend graduate school when I had been rejected by several universities who questioned my ability and dedication. The experience I gained in the food industry between my BS and my MS is invaluable to me. Thank you for offering me a position and later a graduate research assistantship in OSU's Sensory Science Lab. Thank you for being my friend and being supportive through job uncertainties and the highs and lows of graduate school.

Thank you to Dr. Bernadine Strik, Dr. Sara Spayd, Dr. Barclay Poling, Whit Jones and Bill Cline for teaching me about small fruits and about how to be an Extension professional.

To Dr. Mike Parker, thank you for your willingness to let me pursue this degree and study peaches with you. You are an example of the teacher, mentor, and extension professional I want to be. I will be forever grateful for your patience and encouragement.

I would also like to thank Dr. Julia Kornegay for bringing me to NCSU and making me feel valued in Extension and the Department, Dr. Gina Fernandez for being supportive when I didn't feel smart enough but was willing to work hard, and Drs. Dave Ritchie and Larry Grand in the Department of Plant Pathology for encouraging my interest in their discipline. Thank you to Dr. Penny Perkins-Veazie for serving as vice-chair of my graduate committee

and for carefully editing and commenting on my many manuscript drafts, Drs. Shuijin Hu and Cong Tu for allowing me to work in your lab and explaining procedures to me until I was able to understand what I was doing, Bernadette Clark for being my friend and helping me in the field and the lab, and the staff at the Sandhills Research Station for all your work maintaining the orchards for my project, for helping me pull endless samples, and for sharing your lunch table with me.

And last, but certainly not least, I would like to thank my family. Thank you to my mom who didn't kill me in my youth and who supported every move and job change I've made as an adult. Thank you to my oldest daughter, Stephanie, for motivating me to go to college and make a better life for our family. It was scary and never easy, but we survived and are stronger for it. Thank you to my husband Brent Fisk. I couldn't have done any of this without your unwavering love and support and I'm sure you've earned a spot in heaven for putting up with me. Hunter and Kassidy, you make me want to be a better person. Don't ever doubt how much I love you all.

TABLE OF CONTENTS

LIST OF TABLES viii
LIST OF FIGURES x

LITERATURE REVIEW 1
Introduction 2
Peach Tree Short Life 3
Orchard Management Practices 4
Orchard Soil Ecology 11
Mycorrhizae in Fruit Production 16
Research Objectives 22
Literature Cited 23

EFFECT OF VEGETATION-FREE WIDTH AND IRRIGATION ON PEACH TREE GROWTH, YIELD, AND FRUIT SIZE 37
Introduction 40
Materials and Methods 43
Results 45
Discussion 49
Literature Cited 51

EFFECTS OF WEED CONTROL AND IRRIGATION ON SOIL MICROBES IN A REPLANTED PEACH ORCHARD 67
Introduction 70
Materials and Methods 74
Results 78
Discussion 80
Literature Cited 82

IMPACT OF ORCHARD FLOOR MANAGEMENT PRACTICES ON CATFACING DAMAGE IN PEACH 93
Introduction 95
Materials and Methods 97
Results 99
Discussion 100
Literature Cited 102

ROOTSTOCK EFFECT ON SOIL ECOLOGY IN A PEACH ORCHARD 106
Introduction 109
Materials and Methods 112
Results 116
Discussion 117
Literature Cited 118

APPENDICES 128
Appendix 1. Effect of Vegetation-free Width and Irrigation on Peach Tree Growth, Yield, and Fruit Size, Additional Figures 129
Appendix 2. Soil Chemical Properties 135
Appendix 3. Nematode Sampling Results 137
Appendix 4. Monthly Temperatures and Precipitation 138

LIST OF TABLES

EFFECT OF VEGETATION-FREE WIDTH AND IRRIGATION ON PEACH TREE GROWTH, YIELD, AND FRUIT SIZE

Table 1. Effect of vegetation-free strip width, with and without irrigation, on trunk cross-sectional area (cm^2) of peach trees, years 3-6 55

Table 2. Effect of vegetation-free strip width and irrigation on trunk cross-sectional area (cm^2) of peach trees, years 3-6 56

Table 3. Vegetation-free strip width and irrigation effects on peach yield (kg), years 3-7 57

Table 4. Effect of vegetation-free strip and irrigation on peach yield (kg), years 3-7 58

Table 5. Effect of vegetation-free strip width, with and without irrigation, on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7 59

Table 6. Effect of vegetation-free strip width and irrigation on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7 60

Table 7. Effect of vegetation-free strip width and irrigation on % of total yield harvested on the second harvest date of each year, years 3-7 61

Table 8. Effect of vegetation-free strip width and irrigation on % of total yield harvested on the third harvest date of each year, years 3-7 62

Table 9. Effect of vegetation-free strip width, with and without irrigation, on average peach weight (g), years 3-7 63

Table 10. Effect of vegetation-free strip width and irrigation on average peach weight (g), years 3-7 64

Table 11. Effect of vegetation-free strip width, with and without irrigation, on average peach diameter (cm), years 3-7 65

Table 12. Effect of vegetation-free strip width and irrigation on average peach diameter (cm), years 3-7 66

EFFECTS OF WEED CONTROL AND IRRIGATION ON SOIL MICROBES IN A REPLANTED PEACH ORCHARD

Table 1. Effects of vegetation-free strip width and irrigation on endomycorrhizal root colonization of peach on sandy soil in the NC Sandhills, years 3-4 after planting 91

Table 2. Effects of vegetation-free strip width and irrigation on rhizosphere soil microbial biomass carbon (MBC) and nitrogen (MBN), soil microbial respiration (SMR), and net nitrogen mineralization (NNM) for peach on sandy soil in the NC Sandhills, years 3-4 after planting 92

IMPACT OF ORCHARD FLOOR MANAGEMENT PRACTICES ON CATFACING DAMAGE IN PEACH

Table 1. Effect of vegetation-free strip width and irrigation on percent catfacing damage in 'Contender peach, years 3-5 after planting 105

ROOTSTOCK EFFECT ON SOIL ECOLOGY IN A PEACH ORCHARD

Table 1. Rootstock rhizosphere soil microbial biomass carbon (MBC) and nitrogen (MBN), soil microbial respiration (SMR), and net nitrogen mineralization (NNM) for peach in second leaf on sandy soil in the NC Sandhills 126

APPENDICES

Table 1a. Effect of vegetation-free strip width and irrigation on soil moisture. 135

Table 1b. Effect of vegetation-free strip width and irrigation on soil pH 135

Table 1c. Effect of vegetation-free strip width and irrigation on soil electrical conductivity..... 136

Table 2. Peach rootstock rhizosphere soil moisture, pH and EC 136

Table 3. Effect of vegetation free strip and irrigation on nematode populations, April 2010..... 137

Table 4. Monthly weather data for the Sandhills Research Station 138

LIST OF FIGURES

EFFECT OF VEGETATION-FREE WIDTH AND IRRIGATION ON PEACH TREE GROWTH, YIELD, AND FRUIT SIZE

Figure 1. Interaction between vegetation-free strip width and irrigation on the harvest maturity of peach, years 3-4 60

EFFECTS OF WEED CONTROL AND IRRIGATION ON SOIL MICROBES IN A REPLANTED PEACH ORCHARD

Figure 1. A) The gridline intersection method was used to determine the percentage of infected roots. B) The root at top is not infected; the root at bottom is infected..... 90

Figure 2. Magnified view of endomycorrhizal colonization of peach roots 90

ROOTSTOCK EFFECT ON SOIL ECOLOGY IN A PEACH ORCHARD

Figure 1. Endomycorrhizal root colonization by rootstock for peach in second leaf on sandy soil in the NC Sandhills 127

APPENDICES

Figure 1. Effect of vegetation-free strip width, with and without irrigation, on trunk cross-sectional area of peach trees, years 3-6..... 129

Figure 2. Effect of vegetation-free strip width on trunk cross-sectional area (cm^2) of peach trees, years 3-6..... 129

Figure 3. Effect of irrigation on trunk cross-sectional area (cm^2) of peach trees, years 3-6..... 130

Figure 4. Effect of vegetation-free strip width, with and without irrigation, on peach yield (kg), years 3-7 130

Figure 5. Effect of vegetation-free strip on peach yield (kg), years 3-7 131

Figure 6. Effect of irrigation on peach yield (kg), years 3-7 131

Figure 7. Effect of vegetation-free strip width, with and without irrigation, on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7 132

Figure 8. Effect of vegetation-free strip width on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7 132

Figure 9. Effect of irrigation on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7 133

Figure 10. Effect of vegetation-free strip width, with and without irrigation, on average peach weight (g), years 3-7 133

Figure 11. Effect of vegetation-free strip width, with and without irrigation, on average peach diameter (cm), years 3-7 134

LITERATURE REVIEW

Introduction

The peach [*Prunus persica* (L.) Batsch] is grown commercially in 23 states of the United States on about 113,000 acres (USDA, 2012). In North Carolina, peaches were historically grown in the Sandhills region of Montgomery, Moore, Richmond, and Anson counties on sandy to sandy-loam soils (Ritchie et al., 2005). Today peaches are grown on nearly 3,000 acres across the state with the exception of the high mountains (M.L. Parker, personal communication).

The peach fruit is a drupe consisting of an exocarp (outer, fuzzy skin), a mesocarp (the edible flesh), and an endocarp (the pit). The size of a peach at harvest is limited by the number of cells within the fruit and the size of these cells. Maintaining adequate moisture during the first fifty days of growth affects cell division (the number of cells), while adequate moisture during the last three to four weeks of growth affects cell enlargement (the size of the cells and therefore the fruit) (Lockwood and Coston, 2005).

In NC, the peach tree produces its first commercial fruit crop in the third year after planting, with maximum yields achieved by the fifth or sixth year, and generally lives for only fifteen to twenty years, even less on sandy soils or replant sites (Ritchie and Clayton, 1981). The focus of the first two to three years after planting is on tree growth (size) and training (shape) because initial fruit yield is directly related to tree size (Belding et al., 2004).

Peach Tree Short Life

One challenge to peach production in the southeastern United States is the peach tree short life (PTSL) complex. PTSL is most common to sandy peach replant sites and results in premature tree death in the spring, three to six years after planting (Ritchie and Clayton, 1981). While the PTSL complex is still only partly understood, contributing factors are known to include ring nematode (*Criconemella xenoplax* (Raski) Lúc & Raski), bacterial canker (caused by *Pseudomonas syringae* pv. *Syringae* van Hall), and cold damage (Nesmith et al., 1981; Ritchie and Clayton, 1981; Zehr et al., 1976). Recommendations to minimize the potential for PTSL losses in orchards with sandy soil focus on minimizing the effect of nematodes, including not planting on a previous peach site within five years, preplant fumigation with a nematicide, and purchasing trees grafted onto nematode resistant rootstocks (Nyczepir and Beckman, 1997; Ritchie and Clayton, 1981; Sharpe et al., 1989; Wehunt et al., 1980; Zehr et al., 1976). The current preferred rootstock, 'Guardian®' (BY520-9) survives better than other commercial peach rootstocks on sandy replant sites infested with ring nematode and is also tolerant of root knot nematodes, bacterial canker and cold injury (Okie et al., 1994; Parker et al., 1997; Reighard, 2005; Reighard et al., 1997). Additional precautions recommended to growers include keeping soil pH above 6, avoiding late season nitrogen fertilization, and pruning just before bloom in February or March (Nesmith and Dowler, 1976; Ritchie and Clayton, 1981; Weaver, 1998).

Orchard Management Practices

There is a direct relationship between the amount of orchard floor vegetation control and subsequent peach 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). Weeds compete with trees for water and nutrients and also serve as alternate hosts for pathogens and insects, including insects that damage and distort fruit, generally referred to as catfacing insects (Meagher et al., 1987; Meagher and Meyer, 1990; Mitchem, 2005). Certain weeds also have allelopathic activities that adversely affect growth and yield of many crop species (Inderjit and Keating, 1999). Weller et al. (1985) reported that reduced peach tree growth with severe stunting and a 2- to 3-year delay in fruit production with Bermuda grass ground cover cannot be explained entirely by competition for essential nutrients and attributed the difference to allelopathy.

In the southeastern US the recommended orchard floor management program for peaches is to establish a cover crop or a permanent sod in the row middles to prevent erosion and facilitate equipment movement during wet weather, plus maintain a vegetation-free strip in the tree row maintained with two to three herbicide applications each year (Foy et al., 1994; Layne and Tan, 1988; Mitchem, 2005). The use of permanent sod in the row middles will collect runoff and improve water infiltration (Glenn and Welker, 1989) and can reduce daily soil temperature fluctuations, such as reducing soil temperature in the summer and raising it in the winter (Tan and Layne, 1993). The choice of vegetative cover for the row

middles is also an important decision and should be chosen to favor varieties that 1) are the least competitive with trees for water and nutrients (Kentucky bluegrass is a better choice than tall fescue, for example) (Parker et al., 1993; Tworkoski and Glenn, 2001), 2) have the greatest ease of establishment, 3) suppress nematodes such as the ring nematode (*C. zenoplax*), and 4) do not harbor orchard pests such as catfacing insects (Meyer et al., 1992). Zehr et al. (1986) reported that *C. zenoplax* reproduces on perennial ryegrass (*Lolium perenne* L.) and is maintained on tall fescue (*Festuca arundinacea* Schreb.), which are two of the most common orchard cover crops in the southeastern US. However, peach and crimson clover (*Trifolium incarnatum* L.) support the most rapid *C. zenoplax* population growth (Zehr et al.,1986). Townshend et al. (1984) reported that tall fescue supports lower root-lesion nematode (*Pratylenchus penetrans* Cobb.) populations compared to other turfgrasses, while having a lower relative cost of seed and greater ease of sod establishment. Nyczepir and Bertrand (2000) and Nyczepir et al. (1998) reported that wheat is a poor host to *C. xenoplax* and shows potential as a preplant ground cover management tool for suppressing *C. xenoplax* population density and prolonging tree survival on PTSL sites.

The vegetation-free strip minimizes weed competition with trees, leading to greater tree growth and fruit yield, and may provide some protection from freezing temperatures due to greater freeze resistance of bark and wood tissues (Marriage and Quamme, 1980). Meagher and Meyer (1990) observed that bare ground plots have higher soil temperature

and soil moisture than plots with vegetation and Mitchem (2005) reported that bare ground in the tree row provides some protection from spring frosts due to the radiant heat benefit; heat absorbed by the bare soil surface during the day can be released at night. Trees grown in vegetation-free soil have been shown to root deeper and develop greater root densities than trees grown with weed or grass competition in the tree row (Parker and Meyer, 1996). The length of the vegetation-free period is also important. MacRae et al. (2007) reported that maintaining a weed free orchard floor for twelve weeks after bloom resulted in greatest peach fruit size (individual fruit weight and diameter), total yield, and fruit number.

Growth of peach trees has been shown to increase as the width of the vegetation-free strip increases (Buckelew, 2009; Welker and Glenn, 1989). The common orchard floor management system in the southeastern US is a 3 to 3.6 m wide vegetation-free strip in the tree row. Buckelew (2009) found that with irrigation, the vegetation-free strip can be reduced to 1.5, 1.3, and 0.8 m to achieve equivalent growth (trunk cross-sectional area) for trees aged one, two and three years, respectively, and reduced to 1.16 m to achieve similar yields to the standard 3.6 m non-irrigated.

In orchards where herbicide is used to manage weeds, applications consist of at least one pre-emergent herbicide in combination with a postemergent, nonselective herbicide, followed by additional applications as needed and a winter application of 2,4-D for

broadleaf weed control. A small percentage of peach producers use this method to maintain a complete vegetation-free soil throughout the orchard.

Unfortunately, vegetation control also reduces soil organic matter and its associated benefits (ie. microbial biomass and activity) (Wardle et al., 2001; Yao et al., 2005). An alternative to the herbicide managed vegetation-free strip is the use of natural (hay, wood chips, recycled paper pulp) or synthetic (polypropylene film, polyester fabric) mulch in the tree row. Natural mulch can act directly on soils, increasing soil organic matter, pH, and cation exchange capacity, improving soil structure, reducing soil compaction, reducing erosion and runoff, increasing moisture infiltration capacity and available soil water, suppressing weed growth, and lowering soil temperatures (Glenn and Welker, 1989; Merwin and Stiles, 1994; Merwin et al., 1995; Merwin et al., 1996; Yao et al., 2005). Mulch can also act indirectly on trees by reducing soil-induced plant stresses, resulting in increased tree growth and yield (Glenn and Welker, 1989; Merwin and Stiles, 1994; Merwin et al., 1995; Merwin et al., 1996; Yao et al., 2005). Composted plant material and mowed grass in tree rows may also play an active role in tree growth through increased nutrient availability, either directly from the added material or as a function of microbial activity (Merwin and Stiles, 1994; Merwin et al., 1995; Neilsen and Hogue, 1992; Wardle et al., 2001; Yao et al. 2005). Composted poultry litter (CPL) offers another mulch source for nutrient and weed control in the peach orchard, as well as an environmentally friendly manure disposal system (Preusch and Tworkoski, 2003). The recommended orchard layout of vegetation-free strips

alternated with cover crops or sod between the rows is particularly well suited to the utilization of CPL because growers could reduce their use of synthetic herbicides and fertilizers within the rows while any nutrient runoff would be captured between the rows (Preusch and Tworkoski, 2003).

Supplemental irrigation of peach orchards is encouraged and has been shown to increase fruit yield per tree, fruit size, number of fruit buds per tree (due to greater shoot length), and trunk diameter over non-irrigated trees (Layne and Tan, 1988; Layne et al., 1994; Reeder et al., 1979). In particular, lack of water during the fruit swell period (three to four weeks preceding maturity) will significantly reduce fruit size and quality (Lockwood and Coston, 2005), and therefore economic returns. Drip irrigation from April or May through harvest in Georgia, USA on Faceville and Greenville soils was as effective at maximizing total yield and fruit diameter as irrigating all season (Horton et al., 1981). However, in Oklahoma on a Teller sandy loam there was no increase in fruit yield or size when irrigated from budbreak through harvest compared to only irrigating during the swell period (Huslig et al., 1993). Reeder et al. (1979) observed a tendency for delayed bud break in Texas in the spring with trickle irrigation and believe that the greater number of fruit buds per tree will result in increased crop potential after a spring freeze. Layne et al. (1994) reported delayed defoliation with irrigation, with no difference between plots with or without groundcover, in Ontario, Canada. Irrigation from May to August reduced the fluctuations in soil temperatures in summer and winter, lowering soil temperatures in the summer and raising

them in the winter (Tan and Layne, 1993). Spray stakes or micro-sprinklers are the current irrigation method of choice on sandy soils where lateral movement of water is limited.

Post-harvest applications of insecticides for peachtree borer (*Synanthedon exitiosa* Say) and lesser peachtree borer (*S. pictipes* Grote & Robinson) are made in August and September. Oil is applied during dormancy (November to February) to control scale insects such as white peach scale (*Pseudaulacaspis pantagona* Targioni) and San Jose scale (*Aspidiotus perniciosus* Comstock). Fruitworms, such as the plum curculio (*Conotrachelus nenuphar* Herbst), and catfacing insects, including the tarnished plant bug (*Lygus lineolaris* Palisot de Beauvois) and stink bugs in the genera *Acrosternum*, *Euschistus*, *Thyanta*, and *Nezara*, that distort fruit shape with irregular and variable-sized necrotic skin spots can be controlled by four to six early-season applications of broad-spectrum insecticides. However, even vigorous chemical applications in the southeastern US will only provide partial control unless combined with a weed management program that suppresses pest habitats such as legumes (clover and vetch) and winter annual broadleaf weeds (henbit and chickweed) in the orchard floor vegetation (Meagher et al., 1987; Meyer, 1984). Weed management within and between rows can also reduce the number of insecticide applications needed (Atanassov et al., 2002; Killian and Meyer, 1984).

Several species of nematodes are of concern where peaches are planted in light, sandy soils and in soils that were previously planted to peaches or other crops that are susceptible to

root-knot nematodes. Root-knot nematodes (*Meloidogyne* spp.) can severely affect tree establishment and the ring nematode (*C. xenoplax*) is associated with premature tree death in the PTSL complex (Nyczepir, 2005). Peach tree growth and survival can also be affected by lesion (*Pratylenchus* spp.) and dagger (*Xiphenema americanum* Cobb) nematodes (Nyczepir, 1991; Reighard, 2005). Treatment with a nematicide is a common pre-plant practice on sandy soils and has been shown to increase survival, trunk cross-sectional area and water uptake (Horton et al., 1981). The nematicide Telone II (1,3-dichloropropene) has few negative environmental effects, has little impact on soil microbial communities (Ibekwe et al., 2001), and is the product commonly used in the southeastern US for commercial peach production.

In the southeastern US, peach trees are annually pruned during dormancy, preferably right before bloom, for tree health and disease control, and to maximize fruit size and quality. Most commercial peach trees are pruned to an open center or vase system to allow maximum sunlight penetration in the canopy, to achieve uniform fruit quality, and to ease worker comprehension (Lockwood and Myers, 2005). Additionally, flowers and fruit are thinned to increase fruit size, maximize crop value, and maintain tree integrity. Chemical thinning is an option for flowers and fruitlets, but most growers prefer mechanical or manual removal of fruit beginning approximately forty days after full bloom (Reighard and Byers, 2005). With the manual removal method, fruit are removed to leave at least 15 cm

between remaining fruit, to achieve optimum fruit size and quality. Yield may be as high as four to five bushels (91-113 kg) per tree when thinned correctly (Reighard and Byers, 2005).

Bearing peach trees are fertilized with nitrogen annually. Phosphorus, potassium, calcium, and magnesium are applied based on soil test and foliar analysis results (Lockwood et al., 2005). Deficiencies of manganese, iron, boron, copper, and zinc may also occur and should be monitored with periodic foliar analysis (Lockwood et al., 2005). Nutrient status plays an important role in cold tolerance and susceptibility to PTSL; overfertilization with nitrogen will push the tree toward vigorous vegetative growth, making it more *susceptible* to cold damage, while adequate potassium will make trees and fruit buds more *resistant* to cold damage (Lockwood et al., 2005). The balance of nitrogen to potassium is also important, affecting the desirable red color development of peach fruit (low N and high K in leaf samples) (Lockwood et al., 2005). Direct light to the fruit is necessary for red color development, so excess nitrogen, and the overabundance of leaves it promotes, can reduce color due to shading of the fruit. To optimize nutrient availability to the trees, the soil pH should be maintained between 6.0 and 6.5 with the annual or periodic addition of lime, based on soil test results.

Orchard Soil Ecology

Soil is a microbiologically dynamic and complex environment. In addition to plant support, its functions include supplying nutrients, retaining water, supporting soil food webs,

recycling nutrients, remediating pollutants, and suppressing plant pathogens (Moore-Kucera et al., 2008). The rhizosphere, the soil immediately in the vicinity of plant roots, is a biological niche with additional levels of complexity due to interactions with the plant's root system. The physical and chemical properties of soil are affected by roots in the following three ways: 1) roots exude nutrients into the soil, mainly in the form of nitrogen compounds and carbohydrates, 2) roots contribute organic matter through sloughing of epidermal tissue, and 3) roots withdraw water from the system (Bot and Benites, 2005). Root exudates, in particular, play an important role in microbial dynamics (Campbell and Greaves, 1990; Kennedy and Gewin, 1997; Kennedy and Stubbs, 2006). A rhizosphere that supports a diverse microbial community may indirectly benefit the plant through greater resistance to environmental stresses and external disturbance (Crecchio et al., 2004).

Soil chemical and biological properties are highly sensitive to soil management and environmental stress and thus can be used to assess quality (Trasar-Cepeda et al., 1998). Chemical properties include electrical conductivity (EC) and pH which are affected by lime and fertilizer application but are not expected to differ much between orchard floor management treatments. Biological indicators of soil quality include microbial biomass and respiration, net nitrogen mineralization, nematode communities and mycorrhizal associations (Karlen et al., 1997) which will differ with plant community and management practices (Bot and Benites, 2005).

Soil microorganisms (the soil microbial biomass) decompose plant residues and soil organic matter to release carbon dioxide and plant-available nutrients, aid pesticide degradation, and contribute to soil aggregation (Kennedy and Stubbs, 2006). Seasonality may influence the microbial biomass directly, by inducing microbial responses to soil moisture and temperature, or indirectly by influencing plant productivity and therefore organic matter release (Wardle, 1992). For example, Lynch and Panting (1982) found that the amount of microbial biomass reached a maximum around the time of maximum root biomass (late spring) and thereafter declined.

Agricultural inputs and management practices affect the microorganisms directly or by altering the quality or quantity of organic matter and can subsequently affect the functioning of the soil ecosystem (Bot and Benites, 2005; Kennedy and Stubbs, 2006). Specifically, microbial biomass is affected by factors that change the water or carbon content of the soil, including management practices like orchard sanitation, weed management and irrigation (Bot and Benites, 2005). This may be even more critical in warm climates and sandy soils, where organic matter is broken down rapidly (Bot and Benites, 2005).

Measurement of microbial biomass carbon and microbial biomass nitrogen are frequently used as early indicators of changes in soil chemical and physical properties (Brookes, 1995; Moore et al., 2000; Rice et al., 1996). Soil microbial respiration (SMR) is widely used as an

index of both microbial activity and microbial biomass (Brookes, 1995). The rate of net nitrogen mineralization (NNM; the conversion of organic N to NH_4^+, resulting in the liberation of plant-available inorganic N forms) is an indicator of soil fertility (Heumann et al., 2012).

