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Irrigation and weed control alter soil microbiology and nutrient availability in North Carolina Sandhill peach orchards

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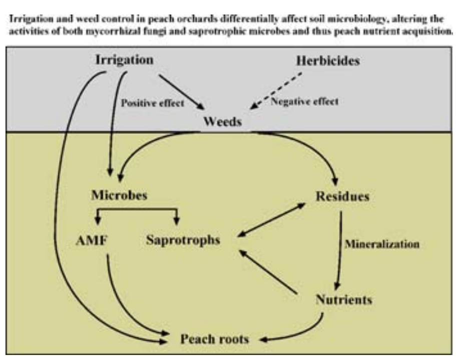
HIGHLIGHTS

- Irrigation and weed control effects were assessed in peach Sandhill orchards.
- Irrigation increased AMF infection and activities without altering AMF community.
- Weed control reduced soil nutrient availability, microbial biomass and activities.
- Weed control reduced mycorrhizal spore density but not AMF infection and community.

GRAPHICAL ABSTRACT



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ABSTRACT

Orchard management practices such as weed control and irrigation are primarily aimed at maximizing fruit yields and economic profits. However, the impact of these practices on soil fertility and soil microbiology is often overlooked. We conducted a two-factor experimental manipulation of weed control by herbicide and trickle irrigation in a nutrient-poor peach (*Prunus persica* L. cv. Contender) orchard near Jackson Springs, North Carolina. After three and eight years of treatments, an array of soil fertility parameters were examined, including soil pH, soil N, P and cation nutrients, microbial biomass and respiration, N mineralization, and presence of arbuscular mycorrhizal fungi (AMF). Three general trends emerged: 1) irrigation significantly increased soil microbial biomass and activity, 2) infection rate of mycorrhizal fungi within roots were significantly higher under irrigation than non-irrigation treatments, but no significant difference in the AMF community composition was detected among treatments, 3) weed control through herbicides reduced soil organic matter, microbial biomass and activity, and mineral nutrients, but had no significant impacts on root mycorrhizal infection and AMF communities. Weed-control treatments directly decreased availability of soil nutrients in year 8, especially soil extractable inorganic N. Weed control also appears to have altered the soil nutrients via changes in soil microbes and altered net N mineralization via changes in soil microbial biomass and activity. These results indicate that long-term weed control using herbicides reduces soil fertility through reducing organic C inputs, nutrient retention and

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soil microbes. Together, these findings highlight the need for alternative practices such as winter legume cover cropping that maintain and/or enhance organic inputs to sustain the soil fertility.

1. Introduction

Effective weed and water management can critically affect the growth of fruit trees and development and productivity of young orchards in the southeastern US (Horton et al., 2004; Ritchie et al., 2005). In this region, sandy soils, high precipitation and warm temperature all facilitate rapid decomposition of organic residues, reducing the nutrient reservoir and water retention (Sierra et al., 2001; Tu et al., 2006a; Cross and Grace, 2010). However, irrigation is necessary in this region as nutrient limitation and periodical drought often occurs. Also, orchard floor vegetation can compete for water and nutrients, greatly impacting fruit trees during the first few years after establishment (Buckelew, 2009). Therefore, young orchards may take longer to be a high-productive system if infested with weeds. Traditional management regimes of weeds and water emphasize the net effects on short-term tree growth and productivity (Forey et al., 2016), and limited attention has been paid to the long-term consequences of irrigation and weed control on soil microbes, a major component of soil fertility, and also the long-term sustainability of peach orchards.

Soil microbes are the primary agent of residue decomposition and nutrient releases, and therefore critically affect plant growth by regulating nutrient availability (Yao et al., 2005; Floch et al., 2009). They also function as a temporary nutrient reservoir that retain soil N and influence plant productivity (van Der Heijden et al., 2008). In addition, many soil microbes have suppressive effects on soil pathogens and parasitic nematodes (Weller et al., 2002; Neher, 2010). Finally, some soil microbes, particularly mycorrhizal fungi, form symbiotic associations with peach trees (Gilmore, 1971). Arbuscular mycorrhizal fungi (AMF) in general enhance the nutrient uptake of host plants (particularly P and also N) and increase the tolerance and resistance of their host plants to environmental stresses such as drought (Gilmore, 1971; Augé, 2004; Hodge and Fitter, 2010; Bowles et al., 2016; Yang et al., 2017; Zou et al., 2017). Wu et al. (2011) showed that AMF improved plant growth performance and nutrient acquisition of peach seedlings, but different AMF species led to different magnitudes of benefits. Some experiments have shown that various orchard management practices (e.g. use of fertilizers or agrochemicals) may alter AMF communities and be detrimental to AMF colonization of fruit plants, reducing AMF benefits (Ocampo and Barea, 1985; Jeffries et al., 2003; Baumgartner et al., 2005; Gosling et al., 2006; Druille et al., 2013; Van Geel et al., 2016; Turrini et al., 2017). However, little is known about the effects of management practices on the biomass and activities of the soil microbial community and symbiotic mycorrhizal fungi and their colonization of roots in peach orchards.

