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EVALUATION OF ORCHARD FLOOR MANAGEMENT SYSTEMS FOR APPLE UNDER ORGANIC PROTOCOL: EFFECT ON SOIL ORGANIC MATTER AND NITROGEN, NEMATODE COMMUNITY, ROOT ARCHITECTURE AND DEVELOPMENT, AND ROOTSTOCK PERFORMANCE.

By

Dario Stefanelli

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Abstract

Evaluation of Orchard Floor Management Systems for apple orchards under organic protocol: effect on soil organic matter and nitrogen, nematode community, root architecture and development, and rootstock performance.

By Dario Stefanelli

Orchard floor managements systems (OFMS) play the fundamental role in establishing the soil conditions for tree growth. Organic growers rely on the soil food web to provide nutrient availability for the plant. A change in soil biology by changing or modifying OFMS could reflect on the food web, the plant root responses, and ultimately the tree production.

With this experiment we evaluated the effect of three different OFMS on soil nitrogen, food web structure, tree root dynamics and architecture, and responses of three rootstocks. The experiment was conducted in an organically certified (Organic Crop Improvement Agency - OCIA) orchard of "Pacific Gala". Three rootstocks were evaluated: M.9 NAKB 337 (dwarfing), M.9 RN 29 (semi-dwarfing), and Supporter 4 (semi-vigorous). Three OFMS were used: Mulch of alfalfa hay (MU), propane Flaming (FL), and strip tilling at each side of the tree row while natural vegetation was allowed to grow undisturbed on the tree row (Swiss Sandwich System, SS). The effect of OFMS was evaluated by measuring SOM and N content at 2 depths (0-10 and 0-30 cm). The effect on soil biology structure was measured by the relative percentage of the populations categorized by feeding habit. Root infections by mycorrhizae and number of root feeders' nematodes in the roots were also measured. Fine root responses to the soil conditions were measured by minirhizotrons only in MU and SS, while the response of the root

distribution was measured by trenching in the soil profile in all the treatments. These last two measurements were performed only on M.9 NAKB 337 rootstock.

The Mulch treatment had the highest values of SOM and N with no differences between the SS and FL treatments. These parameters are still growing in MU while they seem stabilized in FL and SS. This had an effect on the structure of the soil biology. Mulch presented the highest number of bacterial feeding nematodes (85% against 60% of SS and FL) with continued increases. Swiss Sandwich and FL had higher fungal feeders, which play an important role in nutrient release in depleted soils and higher root feeding nematodes, both in soil and in roots, but the trees did not suffer. Flame and SS presented the highest number of mycorrhizal infection in roots. A positive linear correlation between root infection % and number of spores in the soil was found.

Supporter 4 had the highest values in all the growth parameters. M.9 RN 29 showed the highest values of production parameters both in FL and SS where there was less N content.

Root architecture was affected by the OFMS. Mulch and FL had almost the same root frequency along the soil profile, with the majority of the roots localized closer to the surface and to the tree trunk inside the weed free area of the treatments. Swiss Sandwich had a more expanded root system both vertically and horizontally. Fine root development was also affected by the OFMS. Swiss Sandwich had a higher fine root lifespan (50-60 day against 30 of MU) possibly related to the lower N content in the soil and a higher % of very fine roots (0.2-0.4 mm) deeper in the soil profile.

Overall, SS seemed to be a better balanced OFMS and if coupled with M.9 RN 29 it could help organic apple growers in Michigan.

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LITERATURE REVIEW

Organic agriculture focuses on soil management systems and a common phrase used to characterize organic growing is, "Feed the soil, not the plant". Organic matter plays a central role in the building of a healthy and productive soil (Magdoff and van Es, 2000). In organic fruit production, in contrast to conventional production that relies on regular fertilization, one of the main goals is to build organic matter in the soil (Bloksma, 2000). Organic matter is also an indicator of carbon sequestered in the soil (Stevenson, 1994).

A goal in organic agriculture is the development and implementation of an integrated approach to agriculture that considers potential impacts on the environment and the soil (FAOa). Consideration of biological, chemical and physical implications of land use and management practices and of ecological principles will allow agricultural productivity to be sustained in low and high input agricultural systems. Effective soil biology management will provide opportunities for enhancing productivity and for the restoration of degraded soils (FAOb). Orchard floor management systems in orchards are the main tool to implement these concepts.

Orchard floor management systems available to organic growers are limited. Unlike herbaceous crops, limitations exist in woody perennial crops that restrict the incorporation of soil amendments. Also in organic fruit production there is the need for a more sustainable approach to weed management that is compatible with organic protocols and also provides careful utilization instead of suppression (Sooby, 1999).

Orchard floor management systems (OFMS) affect soil conditions and consequently nutrient availability, tree growth and yield (Yao et al, 2005). Organic growers have to rely on the soil food web to obtain the nutrient availability for the plants, since the N release varies with the quantity and quality of the amendments and the soil environment (Myers et al., 1997; Wardle and Lavelle, 1997; Magdoff and van Es, 2000; Brady and Weil, 2002). OFMS will change the microbial composition of the soil (Yao et al, 2005). There have been several studies on the effects of soil management systems on soil microbes and the structure of the soil food web (Mader et al., 2002; Ferris et al., 2004; Yao et al., 2005). Most of these studies were on herbaceous crops (Ferris et al., 1996; Robertson et al., 1997) and very few on apples (Forge et al., 2003; Yao et al, 2005). Rhizosphere microorganisms may affect the hormonal balance and competitive ability of the plant, which will modify the rhizosphere community and the ecosystem (El-Shatnawi and Makhadmeh, 2001). Factors that are more likely to enhance stability of the soil microbial biomass are more likely to enhance nutrient conservation in the soil (Wardle and Nicholson, 1996). Alleviating stress on the microbial community has stabilizing effects (Wardle, 1998). Factors that stabilize the microbial biomass reduce turnover, and are likely to have important consequences for soil nutrient dynamics and ultimately plant growth and ecosystem productivity (Wardle, 1998).

The more active microorganisms in the organic system control the release of available nitrogen to the trees in the soil (Forge et al., 2003). OFMS provide organic forms of C and N which are quickly metabolized to inorganic nitrogen and other nutrients, primarily by bacteria and fungi (Ferris et al., 1998). N is also mineralized as predators of bacteria and fungi, such as protozoa and microbivorous ("microorganism eating") nematodes, graze on prey which contain more N than required by the predators (Ferris et al., 1998). Although more research attention is given to the plant parasitic nematodes, microbivorous organisms make up a large portion of the nematode community. Excess N generated by grazing is released to the soil and becomes available for plant uptake (Ferris et al., 1998). Nematodes feeding types play an overall positive contribution to soil and thus ecosystem processes (Yeates, 1987; Bongers and Ferris, 1999; Bardgett et al., 1999). Nematodes can be used as indicators of soil functional and biodiversity aspects (Yeates, 2003) since they reflect the soil and ecological processes (Yeates, 1999). Most of the studies on the benefits of nematodes on nutrient release and availability in the soil have been done on the bacterial and fungal feeder nematodes. Bacterial feeders are responsible for a higher release of N when soil conditions are closer to optimal (Ferris et al., 1996; Ferris et al, 1997; Laakso et al., 2000; Forge et al., 2003) while fungal feeders have a greater effect when soil conditions are not optimal (Ingham et al., 1985; Ferris et al., 1998; Ferris and Chen, 1999; Ferris et al., 2004). Most of the current ecological research agrees that a food web becomes more beneficial with increased structure and diversification (Power, 1992; Paine, 1996; Sugihara et al., 1997; Garlaschelli, 2004).

The interaction between the OFMS and soil food web will have an impact on edaphic conditions and nutrient availability. The degree to which kinetics of nutrient uptake or other potential adjustments are expressed would ultimately depend on soil nutrient availability and soil factors that determine nutrient transport to the root surface (Bassirirad, 2000). The retention of nutrients within an ecosystem depends on temporal and spatial synchrony between nutrient availability and nutrient uptake (Tierney et al., 2001).

Plant root systems have the ability to adjust nutrient acquisition capacity to meet variation in shoot demand caused by environmental changes (Chapin, 1980; Clarkson and Hanson 1980; Clarkson 1985). Plant roots can alter water and nutrient absorption by adjusting physiological longevity, morphological and/or architectural characteristics to meet changes in shoot nutrient demand (Chapin, 1980; Clarkson and Hanson 1980; Clarkson 1985). It becomes important then, to evaluate the usefulness of root parameters, such as lifespan and turnover, as indicators of growth potential of the plant and its actual nutrient acquisition (Bakker, 1999).