Soil microorganisms are the primary agents of organic residue decomposition and nutrient immobilization and mineralization, and therefore critically affect plant growth through regulation of available plant nutrients (Bot and Benites, 2005; Campbell and Greaves, 1990; Yao et al., 2005). In addition, some soil microorganisms, particularly mycorrhizal fungi, form symbiotic associations with roots, effectively increasing the root surface area and enhancing uptake of water and nutrients (Bot and Benites, 2005). These microbial functions help maintain a soil system with available nutrients as well as aggregate stability to reduce erosion and maintain waterholding capacity (Bot and Benites, 2005; Kennedy and Gewin, 1997).

Soil microorganisms are often carbon limited and variations in plant biomass will influence soil biota (Kennedy and Gewin, 1997; Wardle et al., 2001). This is supported by the work of Tu (1996) who reported that indigenous soil microorganisms can tolerate the direct effects of herbicides, exhibiting no long term effects; therefore the impacts on soil biota are indirect, due to the elimination of plant biomass and C supply. Yao et al. (2005) reported a higher bacterial population (CFU/g soil) in plots where weeds were managed with post-

emergent herbicide (some weeds persist), grass, or mulch compared with the vegetation-free strip maintained with pre-emergent herbicides (bare ground most of the year). A higher fungi population (CFU/g soil) was observed in the grass treatment compared to the pre-emergent, post-emergent, and mulch treatments, suggesting that soil bacterial populations are more dependent than soil fungi upon C inputs (Yao et al., 2005).

Irrigation has a positive effect on soil productivity as indicated by increased soil C and N and microbial biomass C (Li et al., 2005). Fertilizers can interact with microbial communities in soils either directly by providing nutrients that promote microbial growth and activity (Lynch and Panting, 1982) or indirectly by stimulating plant growth and thus enhancing root C flow (Bot and Benites, 2005). Li et al. (2005) reported increased soil C and N and increased microbial biomass C and N with fertilization. On the other hand, fertilization with P may reduce mycorrhizae activity in the soil (Grant et al., 2005). And certain fertilizers may reduce soil pH which can limit soil microbial growth and activity (Rousk et al., 2010; Wardle, 1992) as well as nutrient availability for plants. Choice of fertilizer also impacts microbial diversity and biomass in soil. O'Donnell et al. (2001) reported that microbial biomass C and P was higher in hay meadow plots fertilized with manure than in plots with no fertilizer or those treated with mineral fertilizers alone (N, P, or K) or in combination(NP, NK, PK, or NPK).

In general, organic production practices result in greater microbial biomass and diversity. Higher soil biomass C was observed by Franca et al. (2007) in citrus under organic management compared to conventional management. Liu et al. (2007) reported higher microbial biomass C and N, net mineralized N, and extractable C in soils from organic plots than in soils from conventional and sustainable plots and attributed the difference to the fact that organic farmers apply more organic C to their fields which may increase the microbial populations and microbial respiration rate. Both studies suggest that organic production has a positive effect on soil ecology (Franca et al., 2007; Liu et al., 2007).

Mycorrhizae in Tree Fruit Production

Plant root symbioses with fungi are referred to as mycorrhiza (from the Greek "mycos", meaning fungus, and "rhiza", meaning root). Mycorrhizal fungi are a diverse group, classified according to 1) structures formed in the root and 2) families of plants that they infect. The two most widespread and important groups are the ectomycorrhizae ("ecto" meaning outside) and the endomycorrhizae ("endo" meaning inside), classified based on whether or not they penetrate the cells of roots. Endomycorrhizal fungi can further be classified into arbuscular (previously known as vesicular-arbuscular mycorrhizae (VAM) because some species form storage organs termed "vesicles" within root cells), ericoid, and orchid, with the latter two occurring in association with the Ericaceae and Orchidaceae, respectively (Harley and Smith, 1983; Redecker, 2008). The arbuscular mycorrhizal (AM) fungi are obligate symbionts that form associations with most of our major food crops,

including most fruit trees, effectively increasing the tree's root surface area and enhancing uptake of water (Tinker, 1976) and nutrients (Ocampo, 1986). The symbiotic association occurs naturally in most fruit tree species in the nursery or shortly after seedlings are transplanted in the field (Pinochet et al., 1995). In studies of apple replant disease, healthy tree roots were shown to possess more AM fungi colonization than diseased trees (Caruso et al., 1989).

AM are endosymbiotic soil fungi of the phylum Glomeromycota (formerly Zygomycota) (Schuβler et al., 2001). *Glomus* Tul. & C. Tul. is the genus most abundant in peach soil samples (Traquair and Berch, 1988). In addition to *Glomus, Scutellospora aurigloba* (I.R. Hall) C. Walker & F.E. Sanders, *S. calospora* (T.H. Nicolson & Gerd.) C. Walker & F.E. Sanders, and *Gigaspora margarita* W.N. Becker & I.R. Hall, were observed in peach studies (Rutto and Mizutani, 2006; Strobel et al., 1982; Traquair and Berch, 1988).

Most species of AM fungi form spores (20-400 µm, and 200-600 µm in diameter for *Glomus* and *Gigaspora*, respectively) in the soil near plant roots (Kendrick, 2000). Spores germinate, infect fine roots of host plants by producing non-septate, coenocytic hyphae that grow within the host's root cortex cells (intercellularly and intracellularly), and form the characteristic tree-like arbuscules inside the roots (Redecker, 2008). Arbuscules penetrate cortical cell walls and interface with the cell's plasma membrane. Arbuscules are regarded as the primary avenue of bidirectional transfer of material between the two symbionts. In

addition to arbuscules, vesicular species form globose to irregularly shaped vesicles within the root that contain large amounts of lipid. Vesicles function as food storage organs or, if they develop into thick-walled chlamydospores, may function as reproductive structures. Outside the feeder roots, mycelia spread profusely in the soil, providing a greater surface area for absorption of water and nutrients (Hussey and Roncadori, 1982; Redecker, 2008). Endomycorrhizal roots are usually similar in appearance to uninfected roots, so histological preparation is necessary to observe the internal morphological structures.

Good development of endomycorrhizae is beneficial to the growth of peach (*Prunus persica*) (Gilmore, 1971; Pinochet et al., 1995), plum (*Prunus* spp.) (Camprubí et al., 1993), apple (*Malus domestica* Borkh.) (Granger et al., 1983; Mosse, 1957), and *Citrus* trees (Franca et al., 2007; Marx et al., 1971). Mycorrhizae can increase plant growth, especially in infertile soils, as a result of an enhanced ability of infected roots to absorb nutrients (Gerdemann, 1968). Strobel et al. (1982) reported that inoculation with either *Gigaspora margarita* or *Glomus etunicatus* was as effective as an additional 500 µg 10-10-10 NPK per gram of soil in stimulating growth of peach trees. Phosphorus is the nutrient most associated with AM and research has shown that mycorrhizal plants absorb nearly twice as much phosphate as uninfected plants (Bowen et al., 1975). Enhanced nutrient uptake is not limited to phosphorus though; mycorrhizae also enhance absorption of water and minor mineral elements such as Zn, S, and Cu (Gerdemann, 1968; Hussey and Roncadori, 1982;

Strobel et al., 1982). In return for the improved water and nutrient uptake, up to 20% of plant-fixed carbon is transferred to the fungus (Bago et al., 2000).

The primary economic benefit of mycorrhizal fungi is to promote soil nutrient absorption in their capacity as symbiont (Redecker, 2008). Secondarily, AM benefit plants under physiological stress, such as drought conditions (Barea, 1991; Nelson, 1987), and when impacted or infected by diseases (Azcón-Aguilar and Barea, 1996; Dehne, 1982) and nematodes (Francl, 1993; Hussey and Roncadori, 1982). Mechanisms that could account for the protective activity ascribed to AM include root damage compensation, physiological alteration or reduction of root exudates responsible for chemotactic attraction of pathogens or nematodes, competition for colonization/infection sites, production of anatomical or morphological changes in the root system, and activation of plant defense mechanisms (Azcón-Aguilar and Barea, 1996; Hussey and Roncadori, 1982). Mycorrhizae may also decrease the penetration rate of parasitic nematodes, retard their development inside the root, decrease their reproduction rate (*Pratylenchus* spp. and *Meloidogyne* spp.), or lower their degree of damage (Dehne, 1982; Pinochet et al., 1995).

Francl (1993) and Hussey and Roncadori (1982) argued that the benefit of AM does *not* result from inhibition of nematode penetration or development, but rather by increasing the plant's tolerance of nematodes. Pinochet et al. (1996) added that the increase in tolerance is due to mycorrhiza-assisted nutrition rather than a direct suppression of

nematodes. In fact, the absolute reproduction rate of the nematode may be higher on symbiotic plants, as a reflection of the larger root system, though their density may remain unchanged (Camprubí et al., 1993; Dehne, 1982).

Soil fumigation can either negatively (Lambert et al., 1979) or positively (Bird et al., 1974) impact mycorrhizal fungi depending on the fumigant used. Elimination of mycorrhizal fungi, and the phosphorus and zinc they provide, is the primary factor in methyl bromide-chloropicrin fumigation-induced stunting of peach trees (Lambert et al., 1979). Research on Telone II (1,3 dichloropropene) in cotton actually showed an increase in AM fungi infection rate with fumigation (Bird et al., 1974).

The application of certain herbicides, paraquat (N,N'-dimethyl-4,4'-bipyridinium dichloride) and simazine (6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine) in particular, may interfere with the mycorrhization of fruit trees (Granger et al., 1995; Nemec and Tucker, 1983). Even mechanical weed removal decreases AM fungi spore numbers, which Nappi and Jodice (1985) speculate is due to lower soil organic matter content. This is in agreement with the information presented above regarding mulch and its effect on microbial biomass and activity.

Sukarno et al. (1993) reported a negative effect on AM following fungicide application to onion, though the practice of applying fungicides only to the tree canopy should prevent

this side effect in peach orchards. In general, AM fungi richness and diversity are higher under organic management (Franca et al., 2007) and any steps growers can take to adopt integrated pest management and sustainable practices should have a positive effect on AM in the orchard.

Different rootstocks within a genus may be more or less mycorrhizally dependent (Camprubí et al., 1993). The soil microorganisms in the rhizosphere will vary with the size of the root system and the metabolic exudates released in the soil (Kennedy and Stubbs, 2006), both functions of the rootstock. In fact, the affinity for mycorrhizal colonization appears to be cultivar specific rather than species specific (Granger et al., 1983; Pinochet et al., 1995). Therefore rootstock breeding programs should evaluate new crosses for their mycorrhizal affinity to provide growers with plants that have an increased capacity to withstand stress conditions and tolerance of pathogenic soilborne fungi and nematodes (Calvet et al., 2004). This may allow growers to reduce soil chemical treatments which are expensive and could be hazardous to orchard workers (Azcón-Aguilar and Barea, 1996). Likewise, mycorrhizal inoculation may be of special interest to nurseries producing both cuttings and micropropagated material that utilize substrate-based potting mixtures that are usually free of mycorrhizae. Of course the mycorrhizal fungus strain would need to be matched with each given rootstock for optimal results (Calvet et al., 2004; Granger et al., 1983). The production of mycorrhizal plants with the adequate selected fungal symbionts may represent an advantage when these young rootstocks are transplanted into the field

where the symbiosis can help the plants to withstand stressful conditions (Calvet et al., 2004). Mycorrhizal fungi are ubiquitous and most growers will not need to inoculate their soil prior to planting. In fact, Traquair and Berch (1988) reported heavy colonization by indigenous AM fungi within six months after planting peach, and Rutto and Mizutani (2006) reported high seedling infection rates in both replant and nonreplant soils after one season. After a couple of seasons AM fungal infection rate would be expected to equalize as the effects of preplant fumigants wear off and the microorganism populations in the rhizosphere stabilize. However, if an orchard site were known to be severely compromised then use of mycorrhizal plant material may offer a benefit to tree growth in the first couple of years.

Research Objectives

Research was conducted in a young peach orchard at the Sandhills Research Station in North Carolina in years three through seven after planting to determine the effects of certain orchard management practices on various tree, fruit, and soil parameters in the orchard. The objective of the first study in this dissertation was to measure the effects of different under-tree vegetation-free strip widths (0, 0.6, 1.2, 2.4, 3.0, and 3.6 m) and irrigation on peach tree growth and fruit yield, harvest maturity, and size. Defining the impacts of orchard management decisions on soil ecology and pest behavior is critical to understanding peach tree short life (PTSL), a disease complex common to sandy peach replant sites that results in premature tree death in the spring, three to six years after

planting. The objective of the second study in this dissertation was to examine the impacts of vegetation-free strip width and irrigation on soil ecology at the age when a peach orchard is most prone to PTSL (three to six years after planting). No trees were lost to PTSL during this study so the results focus on measures of microbial activity and soil health in the tree's rhizosphere. The impact of different vegetation-free strip widths and irrigation on the incidence of catfacing damage of fruit was investigated and is reported in the third study of this dissertation. Additionally, a fourth study was conducted to compare the soil ecology of six genetically diverse peach rootstocks, 'Guardian®', 'Lovell', 'Controller 5', 'Krymsk 1', 'Empyrean® 2', and 'Viking', in the North Carolina Sandhills after one year in the field.

Literature Cited

Arnold, M.E. and J.H. Aldrich. 1980. Herbicidal effects on peach seedling growth and weed control. HortScience 15:293-294.

Atanassov, A., P.W. Shearer, G. Hamilton, and D. Polk. 2002. Development and implementation of a reduced risk peach arthropod management program in New Jersey. J. Econ. Entomol. 95:803-812.

Azcón-Aguilar, C. and J.M. Barea. 1996. Arbuscular mycorrhizas and biological control of soil-borne plant pathogens – an overview of the mechanisms involved. Mycorrhiza 6:457-464.

Bago, B., P.E. Pfeffer, and Y. Shachar-Hill. 2000. Carbon metabolism and transport in arbuscular mycorrhizas. Plant Physiol. 124:949-958.

Barea, J.M. 1991. Vesicular-arbuscular mycorrhizae as modifiers of soil fertility. Adv. Soil Sci. 15:2-40.

Belding, R.D., B.A. Majek, G.R.W. Lokaj, J. Hammerstedt, and A.O. Ayeni. 2004. Orchard floor management influence on summer annual weeds and young peach tree performance. Weed Tech. 18:215-222.

Bird, G.W., J.R. Rich, and S.U. Glover. 1974. Increased endomycorrhizae of cotton roots in soil treated with nematicides. Phytopathology 64:48-51.

Bot, A. and J. Benites. 2005. The importance of soil organic matter. FAO Soils Bulletin 80. 19 September 2013. <http://www.fao.org/docrep/009/a0100e/a0100e00.htm>.

Bowen, G.D., D.I. Bevage, and B. Mosse. 1975. Phosphate physiology of vesicular-arbuscular mycorrhizas. Endomycorrhizas; Proceedings of a Symposium, 1974, p. 241-260.

Brookes, P.C. 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. Biol. Fertil. Soils. 19:269-279.

Buckelew, J.K. 2009. Orchard floor management in young peach [*Prunus persica* (L.) Batch.]: Effects of irrigation, vegetation-free width, and certain PRE herbicides. NC State Univ., Raleigh, NC, PhD Diss.

Calvet, C., V. Estaún, A. Camprubí, A. Hernández-Dorrego, J. Pinochet, and M.A. Moreno. 2004. Aptitude for mycorrhizal root colonization in *Prunus* rootstocks. Sci. Hort. 100:39-49.

Campbell, R. and M.P. Greaves. 1990. Anatomy and community structure of the rhizosphere, p. 11-34. In Lynch, J.M. (ed.). The rhizosphere. John Wiley & Sons, Chichester.

Camprubí, A., J. Pinochet, C. Calvet, and V. Estaun. 1993. Effects of the root-lesion nematode *Pratylenchus vulnus* and the vesicular-arbuscular mycorrhizal fungus *Glomus mosseae* on the growth of three plum rootstocks. Plant Soil 153:223-229.

Caruso, F.L., B.F. Neubauer, and M.D. Begin. 1989. A histological study of apple roots affected by replant disease. Can. J. Bot. 67:742-749.

Crecchio, C., A. Gelsomino, R. Ambrosoli, J.L. Minati, and P. Ruggiero. 2004. Functional and molecular responses of soil microbial communities under differing soil management practices. Soil Biol. Biochem. 36:1873-1883.

Dehne, H.W. 1982. Interaction between vesicular-arbuscular mycorrhizal fungi and plant pathogens. Phytopathology 72:1115-1119.

Foy, C.L., S.B. Harrison, and H.L. Witt. 1994. Herbicide effects on weed control and shoot growth of young apple (*Malus sylvestris*) and peach (*Prunus persica*) trees. Weed Tech. 8:840-848.

França, S.C., S.M. Gomes-da-Costa, and A.P.D. Silveira. 2007. Microbial activity and arbuscular mycorrhizal fungal diversity in conventional and organic citrus orchards. Biol. Agric. Hortic. 25:91-102.

Francl, L.J. 1993. Interactions of nematodes with mycorrhizae and mycorrhizal fungi, p. 203-216. In Khan, M.W. (ed.). Nematode interactions. Chapman & Hall, London.

Gerdemann, J.W. 1968. Vesicular-arbuscular mycorrhizal and plant growth. Annu. Rev. Phytopathol. 6:397-418.

Gilmore, A.E. 1971. The influence of endotrophic mycorrhizae on the growth of peach seedlings. J. Amer. Soc. Hort. Sci. 96:35-38.

Glenn, D.M. and W.V. Welker. 1989. Orchard soil management systems influence rainfall infiltration. J. Amer. Soc. Hort. Sci. 114:10-14.

Granger, R.L., C. Plenchette, and J.A. Fortin. 1983. Effect of vesicular-arbuscular (VA) endomycorrhizal fungus (*Glomus epigaeum*) on the growth and leaf mineral content of two apple clones propagated in vitro. Can. J. Plant Sci. 63:551-555.

Granger, R.L., S. Khanizadeh, M. Meheriuk, L.S. Bérard, and Y. Dalpé. 1995. Effects of simazine on the mycorrhizal population in soil beneath an apple tree canopy. Fruit Varieties J. 49:90-93.

Grant, C. S. Bittman, M. Montreal, C. Plenchette, and C. Morel. 2005. Soil and fertilizer phosphorus: effects on plant P suuply and mycorrhizal development. Can. J. Plant Sci. 85:3-14.

Harley, J.L. and S.E. Smith. 1983. Mycorrhizal symbiosis. Academic Press, New York.

Heumann, S., H. Ringe, and J. Böttcher. 2012. Long-term net N mineralization potential as an indicator for soil fertility: chances and constraints. Arch. Agron. Soil Sci. 58(sup1):S107-S111.

Horton, B.D., E.J. Wehunt, J.H. Edwards, R.R. Bruce, and J.L. Chesnee. 1981. The effects of drip irrigation and soil fumigation on 'Redglobe' peach yields and growth. J. Amer. Soc. Hort. Sci. 106:438-443.

Huslig, S.M., M.W. Smith, and G.H. Brusewitz. 1993. Irrigation schedules and annual ryegrass as a ground cover to conserve water and control peach tree growth. HortScience 28:908-913.

Hussey, R.S. and R.W. Roncadori. 1982. Vesicular-arbuscular mycorrhizae may limit nematode activity and improve plant growth. Plant Dis. 66:9-14.

Ibekwe, A.M., S.K. Papiernik, J. Gan, S.R. Yates, C.H. Yang, and D.E. Crowley. 2001. Impact of fumigants on soil microbial communities. Appl. Environ. Microb. 67:3245-3257.

Inderjit and K.I. Keating. 1999. Allelopathy: principles, procedure, processes, and promises for biological control. Adv. Agron. 67:141-231.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: a concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 61:4-10.

Kendrick, B. 2000. The fifth kingdom. Focus Publishing, Newburyport, MA.

Kennedy, A.C. and V.L. Gewin. 1997. Soil microbial diversity: present and future considerations. Soil Sci. 162:607-617.

Kennedy, A.C. and T.L. Stubbs. 2006. Soil microbial communities as indicators of soil health. Ann. Arid Zone 45: 287-308.

Killian, J.C. and J.R. Meyer. 1984. Effect of orchard weed management on catfacing damage to peaches in North Carolina. J. Econ. Entomol. 77:1596-1600.

Lambert, D.H., R.F. Stouffer, and H. Cole, Jr. 1979. Stunting of peach seedlings following soil fumigation. J. Amer. Soc. Hort. Sci. 104:433-435.

Layne, R.E.C. and C.S. Tan. 1988. Influence of cultivars, ground covers, and trickle irrigation on early growth, yield, and cold hardiness of peaches on Fox sand. J. Amer. Soc. Hort. Sci. 113:518-525.

Layne, R.E.C., C.S. Tan, and D.M. Hunter. 1994. Cultivar, ground-cover, and irrigation treatments and their interactions affect long-term performance of peach trees. J. Amer. Soc. Hort. Sci. 119:12-19.

Li, Q., H.L. Allen, and A.G. Wollum II. 2005. Effects of irrigation and fertilization on soil microbial biomass and functional diversity. J. Sustainable For. 20(4):17-35.

Liu, B., C. Tu, S. Hu, M. Gumpertz, and J.B. Ristaino. 2007. Effect of organic, sustainable, and conventional management strategies in grower fields on soil physical, chemical, and biological factors and the incidence of Southern Blight. Appl. Soil Ecol. 37:202-214.

Liverani, A., D. Cobianchi, A. Crociani, and D. Missere. 1992. Effect of soil management systems on hillside peach orchards. Acta Hort. 315:123-127.

Lockwood, D.W. and D.C. Coston. 2005. Peach tree physiology, p. 5-10. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Lockwood, D.W. and S.C. Myers. 2005. Tree density, orchard design, and training systems, p. 51-64. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Lockwood, D.W., M.E. Ferree, and S.C. Myers. 2005. Nutrition, p. 75-84. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Lynch, J.M. and L.M. Panting. 1982. Effects of season, cultivation and nitrogen fertiliser on the size of the soil microbial biomass. J. Sci. Food Agric. 33:249-252.

MacRae, A.W., W.E. Mitchem, D.W. Monks, M.L. Parker, and R.K. Galloway. 2007. Tree growth, fruit size, and yield response of mature peach to weed-free intervals. Weed Tech. 21:102-105.

Majek, B.A., P.E. Neary, and D.F. Polk. 1993. Smooth pigweed interference in newly planted peach trees. J. Prod. Agric. 6:244-246.

Marriage, P.B. and H.A. Quamme. 1980. Effect of weed control on the winterhardiness of the bark and wood of young peach trees. HortScience 15:290-291.

Marx, D.H., W.C. Bryan, and W.A. Campbell. 1971. Effect of endomycorrhizae formed by *Endogone mosseae* on growth of citrus. Mycologia 63:1222-1226.

Meagher, R.L., J.R. Meyer, and J.C. Killian. 1987. Within-tree distribution of cat-facing injury on peaches in North Carolina. J. Agric. Entomol. 4:78-81.

Meagher, R.L. and J.R. Meyer. 1990. Effects of ground cover management on certain abiotic and biotic interactions in peach orchard ecosystems. Crop Prot. 9:65-72.

Merwin, I., J.A. Ray, T.S. Steenhuis, and J. Boll. 1996. Groundcover management systems influence fungicide and nitrate-N concentrations in leachate and runoff from a New York orchard. J. Am. Soc. Hort. Sci. 121:249-257.

Merwin, I., D. Rosenberger, C. Engle, D. Rist, and M. Fargione. 1995. Comparing mulches, herbicides, and cultivation as orchard groundcover management systems. HortTechnology. 5:151-158.

Merwin, I.A. and W.C. Stiles. 1994. Orchard groundcover management impacts on apple tree growth and yield, and nutrient availability and uptake. J. Amer. Soc. Hort. Sci. 119:209-215.

Meyer, J.R., E.I. Zehr, R.L. Meagher, Jr., and S.K. Salvo. 1992. Survival and growth of peach trees and pest populations in orchard plots managed with experimental ground covers. Ag. Ecosyst. Environ. 41:353-363.

Mitchem, W.E. 2005. Weed management considerations for peach orchards, p. 279-284. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Moore, J.M., S. Klose, and M.A. Tabatabai. 2000. Soil microbial biomass carbon and nitrogen as affected by cropping systems. Biol. Fertil. Soils 31:200-210.

Moore-Kucera, J., A.N. Azarenko, L. Brutcher, A. Chozinski, D.D. myrold, and R. Ingham. 2008. In search of key soil functions to assess soil community management for sustainable sweet cherry orchards. HortScience 43:38-44.

Mosse, B. 1957. Growth and chemical composition of mycorrhizal and non-mycorrhizal apples. Nature 179:922-924.

Nappi, P. and R. Jodice. 1985. VA micorrhizae (sic) of apples: the influence of soil treatments and season, p. 318. In Proceedings of the 6th North American Conference on Mycorrhizae, held June 25-29, 1984 in Bend, OR.

Neilsen, G.H. and E.J. Hogue. 1992. Long-term effects of orchard soil management on tree vigor and extractable soil nutrients. Can. J. Soil Sci. 72:617-621.

Nelson, C.E. 1987. The water relations of vesicular-arbuscular mycorrhizal systems, p. 71-79. In: G.R. Safir (ed). Ecophysiology of VA mycorrhizal plants. CRC Press, Boca Raton.

Nemec, S. and D. Tucker. 1983. Effects of herbicides on endomycorrhizal fungi in Florida citrus (*Citrus* spp.) soils. Weed Sci. 31:427-431.