In a long-term field experiment examining the impact of two major management practices (weed control and irrigation) on peach tree growth and productivity, we observed that peach leaves had premature discoloration and defoliation in the fall in both weed-control and irrigated system in the third year of the experiment (Buckelew, 2009; Fisk, 2013). We speculate that irrigation and weed control may have negatively affected soil nutrient retention and plant health through altering soil microbiology. More specifically, we hypothesized that 1) irrigation reduces nutrient retention through increasing leaching and plant uptake, 2) weed control reduces soil organic carbon for microbes and microbial nutrient retention, and 3) both irrigation and weed control suppress AMF infection of peach roots through reducing water stresses and AMF spores in soil. Therefore, we collected soil samples in the fall of the 3rd year, and also in the growing season and the fall of the 8th year following orchard establishment. Our specific objectives were: (1) to assess the effects of irrigation and/or weed control by herbicides on nutrient availability of peach orchard soils, (2) to determine the impact of weed control and irrigation practices on soil microbial biomass and activities as well as mycorrhizal colonization of peach roots and AMF community in the roots.

2. Materials and methods

2.1. The experimental location and design

The experiment was located at the Sandhills research station near Jackson Springs, North Carolina, located at 35°13′N and 79°41′W with an elevation of approximately 200 m. Average annual precipitation is about 1180 mm, and average monthly temperature ranges 9.9–21.6 °C. The soil was a sedimentary Candor sand (sandy, kaolinitic, thermic Grossarenic Kandiudults in the US Soil Taxonomy) with low fertility (Buckelew, 2009) and a pH of ca. 5.0. The experiment was a 2×2 factorial design with weed-control by chemical herbicides and trickle irrigation to the rhizosphere of trees as two treatment factors. Four experimental systems were thus formed, including no weed-control plus irrigation (NWC-I), no weed-control plus no irrigation (NWC-NI), weed-control by herbicides plus irrigation (WC-I), and weed-control by herbicides plus no irrigation (WC-NI). The plot size was 21.9 m by 3.7 m with four plants per plot. Each treatment system was replicated four times with a randomized block arrangement. Native weed species across the field were mowed periodically to a height of 10–13 cm tall and the weed-control treatment was applied by using herbicides (see below for details).

2.2. Peach tree establishment and management treatments

2.2.1. Peach orchard establishment and fertilizer application

On Feb. 3, 2006, one-year-old grafted trees of peach (*Prunus persica* L. cv. Contender on Guardian rootstock) were planted. In the previous summer-fall, 4500 kg of chicken litter and 1125 kg of dolomitic lime per hectare were incorporated into the soil to raise the pH of ca. 5.8 (Buckelew, 2009). The trees were planted with a space of 5.5 m within row and 6.0 m between rows. On May 9, 2006, 280 g of compound fertilizer (a particular mix of fertilizers: urea, ammonium phosphate and muriate of potash, with N: P_2O_5: K_2O = 10:10:10) per tree was applied. In 2007, fertilizer was surface-applied with 34 kg each of N and K_2O ha^{-1} in March, and 28.9 kg each of N, K_2O and P_2O_5 ha^{-1} in May. In 2008, equal amounts of N and K_2O were applied in two separate dressings of 45.4 and 22.7 kg ha^{-1} in April and June, respectively. Since 2009, all trees were fertilized uniformly with two applications of 44.8 kg each of N and K_2O ha^{-1} in March, and 33.6 kg ha^{-1} again in May. Also, dolomitic lime were incorporated into the soil every three or four years to neutralize the acidity so that soil pH is more suitable for peach plants.

2.2.2. Weed control through herbicide applications

The herbicides Chateau (flumioxazin, for PRE emergent control of weeds) at 440 mL ha^{-1} and Gramoxone Inteon (paraquat dichloride, as a POST emergent burndown) at 3550 mL ha^{-1} were applied (plus nonionic surfactant) to maintain a 3.6 m weed-free strip under the trees in the weed-control systems. The herbicides were tank-mixed together and broadcast applied in the spring (March) and again when needed in the summer (usually early July). Other weeds like yellow nutsedge were spot treated as needed with the herbicide Basagran (sodium salt of bentazon). Therefore, the soil surface in these systems was free of vegetative ground cover throughout the growing season and without plant residues other than defoliated peach leaves all years prior to collection of soil samples.