Roots, and fine roots in particular, play a central role (Schulze et al., 1997) in soil chemical (pH, O_2, CO_2 and other chemicals), physical (moisture and aeration), and biological (soil pathogens, beneficial microorganisms and allelopathy) composition (Makhadmeh and El-Shatnawi, 2001) with important consequences for plant growth and productivity, plant competition, biological activity, and carbon and nutrient cycling at an ecosystem scale by releasing in the soil a wide variety of exudates (Makhadmeh and El-Shatnawi, 2001; Bertin et al., 2003; Walker et al., 2003). Plants expend a substantial proportion of photosynthate below ground in the annual production of fine roots (Eissenstat et al., 2000) and release of exudates (Walker et al., 2003). In many cases, more than 50% of annual net primary production is allocated below ground, and the return of nutrient to the soil by tree fine root death may exceed that of the above ground litterfall (Kasuya N., 1997). Tree root turnover may return four to five times more carbon to the soil than above ground litter (Zech and Lehrmann, 1998). Consequently there is a need to include the effects of root turnover in models of carbon and nutrient cycling (Cox et al., 1978; Vogt et al., 1986; Hendricks et al., 1993; Jackson et al., 1997; Norby and Jackson, 2000).

Moreover, through the exudation of a wide variety of compounds, roots regulate the soil microbial community in their immediate vicinity, cope with herbivores, and encourage beneficial symbioses (Nardi et al., 2000, Walker et al., 2003).

Assessing root turnover is very important as an indicator of plant productivity and a measurement of carbon return to the soil. In the last decade the most common technique to measure fine root turnover is by minirhizotrons installed in the ground. They can be used to characterize fine root production, phenology, growth, mortality and lifespan, and are useful in developing ecosystem carbon budgets (Hendrick and Pregitzer, 1996; Majdi, 1996). Data reliability depends on the accuracy of assessing physiological status of the roots (alive or dead) (Wang et al, 1995; Tingey et al, 2000) mostly based on color (Hendrick and Pregitzer 1992a, b; Comas et al, 2000).

However, the determination of fine root physiological status is a common problem (Comas et al., 2000). Also there is a certain inconsistency in the definition of the proper diameter for fine roots. Lately, several authors reported that, for woody perennials, fine roots should be ≥ 1 mm in diameter (McCrady and Comerford, 1998; Eissenstat et al, 2000; Comas and Eissenstat 2001).

Processes and responses vary not only with root diameter, but with other root characteristics as well (Norby and Jackson, 2000). It is necessary to couple the total size of the root system with physiological information on the response of root specific nutrient uptake efficiency (Norby and Jackson, 2000). The size of the root system and its efficiency to deploy roots at the time and place nutrients are present (Fitter et al., 1991), as well as the efficiency by which a particular root segment can take up a nutrient from the soil solution (Norby and Jackson, 2000), are fundamental for the plant uptake capacity (Tjeerd et al., 2001). The degree to which kinetics of nutrient uptake or other potential adjustments are expressed would ultimately depend on the availability of soil nutrients (Tjeerd et al., 2001) and soil factors that determine transportation of nutrients to the root surface (Bassirirad, 2000). The retention of nutrients within an ecosystem depends on temporal and spatial synchrony between nutrient availability and nutrient uptake. Disruption of fine root processes can have dramatic impacts on nutrient retention (Tierney et al., 2001).

In general, increased N concentrations in the soil decrease fine root turnover because of increased root lifespan (Pregitzer et al., 1993; Ostonen et al., 1999; Burton et al., 2000; Hendricks et al., 2000; King et al., 2002), allowing the plant to reduce carbon costs. However, several authors report that with increased N concentration in soil, root turnover rates accelerate reducing fine root lifespan (Aber et al, 1985; Nadelhoffer et al., 1985; Persson and Ahlström, 2002). Burton et al. (2000), in an experiment on fine root (<1 mm) dynamics within and across forest species related to different ranges in N availability, found that root lifespan decreases with increasing N availability, while within species there is the opposite trend. Tjeerd et al. (2001) found that citrus fine root life span was diminished in P depleted soils.

In any case all the authors agree on the importance of the interaction between N availability and fine root dynamics, especially for the effects on organic matter

(McClaugherty et al, 1982), on the organic N pool in the soil (Ehrenfeld et al., 1997) and on the control of the substrate quality (Hendricks et al., 2000).

Root turnover has been extensively studied in grassland and forest ecosystems, but there is not much literature on fruit trees and none in organic tree production.

The ability of trees to adapt their roots dynamics to different soil conditions is not limited only to life span, turnover and nutrient uptake, but is extended to entire root system architecture.

Plants tend to expand their root system (both vertically and horizontally) in response to drought conditions (Schenk and Jackson, 2002). This finding is also confirmed in fruit trees in response to irrigation and drought stress (Perry et al., 1983; Layne et al., 1986; Bassoi et al., 1998; Smart et al., 2006). Soil type also affects root distribution. Soil properties, such as the presence of soil profiles impermeable to root penetration, stoniness, and presence of gravel lenses, have a greater influence on depth distributions than does genotype, even in deep fertile soils (Smart et al., 2006). Higher fertility tends to increase root density, induce a more superficial root system and/or encourage localized rooting in the more fertile area (Lyons et al., 1962; Smith, 1965). Root architecture also responds to competition from other species, which reduces the amount of roots in the competitive area and expands it both horizontally and vertically as a result (Atkinson and White, 1976; Glen and Welker, 1989; Parker, 1993; Merwin and Stile, 1994; Merwin et al., 1995).

Ground floor management practices, in regards to perennial woody species, which can reduce nutrient uptake competition by influencing root morphology, have great value in conventional and sustainable systems. It is important to develop OFMS that will optimize productivity without disrupting soil-food web-root processes. It is a goal not easily achieved, given the restriction of the organic protocols, which create different edaphic conditions than conventional management. Therefore, an OFMS needs to be implemented which will create the best environment for tree growth allowing the maximization of its performance (Weibel, 2002).

Another form of management that growers can use is the selection of beneficial herbaceous species that can coexist with woody perennials. In the case of fruit trees, rootstocks can be selected that vary in reaction to flora competition, edaphic conditions, disease resistance, and vigor and production characteristics that they induce on the scion (Ferree and Carlson, 1987). There are extensive research programs that focus on rootstock evaluation for the above mentioned characteristics, but managed with conventional practices, and often under optimal growing conditions. This factor alone reduces the utility of the rootstock outside of those conditions. Thus inducing the growers to adapt their orchard conditions to the optimal in which the rootstocks were tried. Environmental factors seem to be more influential on the uptake of nitrogen and phosphorus than the rootstock genotype (Kennedy et al., 1980), but not enough is known on the subject. There is a strong relationship between genetic (vigor) and environmental factors in determining the adaptability of the root system, and consequently its capability of nutrient uptake and tree performance under adverse conditions.

In this study we decided to evaluate different organic OFMS that present different practical and rationale approaches to management. We avoided a comparison that allows the entire ground floor area inhabited by competitive indigenous herbaceous flora as a treatment. Numerous studies have been conducted over many years demonstrating the detrimental effect of this practice (Merwin and Ray, 1997; Giovannini et al., 1998).

Mulching keeps the soil free from weed competition, keeps soil moisture and temperature constant, increases organic matter through its decomposition, releases nutrients to the soil, and improves the soil environment, enhancing the microbial activity (Merwin and Stiles, 1994; Merwin et al., 1995; Marsh et al., 1996; Lloyd et al, 2000).

Tillage of the entire orchard floor also keeps the soil free from weed competition but encourages soil compaction, reduces internal soil water drainage, accelerates superficial organic matter losses (Merwin and Stiles, 1994) and disrupts and injures surface roots by mechanical cultivation (Cockroft and Wallbrink, 1996). Tillage is still widely used in the world even if it is expensive, requires specialized machinery, and encourages risks of water run-off.

Recently a modified tilling system has been implemented in Switzerland, called the Swiss Sandwich System. It consists of a strip where spontaneous vegetation is allowed to grow on the tree row and two shallow tilled narrow strips at each side of the tree row. This system permits predator insects to complete their cycle in the volunteer weeds that grow on the tree row, becoming more efficient in controlling pests and diseases, and increasing biodiversity (Luna and Jepson, 1998; Horton, 1999; Schmid and Weibel, 2000; Galoach, 2002). The resulting weeds in the tree row can be considered as cover crops by contributing to the prevention of soil erosion, increasing soil organic matter, assisting to the recycling of soil nutrients, and helping in reducing the amount of nitrate runoff and leaching from the soil (Miles and Chen, 2001). This system also simplifies management, since there is no need to reach under the tree canopy to mow weeds or till (Schmid and Weibel, 2000; Schmid et al.; 2001; Weibel, 2002; Weibel and Haseli, 2003). There is less chance for harm to tree trunks by passing implements. The two strips of shallow tilled bare soil reduce weed competition for water and nutrients (Merwin and Ray, 1997) and increase yield and fruit size of apples (Schupp and McCue, 1996).

Flaming of herbaceous weeds is another practice used by organic growers (Gourd, 2002; Robinson, 2003). The impacts of this system are relatively unknown. Some drawbacks include initiation of spontaneous fires, damage to the trees, encouragement of rodents (Zoppolo, 2004), need of special equipment, and usage of valuable energy source (propane).