Nesmith, W.C., E.I. Zehr, and W.M. Dowler. 1981. Association of *Macroposthonia xenoplax* and *Scutellonema brachyurum* with the peach tree (*Prunus persica*) short life syndrome. J. Nematol. 13:220.

Nesmith, W.C. and W.M. Dowler. 1976. Cultural practices affect cold hardiness and peach tree short life. J. Amer. Soc. Hort. Sci. 101:116-119.

Nyczepir, A.P. 1991. Nematode management strategies in stone fruits in the United States. J. Nematol. 23:334-341.

Nyczepir, A.P. 2005. Nematodes, p. 191-198. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Nyczepir, A.P. and T. Beckman. 1997. Guardian™ rootstock: nematode control for peach orchards. USDA ARS Methyl Bromide Alternatives Newsletter. 26 Oct 2012. <http://www.ars.usda.gov/is/np/mba/jan97/guard.htm>.

Ocampo, J.A. 1986. Vesicular-arbuscular mycorrhizal infection of "host" and "non-host" plants: effect on the growth responses of the plants and the competition between them. Soil Biol. Biochem. 18:607-610.

O'Donnell, A.G., M. Seasman, A. Macrae, I. White, and J.T. Davies. 2001. Plants and fertilisers as drivers of change in microbial community structure and function in soils. Plant Soil 232:135-145.

Okie, W.R., G.L. Reighard, T.G. Beckman, A.P. Nyczepir, C.C. Reilly, E.I. Zehr, W.C. Newall, Jr., and D.W. Cain. 1994. Field-screening *Prunus* for longevity in the southeastern United States. HortScience 29:673-677.

Parker, M.L, J. Hull, and R.L. Perry. 1993. Orchard floor management affects peach rooting. J. Amer. Soc. Hort. Sci. 118:714-718.

Parker, M.L. and J.R. Meyer. 1996. Peach tree vegetative and root growth respond to orchard floor management. HortScience 31:330-333.

Parker, M.L., D. Ritchie, and A. Nyczepir. 1997. Peach rootstock performance by BY-520-9 and Lovell in a peach tree short life replant site. HortScience 32:497 (abstr.).

Pinochet, J., C. Calvet, A. Camprubí, and C. Fernández. 1995. Growth and nutritional response of Nemared peach rootstock infected with *Pratylenchus vulnus* and the mycorrhizal fungus *Glomus mosseae*. Fundam. Appl. Nematol. 18:205-210.

Pinochet, J., C. Calvet, A. Camprubí, and C. Fernández. 1996. Interactions between migratory endoparasitic nematodes and arbuscular mycorrhizal fungi in perennial crops: a review. Plant Soil 185:183-190.

Preusch, P.L. and T.J. Tworkoski. 2003. Nitrogen and phosphorus availability and weed suppression from composted poultry litter applied as mulch in a peach orchard. HortScience 38:1108-1111.

Redecker, D. 2008. Glomeromycota: Arbuscular mycorrhizal fungi and their relative(s). 6 November 2012. <http://toleweb.org/Glomeromycota/28715/2008.01.14>

Reeder, B.D., J.S. Newman, and J.W. Worthington. 1979. Effect of trickle irrigation on peach trees. HortScience 14:36-37.

Reighard, G.L. 2005. Rootstocks, p. 41-44. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Reighard, G.L. and R.E. Byers. 2005. Peach thinning, p. 85-90. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Reighard, G.L., W.C. Newall, T.G. Beckman, W.R. Okie, E.I. Zehr, and A.P. Nyczepir. 1997. Field performance of *Prunus* rootstock cultivars and selections on replant soils in South Carolina. Acta Hort. 451:243-250.

Rice, C.W., T.B. Moorman, M. Beare. 1996. Role of microbial biomass carbon and nitrogen in soil quality, p. 203-215. In: J.W. Doran and A.J. Jones (eds.). Methods for assessing soil quality. SSSA special publication no. 49. Soil Science Society of America, Madison, WI.

Ritchie, D.F. and C.N. Clayton. 1981. Peach tree short life: a complex of interacting factors. Plant Dis. 65:462-469.

Ritchie, D.F., M. Parker, K.A. Sorensen, J.R. Meyer, W.E. Mitchem, and S.J. Toth, Jr. (eds.). 2005. Crop profile for peaches in North Carolina. 25 October 2012. <http://www.ipmcenters.org/cropprofiles/docs/ncpeaches.pdf>.

Rousk, J., E. Bååth, P.C. Brookes, C.L. Lauber, C. Lozupone, J.G. Caporaso, R. Knight, and N. Fierer. 2010. Soil bacteria and fungal communities across a pH gradient in an arable soil. ISME J. 4:1340-1351.

Rutto, K.L. and F. Mizutani. 2006. Peach seedling growth in replant and non-replant soils after inoculation with arbuscular mycorrhizal fungi. Soil Biol. Biochem. 38:2536-2542.

Schuβler, A., D. Schwarzott, and C. Walker. 2001. A new fungal phylum, the *Glomeromycota*: phylogeny and evolution. Mycol. Res. 105:1413-1421.

Sharpe, R.R., C.C. Reilly, A.P. Nyczepir, and W.R. Okie. 1989. Establishment of peach in a replant site as affected by soil fumigation, rootstock, and pruning date. Plant Dis. 73:412-415.

Strobel, N.E., R.S. Hussey, and R.W. Roncadori. 1982. Interactions of vesicular-arbuscular mycorrhizal fungi, *Meloidogyne incognita*, and soil fertility on peach. Phytopathology 72:690-694.

Sukarno, N., S.E. Smith, and E.S. Scott. 1993. The effect of fungicides on vesicular-arbuscular mycorrhizal symbiosis. New Phytol. 25:139-147.

Tan, C.S. and R.E.C. Layne. 1993. Irrigation and ground cover management effect on soil temperature in a mature peach orchard. Can. J. Plant Sci. 73:857-870.

Tinker, P.B. 1976. Roots and water: transport of water to plant roots in soil. Phil. Trans. R. Soc. Lond. B. 273:445-461.

Traquair, J.A. and S.M. Berch. 1988. Colonization of peach rootstocks by indigenous vesicular-arbuscular mycorrhizal (VAM) fungi. Can. J. Animal Sci. 68:893-898.

Trasar-Cepeda, C., C. Leirós, F. Gil-Sotres, and S. Seoane. 1998. Towards a biochemical quality index for soils: an expression relating several biological and biochemical properties. Biol. Fertil. Soils 26:100-106.

Tu, C.M. 1996. Effect of selected herbicides on activities of microorganisms in soils. J. Environ. Sci. Health, Part B. 31:1201-1214.

Tworkoski, T.J. and D.M. Glenn. 2001. Yield, shoot and root growth, and physiological responses of mature peach trees to grass competition. HortScience 36:1214-1218.

USDA. 2012. Noncitrus fruits and nuts 2011 preliminary summary. 25 October 2012. <http://www.usda.gov/nass/PUBS/TODAYRPT/ncit0312.pdf>.

Wardle, D.A. 1992. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biol. Rev. 67:321-358.

Wardle, D.A., G.W. Yeates, K.I. Bonner, K.S. Nicholson, and R.N. Watson. 2001. Impacts of ground vegetation management strategies in a kiwifruit orchard on the composition and functioning of the soil biota. Soil Biol. Biochem. 33:893-905.

Weaver, T. 1998. A guardian angel for peach trees. Agric. Res. 46:10-11.

Wehunt, E.J., B.D. Horton, and V.E. Prince. 1980. Effects of nematicides, lime and herbicide on peach tree (*Prunus persica*) short life in Georgia. J. Nematol. 12:183-189.

Welker, W.V. and D.M. Glenn. 1989. Sod proximity influences the growth and yield of young peach trees. J. Amer. Soc. Hort. Sci. 114:856-859.

Weller, S.C., W.A. Skroch, and T.J. Monaco. 1985. Common bermudagrass (*Cynodon dactylon*) interference in newly planted peach (*Prunus persica*) trees. Weed Sci. 33:50-56.

Yao, S., I.A. Merwin, G.W. Bird, G.S. Abawi, and J.E. Thies. 2005. Orchard floor management practices that maintain vegetative or biomass groundcover stimulate soil microbial activity and alter soil microbial community composition. Plant Soil 271:377-389.

Zehr, E.I., R.W. Miller, and F.H. Smith. 1976. Soil fumigation and peach rootstocks for protection against peach tree short-life. Phytopathology 66:689-694.

EFFECT OF VEGETATION-FREE WIDTH AND IRRIGATION ON PEACH TREE GROWTH, YIELD, AND FRUIT SIZE

Effect of Vegetation-free Width and Irrigation on Peach Tree Growth, Yield, and Fruit Size

Connie L. Fisk, Michael L. Parker, and Wayne Mitchem

Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695

We thank Bernadette Clark and the staff at the Sandhills Research Station for their assistance with orchard management and sample collection, and Robert Hoyt for herbicide applications.

Effect of Vegetation-free Width and Irrigation on Peach Tree Growth, Yield, and Fruit Size

Additional index words: *Prunus persica*, orchard floor management

Abstract. Peach orchard floor vegetation competes with trees for water and nutrients. Tree growth and fruit yield can be optimized through management of vegetation in the tree row and irrigation. Under-tree vegetation-free strip widths (0, 0.6, 1.2, 2.4, 3.0, and 3.6 m) and irrigation were studied in years three through seven of a young peach orchard to determine their effects on peach tree growth and fruit yield, harvest maturity, and fruit size. Trunk cross-sectional area (TCSA), as a measure of tree growth, increased with increasing vegetation-free strip width; trees grown in the 3.6 m vegetation-free strip had TCSAs 2.3 times greater, on average, than those grown in the 0 m vegetation-free strip. Trunk cross-sectional area also increased with irrigation; trees grown with irrigation had TCSAs 1.2 times greater, on average, than trees grown without irrigation. Yield increased with increasing vegetation-free strip width, from 9.6 kg per tree in the 0 m plot to 27.7 kg per tree in the 3.6 m plot in year three, to 24.3 kg per tree in the 0 m plot and 40.o kg in the 3.6 m plot in year 7. Yield, average fruit weight, and average fruit diameter increased with irrigation in three of five years; the other two years had higher than average rainfall reducing the need for supplemental irrigation. In three out of five years fruit in irrigated plots matured earlier than fruit in non-irrigated plots. In all years, fruit grown in the 0 m strip matured earliest and had the smallest diameter.

Introduction

Orchard floor management strategies for peach (*Prunus persica* (L.) Batsch.) production include establishing a cover crop or a permanent sod in the row middles to prevent erosion 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). The vegetation-free strip minimizes the vegetative competition with trees and may provide some protection from freezing temperatures due to greater freeze resistance of bark and xylem tissues (Marriage and Quamme, 1980). The vegetation-free strip may also provide some protection from blossom damage from spring freeze events due to the radiant heat benefit of heat absorbed by the bare soil surface during the day and released at night (Mitchem, 2005). Trees grown in vegetation-free soil have been shown to root deeper and develop greater root densities than trees grown with weed or grass competition in the tree row (Parker and Meyer, 1996).

The level of under-tree vegetation control is directly related to subsequent peach 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; Welker and Glenn, 1989). Vegetation competes with trees for water and nutrients and can also serve as an alternate host for insect pests, including catfacing insects that damage and distort fruit (Meagher et al., 1987; Mitchem, 2005). Certain weeds also have allelopathic activities that adversely affect growth and yield of many crop species (Inderjit and Keating, 1999). Weller et al. (1985) reported

that reduced peach tree growth with severe stunting and a 2- to 3-year delay in fruit production with Bermuda grass ground cover cannot be explained entirely by competition for essential nutrients and attributed the difference to allelopathy.

Growth of young peach trees was shown to increase when grown in vegetation-free soil compared to trees grown with ground cover (Liverani et al., 1992; Meyer et al., 1992; Parker and Meyer, 1996). In peach orchards with vegetation in the row middles, growth increased as the width of the vegetation-free area in the tree row increased (Buckelew, 2009; Welker and Glenn, 1988; Welker and Glenn, 1989).

A 3 to 3.6 m wide vegetation-free strip in the tree row is the common orchard floor management system in the southeastern US (Mitchem, 2005). Buckelew (2009), in a study on a Candor sand, reported that with irrigation, the vegetation-free strip can be reduced to 1.5, 1.3, and 0.8 m to achieve equivalent trunk cross-sectional area for trees grown in a 3.6 m vegetation-free strip and not irrigated for trees aged one, two and three years, respectively. To achieve maximum yield on young trees the vegetation-free strip needs to be 3.6 m. For irrigated two-year-old trees, the vegetation-free strip width can be reduced to 1.2 m to achieve similar yields to the standard 3.6 m non-irrigated soil (Buckelew, 2009). Welker and Glenn (1989), in a study of three-year-old trees on Hagerstown silt loam, reported that yield efficiency (kg fruit/cm^2 TCSA) increased as the size of the vegetation-free

square increased, reaching a maximum at 9 m^2, and that as the size of the vegetation-free area increased, the percentage of large fruit (> 7.0 cm) also increased.

Supplemental irrigation of peach orchards is encouraged on sandy soils. The current recommended irrigation method in North Carolina is under-tree micro-sprinklers. On heavier clay soils, drip or trickle irrigation is effective and requires a lower volume of water. Supplemental irrigation was shown to increase peach trunk diameter, fruit yield per tree, fruit size, and number of fruit buds per tree (due to greater shoot length) over non-irrigated trees (Buckelew, 2009; Layne and Tan, 1988; Layne et al., 1994; Reeder et al., 1979). Water stress during the final fruit swell period (three to four 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, USA on Faceville and Greenville soils was as effective at maximizing total yield and fruit diameter as irrigating all season (Horton et al., 1981). However, in Oklahoma on a Teller sandy loam there was no increase in either fruit yield or size when irrigated from budbreak through harvest compared to only irrigating during the swell period (Huslig et al., 1993). In Texas a tendency for delayed bud break in the spring with trickle irrigation was observed (Reeder et al., 1979). The greater number of fruit buds per tree increases crop potential after a spring freeze. Layne et al. (1994) reported delayed defoliation of irrigated mature trees (5-9 yrs of age) with no difference between plots with or without groundcover in Ontario, Canada. Irrigation from May to August reduced the fluctuations in soil temperatures in summer and winter,

lowering soil temperatures in the summer and raising them in the winter (Tan and Layne, 1993).

The objective of this study was to measure the effects of vegetation-free strip width and irrigation on peach tree growth and fruit yield, harvest maturity, and size in years three through seven of a young peach orchard on sandy soil.

Materials and Methods

The experiment was conducted from 2009-2013 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, Koalinitic, thermic Grossarenic Kandiudults) with a pH of 5.8 and humic matter of 0.60%. The orchard consisted of 'Contender' peach trees (*Prunus persica* (L.) Batsch.) grafted onto 'Guardian®' rootstock. One-year whips were planted on Feb. 3, 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). Fruit thinning occurred each spring within 30-40 days of full bloom and involved hand thinning fruit so that those remaining were no closer than 15 cm apart.

Six vegetation-free strip widths (0, 0.6, 1.2, 2.4, 3.0, and 3.6 m) were maintained around the trees with one half of the plots receiving irrigation. Details of the treatments were described by Buckelew (2009). Each plot contained four trees, the two center trees being

record trees. Vegetation-free strips were chemically maintained using Chateau (flumioxazin at 213.3 g ha^{-1} active ingredient) for PRE emergent weed control and Gramoxone Inteon (paraquat at 0.67 to 1.0 kg ha^{-1} active ingredient with non-ionic surfactant at 0.25% v/v) as a POST emergent burndown. Row middles were allowed to populate with native weedy species and were maintained by mowing to a height of 10-13 cm tall. All trees were fertilized uniformly with two applications of 20-0-20 each spring (224 kg/ha in March and 168 kg/ha in April).

For the irrigated plots, one Dan Modular micro-sprinkler (Jain Irrigation Inc., Fresno, CA, USA) was placed 15 cm from the tree trunk on a 30 cm spray stake. Irrigated plots were irrigated as needed based on precipitation during the growing season. No irrigation was applied when precipitation during the week was 2.54 cm or greater. On average, the irrigation system was used seven times per year, April through July. The micro-sprinklers delivered 2.54 cm of water at each irrigation treatment in a 6.0 m diameter around the tree.

Trunk cross-sectional area (TCSA) was calculated from two perpendicular trunk diameter measurements taken 25 cm above the soil line during the dormant season. Fruit were harvested over three or four harvest dates each year (July 20, 23, and 27, 2009; July 16, 20, and 23, 2010; July 13, 18, and 21, 2011; July 2, 5, and 9, 2012; July 16, 19, 22, and 25, 2013). Fruit from each record tree were weighed for total yield and percentage of total yield was calculated (tree yield for each date ÷ by tree total yield x 100) to determine differences in

harvest maturity. Ten random fruit were sampled and weighed to calculate the average weight per fruit and were measured for average diameter.

The experimental design was a two factor factorial of irrigation and vegetation-free strip width in a randomized complete block design with six replications. Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, N.C.). The effects of vegetation-free strip width and irrigation on TCSA, yield, harvest maturity, and individual fruit weight and diameter were analyzed using PROC GLM. TCSA was analyzed as repeated measures by year. Treatment means were compared using Duncan's new multiple range test (α=0.05).

Results

The effect of vegetation-free strip width, with and without irrigation, on TCSA is shown in Table 1. TCSA increased with increasing vegetation-free strip width in both irrigated and non-irrigated treatments. The difference between the size of trees in 0 m treatments and trees in 3.6 m treatments averaged 44.6 cm^2 for irrigated plots and 44.1 cm^2 for non-irrigated plots. Trees in the irrigated 3.0 m treatment exhibited smaller TCSA than trees in the irrigated 2.4 m treatment; this anomaly does not appear to be due to data outliers or border effects with other treatments.

The effect of vegetation-free strip width and irrigation on TCSA is shown in Table 2. In all years, trees in the 0 m vegetation-free strip width had the smallest TCSA, followed by trees

in the 0.6 m vegetation-free strip, and trees in the 3.6 m strip had the greatest TCSA. Trees in the 1.2, 2.4, and 3.0 m vegetation-free strips had intermediate TCSA measurements. In each year irrigated trees had greater TCSA than non-irrigated trees, by 11 cm^2 on average. There were no irrigation*strip width interactions in the four years studied.

The effect of vegetation-free strip width, with and without irrigation, on total yield is shown in Table 3. Yield increased with increasing vegetation-free strip width in both irrigated and non-irrigated treatments. The difference between the yield in the 0 m plot and the yield in the 3.6 m treatment averaged 23.6 kg for irrigated plots and 22.7 kg for non-irrigated plots. As with TCSA, trees in the irrigated 3.0 m treatment exhibited smaller yields than trees in the irrigated 2.4 m treatment; this anomaly does not appear to be due to data outliers or border effects with other treatments.

The effect of vegetation-free strip width and irrigation on total yield is shown in Table 4. In all years, yield was highest 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. In 2009, 2010, 2011, and 2013 irrigation increased yield by an average of 4.8 kg. Numerically greater yield also occurred in 2012, though the difference was not significant, likely due to the higher than average rainfall that year which increased the yield in non-irrigated plots. There were no irrigation*strip width interactions in the five years studied.

The effect of vegetation-free strip width, with and without irrigation, on harvest maturity (percent of total yield harvested on the first harvest date of each year) is shown in Table 5. The effect of strip width in irrigated and non-irrigated plots on maturity at first harvest each year is not as clear as the previous figures and tables, but in general, for both irrigated and non-irrigated plots, a greater proportion of fruit grown in the 0 m strip are mature on the first harvest date compared to all other strip widths and fruit grown in the 3.6 m strip are the least ready to harvest on the first harvest date.

The effect of vegetation-free strip width and irrigation on harvest maturity is shown in Table 6. In general, fruit grown in the 0 m strip width mature earliest (have the highest percentage of total yield at the first harvest) and fruit grown in the 3.6 m strip have the lowest percentage of total yield at the first harvest. Trees grown in the 0.6-3.0 m vegetation-free strips demonstrated intermediate maturity values. There were differences in maturity on the first harvest date due to irrigation. In 2012 fruit in non-irrigated plots ripened earlier than fruit grown in irrigated plots. And in 2011 and 2013 there was no difference between irrigated and non-irrigated plots for harvest maturity. There were irrigation*strip width interactions in two of the five years studied (Figure 1).

The effect of vegetation-free strip width and irrigation on the percentage of total yield on the second and third harvest dates each year are shown in Table 7 and Table 8, respectively. In 2011 and 2012, percentage of total yield collected on the second harvest date increased

with greater vegetation-free strip widths. In 2011, irrigated treatments had a smaller percentage of total yield collected on the second harvest date than non-irrigated treatments while in 2012 irrigated treatments had a greater percentage of total yield collected on the second harvest date than non-irrigated treatments. There were no significant differences for percentage of total yield collected on the second harvest date due to treatments in 2010 or 2013. In 2009 and 2012 the 3.6 m vegetation-free strip width treatment had the highest percentage of total yield collected at the third harvest and the 0 m plot had the lowest. This same trend was also seen in 2011, though not statistically significant (P=0.1617). Non-irrigated treatments had a greater percentage of total harvest collected on the third harvest date than non-irrigated treatments in 2009 and 2010, with no significant differences due to irrigation in years 2011-2013. There were no significant strip*irrigation interactions for percentage of total yield collected on the third harvest date in the five years studied.

The effect of vegetation-free strip width, with and without irrigation, on average peach weight is shown in Table 9. In general, individual fruit weighed more in 3.6 m strip width plots than in 0 m strip width plots though the differences were only significant in two of the five years studied.

The effect of vegetation-free strip width and irrigation on average peach weight is shown in Table 10. In 2009 and 2010 fruit grown in the 3.0 and 3.6 m vegetation-free strips had the

greatest average weights followed by fruit from the 1.2 and 2.4 m vegetation-free strips. Fruit grown in the 0 m strip were the lowest weight in four out of five years. In years 2009-2011 fruit were larger in irrigated versus non-irrigated plots while in 2012 fruit were larger in non-irrigated plots than in irrigated plots. There was a slight (P=0.0496) irrigation*strip width interactions in 2013.

The effect of vegetation-free strip width, with and without irrigation, on average peach diameter is shown in Table 11. In general, average fruit diameter increases with increasing vegetation-free strip width in irrigated and non-irrigated plots with the greatest differences observed in non-irrigated plots where the diameter of fruit grown in 0 m plots was 0.44 cm less than fruit grown in 3.6 m plots, on average.

The effect of vegetation-free strip width and irrigation on average peach diameter is shown in Table 12. 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. Irrigation increased fruit diameter in years 2009-2011 and decreased diameter in 2012 and 2013. There were no irrigation*strip width interactions in the five years studied.

Discussion

This work demonstrates that increasing vegetation-free strip widths under peach trees results in greater tree growth and greater yield in agreement with other studies (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). Yields in 2013 were lower due to frost/freeze damage in the spring, but fruit size was greater. Yield increased, on average, by 23.6 kg between the irrigated 0 m and 3.6 m vegetation-free strip width plots, and 22.7 kg between the non-irrigated 0 m and 3.6 m vegetation-free strip width plots. That represents an additional bushel of peaches per tree, annually. Assuming an expected price of $24 per bushel (M.L. Parker, personal communication) and an average of 299 trees per hectare at a 5.5 by 6.0 m spacing (Lockwood and Myers, 2005), this will increase gross per hectare income by $7176 annually.

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 seven to nine days each year. Although the difference in harvest maturity between 0 m and 3.6 m vegetation-free strip width plots on the first harvest date each year is not great enough to be useful for targeted volume prediction it may offer a simple and useful variable for offsetting rainfall losses or staggering harvests.

Welker and Glenn (1989) reported that the percentage of large fruit (greater than 7.0 cm) increased as the size of the vegetation-free area increased. We observed a trend for greater individual fruit weight and diameter with increasing vegetation-free strip width, with the 3.0 and 3.6 m vegetation-free strip widths each producing fruit greater than or

equal to 7.0 cm in diameter in four out of five years. In 2013 fruit from all strip widths, with and without irrigation, were greater than 7.0 cm, likely due to the above average rainfall that year (Appendix 4).

Supplemental irrigation increases 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 yeas of average rainfall (2009-2011) further indicate a benefit of irrigation for peach, even in an area with relatively high annual rainfall.

Literature Cited

Arnold, M.E. and J.H. Aldrich. 1980. Herbicidal effects on peach seedling growth and weed control. HortScience 15:293-294.

Belding, R.D., B.A. Majek, G.R.W. Lokaj, J. Hammerstedt, and A.O. Ayeni. 2004. Orchard floor management influence on summer annual weeds and young peach tree performance. Weed Tech. 18:215-222.

Buckelew, J.K. 2009. Orchard floor management in young peach [*Prunus persica* (L.) Batch.]: Effects of irrigation, vegetation-free width, and certain PRE herbicides. NC State Univ., Raleigh, NC, Ph.D. Diss.

Foy, C.L., S.B. Harrison, and H.L. Witt. 1994. Herbicide effects on weed control and shoot growth of young apple (*Malus sylvestris*) and peach (*Prunus persica*) trees. Weed Tech. 8:840-848.

Glenn, D.M. and W.V. Welker. 1989. Orchard soil management systems influence rainfall infiltration. J. Amer. Soc. Hort. Sci. 114:10-14.

Horton, B.D., E.J. Wehunt, J.H. Edwards, R.R. Bruce, and J.L. Chesnee. 1981. The effects of drip irrigation and soil fumigation on 'Redglobe' peach yields and growth. J. Amer. Soc. Hort. Sci. 106:438-443.