Since organic OFMS do create environmental conditions and stresses that are different from the conventional ones under which rootstocks are normally evaluated, perhaps differences in rootstock vigor can compensate for different conditions.

We therefore hypothesize that the different soil conditions that OFMS creates will have an impact on all factors involved in soil processes, including plant roots (both fine and at system level). Eventually, the best OFMS should create a balanced and self sustaining edaphic condition. We also hypothesize that the right rootstock, with different vigor, can compensate for stresses imposed by an organic OFMS, thus improving above ground performance.

The objectives of this research were: 1) to determine the effect of OFMS on soil nutrition and SOM; 2) to estimate the effect of OFMS on the soil food web; 3) to determine the effect of OFMS on fine root development; 4) to estimate the effect on root architecture; 5) to evaluate rootstock performance related to the soil condition established by OFMS treatments. The overall objectives are to determine the best OFMS for the growers coupled with the ideal rootstock to maximize production.

Abstract

CHAPTER 1. Soil Nitrogen, Organic Matter and Nematode Communities as Affected from Orchard Floor Management Systems in Apple under Organic Protocol.

By Dario Stefanelli

A common phrase used to characterize organic growing is "Feed the soil, not the plant". In organic agriculture the consideration of biological, chemical and physical implications of land use and management practices and of ecological principles will allow agricultural productivity to be sustained in low and high productive environments. Organic growers can implement these concepts by using different Orchard Floor Management Systems (OFMS) that provide organic forms of C and N, which are quickly metabolized primarily by bacteria and fungi. Nitrogen is also mineralized by predators of bacteria and fungi; for this reason nematode feeding types play an overall positive contribution to soil and thus ecosystem processes. Nematodes can be used as indicators of soil functional and biodiversity aspects since they reflect the status of soil and ecological processes. Fungal feeders have a higher effect in water and nutrient depleted soils. Orchard floor management systems will change the microbial composition of the soil. The objectives of this experiment were: 1) to determine the effect of the OFMS on the nutritional status of the soil; 2) to evaluate the different structures of the food web; 3) to determine which system would create a more suitable environment to maximize tree performance.The experiment was conducted in an organic certified orchard of apple cultivar "Pacific Gala". Three OFMS treatments were implemented: mulch of alfalfa hay (MU), propane flaming (FL), and strip tilling at each side of the tree row where natural vegetation was allowed to grow undisturbed in the tree row (Swiss Sandwich System,

SS). We evaluated the effect of the treatment on soil nutrition by measuring SOM and N concentration at 2 depths (0-10 and 0-30 cm) for 4 years. The effect on food web structure was measured, 4 times in 2 years at fixed intervals, by the relative percentage of the populations divided by feeding habit. We also measured root infection by mycorrhizae and root feeder nematodes in the roots. The mulch treatment had the highest values of SOM, and nitrogen in the soil at both sampling depths, but had the least structured food web with the majority of the populations represented by bacteria feeding nematodes. One positive factor was that it showed the lowest percentage of herbivore nematode species. Soil organic matter and mineral nitrogen was lowest in SS. Soil organic matter is progressively decreasing at 0-10 cm depth in the tilled area and increasing at the deeper sampling (due to tilling), while mineral N is decreasing in the vegetated area at 0-10 cm depth (due to higher competition). The food web structure is more balanced in SS than MU, with the vegetated area having highest values of herbivore nematodes and root mycorrhizal infection, while the tilled area has the highest value of fungivores with a similar percentage to MU of root mycorrhizal infection. Flaming produced similar soil conditions as the Swiss sandwich, having a reduction in SOM at 0-10 cm. Soil food web structure and percentage of feeding habit nematode populations was similar for FL and SS suggesting that the two treatments have less SOM and N than MU, but they are coping through a shift in microbial populations. Based on this study there is a high correlation between the amount of mycorrhizal spores in the soil and the percentage of infection in the apple roots. Overall, tree performance and soil microbial conditions for SS compare similarly with FL, where all weeds are suppressed. Data supports further study of this system for organic apple growers in Michigan.

Introduction

Organic agriculture focuses on soil management systems and a common phrase used to characterize organic growing is, "Feed the soil, not the plant". Organic matter plays a central role in the building of a healthy and productive soil (Magdoff and van Es, 2000). In organic fruit production, in contrast to conventional production that relies on regular fertilization, one of the main goals is to build organic matter in the soil (Bloksma, 2000). Organic matter is also an indicator of carbon sequestered in the soil (Stevenson, 1994).

A goal in organic agriculture is the development and implementation of an integrated approach to agriculture that considers potential impacts on the environment and the soil (FAOa). Consideration of biological, chemical and physical implications of land use and management practices and of ecological principles will allow agricultural productivity to be sustained in low and high input agricultural systems. Effective soil biological management will provide opportunities for enhancing productivity and for the restoration of degraded soils (FAOb). Orchard floor management systems are the main tool to implement these concepts.

Unlike herbaceous crops, limitations exist in woody perennial crops that restrict the incorporation of soil amendments. Also, in organic fruit production there is the need for a more sustainable approach to weed management compatible with organic protocols that provides careful utilization instead of suppression (Sooby, 1999).

Orchard floor management systems (OFMS) affect soil conditions and consequently nutrient availability, tree growth and yield (Yao et al, 2005). Organic growers have to rely on the soil food web to obtain the nutrient availability for the plants since the N release from different sources varies with the quantity and quality of the material used and the soil environment (Myers et al., 1997; Wardle and Lavelle, 1997; Magdoff and van Es, 2000; Brady and Weil, 2002). Orchard floor management systems will change the microbial composition of the soil (Yao et al, 2005).

There have been several studies on the effects of soil management systems on soil microbes and the structure of the soil food web (Mader et al., 2002; Ferris et al., 2004; Yao et al., 2005). Most of these studies were on herbaceous crops (Ferris et al., 1996; Robertson et al., 1997) and very few on apples (Forge et al., 2003; Yao et al, 2005).

Rhizosphere microorganisms may affect the hormonal balance and competitive ability of the plant, which will modify the soil biology community and the soil ecosystem (El-Shatnawi and Makhadmeh, 2001). Factors that are more likely to enhance stability of the soil microbial biomass are more likely to enhance nutrient conservation in the soil (Wardle and Nicholson, 1996). Alleviating stress on the microbial community has stabilizing effects (Wardle, 1998). Factors which stabilize the microbial biomass reduce turnover, and are likely to have important consequences for soil nutrient dynamics and ultimately plant growth and ecosystem productivity (Wardle, 1998).

The microorganism activity in the organic system influences the release of available nitrogen to the trees in the soil (Forge et al., 2003). Orchard floor management systems can provide organic forms of C and N which are quickly metabolized to inorganic nitrogen and other nutrients, primarily by bacteria and fungi (Ferris et al., 1998). Nitrogen is also mineralized as predators of bacteria and fungi, such as protozoa and microbivorous ("microorganism eating") nematodes, graze on prey which contain more N than required by the predators (Ferris et al., 1998). Although more research attention is given to the plant parasitic nematodes, microbivorous organisms make up a large portion of the nematode community. Excess N generated by grazing is released to the soil and becomes available for plant uptake (Ferris et al., 1998). Nematodes feeding types play an overall positive contribution to soil and thus ecosystem processes (Yeates, 1987; Bongers and Ferris, 1999; Bardgett et al., 1999). Nematodes can be used as indicators of soil functional and biodiversity aspects (Yeates, 2003) since they reflect the soil and ecological processes (Yeates, 1999). Most of the studies on the benefits of nematodes on nutrient release and availability in the soil have been done on the bacterial and fungal feeder nematodes. Bacterial feeders are responsible for a greater release of N when soil conditions are closer to optimal (Ferris et al., 1996; Ferris et al, 1997; Laakso et al., 2000; Forge et al., 2003) while fungal feeders have a higher effect when soil conditions are not optimal (Ingham et al., 1985; Ferris et al., 1998; Ferris and Chen, 1999; Ferris et al., 2004). A food web becomes more beneficial with increased structure and diversification (Power, 1992; Paine, 1996; Sugihara et al., 1997; Garlaschelli, 2004).

The interaction between the OFMS and the soil food web has an impact on edaphic conditions and nutrient availability. The degree to which kinetics of nutrient uptake or other potential adjustments are expressed would ultimately depend on soil nutrient availability and soil factors that determine nutrient transport to the root surface (Bassirirad, 2000). The retention of nutrients within an ecosystem depend on temporal and spatial synchrony between nutrient availability and nutrient uptake (Tierney et al., 2001).

Orchard floor management systems that support the most diversified food web will be able to reach a balance in time with an increased probability of a self sustainable environment, thus increasing the long term productivity of the plants.