Huslig, S.M., M.W. Smith, and G.H. Brusewitz. 1993. Irrigation schedules and annual ryegrass as a ground cover to conserve water and control peach tree growth. HortScience 28:908-913.

Inderjit and K.I. Keating. 1999. Allelopathy: principles, procedure, processes, and promises for biological control. Adv. Agron. 67:141-231.

Layne, R.E.C. and C.S. Tan. 1988. Influence of cultivars, ground covers, and trickle irrigation on early growth, yield, and cold hardiness of peaches on Fox sand. J. Amer. Soc. Hort. Sci. 113:518-525.

Layne, R.E.C., C.S. Tan, and D.M. Hunter. 1994. Cultivar, ground-cover, and irrigation treatments and their interactions affect long-term performance of peach trees. J. Amer. Soc. Hort. Sci. 119:12-19.

Liverani, A., D. Cobianchi, A. Crociani, and D. Missere. 1992. Effect of soil management systems on hillside peach orchards. Acta Hort. 315:123-127.

Lockwood, D.W. and D.C. Coston. 2005. Peach tree physiology, p. 5-10. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Lockwood, D.W. and S.C. Myers. 2005. Tree density, orchard design, and training systems, p. 51-64. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Majek, B.A., P.E. Neary, and D.F. Polk. 1993. Smooth pigweed interference in newly planted peach trees. J. Prod. Agric. 6:244-246.

Marriage, P.B. and H.A. Quamme. 1980. Effect of weed control on the winterhardiness of the bark and wood of young peach trees. HortScience 15:290-291.

Meagher, R.L., J.R. Meyer, and J.C. Killian. 1987. Within-tree distribution of cat-facing injury on peaches in North Carolina. J. Agric. Entomol. 4:78-81.

Meyer, J.R., E.I. Zehr, R.L. Meagher Jr., and S.K. Salvo. 1992. Survival and growth of peach trees and pest populations in orchard plots managed with experimental ground covers. Agric. Ecosyst. Environ. 41:353-363.

Mitchem, W.E. 2005. Weed management considerations for peach orchards, p. 279-284. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Parker, M.L. and J.R. Meyer. 1996. Peach tree vegetative and root growth respond to orchard floor management. HortScience 31:330-333.

Reeder, B.D., J.S. Newman, and J.W. Worthington. 1979. Effect of trickle irrigation on peach trees. HortScience 14:36-37.

Tan, C.S. and R.E.C. Layne. 1993. Irrigation and ground cover management effect on soil temperature in a mature peach orchard. Can. J. Plant Sci. 73:857-870.

Welker, W.V. and D.M. Glenn. 1988. Growth suppression of peach trees with competition. Proc. Annu. Meet. Northeast. Weed Sci. Soc. 42:243.

Welker, W.V. and D.M. Glenn. 1989. Sod proximity influences the growth and yield of young peach trees. J. Amer. Soc. Hort. Sci. 114:856-859.

Weller, S.C., W.A. Skroch, and T.J. Monaco. 1985. Common bermudagrass (*Cynodon dactylon*) interference in newly planted peach (*Prunus persica*) trees. Weed Sci. 33:50-56.

Table 1. Effect of vegetation-free strip width, with and without irrigation, on trunk cross-sectional area (cm^2) of peach trees, years 3-6

		Year			
		2009	2010	2011	2012
	Strip Width (m)	**Trunk Cross-Sectional Area (cm^2)**			
Irrigated	0	25.9e*†	37.2d	44.3d	53.5e
	0.6	44.1d	55.1c	62.1c	71.0d
	1.2	51.7cd	64.0bc	72.4bc	78.0cd
	2.4	62.2ab	72.1b	80.2ab	91.4ab
	3.0	55.6bc	67.9b	76.2b	86.4bc
	3.6	69.6a	81.5a	88.7a	99.4a
	p value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Non-irrigated	0	19.8d	28.4e	34.0d	40.5e
	0.6	33.3c	44.2d	53.1c	61.6d
	1.2	39.6bc	51.7cd	60.4bc	67.6cd
	2.4	46.0ab	53.7bc	64.9b	72.4bc
	3.0	44.9ab	59.7b	70.9b	79.4b
	3.6	53.4a	68.7a	86.1a	90.8a
	p value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

*Means within each column within each irrigation treatment followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

†Treatment means are pooled across 6 reps

Table 2. Effect of vegetation-free strip width and irrigation on trunk cross-sectional area (cm^2) of peach trees, years 3-6

	Year			
	2009*	2010	2011	2012
Strip Width (m)	**Trunk Cross-Sectional Area (cm^2)**			
0	22.8e†	32.8d	39.2d	47.0d
0.6	38.7d	49.6c	57.6c	66.3c
1.2	45.7c	57.8b	66.4b	72.8c
2.4	54.1b	62.9b	72.6b	81.9b
3.0	50.2bc	63.8b	73.6b	82.9b
3.6	61.5a	75.1a	87.4a	95.1a
p value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Irrigation				
Irrigated	51.5a	62.9a	70.6a	79.9a
Non-irrigated	39.5b	51.1b	61.6b	68.7b
p value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
p value for strip irrigation interaction*	*0.5214*	*0.6031*	*0.6040*	*0.6997*

*Means within each column within main effects followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

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

Table 3. Vegetation-free strip width and irrigation effects on peach yield (kg), years 3-7

		Year				
		2009	2010	2011	2012	2013
	Strip Width (m)	**Yield (kg)**				
Irrigated	0	11.0c*†	18.6c	23.5d	33.3c	26.3c
	0.6	20.9b	25.3c	30.5cd	38.7c	27.2c
	1.2	19.0b	34.8b	38.4bc	42.8bc	31.0bc
	2.4	30.0a	38.1b	46.3ab	56.2a	35.6b
	3.0	22.2b	34.7b	40.4b	43.1bc	35.4b
	3.6	31.7a	47.7a	52.0a	53.8ab	45.3a
	p value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0005*	*<0.0001*
Non-irrigated	0	8.1d	13.6d	19.9e	22.9c	22.3d
	0.6	14.7c	23.9c	28.6d	39.1b	25.1cd
	1.2	14.8c	22.9c	31.0cd	39.6b	27.8cd
	2.4	19.2bc	27.1bc	36.8bc	45.1b	29.8bc
	3.0	20.1ab	30.6b	37.7b	43.5b	38.2a
	3.6	24.4a	39.6a	44.7a	55.7a	35.7ab
	p value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*

*Means within each column within each irrigation treatment followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

†Treatment means are pooled across 6 reps

Table 4. Effect of vegetation-free strip and irrigation on peach yield (kg), years 3-7

	Year				
	2009*	2010	2011	2012	2013
Strip Width (m)	**Yield (kg)**				
0	9.6d†	16.1d	21.7e	28.1d	24.3e
0.6	17.8c	24.6c	29.5d	38.9c	26.1de
1.2	17.1c	29.4b	35.0c	41.3c	29.5cd
2.4	24.1ab	32.1b	41.1b	50.2ab	32.5bc
3.0	21.2bc	32.8b	39.1bc	43.3bc	36.7ab
3.6	27.7a	43.3a	48.0a	54.8a	40.0a
p value	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
Irrigation					
Irrigated	21.9a	32.5a	37.7a	43.9a	33.0a
Non-irrigated	16.9b	26.3b	33.0b	41.0a	29.7b
p value	*<0.0001*	*<0.0001*	*0.0020*	*0.1554*	*0.0206*
p value for strip irrigation interaction*	*0.3271*	*0.1201*	*0.6029*	*0.2634*	*0.1111*

*Means within each column within main effects followed by the same letter do not significantly differ (α≤0.05)

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

Table 5. Effect of vegetation-free strip width, with and without irrigation, on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7

		Year				
		2009	2010	2011	2012	2013
	Strip Width (m)	**% of total yield at first harvest**				
Irrigated	0	88.1a*†	36.9a	76.8a	66.1a	34.3a
	0.6	50.2b	24.1a	59.0bc	46.2b	19.2b
	1.2	54.5b	25.4a	65.0ab	51.4b	26.8ab
	2.4	58.0b	26.3a	55.2bc	47.6b	19.5b
	3.0	48.1b	32.5a	58.4bc	51.0b	23.1ab
	3.6	49.0b	27.7a	44.6c	29.8c	17.5b
	p value	*<0.0001*	*0.3426*	*0.0185*	*0.0004*	*0.1250*
Non-irrigated	0	51.7a	10.8b	54.8abc	75.3a	32.8a
	0.6	28.5bc	15.8b	65.3ab	62.1ab	29.0a
	1.2	23.6c	8.0b	46.3bc	63.0ab	26.1a
	2.4	43.8ab	35.6a	67.9a	60.0b	36.8a
	3.0	49.9a	30.4a	59.3abc	57.4bc	28.3a
	3.6	33.4bc	21.8ab	42.6c	44.4c	20.3a
	p value	*0.0012*	*0.0003*	*0.0518*	*0.0020*	*0.4108*

*Means within each column within each irrigation treatment followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

†Treatment means are pooled across 6 reps

Table 6. Effect of vegetation-free strip width and irrigation on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7

	Year				
	2009*	2010	2011	2012	2013
Strip Width (m)	**% of total yield at first harvest**				
0	69.9a†	23.9ab	65.8a	70.7a	33.5a
0.6	39.3b	20.0b	62.2a	54.1b	24.1ab
1.2	40.5b	17.5b	56.5ab	56.7b	26.5ab
2.4	50.3b	31.3a	62.1a	54.4b	28.9ab
3.0	48.9b	31.6a	58.8a	53.9b	25.5ab
3.6	40.5b	24.5ab	44.4b	37.8c	19.0b
p value	*<0.0001*	*0.0267*	*0.0336*	*<0.0001*	*0.1550*
Irrigation					
Irrigated	57.7a	28.9a	60.6a	49.2b	23.5a
Non-irrigated	38.6b	20.6b	56.5a	60.3a	29.0a
p value	*<0.0001*	*0.0057*	*0.2836*	*0.0002*	*0.0798*
p value for strip irrigation interaction*	*0.0087*	*0.0408*	*0.0829*	*0.9046*	*0.5239*

*Means within each column within main effects followed by the same letter do not significantly differ (α≤0.05)

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

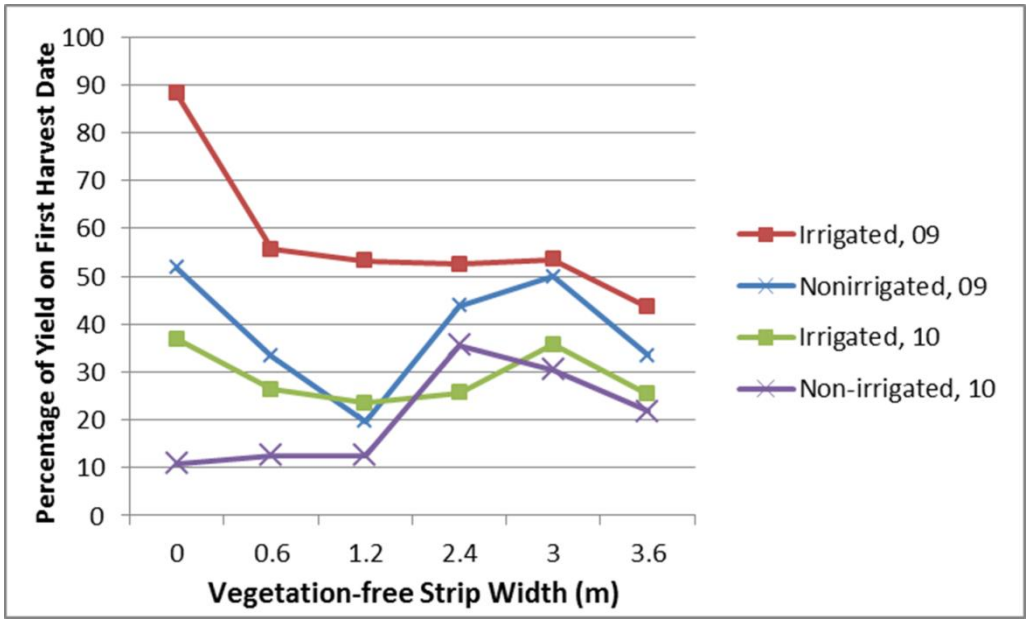

Figure 1. Interaction between vegetation-free strip width and irrigation on the harvest maturity of peach, years 3-4

Table 7. Effect of vegetation-free strip width and irrigation on % of total yield harvested on the second harvest date of each year, years 3-7

	Year				
	2009*	2010	2011	2012	2013
Strip Width (m)	**% of total yield at second harvest**				
0	22.0b†	55.4a	33.0b	25.8c	38.3a
0.6	38.7a	59.3a	35.4b	30.8bc	37.3a
1.2	34.6a	59.2a	41.8ab	31.6bc	34.7a
2.4	33.6a	54.4a	34.6b	33.9b	38.3a
3.0	31.5a	52.9a	38.9ab	31.6bc	39.4a
3.6	32.7a	54.6a	49.8a	41.5a	38.8a
p value	*0.0014*	*0.5836*	*0.0607*	*0.0044*	*0.7692*
Irrigation					
Irrigated	29.4b	57.2a	33.6b	34.6a	36.8a
Non-irrigated	35.3a	54.8a	44.0a	30.0b	38.9a
p value	*0.0112*	*0.3682*	*0.0026*	*0.0307*	*0.2807*
p value for strip irrigation interaction*	*0.0014*	*0.8961*	*0.5165*	*0.9978*	*0.8714*

*Means within each column within main effects followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

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

Table 8. Effect of vegetation-free strip width and irrigation on % of total yield harvested on the third harvest date of each year, years 3-7

	Year				
	2009*	2010	2011	2012	2013
Strip Width (m)	**% of total yield at third harvest**				
0	8.1c†	20.7a	1.2b	3.5c	23.2a
0.6	21.9ab	20.7a	2.4ab	15.1ab	27.6a
1.2	24.9a	23.4a	1.7b	11.7b	30.7a
2.4	15.9bc	14.3a	3.3ab	11.7b	28.3a
3.0	19.6ab	15.5a	2.3ab	14.5ab	28.3a
3.6	27.9a	20.9	5.8a	20.7a	28.7a
p value	*0.0001*	*0.5741*	*0.1617*	*0.0001*	*0.6818*
Irrigation					
Irrigated	9.4b	10.2b	2.0a	13.9a	28.6a
Non-irrigated	30.5a	28.8a	3.5a	11.8a	26.8a
p value	*<0.0001*	*<0.0001*	*0.1599*	*0.2927*	*0.4754*
p value for strip irrigation interaction*	*0.5764*	*0.7047*	*0.3163*	*0.7180*	*0.9876*

*Means within each column within main effects followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

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

Table 9. Effect of vegetation-free strip width, with and without irrigation, on average peach weight (g), years 3-7

		Year				
		2009	2010	2011	2012	2013
	Strip Width (m)	**Average Peach Weight (g)**				
Irrigated	0	187.0b*†	146.5c	198.2a	180.1ab	198.5a
	0.6	188.3b	155.5bc	198.3a	189.5ab	204.1a
	1.2	203.2ab	163.9b	199.8a	172.9b	197.9a
	2.4	207.6a	171.0ab	203.1a	192.3a	215.3a
	3.0	218.1a	170.1ab	206.6a	193.4a	201.2a
	3.6	212.7a	182.9a	192.4a	182.4ab	205.6a
	p value	*0.0006*	*0.0008*	*0.4611*	*0.1197*	*0.2895*
Non-irrigated	0	152.8a	120.7c	172.4a	191.0b	193.7d
	0.6	145.3a	139.4b	166.8a	221.2a	199.1cd
	1.2	150.1a	139.7b	166.1a	197.9ab	210.4bcd
	2.4	147.5a	141.4b	184.3a	187.3b	229.0ab
	3.0	168.0a	156.6ab	179.5a	201.0ab	219.4abc
	3.6	170.2a	161.0a	181.1a	199.0ab	236.2a
	p value	*0.3031*	*0.0002*	*0.1209*	*0.1526*	*0.0003*

*Means within each column within each irrigation treatment followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

†Treatment means are pooled across 6 reps

Table 10. Effect of vegetation-free strip width and irrigation on average peach weight (g), years 3-7

	Year				
	2009*	2010	2011	2012	2013
Strip Width (m)	**Average Peach Weight (g)**				
0	169.9b†	133.6d	185.3a	185.6b	196.1c
0.6	166.8b	147.5c	182.6a	205.4a	201.6bc
1.2	176.7ab	151.8bc	183.0a	185.4b	204.1bc
2.4	178.8ab	156.2bc	193.7a	189.8ab	222.2a
3.0	193.1a	163.4ab	193.0a	197.2ab	210.3ab
3.6	191.5a	172.0a	186.7a	190.7ab	220.9a
p value	*0.0041*	*<0.0001*	*0.1531*	*0.0795*	*0.0002*
Irrigation					
Irrigated	202.8a	165.0a	199.7a	185.1b	203.8b
Non-irrigated	155.8b	143.1b	175.0b	199.6a	214.6a
p value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0014*	*0.0041*
p value for strip irrigation interaction*	*0.7042*	*0.7782*	*0.3129*	*0.2088*	*0.0496*

*Means within each column within main effects followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

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

Table 11. Effect of vegetation-free strip width, with and without irrigation, on average peach diameter (cm), years 3-7

		Year				
		2009	2010	2011	2012	2013
	Strip Width (m)	**Average Peach Diameter (cm)**				
Irrigated	0	7.1b*†	6.4c	7.1a	6.8ab	7.2b
	0.6	7.0b	6.6bc	7.1a	6.9ab	7.3ab
	1.2	7.3ab	6.7bc	7.2a	6.7b	7.2b
	2.4	7.3a	6.8ab	7.2a	7.0a	7.4a
	3.0	7.4a	6.8ab	7.2a	7.0a	7.2ab
	3.6	7.4a	7.0a	7.1a	6.9ab	7.3ab
	p value	*0.0060*	*0.0020*	*0.3662*	*0.1232*	*0.1241*
Non-irrigated	0	6.2b	6.1c	6.7c	6.9a	7.1d
	0.6	6.4b	6.3bc	6.7c	7.1a	7.3cd
	1.2	6.5b	6.4abc	6.7c	7.1a	7.4bcd
	2.4	6.4b	6.4abc	7.0ab	6.9a	7.7ab
	3.0	6.8a	6.6ab	6.9abc	7.1a	7.5abc
	3.6	6.8a	6.6a	7.0a	7.1a	7.7a
	p value	*0.0001*	*0.0019*	*0.0261*	*0.4456*	*0.0005*

*Means within each column within each irrigation treatment followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

†Treatment means are pooled across 6 reps

Table 12. Effect of vegetation-free strip width and irrigation on average peach diameter (cm), years 3-7

	Year				
	2009*	2010	2011	2012	2013
Strip Width (m)	**Average Peach Diameter (cm)**				
0	6.6c†	6.3d	6.9b	6.8a	7.2c
0.6	6.7bc	6.4cd	6.9b	7.0a	7.3bc
1.2	6.9b	6.5bc	7.0ab	6.9a	7.3bc
2.4	6.9b	6.6bc	7.1a	7.0a	7.5a
3.0	7.1a	6.7ab	7.1ab	7.0a	7.4ab
3.6	7.1a	6.8a	7.0ab	7.0a	7.5a
p value	*<0.0001*	*<0.0001*	*0.0688*	*0.2340*	*<0.0001*
Irrigation					
Irrigated	7.2a	6.7a	7.1a	6.9b	7.3b
Non-irrigated	6.5b	6.4b	6.8b	7.0a	7.4a
p value	*<0.0001*	*<0.0001*	*<0.0001*	*0.0138*	*0.0013*
p value for strip irrigation interaction*	*0.3431*	*0.9620*	*0.1002*	*0.3149*	*0.1261*

*Means within each column within main effects followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

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

EFFECTS OF VEGETATION-FREE STRIP WIDTH AND IRRIGATION ON SOIL MICROBES IN A PEACH ORCHARD

Effects of Vegetation-free Strip Width and Irrigation on Soil Microbes in a Peach Orchard

Connie L. Fisk[1], Cong Tu[2], Shuijin Hu[2], and Michael L. Parker[1]

[1]Department of Horticultural Science and [2]Department of Plant Pathology, North Carolina State University, Raleigh, NC 27695

We thank Bernadette Clark for her assistance with sample collection and lab analyses, the staff at the Sandhills Research Station for their assistance with orchard management and sample collection, and Wayne Mitchem and Robert Hoyt for herbicide applications.

Effects of Vegetation-free Strip Width and Irrigation on Soil Microbes in a Peach Orchard

Additional index words: *Prunus persica*, arbuscular mycorrhizal fungi (AMF)

Abstract. An experiment was conducted to determine the effects of vegetation-free strip width and irrigation on the microbial community in the rhizosphere of peach. Different vegetation-free strip widths (0, 1.2, 2.4, and 3.6 m) and irrigation were studied in a peach orchard at the Sandhills Research Station in North Carolina to determine their effects on soil microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), soil microbial respiration (SMR), net nitrogen mineralization (NNM), and endomycorrhizal fungal colonization of peach roots. Vegetation-free strip widths and irrigation did not affect endomycorrhizal fungal colonization. In the spring and fall of 2010 the 0 m vegetation-free strip had the highest MBC and the 2.4 m vegetation-free strip had the lowest MBC. MBN did not differ between treatments in spring 2010 though in fall samplings the smaller strip widths had higher MBN. The 3.6 m vegetation-free strip had the lowest MBN on all sampling dates. In 2009 there were differences between strip widths for SMR with the 0 m strip producing 21.48 mg CO_2 kg^{-1} d^{-1} and the 3.6 m strip only producing 10.08 mg CO_2 kg^{-1} d^{-1}. SMR did not differ between strip widths in the spring or fall of 2010. NNM decreased with greater vegetation-free strip width. The soil in irrigated plots had higher MBN and lower SMR in Spring 2010. These are important implications for peach growers as they strive to maximize fruit yield and quality while optimizing the health of their trees and soil.

Introduction

The recommended orchard floor management program for peach (*Prunus persica* (L.) Batsch.) production in North Carolina is to establish a cover crop or a permanent sod in the row middles to prevent erosion and facilitate equipment movement during wet weather, with a 3 to 3.6 m wide vegetation-free strip in the tree row maintained with herbicides (Foy et al., 1994; Layne and Tan, 1988; Mitchem, 2005). Trees grown in vegetation-free soil have been shown to root deeper and develop greater root densities than trees grown with vegetative competition in the tree row (Parker and Meyer, 1996). Unfortunately, long term vegetation control also reduces soil organic matter and its associated benefits (ie. microbial biomass and activity) (Wardle et al., 2001; Yao et al., 2005).

The level of vegetation or weed control is directly related to peach 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; Welker and Glenn, 1989). Vegetation competes with trees for water and nutrients and can also serve as an alternate host for insect pests, including catfacing insects that damage and distort fruit (Meagher et al., 1987; Mitchem, 2005).

Supplemental irrigation of peach orchards is encouraged on sandy soil and has been shown to increase fruit yield per tree, fruit size, number of fruit buds per tree (due to greater shoot length), and trunk diameter over non-irrigated trees (Layne and Tan, 1988; Layne et al., 1994; Reeder et al., 1979). Buckelew (2009) found that with irrigation, the vegetation-free

strip can be reduced to 1.5, 1.3, and 0.8 m to achieve equivalent growth (trunk cross-sectional area) for trees aged one, two and three years, respectively. A vegetation-free strip of 1.2 m with irrigation is required to achieve similar yields to non-irrigated trees with a vegetation-free strip of 3.6 m (Buckelew, 2009). In addition to its effect on trees and fruit, irrigation has a positive effect on soil productivity as indicated by increased soil carbon and nitrogen and microbial biomass C (Li et al., 2005).

In the southeastern US, nematodes are of concern where peaches are planted in light, sandy soils and in soils that were previously planted to peaches or other crops that are hosts of the root-knot nematode (*Meloidogyne* spp.). Root-knot nematodes can severely affect tree establishment and the ring nematode (*Criconemella xenoplax*) is associated with premature tree death in the peach tree short life (PTSL) complex (Nyczepir, 2005). Treatment with a nematicide is a common pre-plant practice on sandy soils and has been shown to increase trunk cross-sectional area and water uptake (Horton et al., 1981). The nematicide Telone II (1,3-dichloropropene) has few negative environmental effects, has little impact on soil microbial communities (Ibekwe et al., 2001), and is the product currently recommended to commercial peach growers for preplant nematode treatment.

The effect of management practices on soil organic matter is largely mediated by soil microorganisms, and microbial biomass carbon and microbial biomass nitrogen contents are indicators of soil quality (Rice et al., 1996). Soil microorganisms are the primary agents of

organic residue decomposition and nutrient immobilization and mineralization, and therefore critically affect plant growth through regulation of available plant nutrients (Campbell and Greaves, 1990; Yao et al., 2005). In addition, some soil microorganisms, particularly mycorrhizal fungi, form symbiotic associations with roots, effectively increasing the root surface area and enhancing uptake of water and nutrients. These microbial functions help maintain a soil system with available nutrients as well as aggregate stability to reduce erosion and maintain waterholding capacity (Kennedy and Gewin, 1997).