In this experiment we evaluated three different OFMS for their rationale and input of organic material to the soil. One has a constant addition of N containing organic material (alfalfa hay mulch added twice yearly), another has the constant destruction of organic material on the soil surface (flaming), and the last one is a combination between modified cover crop (natural vegetation never mowed) and tillage.

We hypothesize that these differences in management will have an impact on the soil N concentration and organic matter content and therefore will impact the soil food web structure and diversity.

Our objectives were: 1) to determine the effect of the OFMS on the nutritional status of the soil; 2) to evaluate the structure of the soil food web; 3) to determine which system would create a more suitable environment to maximize tree production.

Material and Methods.

The experiment was conducted in an orchard of cultivar "Pacific Gala" (*Malus* x *domestica* Borkh.) apple established in April 2000 at the Clarksville Horticultural Experiment Station. The orchard was certified organic by the Organic Crop Improvement Association (OCIA) in 2003 and 2004 and Organic Grower of Michigan (OGM) in 2005. The site was previously farmed with conventional soybean-corn-corn-alfalfa rotation for two cycles until 1998. Subsequent soil preparation consisted of sowing of buckwheat and chicken compost (1250 kg/ha) and lime (2250 kg/ha) application in 1999 on the entire surface. At plantation (April 2000) a mixture of red mammoth clover and endophytic rye was sown in the alleys.

The predominant soil type of the orchard is Kalamazoo sandy clay loam (Typic Hapludalfs) with 53.1% sand, 23.1% silt, and 23.8% clay. The orchard presents mild slopes (less than 3%).

Drip irrigation with drippers of 2.3 L/h every 0.6 m was installed in May 2001 and suspended from the lowest wire of the trellis on the tree row. All orchard floor management systems received equal irrigation throughout the season. Soil moisture was measured by time domain reflectometry (TDR) using a Mini Trase 6050X3 (Soilmoisture Equipment Corp., Goleta, CA) with 45 cm long stainless steel rods permanently installed in the tree rows in 2001, halfway between two trees and in the middle of the tilled strip in 2002. Measurements were taken for each of the 6 plots per treatment weekly in 2002 and every other week in 2003-2005.

The three orchard floor management systems (OFMS) under study were established in the beginning of the second growing season (2001) and maintained for the entire study. The treatments consisted of mulch (MU) of alfalfa hay, the Sandwich System (SS) and Flaming (FL) with a propane burner. The alfalfa hay mulch was laid underneath the tree canopy in a strip of 1 m on each side of the tree and kept 15-20 cm thick. 105 round alfalfa bales/ha were used with a C:N ratio of 15:1. The treatment was hand-applied every spring and fall to keep the thickness of the mulch constant in order to provide a shading effect for weed suppression, and to maintain soil moisture.

The flaming treatment consists of the burning of weeds underneath the tree canopy and 1 m on each side of the tree with propane gas (estimated 56 L/ha). A custom engineered burner, consisting of 4 burners (200000 BTU/burner) in a row, and covered with a metal protective shield to concentrate the heat and to prevent its escaping and damaging the canopy. On the back of the shield was also mounted a sprinkler system to extinguish eventual fires occurring during the burning. To reach the weeds underneath the canopy on the tree row, a hand burner (150000 BTU) was used. The burner was mounted on the side of a tractor on a hydraulic arm to better control the application of the treatment. The treatment was applied five to six times during the year, starting at the end of April - beginning of May and ending at the end of August. The treatment was repeated every time the weeds would reach 10 cm high. Tractor speed was kept between 1.6 and 3.2 km/h depending on the density of the weeds to be controlled.

The Sandwich System is an adaptation of the Swiss system (Weibel, 2002) and consists of an area 25-30 cm on each side of the tree, underneath the canopy, where spontaneous vegetation is allowed to grow undisturbed (SVA). On each side of this vegetated area, two strips of soil were kept free of vegetation (STS) by shallow tilling (5-10 cm deep). The strips were 70 cm wide from tree planting till 2003 and expanded to 90 cm wide in 2004. Timing of the treatment application was the same as the flaming treatment. The tilling was accomplished from 2001 through 2004 with a spring-tooth (three teeth 2001-2003, 5 teeth 2004) harrow mounted on a side-bar of a tractor. To improve tillage effectiveness, a modified notch-disk tiller, mounted on the tractor side-bar, was deployed during the 2005 growing season.

The alley consisted of an equal mixture of endophytic rye and mammoth clover established soon after planting the orchard in 2000. Clover was also reseeded in 2005 to keep the proportion constant. The alleys were managed equally in all treatments by periodical mowing (3-4 times year).

Soil samples, from which the effect of OFMS on soil conditions and microbial communities were measured, were collected for the three OFMS by mixing 20 soil core sub-samples from the tree row. Soil samples from the alleys and the tilled strip of the SS were obtained by mixing 10 soil core sub-samples from each side of the tree row. Soil samples were collected four times per year (from April till November) at 0-10 and 0-30 cm depth starting from April 2001 till November 2005 to measure the temporal effect on the soil conditions. The two depths have been chosen to represent the surface soil, where most of the microbial processes take place (0-10 cm), and the most frequently explored part of soil by roots (0-30 cm). The two depths also provided an indication of the effect of depth on the soil conditions. Soil samples were stored at 4°C until the analyses were performed.

The effects of the OFMS on the soil conditions were monitored through:

- Soil nitrate (NO_3^-), from 2001 till 2005, and ammonium (NH_4^+), from 2003 till 2005, concentration (ppm) in the soil, to check the immediate available nitrogen released from the treatments available to the trees. The addition of the two forms of nitrogen gave us the total available mineral nitrogen concentration. Soil samples were air dried at 105°C for 24 hrs. Nitrates and ammonium concentration was extracted from the soil by 100 ml of KCl 1 M on 10 g of dried soil, placed for 1 hour on a shaker and then filtered with filter paper. The extraction liquid was sent to the MSU soil lab for the analysis of NH_4^+ and NO_3^- following the procedure described by (Kenney, 1982) using a Lachat automated colorimetric analyzer (Lachat Instruments Inc. Milwaukee, WI).
- Soil organic matter content, from 2002 till 2005, was measured by loss on ignition of 3g of dry soil, from the above described soil samples, at 400 °C for 8 hours in a muffle furnace.
- Soil carbon content was calculated from the organic matter values and divided by 1.724. This value is based on the organic matter containing 58% carbon (Stevenson 1994). Values obtained from the organic matter were corrected for the relative surface covered from each segment of the treatments (alley, tree row, and in case of the sandwich, vegetated area and tilled strip) and reported as the treatments were covering the entire surface of an orchard. Corrected values were then related to the volume of soil, respectively at 0-10 and 0-30 cm depth, contained in a hectare and showed as t/ha. Data were reported for the year 2005 and as average of the period 2002-2005 for both sampling depths (0-10 and 0-30 cm).

The effects of OFMS on microbial communities were measured two times during the growing season (April and November) starting from November 2003 untill April 2005. Nematode populations' composition were utilized as indicators of soil functional and biodiversity aspects (Yeates, 2003) since they reflect the soil and ecological processes (Yeates, 1999). To better understand these effects, apple and grass roots were examined for mycorrhizal infection (November 2004) and root lesion nematodes inside the roots (August 2005). Mycorrhizae spores in the soil were correlated with mycorrhizal root infection to determine eventual relationship between the two.

After collection, soil samples were transported to the soil nematode analysis facility of Dr George Bird at Michigan State University in East Lansing, MI. The extraction of nematodes and mycorrhizal spores from the soil was performed by the centrifugal-flotation (Jenkens, 1964). Nematodes were then sequentially sieved into a counting plate, and identified at 50·x magnification to families, genera and trophic group levels. Nematode communities' composition was calculated as percentage of each group feeding behavior on the total number of nematodes in the soil (Bird personal communication, 2006).

Apple roots from the four treatment positions (mulch row, flame row, sandwich vegetated area, and sandwich tilled strip), as well as a composite sample of weed roots from the vegetated area in the sandwich tree row, were collected in November 2004 were sent to the Dr. Amarantus lab (Grant Pass, Or) to determine the percent of endomycorrhizal infection. The percent of endomycorrhizal colonization was determined using a grid intercept method. This method includes examination for the development of spores, vesicles, arbuscules and fungal hyphae along the sample roots. Sampled roots are placed in capsules in a 10% KOH solution in a water bath at low heat for 24 hours. The KOH is poured off and capsules rinsed in three complete changes of tap water. Capsules are placed in a 1% HCL mixture for 30 minutes then immediately transferred into a water bath of Tri Pan blue for 3 hours and repeatedly rinsed. Roots from each capsule are rinsed and chopped in segments. Segments from each capsule are examined and tallied for percent colonization and presence of arbuscular spores of mycorrhizal fungi using a dissecting microscope. Roots are examined on a graduated Petri dish and each root intersection tallied as mycorrhizal or non mycorrhizal at 100 grid line crossings. Apple roots from the four treatment positions (mulch row, flame row, sandwich row, and sandwich tilled strip) were collected in August 2005 to determine the number of root lesion nematodes in the roots. Root lesion nematodes were extracted with the shake method (Bird 1971) from 1 g of roots and then counted with a counting plate at 50·x magnification.

Statistical analysis was performed with SAS (Version 8, SAS Institute, Cary, NC, USA). Analysis of variance was performed using the MIXED procedure to detect treatment effects. In case of significance, means were separated using the Least-square means test (LSMEANS) with $p \leq 0.05$. All the soil data statistical analysis was considered separately (to determine the effect on microbial populations) as well as repeated measures (to determine the overall effect on microbial dynamics). Repeated measures were preformed using block*OMFS as the subject.

The following timetable explains the history of the plot, sampling and measurements for the duration of the experiment.

Prior to1998	Conventional soybean-corn-corn-alfalfa rotation (2 cycles). Last crop was corn. Minimal tillage.			
1999	Spring: tillage sowing of soybean, Chicken compost (1250kg/ha), lime (2250 kg/ha). Fall: tillage, sowing of Buckwheat			
2000	April: tillage, tree planting. August: sowing of red mammoth clover and endophytic rye in the alleys.			
2001	May: implementation of the 3 orchard floor management systems.	April, June, August, November: soil sampling for NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD	
2002	Maintenance of the OFMS and tree training	April, June, August, November: soil sampling for SOM and NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD	
2003	Same as above	April, June, August, November: soil sampling for SOM, NO_3^- and NH_4^+	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD, yield	November: soil sampling for Food web
2004	Same as above	Same as above	Same as above	April and November: soil sampling for food web. November: root sampling for Mycorrhizal infection
2005	Same as above	Same as above	Same as above	April: soil sampling for food web. August: root sampling for root lesion nematodes counting.

Results

Effect on soil organic matter and carbon content.

The soil organic matter content was similar between the plots prior to the establishment of the treatments. Over the duration of the experiment the treatments did have an effect on organic matter content. Within each year soil organic matter (SOM) content was always significantly higher in the alfalfa hay Mulch (MU) than in the other treatments, except in 2002 where it was similar to the Swiss Sandwich tilled strip (STS) for the depth of 0-10 cm (Figure 1A). Soil organic matter increased during the years in MU, remained constant in the Swiss Sandwich vegetated area (SVA) and decreased in Flame (FL) and in STS. For the deeper sampling (0-30 cm) there is no difference between treatments within the year, however SOM increases during the years in MU and STS while it remains constant in FL and SWA (Fig. 1B). No treatment effect occurred in the alleys at any depth during the experiment period.

Carbon sequestered in the soil was different between the treatments at 0-10 cm depth with MU showing the highest value, FL the lowest and sandwich not differing between the two both in 2005 and as average during the evaluation period (2002-2005) (Table 1). The amount of carbon sequestered in 2005 was not different from the average of the evaluation period at 0-10 cm depth (Table 1). For the deeper sampling (0-30 cm) FL presented the lowest value of carbon sequestered with no differences between the other two treatments in the year 2005. No differences were measured in the average 2002-2005 between the treatments (Table 1). However both mulch and sandwich treatments presented an increase in carbon sequestered during 2005 when compared with the average 2002-2005 (Table 1).

Effect on soil Nitrogen concentration.

Since the implementation of the treatments the NO_3^- - N, at both depths, concentration in the soil of the MU treatment was significantly higher than the other two treatments. Between the years, only SVA shows a decrease in NO_3^- concentration at both depths (Figure 2 A-B). The total mineral N follows the same pattern of NO_3^-, with MU showing the highest concentration between the treatments for the duration of the experiment at both depths (Figure 3 A-B). However all the treatments show a significant increase in 2005, mostly due to the high concentration of NH_4^+ (data not shown).

Effect on Nematode community structure.

Nematode community structure was affected by the treatments during the 18 months of the duration of the experiment (November 2003 – April 2005). MU presented the highest number of total nematodes between the treatments. Bacterivores represented the highest percentage in the community structure in all the treatments followed by the fungivores, except for the vegetated area of the Swiss Sandwich where herbivores presented the same percentage as the fungivores (Table 2). However, between the treatments some differences in the structure composition were noted. While MU presented the highest percentage of bacterivores between the treatments, FL and STS presented the highest percentage of fungivores and omnivores, and SWA presented the highest percentage of herbivores (Table 2). No differences were noted between treatments for the carnivores. Mulch presented the lowest percentage of herbivores. This result was confirmed from the number of lesion nematodes in the apple roots where MU presented the lowest with no differences between the other treatments (Figures 5).

A direct correlation was found between the amount of mycorrhizal spores in the soil and the percentage of roots colonized from arbuscular mycorrhizae with an r^2 value of 0.7059 (Figure 6). However, the percentage of root colonization from arbuscular mycorrhizae was higher in SVA and FL, followed by MU and STS. The weeds present in the vegetated area of the Swiss Sandwich treatment presented the lowest percentage of infected roots (Figure 7).

Temporal effect on the nematode community structure.

Inside of each collecting date the nematode community structure followed the general structure presented in Table 2. With some exceptions, Swiss Sandwich vegetated area always presented the highest number of herbivores during the experiment period (Figure 8). Mulch had the lowest percentage of fungivores in November 2003 and April 2005 and the highest percentage of bacterivores (entire period) (Figure 8).

There was a temporal effect on the community structure inside of each treatment. In all the treatments the total number of nematodes increased in time, except for STS, where it remained constant (Table 3). All the treatments presented an increase in bacterivores during the duration of the experiment, except for STS where there is a decrease (Figure 9). However the feeding groups that compensate this increase in bacterivores vary between treatments (Figure 9). In flame the herbivores diminished, in mulch, herbivores and fungivores, and in SVA there is not a clear variation (Figure 9). In STS, at the diminishing of the bacterivores, there is an increase of fungivores (Figure 9). Omnivores and carnivores did not seem affected by temporal variation during the experiment period (Figure 9).

Soil water content.

Measurements performed with TDR (Figure 10) demonstrated that most of the time there were no differences between OFMS. When some difference was present MU had always the highest values while the SVA had the lowest. Flame and the STS did not differ from the other two.

Discussion

In our study, Orchard Floor Management Systems (OFMS) did have an impact on soil organic matter (SOM), even if it is largely believed that the process should take several years unless large quantities of organic matter are added. The greatest impact occurred under the mulch treatment near the surface (0-10 cm), where it increased during the experiment. Similar results were reported by Merwin et al. (1994), Sanchez et al. (2003) and Zoppolo (2004). At the deeper sampling (0-30 cm), the SOM increased but to a lesser degree, this is probably caused from the fact that the alfalfa mulch was layered on the soil surface without disturbance. Soil organic matter was the highest for the entire duration of the experiment under the mulch treatment. When differences occurred, water content in the soil was also the highest under alfalfa mulch.

The SOM varied in the sandwich treatment depending on the position in the orchard. In the vegetated area SOM content remained constant during the experiment at both sampling depths, while in the tilled area SOM decreased at 0-10 cm depth but increased at 0-30 cm depth. This result is normal for tilled soils where the increased aeration provoked by tilling initiates loss of organic matter (Brady and Weil 2002). When differences occurred, water content in the soil was the lowest in the vegetated area due to weed competition.

In the flame treatment, SOM decreased only at the shallow depth, probably due to the constant burning of the vegetation leaving only ashes on the soil surface.

In the alleys, where vegetation was mowed regularly and left on the soil, SOM remained more or less constant during the experiment.

Organic matter in the soil is mostly responsible for the carbon sequestration in the soil (Stevenson 1994). It is interesting to notice that when we consider the treatments as if applied to the entire surface of an orchard, taking into consideration the relative surface covered from each segment of the treatments (alley, tree row, and in case of the sandwich weeded area and tilled strip), we did not find the same differences reported for the SOM in each single segment. At 0-10 cm depth, mulch is still sequestering the highest amount of carbon/ha, flame the least and sandwich is in the middle, and the values are remaining constant during the years. At 0-30 cm depth, mulch and sandwich sequestered the same, and highest, amount of carbon and it increased during the experiment, while for flame it decreased. If we consider the fact that mulch is the only treatment with continuous addition of external sources of carbon, it appears that the sandwich system is the treatment with the highest potential of sequestering more carbon in the soil.

The effect of the treatments on the SOM correlated with soil nitrogen concentration (Powlson and Jenkinson, 1990; Díaz Rossello, 1992b; Bloksma, 2000) to a certain degree. The highest soil nitrogen concentration (almost double), for both nitrates and total mineral concentration was in the mulch treatment, while ammonium was the same between treatments. Nitrate concentration fluctuated during the years under the mulch treatment ending up being more or less constant compared with the beginning of the experiment. Only the vegetated area of the sandwich had a decrease in NO_3^- concentration. The NH_4^+ concentration increased for all treatments, especially in 2005, resulting in a general increase in total mineral nitrogen concentration. This shows that the treatments reached a sort of equilibrium because even if there was not an increase in SOM (treatments flame and sandwich), there was an increase in nitrogen concentration.