Good development of endomycorrhizae is beneficial to the growth of peach (*Prunus persica*) (Gilmore 1971; Pinochet et al., 1995), plum (*Prunu*s spp.) (Camprubí et al., 1993), apple (*Malus domestica*) (Granger et al., 1983; Mosse, 1957), and *Citrus* trees (Franca et al., 2007; Marx et al., 1971). The symbiotic association occurs naturally in most fruit tree species in the nursery or shortly after seedlings are transplanted in the field (Pinochet et al., 1995). In studies of apple replant disease, healthy tree roots were shown to possess more AM fungi colonization than diseased trees (Caruso et al., 1989).

Mycorrhizae can increase plant growth, especially in infertile soils, as a result of an enhanced ability of infected roots to absorb nutrients (Gerdemann, 1968). Phosphorus is the nutrient most associated with AM and research has shown that mycorrhizal plants absorb nearly twice as much phosphate as uninfected plants (Bowen et al., 1975).

Mycorrhizae also enhance absorption of water and minor mineral elements such as Zn, S, and Cu (Gerdemann, 1968; Hussey and Roncadori, 1982; Strobel et al., 1982).

Mycorrhizae benefit plants under physiological stress, such as drought conditions (Nelson, 1987), and when infected by diseases (Azcón-Aguilar and Barea, 1996; Dehne, 1982) and nematodes (Francl, 1993; Hussey and Roncadori, 1982). Mechanisms that could account for the protective activity ascribed to AM include root damage compensation, physiological alteration or reduction of root exudates responsible for chemotactic attraction of pathogens or nematodes, competition for colonization/infection sites, production of anatomical or morphological changes in the root system or activation of plant defense mechanisms (Azcón-Aguilar and Barea, 1996; Hussey and Roncadori, 1982). Mycorrhizae may also decrease the penetration rate of parasitic nematodes, retard their development inside the root, decrease their reproduction rate (*Pratylenchus* spp. and *Meloidogyne* spp.) or lower their degree of damage (Dehne, 1982; Pinochet et al., 1995).

The application of certain herbicides, paraquat (N,N’-dimethyl-4,4’-bipyridinium dichloride) and simazine (6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine) in particular, may interfere with the mycorrhization of fruit trees (Granger et al., 1995; Nemec and Tucker, 1983). Even mechanical weed removal decreases AM fungi spore numbers, which Nappi and Jodice (1985) speculate is due to lower soil organic matter content.

The primary objective of this study was to examine the impacts of vegetation-free strip width and irrigation on soil ecology in a peach orchard on sandy soil at the age when such an orchard is most prone to peach tree short life (three to six years after planting).

Materials and Methods

The experiment was conducted from 2009-2010 at the Sandhills Research Station in Jackson Springs, NC (35.21°N, 79.63°W). Soil was Candor Sand (sandy, Koalinitic, thermic Grossarenic Kandiudults) with a pH of 5.8 and a humic matter content of 0.60%. The orchard consisted of 'Contender' peach trees (*Prunus persica* L.) grafted onto 'Guardian®' rootstock. One-year whips were planted on Feb. 3, 2006 at a spacing of 5.5 m within the row and 6.0 m between rows.

The experimental design was a factoral randomized complete block with six replications and two factors, vegetation-free strip width (0, 0.6, 1.2, 2.4, 3, and 3.6 m) with or without micro-sprinkler irrigation. Each plot contained four trees, the two center trees being record trees to avoid marginal effect. Vegetation-free strips were chemically maintained using flumioxazin (Chateau) at 213.3 g ha^{-1} active ingredient for PRE emergent weed control and paraquat (Gramoxone Inteon) at 0.67 to 1.0 kg ha^{-1} active ingredient with non-ionic surfactant at 0.25% (v/v) as a POST emergent burndown. Row middles were allowed to populate with native vegetative species and were maintained by mowing to a height of 10-13 cm tall as needed.

For the irrigated plots, one Dan Modular micro-sprinkler (Jain Irrigation Inc., Fresno, CA, USA) was placed 15 cm from the tree trunk. Irrigated plots were irrigated as needed based on precipitation during the growing season. No irrigation was applied when precipitation during the week was 2.54 cm or greater. On average, the irrigation system was used seven times per year, April through July. The micro-sprinklers delivered 2.54 cm of water at each irrigation treatment in a 6.0 m diameter around the tree.

Soil samples were collected from the upper 15 cm layer of soil at the drip line of the tree canopy in October 2009, and May and October 2010. One composite sample consisted of 4 replicate cores (5 cm diameter x 15 cm depth) per tree. Samples were immediately sealed in plastic bags, placed in coolers, and transported to the laboratory. The field-moist samples were sieved with a 2 mm screen and stored in sealed plastic bags at 4°C until analysis. Peach roots collected from each sample on the sieve were stored in separate sealed plastic bags at 4°C.

Soil physical and chemical properties. Soil moisture was determined by placing 10 g of soil in a plastic beaker, oven drying at 105±1°C for 24 hours, and reweighing the sample. For soil pH and electrical conductivity (EC), soil samples were diluted 1:2 with distilled water, allowed to sit for 20 minutes and filtered through Whatman 4 filter paper (Whatman International, England). The pH and EC of the filtrate was measured using a Hanna Meter (HI 9811, Hanna Instruments, Smithfield, RI) standardized to pH 6.0 and EC 0.14.

Arbuscular mycorrhizal colonization of peach roots. One hundred 1 cm lengths of fine peach roots (0.5-1.0 mm diameter) were used to determine mycorrhizal colonization of roots, following the method described by Phillips and Hayman (1970). Root segments were submerged in 10% KOH solution in filtering crucibles in plastic containers. The plastic containers were put into a hot water steamer for 30 minutes or until roots were cleared. The roots were then rinsed with tap water to remove KOH and then submerged in 1% HCl for at least one hour. After removal from the HCl solution roots were stained using a trypan blue solution (0.05% trypan blue, 50% glycerine, 25% lactic acid) and heated again in the steamer for 20 minutes. Excess stain was washed off with tap water. AM colonization was determined using a Nikon SMZ-1B dissecting microscope (Nikon, Tokyo, Japan) and the gridline intersection method (by distributing samples across a petri dish with a 1 cm grid and observing the percentage of infected roots to uninfected roots where they crossed the gridlines; Figure 1). A magnified view of peach root colonized by endomycorrhizal fungi is shown in Figure 2.

Soil microbial biomass. Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were assayed by the chloroform-fumigation extraction method (Ross, 1992; Vance et al., 1987). Twenty grams of soil were fumigated with ethanol-free chloroform for 48 hr. Both fumigated and non-fumigated soils were extracted with 50 mL of 0.5 mol L^{-1} K_2SO_4 by shaking for 30 minutes. A total organic carbon (TOC) analyzer (TOC-5050A, Shimadzu Corporation, Kyoto, Japan) was used to determine the organic carbon (C_{org}) in the extracts.

The MBC was calculated as follows: MBC=(C_{org} in fumigated soil-C_{org} in non-fumigated soil)/k_{ec}, where k_{ec}=0.33, the k factor used here to convert the extracted organic carbon to MBC (Sparling and West, 1988). The concentration of nitrogen in the extract was determined on a Lachat flow injection analyzer (Lachat Instruments, Milwaukee, WI) after digestion using alkaline persulfate oxidation (Cabrera and Beare, 1988). The MBN was calculated using the equation: MBN=(total N in fumigated soil-total N in non-fumigated soil/k_{en}, where k_{en}=0.45, the k factor used to convert the extracted organic nitrogen to MBN (Jenkinson, 1988).

Soil microbial respiration (SMR). Microbial activity was measured using a method modified from Alef and Nannipieri (1995). Twenty grams of soil were placed in an Erlenmeyer flask and distilled water was added to bring the sample to 10% moisture (based on results of the soil moisture test). Flasks were placed in 0.946 L glass jars with 5 ml distilled water in the bottom and a 50 ml beaker containing 5 ml 0.25 mol L^{-1} NaOH, sealed, and incubated in the dark at 25°C. After seven days, the NaOH beaker was replaced with one containing fresh NaOH and the jars were incubated for an additional seven days. The carbon dioxide trapped in the NaOH solution was titrated with 0.1 mol L^{-1} HCl. Microbial respiration was estimated as mg CO_2 kg^{-1} soil d^{-1} by averaging data from both weeks.

Net nitrogen mineralization (NNM). Net nitrogen mineralization was determined using the method described by Hart et al. (1994). After the completion of the two week incubation

for soil microbial respiration the soil samples were incubated for an additional two weeks. Ammonium (NH_4^+) and nitrate (NO_3^-) in the soil were extracted with 50 mL of 0.5 mol L^{-1} K_2SO_4 solution and analyzed with the Lachat flow injection analyzer. Net N mineralized in soil was calculated as the difference between K_2SO_4-extractable inorganic N contents before and after incubation.

Nematode assay. Separate soil samples were collected in April 2010 as described above, packaged into plastic bags and nematode sample boxes, and submitted to the NC Department of Agriculture Agronomic Division for identification of plant-parasitic nematodes. Results were reported as number of each type of nematode (root knot, ring, or other) per 500 cc soil.

Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, N.C.). The effects of vegetation-free strip width and irrigation on soil moisture, pH, EC, MBC, MBN, SMR, NNM, and nematodes were analyzed using PROC GLM. Treatment means were compared using Duncan's new multiple range test (α=0.05).

Results

Average soil moisture was 5.7% in Spring 2009 with no difference between treatments and 5.2% in the fall with irrigated plots having an average soil moisture of 5.7% versus 4.8% for non-irrigated plots (Appendix 2). In Spring 2010 greater strip widths and irrigation had

higher soil moisture (Appendix 2). Soil pH averaged 5.8 in Spring 2009 and was higher with greater vegetation-free strip widths (Appendix 2). Soil pH did not differ by vegetation-free strip width or irrigation in Fall 2009, Spring 2010, or Fall 2010 (average 5.6 in Fall 2009, 5.1 in Spring 2010, and 6.3 in Fall 2010, respectively; Appendix 2). EC was highest in the 0 m strip plots in Spring 2009 and Fall 2010 with no difference between strip widths in Fall 2009 or Spring 2010 (Appendix 2). Irrigation reduced EC in Spring 2009 with no difference on the other three sampling dates (Appendix 2).

Vegetation-free strip widths and irrigation had no significant effect on endomycorrhizal colonization of peach roots in years three through four after planting (Table 1), even though paraquat had been used in the 0.6, 1.2, 2.4, 3.0, and 3.6 m vegetation-free strip width plots.

MBC did not differ significantly between strip width treatments (Table 2). In Fall 2009 MBN was highest in the soil from the 1.2 m vegetation-strip width plots and lowest in the 3.6 m vegetation-free strip width plots. The difference in MBN due to strip width were not significant in Spring or Fall 2010. The 3.6 m vegetation-free strip had the lowest MBN on all sampling dates. In Fall 2009 the 0 m strip had the highest SMR rate (CO_2 kg^{-1} d^{-1}) and the 3.6 m strip had the lowest. SMR did not differ significantly between vegetation-free strip width treatments in Spring or Fall 2010, though numerically the 3.6 m vegetation-free strip had the lowest SMR on all sampling dates. NNM differed between strip widths on each sampling date with NNM decreasing with greater vegetation-free strip width.

Irrigation treatments did not affect MBC or NNM (Table 2). MBN only differed between irrigated and non-irrigated plots in Spring 2010 with irrigation more than doubling MBN. Numerically higher MBN was also observed in irrigated plots in Fall 2009 and Fall 2010, though the difference was not significant. SMR only differed between irrigated and non-irrigated plots in Spring 2010 with irrigation producing lower SMR.

Width of the vegetation-free strip did not significantly affect root knot or ring nematode populations (P=0.5209 and P=0.8071, respectively); there were 0 root knot nematodes collected from the 2.4, 3.0, and 3.6 m vegetation-free strip treatments. The 3.0 and 3.6 m treatments contained the highest populations of other nematodes, though not statistically significant (P=0.3788). Root knot and ring nematode populations tended to increase with irrigation though not significantly (P=0.1797 and P=0.0730, respectively). (See Appendix 3 for more information.)

Discussion

Peach orchard floor vegetation competes with trees for water and nutrients; reducing vegetation in the tree row results in larger trees and greater fruit yields in the early years of the orchard's life (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). However, orchard floor management affects more than just tree size and fruit yield. Orchard floor management can affect soil ecology and pest behavior and defining these impacts is critical

to understanding peach tree short life. This disease complex is common to peach replant sites and results in premature tree death in the spring, three to six years after planting.

Mycorrhizae are known to benefit plants under physiological stress, such as drought conditions (Barea, 1991; Nelson, 1987), and when impacted or infected by diseases (Azcón-Aguilar and Barea, 1996; Dehne, 1982) and nematodes (Francl, 1993; Hussey and Roncadori, 1982) thus their colonization of peach roots is desirable. Endomycorrhizal root colonization was similar among the different vegetation-free strip widths and in both irrigated and non-irrigated plots. Similarity in endomycorrizal root colonization is expected when measured three to four years after planting as the endomycorrhizal fungal populations in the rhizosphere have had sufficient time to stabilize; Traquair and Berch (1988) reported heavy colonization by indigenous AM fungi within six months after planting peach and Rutto and Mizutani (2006) reported high seedling infection rates in both replant and nonreplant soils after one season.

Soil health contributes to the long-term sustainability of the orchard. Soil microorganisms (the soil microbial biomass) decompose plant residues and soil organic matter to release carbon dioxide and plant-available nutrients, aid pesticide degradation, and contribute to soil aggregation (Kennedy and Stubbs, 2006). In the sandy soils of eastern North Carolina, high precipitation and warm temperatures prompt rapid decomposition of organic residues, reducing both the nutrient reservoir and water retention (Tu et al., 2006). Seasonality may

influence the microbial biomass directly, by inducing microbial responses to soil moisture and temperature, or indirectly by influencing plant productivity and therefore organic matter release (Wardle, 1992). Lynch and Panting (1982) found that the amount of microbial biomass reached a maximum around the time of maximum root biomass (late spring) and thereafter declined. In contrast, our results showed higher MBN in the fall and no significant differences for MBC.

Results suggest that increasing the width of the vegetation-free strip reduces microbial biomass and associated activities in the soil. Irrigation had less effect on microbial parameters though it did increase MBN and decrease SMR in Spring 2010. Annual collection and analysis of soil samples is needed throughout the life of the orchard to determine the long-term effects of vegetation-free strips and irrigation on soil health and sustainability.

Literature Cited

Alef, K. and P. Nannipieri. 1995. Estimation of microbial activities, p. 193-270. In Alef, K. and P. Nannipieri (eds.). Methods in applied soil microbiology and biochemistry. Academic Press, London.

Arnold, M.E. and J.H. Aldrich. 1980. Herbicidal effects on peach seedling growth and weed control. HortScience 15:293-294.

Azcón-Aguilar, C. and J.M. Barea. 1996. Arbuscular mycorrhizas and biological control of soil-borne plant pathogens – an overview of the mechanisms involved. Mycorrhiza 6:457-464.

Barea, J.M. 1991. Vesicular-arbuscular mycorrhizae as modifiers of soil fertility. Adv. Soil Sci. 15:2-40.

Belding, R.D., B.A. Majek, G.R.W. Lokaj, J. Hammerstedt, and A.O. Ayeni. 2004. Orchard floor management influence on summer annual weeds and young peach tree performance. Weed Tech. 18:215-222.

Bowen, G.D., D.I. Bevage, and B. Mosse. 1975. Phosphate physiology of vesicular-arbuscular mycorrhizas. Endomycorrhizas; Proceedings of a Symposium, 1974, p. 241-260.

Buckelew, J.K. 2009. Orchard floor management in young peach [*Prunus persica* (L.) Batch.]: Effects of irrigation, vegetation-free width, and certain PRE herbicides. NC State Univ., Raleigh, NC, PhD Diss.

Cabrera, M.L. and M.H. Beare. 1993. Alkaline persulfate oxidation for determining total nitrogen in microbial biomass extracts. Soil Sci. Soc. Am. J. 57:1007-1012.

Campbell, R. and M.P. Greaves. 1990. Anatomy and community structure of the rhizosphere, p. 11-34. In Lynch, J.M. (ed.). The rhizosphere. John Wiley & Sons, Chichester.

Camprubí, A., J. Pinochet, C. Calvet, and V. Estaun. 1993. Effects of the root-lesion nematode *Pratylenchus vulnus* and the vesicular-arbuscular mycorrhizal fungus *Glomus mosseae* on the growth of three plum rootstocks. Plant Soil 153:223-229.

Caruso, F.L., B.F. Neubauer, and M.D. Begin. 1989. A histological study of apple roots affected by replant disease. Can. J. Bot. 67:742-749.

Dehne, H.W. 1982. Interaction between vesicular-arbuscular mycorrhizal fungi and plant pathogens. Phytopathology 72:1115-1119.

Foy, C.L., S.B. Harrison, and H.L. Witt. 1994. Herbicide effects on weed control and shoot growth of young apple (*Malus sylvestris*) and peach (*Prunus persica*) trees. Weed Tech. 8:840-848.

França, S.C., S.M. Gomes-da-Costa, and A.P.D. Silveira. 2007. Microbial activity and arbuscular mycorrhizal fungal diversity in conventional and organic citrus orchards. Biol. Agric. Hortic. 25:91-102.

Francl, L.J. 1993. Interactions of nematodes with mycorrhizae and mycorrhizal fungi, p. 203-216. In Khan, M.W. (ed.). Nematode interactions. Chapman & Hall, London.

Gerdemann, J.W. 1968. Vesicular-arbuscular mycorrhizal and plant growth. Annu. Rev. Phytopathol. 6:397-418.

Gilmore, A.E. 1971. The influence of endotrophic mycorrhizae on the growth of peach seedlings. J. Amer. Soc. Hort. Sci. 96:35-38.

Granger, R.L., C. Plenchette, and J.A. Fortin. 1983. Effect of vesicular-arbuscular (VA) endomycorrhizal fungus (*Glomus epigaeum*) on the growth and leaf mineral content of two apple clones propagated in vitro. Can. J. Plant Sci. 63:551-555.

Granger, R.L., S. Khanizadeh, M. Meheriuk, L.S. Bérard, and Y. Dalpé. 1995. Effects of simazine on the mycorrhizal population in soil beneath an apple tree canopy. Fruit Varieties J. 49:90-93.

Harley, J.L. and S.E. Smith. 1983. Mycorrhizal symbiosis. Academic Press, New York.

Hart, S.C., J.M. Stark, E.A. Davidson, and M.K. Firestone. 1994. Nitrogen mineralization, immobilization, and nitrification, p. 985-1018. In Weaver, R.W., S. Bottomley, P. Bezdicek, D. Smith, S. Tabatabai, and A. Wollum (eds.). Methods of Soil Analysis, Part 2: Microbial and Biochemical Properties. Soil Science Society of America, Madison, WI.

Horton, B.D., E.J. Wehunt, J.H. Edwards, R.R. Bruce, and J.L. Chesnee. 1981. The effects of drip irrigation and soil fumigation on 'Redglobe' peach yields and growth. J. Amer. Soc. Hort. Sci. 106:438-443.

Hussey, R.S. and R.W. Roncadori. 1982. Vesicular-arbuscular mycorrhizae may limit nematode activity and improve plant growth. Plant Dis. 66:9-14.

Ibekwe, A.M., S.K. Papiernik, J. Gan, S.R. Yates, C.H. Yang, and D.E. Crowley. 2001. Impact of fumigants on soil microbial communities. Appl. Environ. Microb. 67:3245-3257.

Jenkinson, D.S. 1988. Determination of microbial biomass carbon and nitrogen in soil, p. 368-386. In Wilson, J.R. (ed.). Advances in nitrogen cycling in agricultural acosystems. CAB International, Wallingford, UK.

Kennedy, A.C. and V.L. Gewin. 1997. Soil microbial diversity: present and future considerations. Soil Sci. 162:607-617.

Kennedy, A.C. and T.L. Stubbs. 2006. Soil microbial communities as indicators of soil health. Ann. Arid Zone 45: 287-308.

Layne, R.E.C. and C.S. Tan. 1988. Influence of cultivars, ground covers, and trickle irrigation on early growth, yield, and cold hardiness of peaches on Fox sand. J. Amer. Soc. Hort. Sci. 113:518-525.

Layne, R.E.C., C.S. Tan, and D.M. Hunter. 1994. Cultivar, ground-cover, and irrigation treatments and their interactions affect long-term performance of peach trees. J. Amer. Soc. Hort. Sci. 119:12-19.

Li, Q., H.L. Allen, and A.G. Wollum II. 2005. Effects of irrigation and fertilization on soil microbial biomass and functional diversity. J. Sustainable For. 20(4):17-35.

Liverani, A., D. Cobianchi, A. Crociani, and D. Missere. 1992. Effect of soil management systems on hillside peach orchards. Acta Hort. 315:123-127.

Lynch, J.M. and L.M. Panting. 1982. Effects of season, cultivation and nitrogen fertiliser on the size of the soil microbial biomass. J. Sci. Food Agric. 33:249-252.

Majek, B.A., P.E. Neary, and D.F. Polk. 1993. Smooth pigweed interference in newly planted peach trees. J. Prod. Agric. 6:244-246.

Marx, D.H., W.C. Bryan, and W.A. Campbell. 1971. Effect of endomycorrhizae formed by *Endogone mosseae* on growth of citrus. Mycologia 63:1222-1226.

Mitchem, W.E. 2005. Weed management considerations for peach orchards, p. 279-284. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Mosse, B. 1957. Growth and chemical composition of mycorrhizal and non-mycorrhizal apples. Nature. 179:922-924.

Nappi, P. and R. Jodice. 1985. VA micorrhizae (sic) of apples: the influence of soil treatments and season, p. 318. In Proceedings of the 6th North American Conference on Mycorrhizae, held June 25-29, 1984 in Bend, OR.

Nelson, C.E. 1987. The water relations of vesicular-arbuscular mycorrhizal systems, p. 71-79. In: G.R. Safir (ed). Ecophysiology of VA mycorrhizal plants. CRC Press, Boca Raton.

Nemec, S. and D. Tucker. 1983. Effects of herbicides on endomycorrhizal fungi in Florida citrus (*Citrus* spp.) soils. Weed Sci. 31:427-431.

Nyczepir, A.P. 2005. Nematodes, p. 191-198. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Parker, M.L. and J.R. Meyer. 1996. Peach tree vegetative and root growth respond to orchard floor management. HortScience 31:330-333.

Phillips, J.M. and D.S. Hayman. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans. Br. Mycol. Soc. 55:158-161.

Pinochet, J., C. Calvet, A. Camprubí, and C. Fernández. 1995. Growth and nutritional response of Nemared peach rootstock infected with *Pratylenchus vulnus* and the mycorrhizal fungus *Glomus mosseae*. Fundam. Appl. Nematol. 18:205-210.

Reeder, B.D., J.S. Newman, and J.W. Worthington. 1979. Effect of trickle irrigation on peach trees. HortScience 14:36-37.

Rice, C.W., T.B. Moorman, M. Beare. 1996. Role of microbial biomass carbon and nitrogen in soil quality, p. 203-215. In: J.W. Doran and A.J. Jones (eds.). Methods for assessing soil quality. SSSA special publication no. 49. Soil Science Society of America, Madison, WI.

Ross, R.J. 1992. Influence of sieve mesh size on estimates of microbial carbon and nitrogen by fumigation extraction procedures in soils under pasture. Soil Biol. Biochem. 24:343-350.

Rutto, K.L. and F. Mizutani. 2006. Peach seedling growth in replant and non-replant soils after inoculation with arbuscular mycorrhizal fungi. Soil Biol. Biochem. 38:2536-2542.

Sparling, G.P. and A.W. West. 1988. A direct extraction method to estimate soil microbial C: calibration in situ using microbial respiration and ^{14}C labeled cells. Soil Biol. Biochem. 20:337-343.

Strobel, N.E., R.S. Hussey, and R.W. Roncadori. 1982. Interactions of vesicular-arbuscular mycorrhizal fungi, Meloidogyne incognita, and soil fertility on peach. Phytopathology 72:690-694.

Traquair, J.A. and S.M. Berch. 1988. Colonization of peach rootstocks by indigenous vesicular-arbuscular mycorrhizal (VAM) fungi. Can. J. Animal Sci. 68:893-898.

Tu, C., J.B. Ristaino, and S.J. Hu. 2006. Soil microbial biomass and activity in organic tomato farming systems: effects of organic inputs and straw mulch. Soil Biol. Biochem. 38:247-255.

Vance, E.D., P.C. Brookes, and D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem. 19:703-707.

Wardle, D.A. 1992. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biol. Rev. 67:321-358.

Wardle, D.A., G.W. Yeates, K.I. Bonner, K.S. Nicholson, and R.N. Watson. 2001. Impacts of ground vegetation management strategies in a kiwifruit orchard on the composition and functioning of the soil biota. Soil Biol. Biochem. 33:893-905.

Welker, W.V. and D.M. Glenn. 1989. Sod proximity influences the growth and yield of young peach trees. J. Amer. Soc. Hort. Sci. 114:856-859.

Yao, S., I.A. Merwin, G.W. Bird, G.S. Abawi, and J.E. Thies. 2005. Orchard floor management practices that maintain vegetative or biomass groundcover stimulate soil microbial activity and alter soil microbial community composition. Plant Soil 271:377-389.