Organic floor management systems change the microbial composition (Yao et al, 2005) that is responsible for the nutrient availability in the soil (Forge et al., 2003; Yao et al, 2005).

Our experiment supports previous studies (Mader et al., 2002; Ferris et al., 2004; Yao et al., 2005) affirming that OFMS has an impact on the soil biology composition that we represented by the relative abundance (% on the total) of nematode populations (Ritz and Trudgil, 1999; Ferris et al., 2001; Yeates, 2003; Zoppolo, 2004) with different feeding habits .

The total number of nematodes was highest in mulch treatment followed by the vegetated area of the Swiss Sandwich (SVA). The difference between these two and the others is probably caused by the continuous decomposition of the vegetative material on the soil (Cookson et al., 2002).

In all the treatments, the bacterivores dominated the nematode population, which was highest in mulch treatment and had no differences between the other treatments. The composition of the remaining nematode populations varied depending on the treatment. According to Ingham et al. (1985) the more stressful the environment, lacking in nutrients (N and P) and/or water, the higher will be the amount of fungal feeding nematodes. This was corroborated in our experiment, where flame and Sandwich Tilled Area (STA) showed the highest number of fungal feeding nematodes, followed by SVA and mulch.

The number of herbivore nematodes (root feeding) in the soil is very important because it could create damage to the crops (Merwin and Stiles, 1989). The percentage of this nematode feeding population in the soil was affected by the OFMS. In fact, the SVA had the highest percentage followed by flame, STA and mulch. This result was not however, confirmed from the number of root feeding nematodes inside the roots where flame, STA, and SVA presented the same number, with mulch showing the lowest. It is not clear if the difference in percentage in the soil and the number inside the roots is due to the fact that the herbivore nematodes measured in the soil are a more expanse composition of populations than those in the roots. Another factor could be that the highest values measured in SVA could be due to the higher number of weed roots present in the treatment, since we did not measure the root feeding nematodes in the weeds.

Most of the current ecological research agrees that the most beneficial food webs are those which are highly structural and diversified (Power, 1992; Paine, 1996; Sugihara et al., 1997; Garlaschelli, 2004). Based on trends, over time, in this study we suggest an impact, and through the evolution of the populations' diversification, on structure. Populations fluctuated according to treatments. Bacterial feeder nematodes increased in flame treatment to the detriment of herbivores. In contrast there was a decrease in herbivore nematodes in mulch with no clear tendency in other populations. The fluctuation was high in SVA of all the populations and STA showed an increase in fungal feeder nematodes with no clear tendency of which population was decreasing. If we consider the last sampling date (April 2005) as an indicator of the treatments to reach a balance in their structure it appears that mulch has the highest percentage of bacterivores, STA the highest of fungivores with mulch the lowest, and that SVA has the highest percentage of herbivores.

To have a better comprehension of the food web structure we measured the amount of endomycorrhizal spores in the soil as well as the percentage of infection from said mycorrhizae in the roots. It is established that mycorrhizae are of extreme importance in aiding the plant to absorb nutrients from the soil in low N conditions (Miller et al., 1985; Grange et al., 1994; Newsham et al., 1995). There is a clear correlation between the amount of spores in the soil and the percentage of infection in the roots indicating that the amount of spores in the soil could be utilized as an indicator of infection. Additionally, mycorrhizal infection in the roots was highest in SVA and flame, with the weeds in the SVA showing the lowest (probably due to a species-host issue). Mulch and STA presented the same percentage of infection in between the other treatments. This could be due to mulch associated with a high nutritional status of the soil and for STA to the disturbance generated from tillage.

All of these results suggest that the mulch treatment has the lowest diversified soil biology among the treatments.

Conclusions

Our study demonstrates that Orchard Floor Management Systems have an impact on the soil conditions such as SOM, carbon sequestration, nitrogen concentration and food web.

The mulch treatment presented the highest values of SOM, carbon sequestered, and nitrogen in the soil at both sampling depths, but had the least structured food web with the majority of the populations represented by bacteria feeding nematodes. One positive outcome is that there appears to be less herbivore nematodes associated with this treatment. The high amount of nitrogen could have potential to leach in the soil profile. Also, the continuous addition of external carbon (alfalfa hay) to the system undermines the capability to sequester high level of carbon.

The sandwich treatment presented lower values of SOM and nitrogen than alfalfa mulch. SOM is decreasing at 0-10 cm depth in the tilled area and increasing at the deeper sampling (due to the tillage), while nitrogen is decreasing in the vegetated area at 0-10 cm depth (due to higher competition). The treatment had the same amount of carbon sequestered as mulch, without external additions, creating a higher potential for carbon sequestration. Sandwich presented a more balanced food web structure than mulch with the weeded area having highest values of herbivore nematodes and root mycorrhizal infection, while the tilled area has the highest value of fungivores with a similar percentage for mulch of root mycorrhizal infection. It is not clear if the tillage is one of the factors responsible for the increase in fungivores and reduction of mycorrhizae, since the nutritional soil status between the two positions inside this treatment are similar.

The flame treatment has similar soil conditions as the sandwich, showing a reduction in SOM at 0-10 cm probably due to the continuous burning of the vegetation. The practice also shows similar food web structure and repartition inside the populations as the sandwich suggesting that the two treatments have more stressful soil conditions than mulch (lower SOM, N and in case of the sandwich vegetated area, water content), but they are coping through a shift in microbial populations. As expected, this treatment provided for the lowest carbon sequestered.

In this study there was a high correlation between the amount of mycorrhizal spores in the soil and the percentage of infection in the apple roots in Michigan conditions.

Overall, organic apple growers should consider the use of the sandwich as a suitable choice of orchard floor management in Michigan. More research is still necessary, especially coupling the structure of the food web with the effect of the tillage and the nutritional status in the soil through fertilization trials and use of growing legumes.

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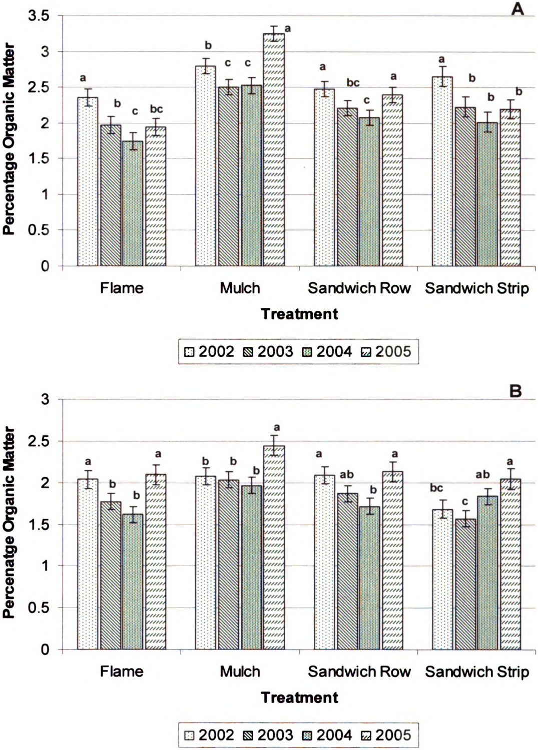


Fig. 1: Effect of the treatments on percentage of organic matter content in the soil during the duration of the experiment (2002-2005) at 0-10 (**A**) and 0-30 (**B**) cm depth. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between years inside of each treatment and should be read separately. Bars represent standard errors.

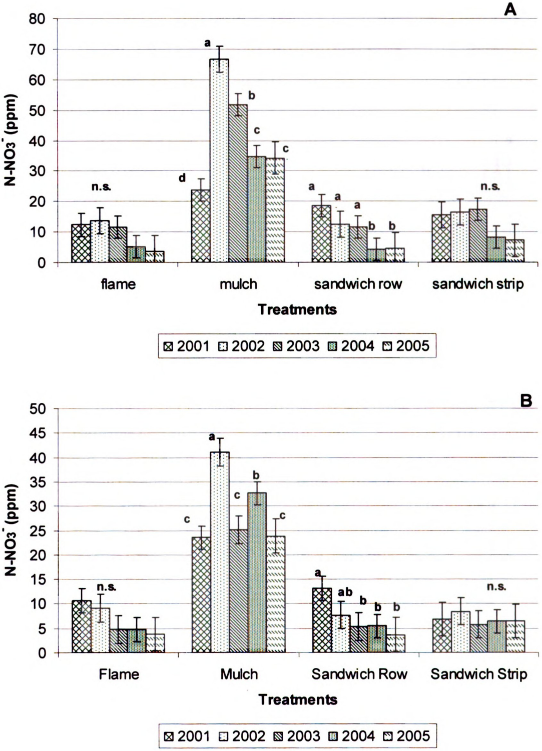


Fig. 2: Effect of the treatments on N-NO_3^- content in the soil during the duration of the experiment (2001-2005) at 0-10 (**A**) and 0-30 (**B**) cm depth. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between years inside of each treatment and should be read separately. Bars represent standard errors.

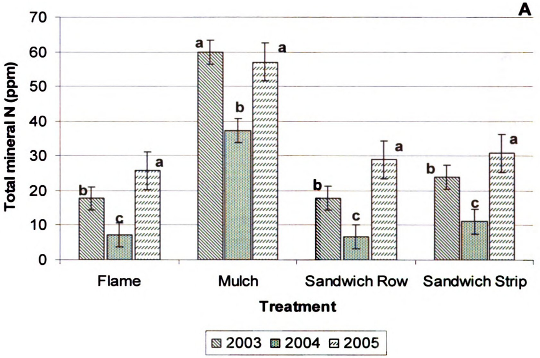
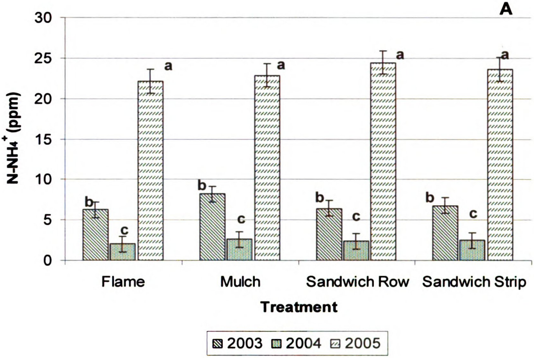


Fig. 3: Effect of the treatments on Total mineral N (N-NO_3^- + N-NH_4^+) content in the soil during the duration of the experiment (2003-2005) at 0-10 (**A**) and 0-30 (**B**) cm depth. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between years inside of each treatment and should be read separately. Bars represent standard errors.



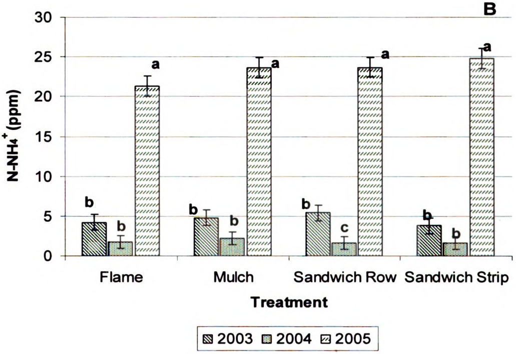


Fig. 4: Effect of the treatments on N-NH_4^+ content in the soil during the duration of the experiment (2003-2005) at 0-10 (**A**) and 0-30 (**B**) cm depth. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between years inside of each treatment and should be read separately. Bars represent standard errors.

Table 1: Tons of carbon sequestered in one hectare of soil considered as entirely covered from each treatment in 2005 and as average of the period 2002-2005. Different small letters represent statistical difference (LSMEANS with P ≤ 0.05) between the treatments inside of the years (letters should be read vertically). Different capital letters represent statistical difference (from orthogonal contrasts at p ≤ 0.05) between the years inside of the each treatment (letters should be read horizontally).

	0-10 cm		0-30 cm	
	2005	2002-2005	2005	2002-2005
Flame	18 b A	18 b A	46 b A	44 a A
Mulch	22 a A	21 a A	51 a A	47 a B
Sandwich	20 ab A	19 ab A	51 a A	45 a B

Table 2: Nematode community structure during the 18 months of the experiment (November 2003-April 2005) at 0-30 cm depth. Feeding behaviors are the percentage of each group based on the absolute nematode density (total nematodes number). Different letters represent statistical difference (LSMEANS with P ≤ 0.05) between the treatments inside of each nematode feeding behavior and should be read horizontally.

	Treatment			
Feeding Behavior (%)	Flame	Mulch	Sandwich Vegetated area	Sandwich tilled Strip
Herbivores	8 b	3 c	14 a	5 bc
Fungivores	18 a	9 c	14 b	21 a
Omnivores	5 a	3 b	4 ab	5 a
Carnivores	1 a	1 a	1 a	1 a
Bacterivores	68 b	84 a	67 b	68 b
Absolute Density	471 c	1246 a	754 b	343 c

Table 3: Total number of nematodes during the 18 months of the experiment (November 2003-April 2005) at 0-30 cm depth. Different letters represent statistical difference (LSMEANS with P ≤ 0.05) between the dates of collection inside of treatment and should be read vertically.

	Treatment			
Date of collection	Flame	Mulch	Sandwich Vegetated area	Sandwich Tilled Strip
November 03	169 b	226 c	225 c	179 a
April 04	264 b	405 c	356 c	235 a
November 04	882 a	1123 b	1356 a	611 a
April 05	572 ab	3231 a	1081 b	345 a

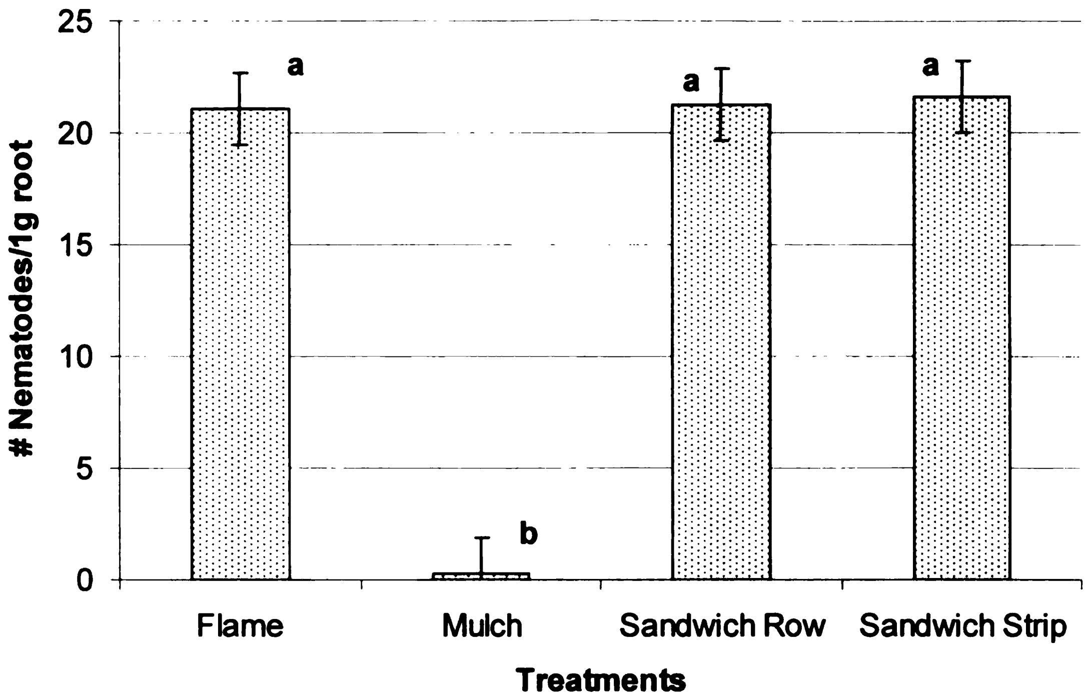


Figure 5: Number of root lesion nematodes in 1 g of apple roots in collected in August 2005. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between the treatments. Bars represent standard errors.

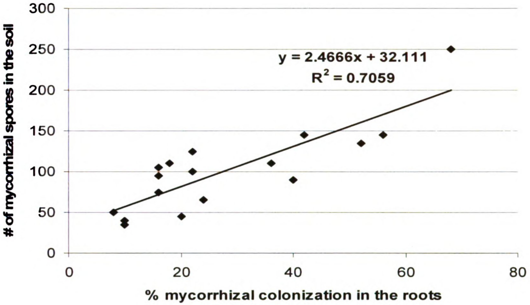


Figure 6: Correlation between percentage of arbuscular mycorrhizal colonization in the roots and number of mycorrhizal spores in the soil (November 2004). (Proc REG Pr > F <0.001)

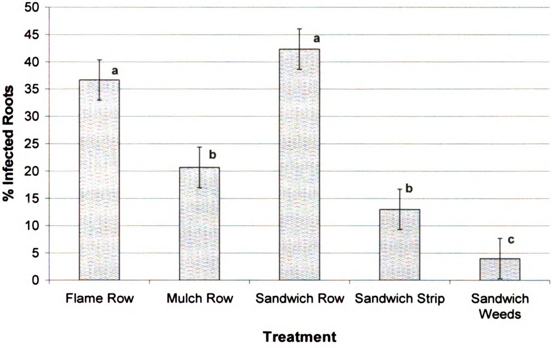


Figure 7: Percentage of roots colonized from arbuscular mycorrhizae (November 2004). Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between the treatments. Bars represent standard errors.

Figure 8: Temporal effect on the Nematode community structure (0-30 cm) during the 18 months of the experiment (November 2003-April 2005). Feeding behaviors (expressed in the legend) are the percentage of each group based on the absolute nematode density (total nematodes numbers). Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between treatments inside each collection date. If there are no letters means no statistical difference.