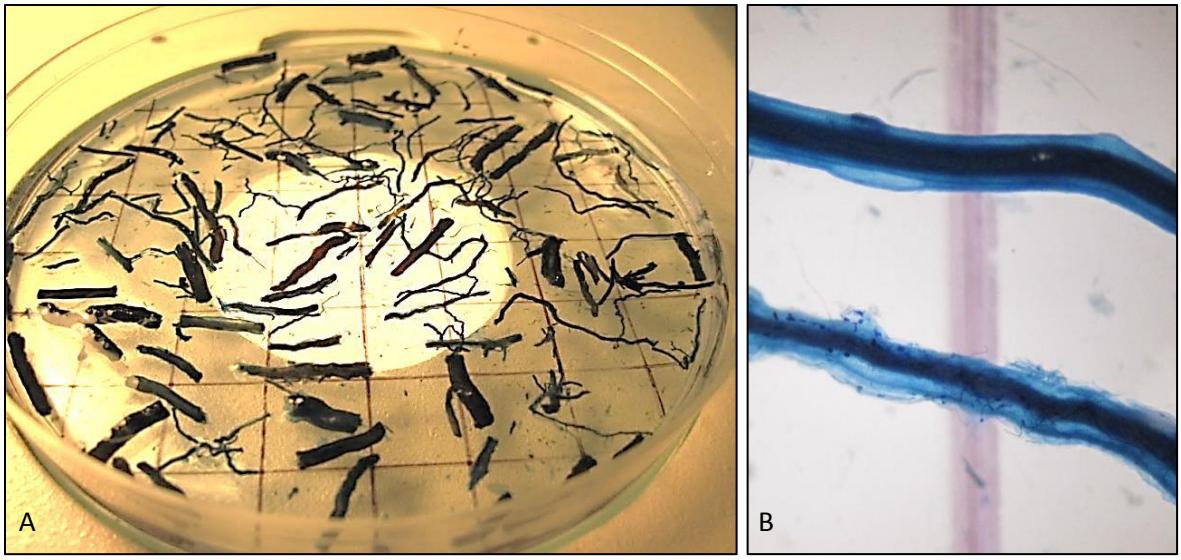

Figure 1. A) The gridline intersection method was used to determine the percentage of infected roots. B) The root at top is not infected; the root at bottom is infected.

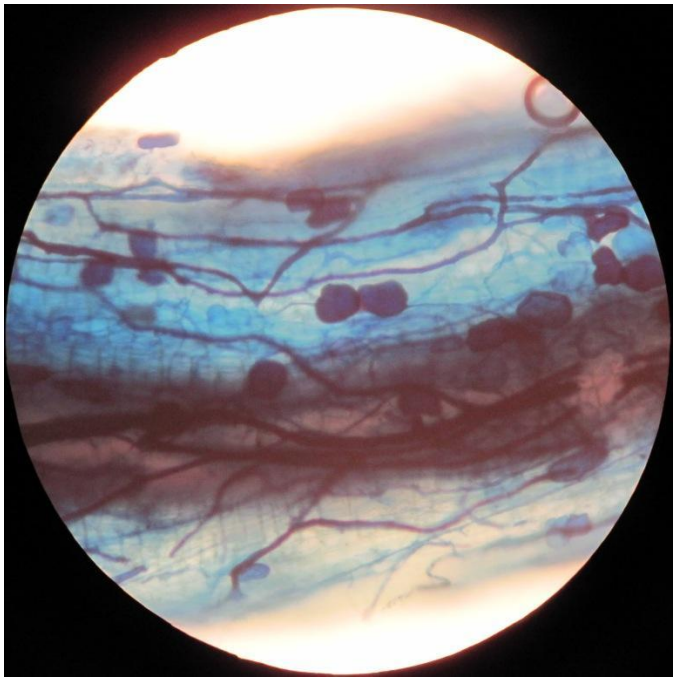
Figure 2. Magnified view of endomycorrhizal colonization of peach roots

Table 1. Effects of vegetation-free strip width and irrigation on endomycorrhizal root colonization of peach on sandy soil in the NC Sandhills, years 3-4 after planting

	Fall 2009*	Spring 2010	Fall 2010
Strip width (m)		**Colonization (%)**	
0	64.5a†	57.1a	68.2ab
1.2	59.0b	47.8a	62.9b
2.4	‡	46.5a	66.9ab
3.6	62.8ab	53.3a	73.9a
p value	*0.0551*	*0.2744*	*0.1327*
Irrigation			
Irrigated	61.8a	52.5a	65.6a
Non-irrigated	62.4a	49.8a	70.3a
p value	*0.7429*	*0.5147*	*0.1564*
*p value for strip*irrigation interaction*	*0.0086*	*0.1601*	*0.9477*

*Means within each column within main effects followed by the same letter do not differ ($\alpha \leq 0.05$)

†Main effect means are pooled across other main effects and 4 reps

‡No samples were collected from 2.4 m plots in 2009

Table 2. Effects of vegetation-free strip width and irrigation on rhizosphere soil microbial biomass carbon (MBC) and nitrogen (MBN), soil microbial respiration (SMR), and net nitrogen mineralization (NNM) for peach on sandy soil in the NC Sandhills, years 3-4 after planting

	Fall 2009				Spring 2010				Fall 2010			
Strip width (m)	**MBC†** mg/kg	**MBN*** mg/kg	**SMR** $mgCO_2/kg/d$	**NNM** mg/kg/d	**MBC** mg/kg	**MBN** mg/kg	**SMR** $mgCO_2/kg/d$	**NNM** mg/kg/d	**MBC** mg/kg	**MBN** mg/kg	**SMR** $mgCO_2/kg/d$	**NNM** mg/kg/d
0	21.74a	8.00ab	21.48a	6.83a	32.69a	5.69a	14.99a	6.29a	36.62a	8.30a	13.11a	3.15a
1.2	18.48a	10.95a	17.17a	6.27a	29.95a	5.43a	13.52a	4.79ab	32.53a	6.18a	12.43a	2.31ab
2.4	‡	‡	‡	‡	25.04b	5.23a	12.05a	3.44b	30.31b	7.14a	11.08a	1.35bc
3.6	15.29a	5.69b	10.08b	4.63b	26.87a	5.10a	11.81a	3.66b	31.31a	4.72a	11.33a	0.88c
p value	*0.1796*	*0.0168*	*0.0199*	*0.0024*	*0.0763*	*0.9263*	*0.8062*	*0.0053*	*0.1192*	*0.2241*	*0.6821*	*0.0010*
Irrigation												
Irrigated	17.06a	9.03a	15.44a	6.07a	27.05a	7.24a	10.16b	4.92a	31.23a	7.31a	12.09a	2.24a
Not Irrigated	19.96a	7.40a	17.04a	5.76a	30.22a	3.48b	16.02a	4.17a	34.16a	5.94a	11.88a	1.61a
p value	*0.2968*	*0.2068*	*0.5929*	*0.4919*	*0.1417*	*<0.0001*	*0.0333*	*0.1820*	*0.1311*	*0.2213*	*0.8734*	*0.0688*
*p value for strip*irrigation interaction*	*0.3662*	*0.7337*	*0.4256*	*0.9019*	*0.5644*	*0.9223*	*0.2886*	*0.9099*	*0.9305*	*0.8617*	*0.6652*	*0.4848*

MBC- microbial biomass carbon; MBN- microbial biomass nitrogen; SMR- soil microbial respiration; NNM- net nitrogen mineralization

* Means within each column within main effects followed by the same letter do not differ ($\alpha \leq 0.05$)

†Main effect means are pooled across other main effects and 4 reps

‡ No samples were collected from 2.4 m plots in 2009

IMPACT OF ORCHARD FLOOR MANAGEMENT PRACTICES

ON CATFACING DAMAGE IN PEACH

Impact of Orchard Floor Management Practices on Catfacing Damage in Peach

Connie L. Fisk and Michael L. Parker

Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695

We thank Bernadette Clark and the crew at the Sandhills Research Station for their help with orchard management and sample collection and Wayne Mitchem and Robert Hoyt for herbicide applications.

Impact of Orchard Floor Management Practices on Catfacing Damage in Peach

Additional index words: *Prunus persica* (L.), ground cover, weed management

Abstract. Orchard floor management practices are primarily aimed at maximizing tree growth and yield while the impacts on fruit quality are often overlooked. This study measured the effect of vegetation-free strip width and irrigation on catfacing damage of peaches. Establishing a vegetation-free strip of as narrow as 0.6 m resulted in less catfacing damage of fruit than was seen in 0 m treatments. The least damage was seen at the industry standard vegetation-free strip width of 3.0 or 3.6 m, with or without irrigation. Treatment differences were seen even though the orchard was on a commercial pesticide spray schedule.

Introduction

Control of orchard floor vegetation and subsequent peach tree growth and yield are directly related (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). Weeds compete with trees for water and nutrients and also serve as alternate hosts for insect pests, including insects that damage and distort fruit, generally referred to as catfacing insects (Meagher et al., 1987; Meagher and Meyer, 1990; Mitchem, 2005).

Catfacing insects, including the tarnished plant bug (*Lygus lineolaris* (Palisot de Beauvois)) and stink bugs in the genera *Acrosternum*, *Euschistus*, *Thyanta*, and *Nezara*, distort fruit

shape with irregular and variable-sized necrotic skin spots and are managed using four to six early-season applications of a broad-spectrum insecticide. However, even vigorous chemical applications in the southeastern US will only provide partial control unless combined with a weed management program (Meagher et al., 1987; Meyer, 1984). Weed management within and between rows can also 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 (Flore, 1999). Reducing the amount of insecticide necessary to control catfacing insects would save money by decreasing inputs, minimizing applicator risk, and reducing the potential for insecticide-resistant pest populations while providing an additional selling point for the product.

In the southeastern US the recommended orchard floor management program for peaches is to establish a cover crop or a permanent sod in the row middles to prevent soil erosion and facilitate equipment movement during wet weather, plus maintain a vegetation-free strip in the tree row using two to three herbicide applications each year (Foy et al., 1994; Layne and Tan, 1988; Mitchem, 2005). The choice of vegetative cover for the row middles is also an important decision and should be chosen to favor varieties that 1) are the least competitive with trees for water and nutrients (Kentucky bluegrass is a better choice than

tall fescue, for example) (Parker et al., 1993; Tworkoski and Glenn, 2001), 2) have the greatest ease of establishment, 3) suppress nematodes such as *Criconemella xenoplax*, the ring nematode, a major contributor to Peach Tree Short Life, and 4) do not harbor orchard pests such as catfacing insects (Meyer et al., 1992).

The purpose of this study was to measure the effect of vegetation-free strip width, with and without irrigation, on catfacing damage of peaches.

Materials and Methods

The experiment was conducted from 2009-2011 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, Koalinitic, thermic Grossarenic Kandiudults) with pH 5.8 and humic matter 0.60% treated before planting with the nematicide Telone II®. The orchard consisted of 'Contender' peach trees (*Prunus persica* L.) grafted onto 'Guardian®' rootstock. One year whips were planted on Feb. 3, 2006 at a spacing of 5.5 m within the row and 6.0 m between rows. Row middles were allowed to populate with native weedy species and were maintained by mowing to a height of 10-13 cm tall. Trees were pruned at the end of dormancy each year 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, and 3.6 m) with or without

micro-sprinkler irrigation. Each plot contained four trees. Data were collected from the two center trees. Vegetation-free strips were chemically maintained using flumioxazin (Chateau®, Valent BioSciences Corp., Libertyville, IL) at 213.3 g ha^{-1} active ingredient for PRE emergent weed control and paraquat (Gramoxone Inteon®, Syngenta Crop Protection, LLC, Greensboro, NC) at 0.67 to 1.0 kg ha^{-1} active ingredient with non-ionic surfactant at 0.25% (v/v) as a post-emergent burndown. Insects were managed per the Southeastern Peach, Nectarine and Plum Pest Management and Culture Guide (Horton et al., 2013) using phosmet (Imidan®, Gowan, Yuma, AZ) at 3.36 kg ha^{-1}, esfenvalerate (Asana®, DuPont, Wilmington, DE) at 0.8 kg ha^{-1}, thiamethoxam (Actara®, Syngenta Crop Protection, LLC) at 0.28 kg ha^{-1}, and permethrin (Helena Chemical, Collierville, TN) at 0.56 kg ha^{-1} all of which help control catfacing insects as well as other peach pests like plum curculio and oriental fruit moth.

For the irrigated plots, one Dan Modular micro-sprinkler (Jain Irrigation Inc., Fresno, CA, USA) was placed 15 cm from the tree trunk. Irrigated plots were irrigated as needed based on precipitation during the growing season. No irrigation was applied when precipitation during the week was 2.54 cm or more. On average, the irrigation system was used seven times per year, April through July. The micro-sprinklers delivered 2.54 cm of water at each irrigation treatment in a 6.0 m diameter around the tree.

Fruit thinning occurred each spring within 30-40 days of full bloom and involved hand thinning excess fruit so that those remaining were no closer than 15 cm apart. Fruit were thinned indiscriminately, whereas a grower may choose to selectively thin catfaced fruit at this point. In 2009 all thinned fruit from one record tree in each plot were retained and examined for catfacing damage. In 2010 and 2011 a subsample of 200 thinned fruit from each replication was retained and examined for catfacing damage. Results were converted to percentages for analysis.

Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, N.C.). The effects of vegetation-free strip width and irrigation on percent catfacing damage were analyzed using PROC GLM with treatment means compared using Duncan's new multiple range test (α=0.05).

Results

In 2009 and 2011 the highest catfacing damage occurred in the 0 m treatment and the lowest catfacing damage in the 3.0 and 3.6 m treatment (Table 1). The 0.6, 1.2, and 2.4 vegetation free strips had intermediate catfacing damage. In 2009 the 3.0 and 3.6 m treatments had 9% less catfacing damage compared with the 0 m treatment. In 2010 vegetation-free strip widths did not affect the level of catfacing and overall, catfacing damage was less than 7%.

Of the three years of the study, 2011 was the only year that irrigation affected catfacing damage with irrigated plots having a higher percentage of catfacing damage than non-irrigated plots (Table 2).

Discussion

Buckelew (2009), observing younger trees in the same orchard as this study, reported that peach tree yields of the grower standard of non-irrigated 3.6 m vegetation-free strip could be matched by reducing the vegetation-free strip to 1.2 m with irrigation. Reducing the vegetation-free area will increase the amount of surface covered with vegetation which may decrease soil degradation in the bare areas. Reducing the width of the vegetation-free strip will also reduce the amount of herbicide growers need to apply each year. Our results show that a vegetation-free strip of as little as 0.6 m can reduce damage from catfacing insects, potentially reducing the amount of insecticide that will need to be sprayed each year. Use of a vegetation-free strip in the tree row will certainly not eliminate the need for insecticide sprays but may make them more effective.

Killian and Meyer (1984) reported a reduction in the frequency of catfacing damage on peaches with herbicide control of winter annual weeds in the tree row (2% damage with treatment compared to 14% without) or over the entire orchard floor (4% damage with treatment compared to 9% without). Our results support this finding and show that benefits can be seen with a vegetation-free strip (eliminating all weeds, not just winter

annuals) as narrow as 0.6 m though greatest benefit is seen when a vegetation-free strip of 3.0 or 3.6 is maintained. Important to note, although the orchard used in the present study was on a commercial pesticide spray 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 865 bushels per hectare and an expected price of $24 per bushel (M.L. Parker, personal communication), a 9% increase in saleable yield would produce an additional 78 bushels worth $1868 per hectare. This increase in saleable yield would more than offset the cost of herbicides necessary to maintain the vegetation-free strip.

This data was collected in years three through five after planting. As the trees age and grow a larger diameter canopy they may require a wider vegetation-free strip to minimize catfacing damage and maximize orchard profitability. The interaction between irrigation x strip width needs further exploration to determine the optimum vegetation-free strip width and irrigation for maximum fruit yield *and* quality.

It is important to note that only one peach variety, 'Contender', was used in this study. 'Contender' has a high blossom density so results with catfacing may be further improved on varieties with a lower bloom density, as growers remove fewer fruit at thinning and proportional loss of marketable fruit will cause higher economic losses.

Literature Cited

Arnold, M.E. and J.H. Aldrich. 1980. Herbicidal effects on peach seedling growth and weed control. HortScience 15:293-294.

Atanassov, A., P.W. Shearer, G. Hamilton, and D. Polk. 2002. Development and implementation of a reduced risk peach arthropod management program in New Jersey. J. Econ. Entomol. 95:803-812.

Belding, R.D., B.A. Majek, G.R.W. Lokaj, J. Hammerstedt, and A.O. Ayeni. 2004. Orchard floor management influence on summer annual weeds and young peach tree performance. Weed Tech. 18:215-222.

Buckelew, J.K. 2009. Orchard floor management in young peach [*Prunus persica* (L.) Batch.]: Effects of irrigation, vegetation-free width, and certain PRE herbicides. NC State Univ., Raleigh, NC, PhD Diss.

Flore, J.A. 1999. Reduced chemical input production of peach. SARE in Michigan, Michigan State University Extension Bulletin E-2692: 2-3.

Foy, C.L., S.B. Harrison, and H.L. Witt. 1994. Herbicide effects on weed control and shoot growth of young apple (*Malus sylvestris*) and peach (*Prunus persica*) trees. Weed Tech. 8:840-848.

Horton, D., P. Brannen, B. Bellinger, D. Lockwood, and D. Ritchie (eds.) 2013. Southeastern peach, nectarine and plum pest management and culture guide. 18 July 2013. <http://www.ent.uga.edu/peach/peachguide.pdf>

Killian, J.C. and J.R. Meyer. 1984. Effect of orchard weed management on catfacing damage to peaches in North Carolina. J. Econ. Entomol. 77:1596-1600.

Layne, R.E.C. and C.S. Tan. 1988. Influence of cultivars, ground covers, and trickle irrigation on early growth, yield, and cold hardiness of peaches on Fox sand. J. Amer. Soc. Hort. Sci. 113:518-525.

Liverani, A., D. Cobianchi, A. Crociani, and D. Missere. 1992. Effect of soil management systems on hillside peach orchards. Acta Hort. 315:123-127.

Lockwood, D.W. and S.C. Myers. 2005. Tree density, orchard design, and training systems, p. 51-64. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Majek, B.A., P.E. Neary, and D.F. Polk. 1993. Smooth pigweed interference in newly planted peach trees. J. Prod. Agric. 6:244-246.

Meagher, R.L., J.R. Meyer, and J.C. Killian. 1987. Within-tree distribution of cat-facing injury on peaches in North Carolina. J. Agric. Entomol. 4:78-81.

Meagher, R.L. and J.R. Meyer. 1990. Effects of ground cover management on certain abiotic and biotic interactions in peach orchard ecosystems. Crop Prot. 9:65-72.

Meyer, J.R. 1984. Catfacing in peaches: effects of ground cover and surrounding vegetation. Proc. Joint Natl. Peach Counc. Southeast Peach Conven.: 5-11.

Meyer, J.R., E.I. Zehr, R.L. Meagher, Jr., and S.K. Salvo. 1992. Survival and growth of peach trees and pest populations in orchard plots managed with experimental ground covers. Ag. Ecosyst. Environ. 41:353-363.

Mitchem, W.E. 2005. Weed management considerations for peach orchards, p. 279-284. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Parker, M.L, J. Hull, and R.L. Perry. 1993. Orchard floor management affects peach rooting. J. Amer. Soc. Hort. Sci. 118:714-718.

Snodgrass, G.L. 1996. Insecticide resistance in field populations of the tarnished plant bug (Heteroptera: Miridae) in cotton in the Mississippi Delta. J. Econ. Entomol. 89:783-790.

Tworkoski, T.J. and D.M. Glenn. 2001. Yield, shoot and root growth, and physiological responses of mature peach trees to grass competition. HortScience 36:1214-1218.

Welker, W.V. and D.M. Glenn. 1989. Sod proximity influences the growth and yield of young peach trees. J. Amer. Soc. Hort. Sci. 114:856-859.

Table 1. Effect of vegetation-free strip width and irrigation on percent catfacing damage in 'Contender peach, years 3-5 after planting

	Year		
	2009*	2010	2011
Strip Width (m)	**Catfacing (%)**		
0	14.5a†	6.9a	5.3a
0.6	9.8ab	6.4a	2.7b
1.2	11.5ab	4.9a	2.9b
2.4	7.5bc	4.8a	3.2b
3.0	5.5c	6.4a	2.2b
3.6	5.4c	5.2a	1.7b
p value	*0.0018*	*0.1412*	*0.0059*
Irrigation			
Irrigated	8.6a	5.9a	3.7a
Non-irrigated	9.4a	5.6a	2.3b
p value	*0.5539*	*0.5699*	*0.0145*
p value for strip irrigation interaction*	*0.0500*	*0.3881*	*0.5700*

*Means within each column within main effects followed by the same letter do not significantly differ ($\alpha \leq 0.05$)

†Main effect means are pooled across other main effects and 4 reps

ROOTSTOCK EFFECT ON SOIL ECOLOGY IN A PEACH ORCHARD

Rootstock Effect on Soil Ecology in a Peach Orchard

Connie L. Fisk[1], Cong Tu[2], David Ritchie[2], Shuijin Hu[2], Michael L. Parker[1]

[1]Department of Horticultural Science and [2]Department of Plant Pathology, North Carolina State University, Raleigh, NC 27695

We thank Bernadette Clark for her help with sample collection and lab analyses and the staff at the Sandhills Research Station for their help with orchard management and sample collection.

Rootstock Effect on Soil Ecology in a Peach Orchard

Abstract. Peach tree short life (PTSL) is a disease complex impacted by many factors, including choice of rootstock and inherent changes in the rhizosphere. The effect of several genetically diverse peach rootstocks on soil microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), soil microbial respiration (SMR), net nitrogen mineralization (NNM), and endomycorrhizal fungal colonization of peach roots was studied in a peach orchard in second leaf at the Sandhills Research Station in North Carolina. MBC was highest in the 'Guardian®' rootstock rhizosphere in the fall. Differences among rootstocks in SMR were apparent, but were not related to rootstock species parentage. In the spring, soil at the dripline of 'Krymsk® 1' rootstock had the highest SMR and 'Lovell' had the lowest. In the fall, soil around 'Empyrean® 2' had the highest SMR and 'Krymsk 1' had the lowest. Microbial respiration changes among seasons and rootstocks may be a function of the microbial ecology of the rootstock's rhizosphere or a symptom of failing peach tree health. 'Controller 5' and 'Viking' had the highest endomycorrhizal root colonization while 'Guardian®' and 'Empyrean® 2' had the lowest. The purported resistance of 'Guardian®' to PTSL is evidently not due to superior mycorrhizal dependency. Rootstock rhizospheres did not differ in either fall or spring for MBN or NNM.

Introduction

Soil is a microbiologically dynamic and complex environment. In addition to plant support, its functions include supplying nutrients, retaining water, supporting soil food webs,

recycling nutrients, remediating pollutants, and suppressing plant pathogens (Moore-Kucera et al., 2008). The rhizosphere (the soil immediately in the vicinity of plant roots) is a biological niche with additional levels of complexity from interactions with the plant root system. The physical and chemical properties of soil are affected by roots in the following three ways: 1) roots exude nutrients into the soil, mainly in the form of nitrogen compounds and carbohydrates), 2) roots contribute organic matter through sloughing of epidermal tissue, and 3) roots withdraw water from the system (Bot and Benites, 2005). Root exudates, in particular, play an important role in microbial dynamics (Campbell and Greaves, 1990; Kennedy and Gewin, 1997; Kennedy and Stubbs, 2006) and will vary between plant species and between rootstocks within a species. Fruit trees grafted onto rootstocks with a rhizosphere that supports a diverse microbial community may indirectly benefit through greater resistance to environmental stress and external disturbance (Crecchio et al., 2004).

Soil chemical and biological properties are highly sensitive to soil management and environmental stress and thus can be used to assess soil quality (Trasar-Cepeda et al., 1998). Biological indicators of soil quality include microbial biomass and respiration, net nitrogen mineralization, nematode communities and mycorrhizal associations (Karlen et al., 1997) that will differ with plant community and management practices (Bot and Benites, 2005).

Soil microorganisms (the soil microbial biomass) decompose plant residues and soil organic matter to release carbon dioxide and plant-available nutrients, aid pesticide degradation, and contribute to soil aggregation (Kennedy and Stubbs, 2006). Measurement of microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) are frequently used as early indicators of changes in soil chemical and physical properties (Brookes, 1995; Moore et al., 2000; Rice et al., 1996). Soil microbial respiration (SMR) is widely used as an index of both microbial activity and microbial biomass (Brookes, 1995). The rate of net nitrogen mineralization (NNM; the conversion of organic N to NH_4^+, resulting in the liberation of plant-available inorganic N forms) is an indicator of soil fertility (Heumann et al., 2012).

Several species of nematodes are of concern where peaches are planted in light, sandy soils and in plots that were previously planted to peaches or other crops that are susceptible to root-knot nematodes. Root-knot nematodes (*Meloidogyne* spp.) can severely affect tree establishment and the ring nematode (*Criconemella xenoplax*) is associated with premature tree death to the peach tree short life (PTSL) complex (Nyczepir, 2005). While PTSL is still only partially understood, contributing factors are known to include ring nematode (C. *xenoplax*), bacterial canker (caused by *Pseudomonas syringae* pv. *syringae*), and cold damage (Nesmith et al., 1981; Nyczepir, et al., 1983; Ritchie and Clayton, 1981; Zehr et al., 1976). Peach tree growth and survival can also be affected by lesion (*Pratylenchus* spp.) and dagger (*Xiphenema americanum*) nematodes (Nyczepir, 1991; Reighard, 2005). Treatment with a nematicide is a common pre-plant practice on sandy soils and was shown

to increase survival, trunk cross-sectional area and water uptake (Horton et al., 1981). At present, the nematicide Telone II (1,3-dichloropropene) is commonly used in the southeastern US for commercial peach production with minimal impact on soil microbial communities (Ibekwe et al., 2001).

Good development of endomycorrhizae, a symbiotic relationship between plant roots and arbuscular mycorrhizal (AM) fungi, is beneficial to the growth of peach (*Prunus persica*) (Gilmore 1971; Pinochet et al., 1995), plum (*Prunu*s spp.) (Camprubí et al., 1993), apple (*Malus domestica*) (Granger et al., 1983; Mosse, 1957), and *Citrus* trees (Franca et al., 2007; Marx et al., 1971). Mycorrhizae can increase plant growth, especially in infertile soils, as a result of an enhanced ability of infected roots to absorb nutrients (Gerdemann, 1968). Secondarily, AM benefit plants under physiological stress, such as drought conditions (Barea, 1991; Nelson, 1987), and when impacted or infected by diseases (Azcón-Aguilar and Barea, 1996; Dehne, 1982) and nematodes (Francl, 1993; Hussey and Roncadori, 1982).

Different rootstocks within a genus may be more or less mycorrhizally dependent (Camprubí et al., 1993). The soil microorganisms in the rhizosphere will vary with the size of the root system and the metabolic exudates released in the soil (Kennedy and Stubbs, 2006), both functions of the rootstock. In fact, the affinity for mycorrhizal colonization appears to be cultivar specific rather than species specific (Granger et al., 1983; Pinochet et al., 1995). Therefore rootstock breeding programs should evaluate new crosses for their

mycorrhizal affinity to provide growers with plants that have an increased capacity to withstand stress conditions and tolerance of pathogenic soilborne fungi and nematodes (Calvet et al., 2004). This may allow growers to reduce soil chemical treatments which are expensive and hazardous to orchard workers (Azcón-Aguilar and Barea, 1996).

Mycorrhizal fungi are ubiquitous and most growers will not need to inoculate their soil prior to planting. Traquair and Berch (1988) reported heavy colonization by indigenous AM fungi within six months after planting peach. Rutto and Mizutani (2006) reported high seedling infection rates in both replant and nonreplant soils after one season.

The objective of this study was to compare the soil ecology of six peach rootstocks, 'Guardian®', 'Lovell', 'Controller 5', 'Krymsk 1', 'Empyrean® 2', and 'Viking', in the North Carolina Sandhills after one year in the field.

Materials and Methods

The experiment was conducted at the Sandhills Research Station in Jackson Springs, NC (35.21°N, 79.63°W). Soil was Candor Sand (sandy, Koalinitic, thermic Grossarenic Kandiudults) with a pH of 5.8 and a humic matter content of 0.66% treated before planting with the nematicide Telone II® (281 L ha^{-1}) over a 2 m strip centered on the tree row. The evaluated trees were 'Redhaven' peach (*Prunus persica* L.) grafted onto the following rootstocks: 'Guardian®' (*P. persica*), 'Lovell' (*P. persica*), 'Controller™ 5' (*P. salicina* x *P.*

persica), 'Krymsk® 1' (*P. tomentosa* x *P. cerasifera*), 'Empyrean® 2' (Penta; *P. domestica*), and 'Viking' (interspecific hybrid between peach, almond, plum, and apricot). Trees were planted as part of the larger NC-140 Peach Rootstock Trial (http://www.nc140.org/plantings/2009peachrootstock.html) on Mar 10, 2009 at a spacing of 4.9 m within the row and 6.0 m between rows in a randomized block design with eight replications. For the present study, samples were only collected from four replications due to tree death attributed to bacterial canker (*Pseudomonas syringae*) in several of the rootstocks. Trees were irrigated using micro-sprinklers during the growing season when precipitation during the week was less than 2.54 cm. A 3.6 m weed free strip in the tree rows was maintained by broadcast application of tank mixed herbicides per commercial recommendations. Row middles were allowed to populate with native weedy species and were maintained by mowing to a height of 10-13 cm tall as needed.

Soil samples were collected from the upper 15 cm layer of soil at the drip line of the tree canopy in May (spring) and October (fall). One composite sample consisted of 4 replicate cores (5 cm diameter x 15 cm depth) per tree. Samples were immediately sealed in plastic bags, placed in coolers, and transported to the laboratory. The field-moist samples were sieved with a 2 mm screen and stored in sealed plastic bags at 4°C until analysis. Peach roots collected in the fall from each sample on the sieve were stored in separate sealed plastic bags at 4°C.

Soil physical and chemical properties. Soil moisture was determined by placing 10 g of soil in a plastic beaker, oven drying at 105±1°C for 24 hours, and reweighing the sample. For soil pH and electrical conductivity (EC), soil samples were diluted 1:2 with distilled water, allowed to sit for 20 minutes and filtered through Whatman 4 filter paper (Whatman International, England). The pH and EC of the filtrate was measured using a Hanna Meter (HI 9811, Hanna Instruments, Smithfield, RI) standardized to pH 6.0 and EC 0.14.

Soil microbial biomass. Microbial biomass C (MBC) and microbial biomass N (MBN) were extracted by the chloroform-fumigation method (Ross, 1992; Vance et al., 1987). Twenty grams of soil were fumigated with ethanol-free chloroform for 48 hr. Both fumigated and non-fumigated soils were extracted with 50 mL of 0.5 mol L^{-1} K_2SO_4 by shaking for 30 minutes. A total organic carbon (TOC) analyzer (TOC-5050A, Shimadzu Corporation, Kyoto, Japan) was used to determine the organic C (C_{org}) in the extracts. MBC was calculated as follows: MBC=(C_{org} in fumigated soil-C_{org} in non-fumigated soil)/k_{ec}, where k_{ec}=0.33, the factor used here to convert the extracted organic C to MBC (Sparling and West, 1988). N concentration in the extract was determined on a Lachat flow injection analyzer (Lachat Instruments, Milwaukee, WI) after digestion using alkaline persulfate oxidation (Cabrera and Beare, 1993). The MBN was calculated using the equation: MBN=(total N in fumigated soil-total N in non-fumigated soil/k_{en}, where k_{en}=0.45, the factor used to convert the extracted organic N to MBN (Jenkinson, 1988).

Soil microbial respiration (SMR). Microbial activity was measured using a method modified from Alef and Nannipieri (1995). Twenty grams of soil were placed in an Erlenmeyer flask and distilled water was added to bring the sample to 10% moisture (based on results of the soil moisture test). Flasks were placed in 0.946 L glass jars with 5 ml distilled water in the bottom and a 50 ml beaker containing 5 ml 0.25 mol L^{-1} NaOH, sealed, and incubated in the dark at 25°C. After seven days, the NaOH beaker was replaced with one containing fresh NaOH and the jars were incubated for an additional seven days. The CO_2 trapped in the NaOH solution was titrated with 0.1 mol L^{-1} HCl. Microbial respiration was estimated as mg CO_2 kg^{-1} soil d^{-1} by averaging data from both weeks.

Net nitrogen mineralization (NNM). Net nitrogen mineralization was determined using the method described by Hart et al. (1994). After the completion of the two week incubation for soil microbial respiration the soil samples were incubated for an additional two weeks. NH_4^+ and NO_3^- in the soil were extracted with 50 mL of 0.5 mol L^{-1} K_2SO_4 solution and analyzed with the Lachat flow injection analyzer. Net N mineralized in soil was calculated as the difference between K_2SO_4-extractable inorganic N contents before and after incubation.

Arbuscular mycorrhizal colonization of peach roots. One hundred 1 cm lengths of fine peach roots (diameters of 0.5-1.0 mm) were used to determine mycorrhizal colonization of roots, following the method described by Phillips and Hayman (1970). Root segments were submerged in 10% KOH solution in filtering crucibles in plastic containers. The plastic

containers were put into a hot water steamer for 30 minutes or until roots were cleared. The roots were then rinsed with tap water to remove KOH and then submerged in 1% HCl for at least one hour. After removal from the HCl solution roots were stained using a trypan blue solution (0.05% trypan blue, 50% glycerine, 25% lactic acid) and heated again in the steamer for 20 minutes. Excess stain was washed off with tap water. AM colonization was determined using a Nikon SMZ-1B dissecting microscope (Nikon, Tokyo, Japan) and the gridline intersection method (by distributing samples across a petri dish with a 1 cm grid and observing the percentage of infected roots to uninfected roots where they crossed the gridlines).

Data were subjected to analysis of variance using PROC GLM with SAS version 9.3 (SAS Institute Inc., Cary, N.C.). Means separation was by Duncan's new multiple range test (α=0.05).

Results

Average soil moisture was 5.7% in the spring with no difference between rootstocks and 5.3% in the fall (Appendix 2). Soil pH averaged 5.27 in the spring and 6.08 in the fall and soil EC averaged 0.05 mS cm^{-1} in the spring and 0.07 mS cm^{-1} in the fall with no difference between rootstocks (Appendix 2).

Neither MBC nor MBN in the spring or MBN in the fall differed due to rootstock (Table 1). In the fall, 'Guardian®' had the highest and 'Controller 5' had the lowest MBC concentrations of all the rootstocks. In the spring 'Krymsk® 1' had the highest SMR and 'Lovell' had the lowest SMR rate of the rootstocks. However, in the fall 'Empyrean® 2' had the highest and 'Controller 5' and 'Krymsk® 1' had the lowest SMR rate of the rootstocks. Rootstocks did not differ in NNM in the spring or fall.

'Controller 5' and 'Viking' had the highest amounts of endomycorrhizal root colonization while 'Guardian®' and 'Empyrean® 2' had the lowest (P=0.0187) (Figure 1).

Discussion

After one year in the field, rootstock rhizosphere soils did not significantly differ for MBC, MBN, SMR, or NNM. Duncan's separations existed for MBC and SMR but were not related to rootstock species parentage. It is interesting that the rootstock with the highest soil microbial respiration rate in the spring, 'Krymsk® 1', had the lowest soil microbial respiration rate in the fall. It is unknown whether this is a function of the microbial ecology of the rootstock's rhizosphere or whether it may be a symptom of failing tree health. The bacterial canker rating for 'Krymsk® 1' was 2.4 in 2010 (0=no visible symptoms, 1=terminal dieback of one limb, 2=dieback on two limbs affecting up to 50% of the tree, 3=dieback on 50-75% of the tree, 4=leaf growth emerged, but a majority of tree is dying, 5=tree is dead), higher than all other rootstocks examined. By the following year, two of the six trees on

'Krymsk® 1' rootstock were dead. 'Guardian®' and 'Empyrean® 2' received a bacterial canker rating of 0 in 2010 and had the two highest soil microbial respiration rates. This relationship needs further examination to determine if reduced soil microbial respiration rate may be an early warning for failing tree health.

The rootstocks 'Controller 5' and 'Viking' had the highest AM root colonization and 'Guardian®' and 'Empyrean® 2' had the lowest. 'Guardian®', the current preferred rootstock in the southeastern US, tolerates peach tree short life with greater survival on sandy, replant sites with ring nematode and is also tolerant of root knot nematodes, bacterial canker and cold injury (Okie et al., 1994; Parker et al., 1997; Reighard, 2005; Reighard et al., 1997). Evidently, the rootstock's survival and tolerance of nematodes is not due to superior mycorrhizal dependency.

Literature Cited

Alef, K. and P. Nannipieri. 1995. Estimation of microbial activities, p. 193-270. In Alef, K. and P. Nannipieri (eds.). Methods in applied soil microbiology and biochemistry. Academic Press, London.

Azcón-Aguilar, C. and J.M. Barea. 1996. Arbuscular mycorrhizas and biological control of soil-borne plant pathogens – an overview of the mechanisms involved. Mycorrhiza 6:457-464.

Barea, J.M. 1991. Vesicular-arbuscular mycorrhizae as modifiers of soil fertility. Adv. Soil Sci. 15:2-40.

Bot, A. and J. Benites. 2005. The importance of soil organic matter. FAO Soils Bulletin 80. 19 September 2013. <http://www.fao.org/docrep/009/a0100e/a0100e00.htm>.

Brookes, P.C. 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. Biol. Fertil. Soils. 19:269-279.

Cabrera, M.L. and M.H. Beare. 1993. Alkaline persulfate oxidation for determining total nitrogen in microbial biomass extracts. Soil Sci. Soc. Am. J. 57:1007-1012.

Calvet, C., V. Estaún, A. Camprubí, A. Hernández-Dorrego, J. Pinochet, and M.A. Moreno. 2004. Aptitude for mycorrhizal root colonization in *Prunus* rootstocks. Sci. Hort. 100:39-49.

Campbell, R. and M.P. Greaves. 1990. Anatomy and community structure of the rhizosphere, p. 11-34. In Lynch, J.M. (ed.). The rhizosphere. John Wiley & Sons, Chichester.

Camprubí, A., J. Pinochet, C. Calvet, and V. Estaun. 1993. Effects of the root-lesion nematode *Pratylenchus vulnus* and the vesicular-arbuscular mycorrhizal fungus *Glomus mosseae* on the growth of three plum rootstocks. Plant Soil 153:223-229.

Crecchio, C., A. Gelsomino, R. Ambrosoli, J.L. Minati, and P. Ruggiero. 2004. Functional and molecular responses of soil microbial communities under differing soil management practices. Soil Biol. Biochem. 36:1873-1883.

Dehne, H.W. 1982. Interaction between vesicular-arbuscular mycorrhizal fungi and plant pathogens. Phytopathology 72:1115-1119.

França, S.C., S.M. Gomes-da-Costa, and A.P.D. Silveira. 2007. Microbial activity and arbuscular mycorrhizal fungal diversity in conventional and organic citrus orchards. Biol. Agric. Hortic. 25:91-102.

Francl, L.J. 1993. Interactions of nematodes with mycorrhizae and mycorrhizal fungi, p. 203-216. In Khan, M.W. (ed.). Nematode interactions. Chapman & Hall, London.

Gerdemann, J.W. 1968. Vesicular-arbuscular mycorrhizal and plant growth. Annu. Rev. Phytopathol. 6:397-418.

Gilmore, A.E. 1971. The influence of endotrophic mycorrhizae on the growth of peach seedlings. J. Amer. Soc. Hort. Sci. 96:35-38.

Granger, R.L., C. Plenchette, and J.A. Fortin. 1983. Effect of vesicular-arbuscular (VA) endomycorrhizal fungus (*Glomus epigaeum*) on the growth and leaf mineral content of two apple clones propagated in vitro. Can. J. Plant Sci. 63:551-555.

Hart, S.C., J.M. Stark, E.A. Davidson, and M.K. Firestone. 1994. Nitrogen mineralization, immobilization, and nitrification, p. 985-1018. In Weaver, R.W., S. Bottomley, P. Bezdicek, D. Smith, S. Tabatabai, and A. Wollum (eds.). Methods of Soil Analysis, Part 2: Microbial and Biochemical Properties. Soil Science Society of America, Madison, WI.

Heumann, S., H. Ringe, and J. Böttcher. 2012. Long-term net N mineralization potential as an indicator for soil fertility: chances and constraints. Arch. Agron. Soil Sci. 58(sup1):S107-S111.

Horton, B.D., E.J. Wehunt, J.H. Edwards, R.R. Bruce, and J.L. Chesnee. 1981. The effects of drip irrigation and soil fumigation on 'Redglobe' peach yields and growth. J. Amer. Soc. Hort. Sci. 106:438-443.

Hussey, R.S. and R.W. Roncadori. 1982. Vesicular-arbuscular mycorrhizae may limit nematode activity and improve plant growth. Plant Dis. 66:9-14.

Ibekwe, A.M., S.K. Papiernik, J. Gan, S.R. Yates, C.H. Yang, and D.E. Crowley. 2001. Impact of fumigants on soil microbial communities. Appl. Environ. Microb. 67:3245-3257.

Jenkinson, D.S. 1988. Determination of microbial biomass carbon and nitrogen in soil, p. 368-386. In Wilson, J.R. (ed.). Advances in nitrogen cycling in agricultural acosystems. CAB International, Wallingford, UK.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: a concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 61:4-10.

Kennedy, A.C. and V.L. Gewin. 1997. Soil microbial diversity: present and future considerations. Soil Sci. 162:607-617.

Kennedy, A.C. and T.L. Stubbs. 2006. Soil microbial communities as indicators of soil health. Ann. Arid Zone 45: 287-308.

Marx, D.H., W.C. Bryan, and W.A. Campbell. 1971. Effect of endomycorrhizae formed by *Endogone mosseae* on growth of citrus. Mycologia 63:1222-1226.

Moore, J.M., S. Klose, and M.A. Tabatabai. 2000. Soil microbial biomass carbon and nitrogen as affected by cropping systems. Biol. Fertil. Soils. 31:200-210.

Moore-Kucera, J., A.N. Azarenko, L. Brutcher, A. Chozinski, D.D. Myrold, and R. Ingham. 2008. In search of key soil functions to assess soil community management for sustainable sweet cherry orchards. HortScience 43:38-44.

Mosse, B. 1957. Growth and chemical composition of mycorrhizal and non-mycorrhizal apples. Nature 179:922-924.

Nelson, C.E. 1987. The water relations of vesicular-arbuscular mycorrhizal systems, p. 71-79. In: G.R. Safir (ed). Ecophysiology of VA mycorrhizal plants. CRC Press, Boca Raton.

Nesmith, W.C., E.I. Zehr, and W.M. Dowler. 1981. Association of *Macroposthonia xenoplax* and *Scutellonema brachyurum* with the peach tree (*Prunus persica*) short life syndrome. J. Nematol. 13:220.

Nyczepir, A.P. 1991. Nematode management strategies in stone fruits in the United States. J. Nematol. 23:334-341.

Nyczepir, A.P. 2005. Nematodes, p. 191-198. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Nyczepir, A.P., E.I. Zehr, S.A. Lewis, and D.C. Harshman. 1983. Short life of peach trees induced by *Criconemella xenoplax*. Plant Dis. 67: 507-508.

Okie, W.R., G.L. Reighard, T.G. Beckman, A.P. Nyczepir, C.C. Reilly, E.I. Zehr, W.C. Newall, Jr., and D.W. Cain. 1994. Field-screening *Prunus* for longevity in the southeastern United States. HortScience 29:673-677.

Parker, M.L., D. Ritchie, and A. Nyczepir. 1997. Peach rootstock performance by BY-520-9 and Lovell in a peach tree short life replant site. HortScience 32:497 (abstr.).

Phillips, J.M. and D.S. Hayman. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans. Br. Mycol. Soc. 55:158-161.

Pinochet, J., C. Calvet, A. Camprubí, and C. Fernández. 1995. Growth and nutritional response of Nemared peach rootstock infected with *Pratylenchus vulnus* and the mycorrhizal fungus *Glomus mosseae*. Fundam. Appl. Nematol. 18:205-210.

Reighard, G.L. 2005. Rootstocks, p. 41-44. In: D. Horton and D. Johnson (eds.). Southeastern peach growers' handbook. Georgia Experiment Station Handbook No. 1. University of Georgia, Athens.

Reighard, G.L., W.C. Newall, T.G. Beckman, W.R. Okie, E.I. Zehr, and A.P. Nyczepir. 1997. Field performance of *Prunus* rootstock cultivars and selections on replant soils in South Carolina. Acta Hort. 451:243-250.

Rice, C.W., T.B. Moorman, M. Beare. 1996. Role of microbial biomass carbon and nitrogen in soil quality, p. 203-215. In: J.W. Doran and A.J. Jones (eds.). Methods for assessing soil quality. SSSA special publication no. 49. Soil Science Society of America, Madison, WI.

Ritchie, D.F. and C.N. Clayton. 1981. Peach tree short life: a complex of interacting factors. Plant Dis. 65:462-469.

Ross, R.J. 1992. Influence of sieve mesh size on estimates of microbial carbon and nitrogen by fumigation extraction procedures in soils under pasture. Soil Biol. Biochem. 24:343-350.

Rutto, K.L. and F. Mizutani. 2006. Peach seedling growth in replant and non-replant soils after inoculation with arbuscular mycorrhizal fungi. Soil Biol. Biochem. 38:2536-2542.

Sparling, G.P. and A.W. West. 1988. A direct extraction method to estimate soil microbial C: calibration in situ using microbial respiration and ^{14}C labeled cells. Soil Biol. Biochem. 20:337-343.

Traquair, J.A. and S.M. Berch. 1988. Colonization of peach rootstocks by indigenous vesicular-arbuscular mycorrhizal (VAM) fungi. Can. J. Animal Sci. 68:893-898.

Trasar-Cepeda, C., C. Leirós, F. Gil-Sotres, and S. Seoane. 1998. Towards a biochemical quality index for soils: an expression relating several biological and biochemical properties. Biol. Fertil. Soils 26:100-106.

Vance, E.D., P.C. Brookes, and D.S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem. 19:703-707.

Zehr, E.I., R.W. Miller, and F.H. Smith. 1976. Soil fumigation and peach rootstocks for protection against peach tree short-life. Phytopathology 66:689-694.

Table 1. Rootstock rhizosphere soil microbial biomass carbon (MBC) and nitrogen (MBN), soil microbial respiration (SMR), and net nitrogen mineralization (NNM) for peach in second leaf on sandy soil in the NC Sandhills

	Spring				Fall			
Rootstock	**MBC[y,z]**	**MBN**	**SMR**	**NNM**	**MBC**	**MBN**	**SMR**	**NNM**
Guardian®	14.44a	3.56a	8.63ab	2.90a	34.36a	7.28a	6.05ab	2.60a
Lovell	15.72a	4.09a	6.68b	3.22a	32.63ab	12.20a	5.31ab	1.93a
Controller 5	14.29a	5.47a	8.39ab	3.02a	30.94b	5.77a	4.33b	2.13a
Krymsk® 1	15.97a	4.82a	13.52a	2.85a	32.19ab	7.79a	3.60b	3.08a
Empyrean® 2	15.42a	5.13a	10.10ab	2.93a	31.97ab	8.09a	7.77a	2.33a
Viking	15.00a	3.80a	11.81ab	4.92a	33.08ab	10.12a	5.32ab	2.40a
p value	*0.9867*	*0.8996*	*0.2793*	*0.4149*	*0.0901*	*0.3526*	*0.0516*	*0.1490*

[z]Samples in each column with the same letter are not significantly different ($\alpha \leq 0.05$)
[y]Means are pooled across 4 reps

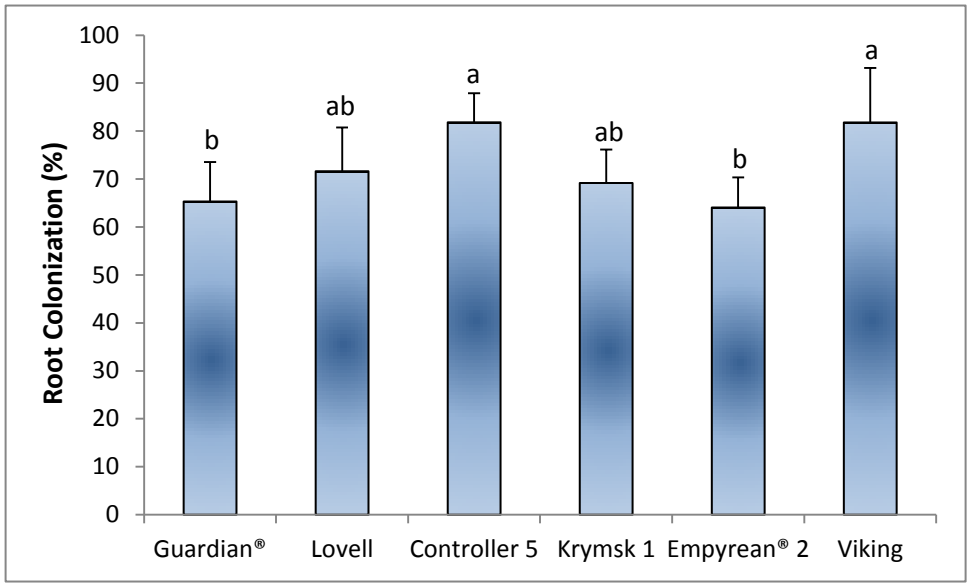

Figure 1. Endomycorrhizal root colonization by rootstock for peach in second leaf on sandy soil in the NC Sandhills (*p*=0.0187). Vertical bars represent standard deviation over four replications. Rootstocks with the same index letter are not significantly different (α≤0.05) separated by Duncan's new multiple range test.

APPENDICES

Appendix 1. Effect of Vegetation-free Width and Irrigation on Peach Tree Growth, Yield, and Fruit Size, Additional Figures

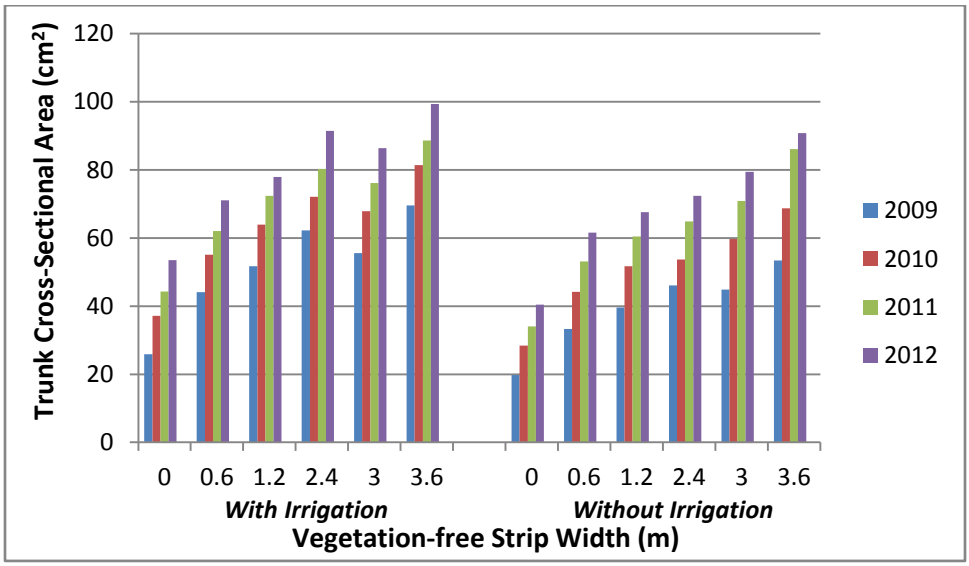

Figure 1. Effect of vegetation-free strip width, with and without irrigation, on trunk cross-sectional area of peach trees, years 3-6

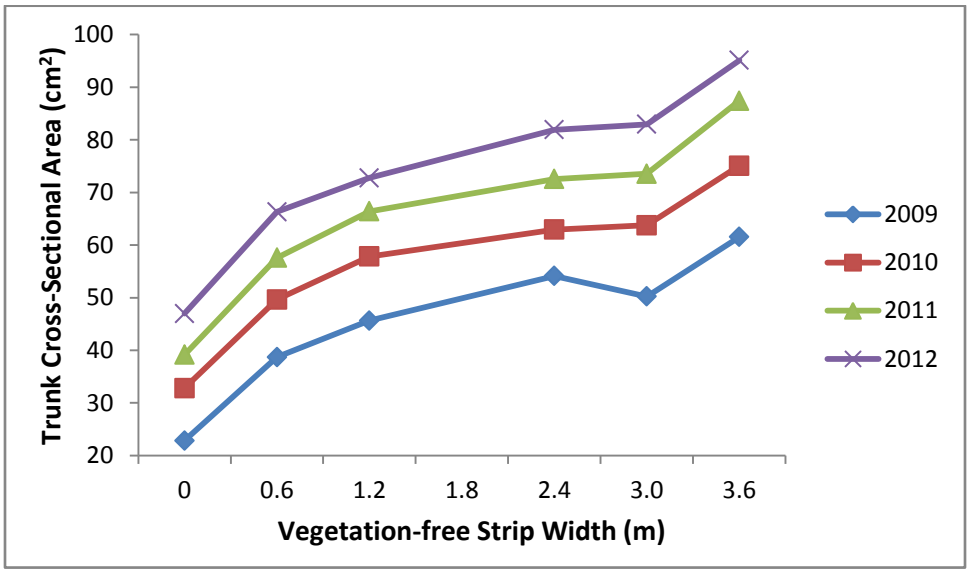

Figure 2. Effect of vegetation-free strip width on trunk cross-sectional area (cm^2) of peach trees, years 3-6

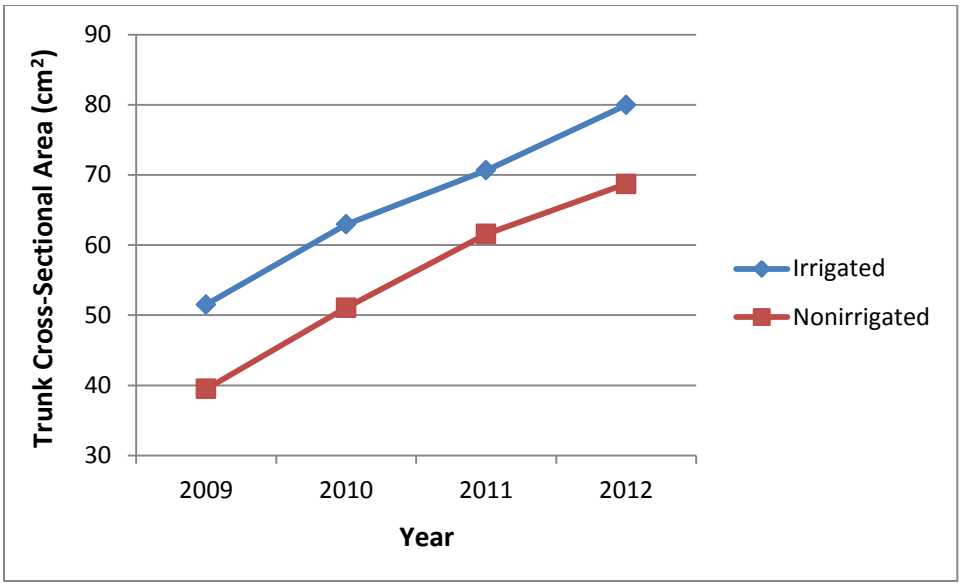

Figure 3. Effect of irrigation on trunk cross-sectional area (cm^2) of peach trees, years 3-6

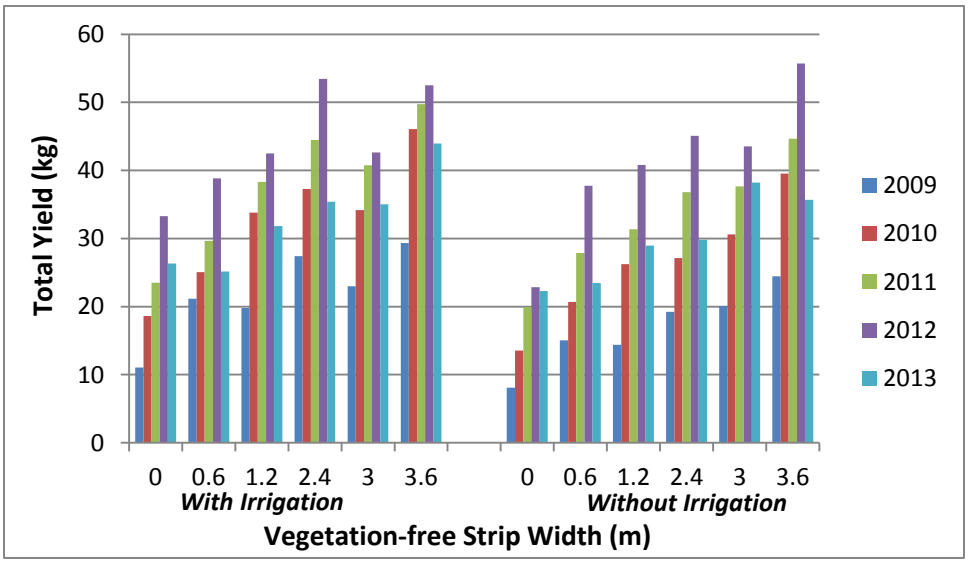

Figure 4. Effect of vegetation-free strip width, with and without irrigation, on peach yield (kg), years 3-7

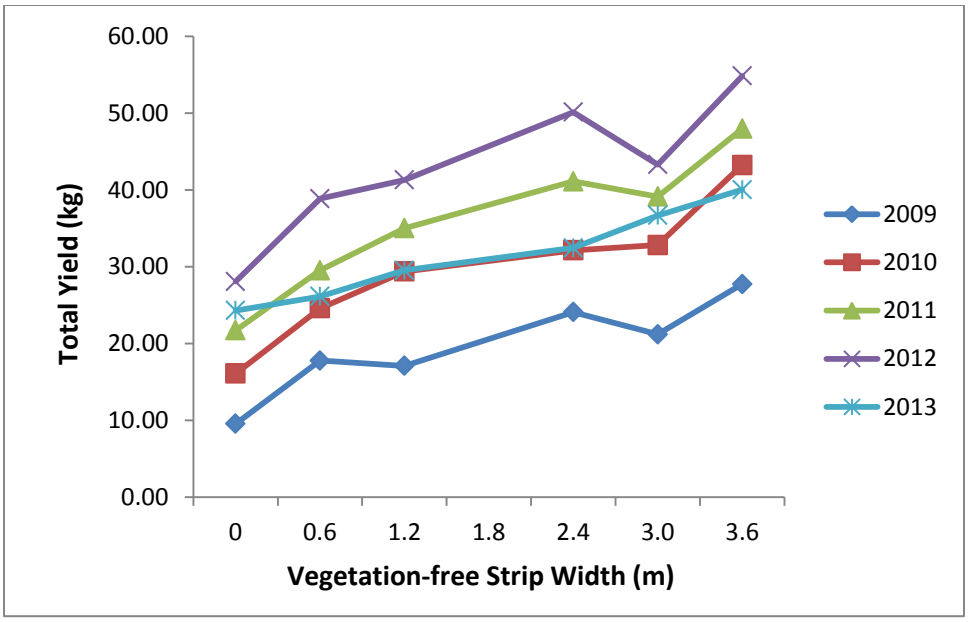

Figure 5. Effect of vegetation-free strip on peach yield (kg), years 3-7

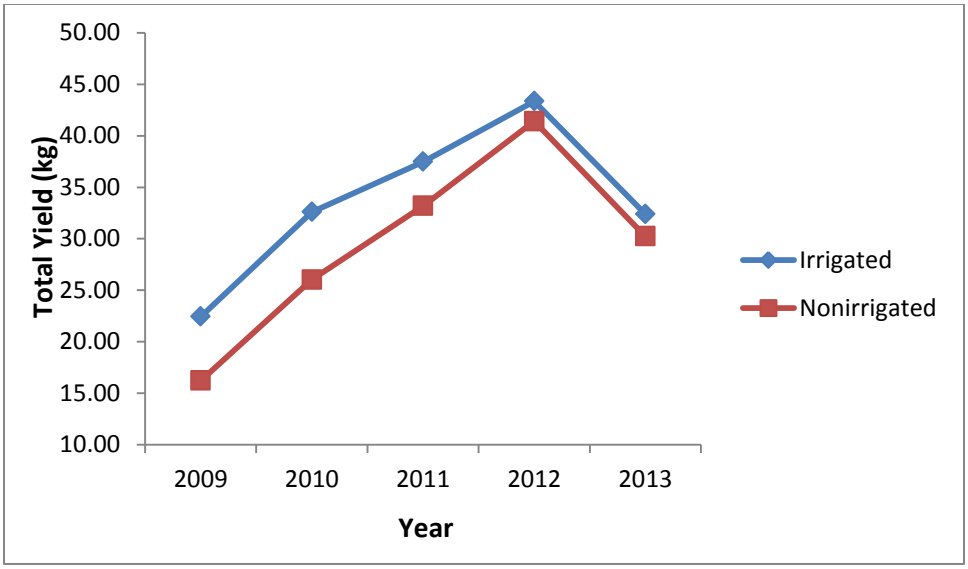

Figure 6. Effect of irrigation on peach yield (kg), years 3-7

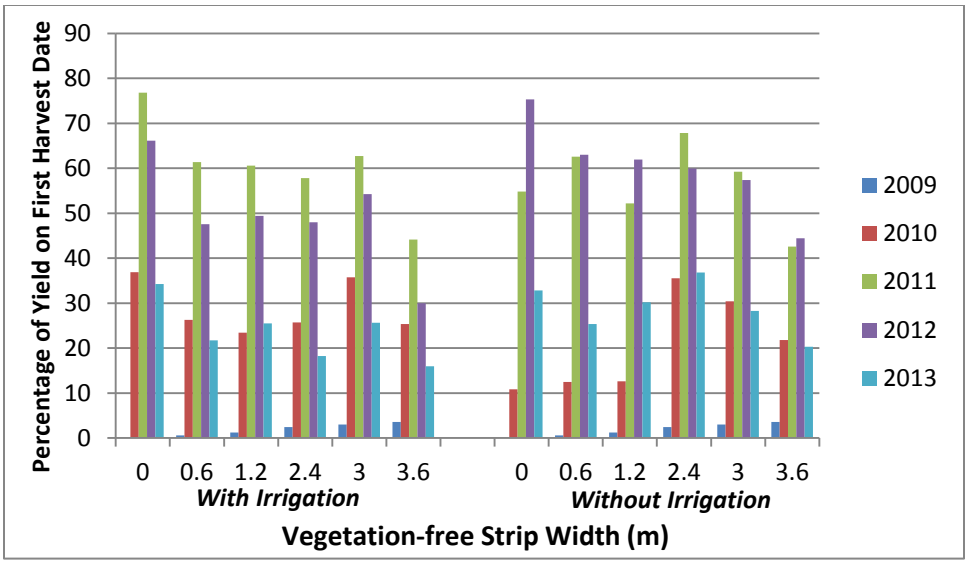

Figure 7. Effect of vegetation-free strip width, with and without irrigation, on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7

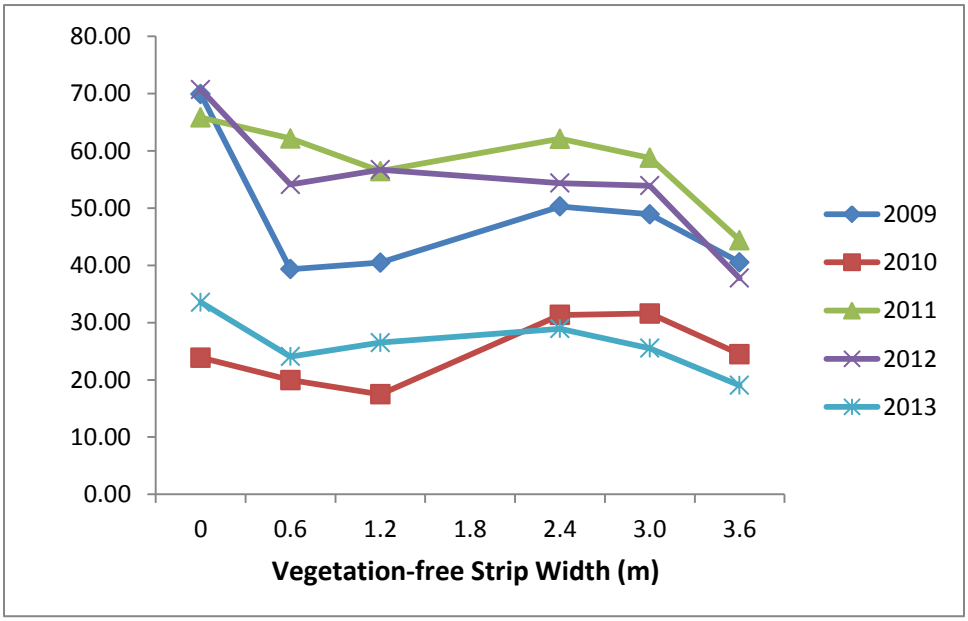

Figure 8. Effect of vegetation-free strip width on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7

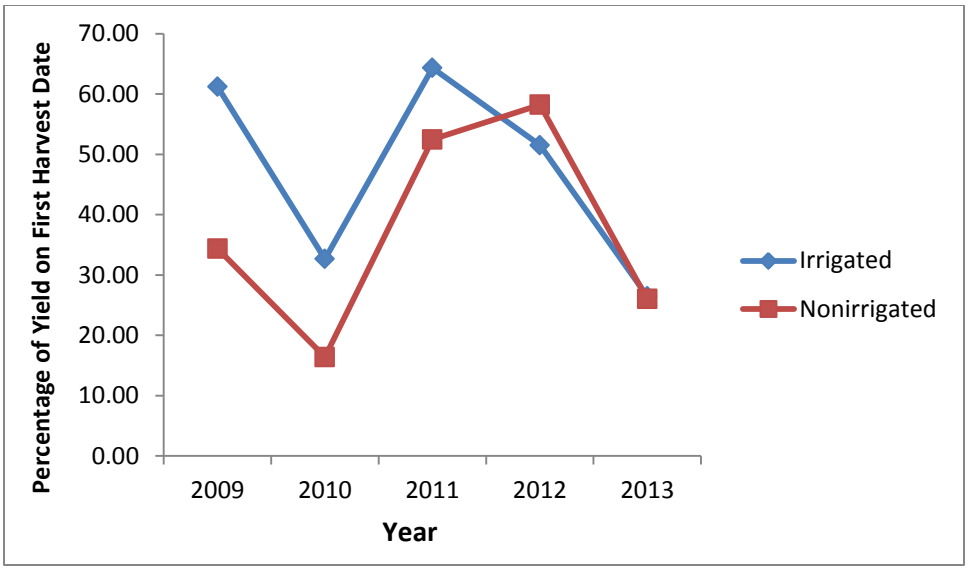

Figure 9. Effect of irrigation on harvest maturity (% of total yield harvested on the first harvest date of each year), years 3-7

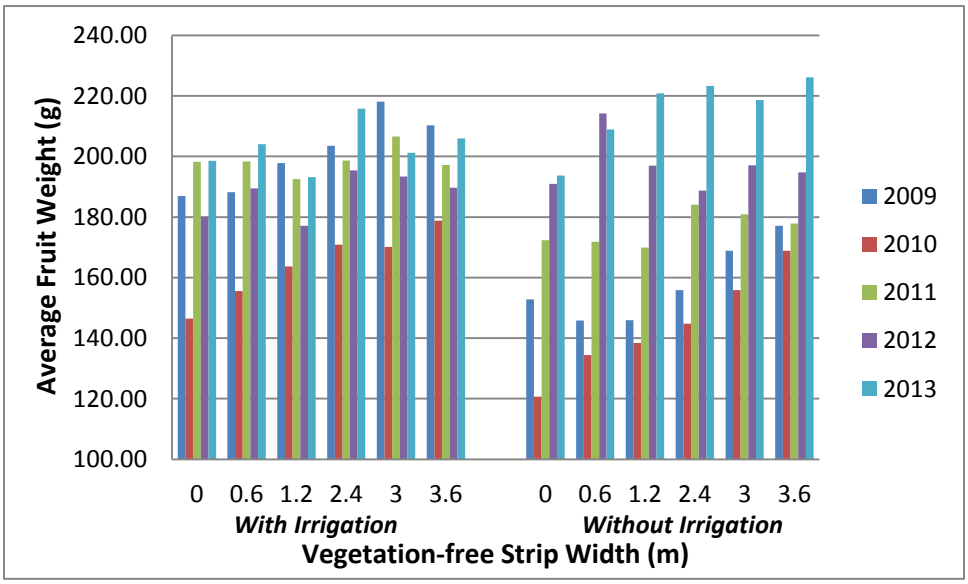

Figure 10. Effect of vegetation-free strip width, with and without irrigation, on average peach weight (g), years 3-7

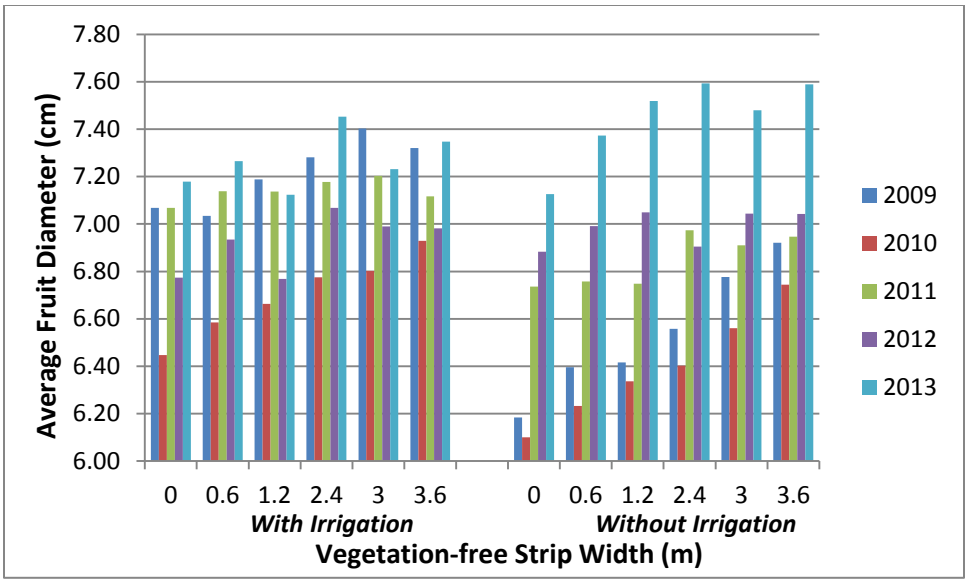

Figure 11. Effect of vegetation-free strip width, with and without irrigation, on average peach diameter (cm), years 3-7

Appendix 2. Soil Chemical Properties

Table 1a. Effect of vegetation-free strip width and irrigation on soil moisture

	Soil Moisture (%)			
Strip width (m)	**Spring 2009***	**Fall 2009**	**Spring 2010**	**Fall 2010**
0	5.3b†	5.4a	3.7b	4.9a
1.2	5.7ab	5.2a	4.4ab	4.9a
2.4	‡	5.0a	4.8a	4.8a
3.6	6.1a	5.3a	5.1a	4.9a
p value	*0.0994*	*0.4750*	*0.0491*	*0.9089*
Irrigation				
Irrigated	5.8a	5.7a	5.4a	5.0a
Non-irrigated	5.5a	4.8b	3.6b	4.8a
p value	*0.4079*	*<0.0001*	*<0.0001*	*0.2180*

*Samples in each column with the same letter are not significantly different (α≤0.05)
‡No samples were collected from 2.4 m plots in Spring2009

Table 1b. Effect of vegetation-free strip width and irrigation on soil pH

	Soil pH			
Strip width (m)	**Spring 2009***	**Fall 2009**	**Spring 2010**	**Fall 2010**
0	5.7b†	5.6a	5.2a	6.3a
1.2	5.8a	5.7a	5.0a	6.3a
2.4	‡	5.6a	5.0a	6.2a
3.6	5.8a	5.7a	5.0a	6.4a
p value	*0.0461*	*0.8286*	*0.1350*	*0.6477*
Irrigation				
Irrigated	5.8a	5.6a	5.1a	6.3a
Non-irrigated	5.7a	5.6a	5.0a	6.3a
p value	*0.0543*	*0.7683*	*0.7040*	*0.8697*

*Samples in each column with the same letter are not significantly different (α≤0.05)
‡No samples were collected from 2.4 m plots in Spring2009

Table 1c. Effect of vegetation-free strip width and irrigation on soil electrical conductivity

	EC (mS cm^{-1})			
Strip width (m)	**Spring 2009***	**Fall 2009**	**Spring 2010**	**Fall 2010**
0	0.10a†	0.28a	0.21a	0.08a
1.2	0.08b	0.26a	0.08a	0.07bc
2.4	‡	0.26a	0.07a	0.06c
3.6	0.08b	0.26a	0.07a	0.07ab
p value	*0.0063*	*0.1227*	*0.4186*	*0.0143*
Irrigation				
Irrigated	0.08b	0.27a	0.07a	0.07a
Non-irrigated	0.09a	0.26a	0.14a	0.07a
p value	*0.0303*	*0.6586*	*0.3465*	*0.1781*

*Samples in each column with the same letter are not significantly different (α≤0.05)
†Main effect means are pooled across other main effects and 4 reps
‡No samples were collected from 2.4 m plots in Spring2009

Table 2. Peach rootstock rhizosphere soil moisture, pH and EC

	Spring 2010			Fall 2010		
Rootstock	**moisture (%)***	**pH**	**EC (mS cm^{-1})**	**moisture (%)***	**pH**	**EC (mS cm^{-1})**
Guardian®	5.7a†	5.4a	0.05a	5.4ab	6.1a	0.07a
Lovell	5.9a	5.2a	0.06a	4.9b	6.0a	0.07a
Controller 5	5.8a	5.3a	0.05a	5.3ab	6.2a	0.07a
Krymsk® 1	5.6a	5.3a	0.05a	5.7ab	6.0a	0.08a
Empyrean® 2	5.5a	5.3a	0.05a	4.9b	6.1a	0.07a
Viking	5.8a	5.3a	0.04a	5.7a	6.1a	0.07a

*Samples in each column with the same letter are not significantly different (α≤0.05)
†Means are pooled across 4 reps

Appendix 3. Nematode Sampling Results

Table 3. Effect of vegetation free strip and irrigation on nematode populations, April 2010

	Nematode		
	Root Knot*	Ring*	Other*
Strip Width (m)	**count/500 cc soil**		
0	5†	24	186
0.6	45	126	361
1.2	31	96	318
2.4	0	44	315
3.0	0	90	865
3.6	0	119	600
p value	*0.5209*	*0.8071*	*0.3788*
Irrigation			
Irrigated	25	129	418
Non-irrigated	2	37	464
p value	*0.1797*	*0.0730*	*0.8138*
p value for strip irrigation interaction*	*0.4512*	*0.2193*	*0.8478*

*No significant difference between treatments at $\alpha \leq 0.05$

†Main effect means are pooled across other main effects and 4 reps

Appendix 4. Monthly Temperatures and Precipitation

Table 4. Monthly weather data for the Sandhills Research Station

March	**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
April					
Temperature Min (C)	9.6	10.9	11.0	10.4	10.6
Temperature Max (C)	22.6	24.7	23.5	22.0	22.0
Precipitation (cm)	4.3	2.8	10.2	11.3	17.6
May					
Temperature Min (C)	15.4	16.6	15.3	16.5	14.0
Temperature Max (C)	26.0	27.4	26.7	27.3	24.7
Precipitation (cm)	9.9	17.6	11.1	19.0	12.4
June					
Temperature Min (C)	19.5	21.1	19.9	17.4	19.3
Temperature Max (C)	30.1	32.4	32.6	29.4	28.9
Precipitation (cm)	6.1	8.9	10.0	10.3	36.0
July					
Temperature Min (C)	19.6	21.4	21.9	21.8	21.4
Temperature Max (C)	30.2	32.4	33.5	32.7	29.7
Precipitation (cm)	14.0	27.9	14.2	42.4	46.3

Sources: State Climate Office of North Carolina CRONOS Database (http://www.nc-climate.ncsu.edu/cronos/) for the weather station located at the Sandhills Research Station, Jackson Springs, NC