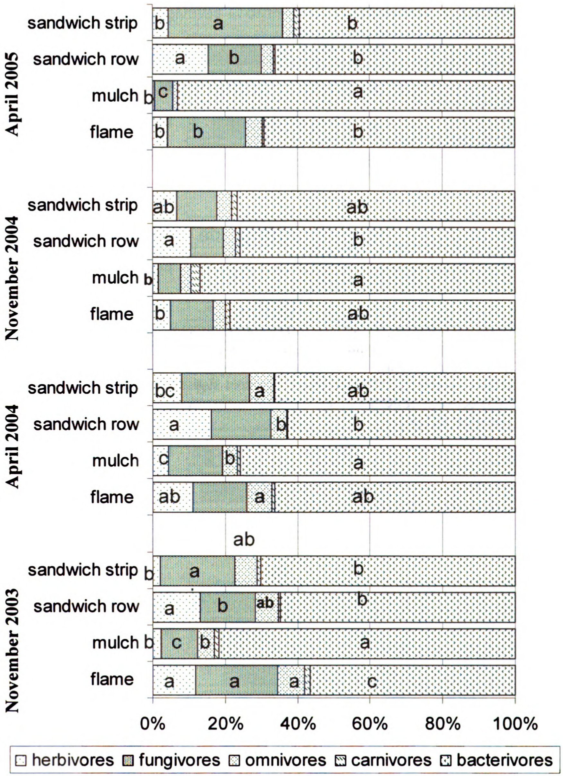
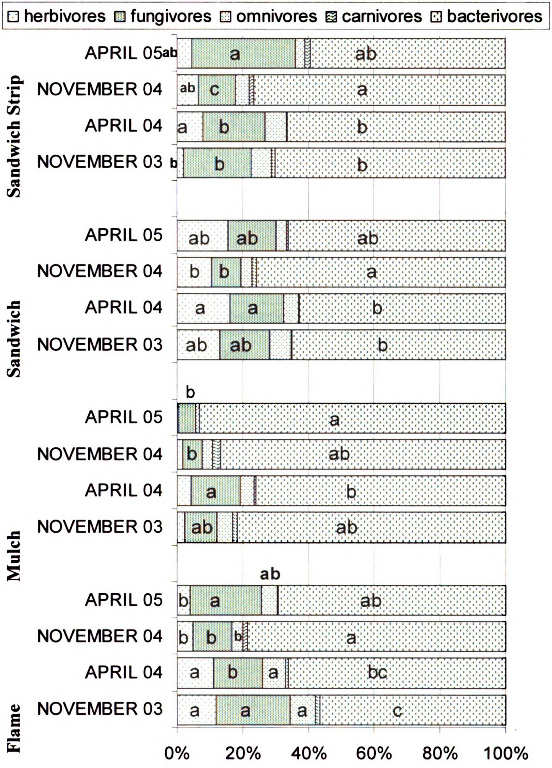

April 2005
November 2004
April 2004
November 2003
sandwich strip
sandwich row
mulch
flame
0%
20%
40%
60%
80%
100%
herbivores
fungivores
omnivores
carnivores
bacterivores

Figure 9: Temporal effect on the Nematode community structure (0-30 cm) during the 18 months of the experiment (November 2003-April 2005). Feeding behaviors (expressed in the legend) are the percentage of each group based on the absolute nematode density (total nematodes numbers). Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between collection dates inside of each treatment. If there are no letters means no statistical difference.



herbivores
fungivores
omnivores
carnivores
bacterivores
Sandwich Strip
Sandwich
Mulch
Flame
APRIL 05
NOVEMBER 04
APRIL 04
NOVEMBER 03
0%
20%
40%
60%
80%
100%

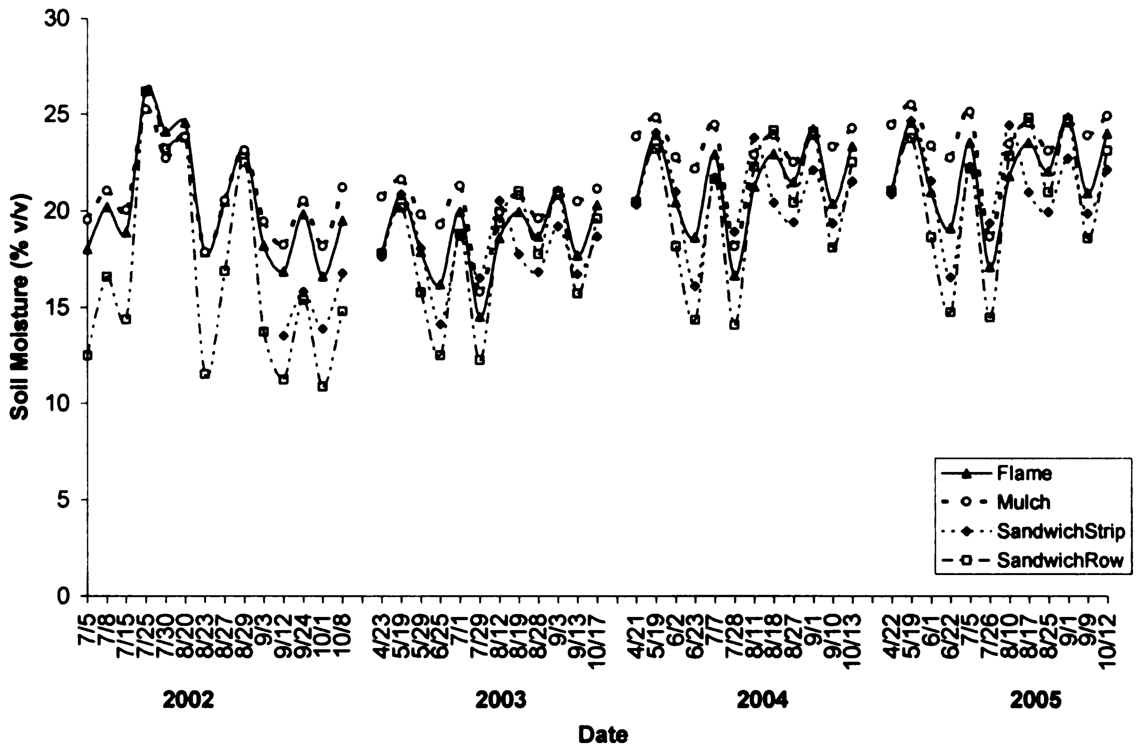


Figure 10: Volumetric soil moisture content (as %) measured with TDR for the average 0-45 cm depth, for the different treatments during 2002-2005.

Abstract

CHAPTER 2. The Response of "Pacific Gala" on three Rootstocks to three Orchard Floor Management Systems under Organic Protocol.

By Dario Stefanelli

In organic apple production, orchard floor management is of greatest importance since it determines weed management and fertility. In this experiment we evaluated the response of the cultivar "Pacific Gala" on three rootstocks of different vigor: M.9 NAKB 337, M.9 RN 29, and Supporter 4 (in respective order of vigor from dwarfing to semi-vigorous). The three rootstocks were also evaluated for the response to three orchard floor management systems: mulching (alfalfa hay), flaming, and strip tillage on each side of the row with natural vegetation allowed to grow on the tree row (Swiss Sandwich System). The experiment was conducted in an orchard planted in 2001 and certified organic since 2003.

The three treatments did change the soil conditions with mulch showing higher concentrations of SOM and N creating different growing conditions for the rootstocks. The OFMS treatments did not have an effect on the tree growth parameters measured except for foliar nitrogen concentration that was higher with alfalfa mulch. Trees on Supporter 4 were most vigorous, as anticipated. There was an interaction between treatments and rootstocks with M.9 RN 29 showing the highest yield and "yield efficiency" per tree in flame and sandwich while no differences were noticed between the rootstocks in mulch despite its better growing conditions. This suggests that M.9 RN 29 is a rootstock that adapts well to more stressful conditions (lower SOM and N, and in

case of the Sandwich vegetated area, water content) posed by sandwich and flame treatments. Cumulative yield/ha was highest in mulch and sandwich and lowest in the flame treatment.

The flame treatment appeared less desirable related to management regarding low SOM, N, fire risk, risk of injures to branches, and irrigation plastic system. On a positive side the flame was economical at an annual expense of $278 in our experimental orchard. Drawbacks to the alfalfa hay mulch system included; expensive ($788), high maintenance (to keep it thick), high risk of rodents damage, and risk of leaching. The sandwich system provided a less suitable growing conditions (lower SOM, N concentration and water content in the vegetated area), it was however, easy to deploy and manage, it did not damage the tree, it was low cost at $98, and it requires only an easily modified notch disk tiller.

Overall, considering the sandwich system coupled with the M.9 RN 29 rootstock seems to be a suitable choice for growers that want to grow Pacific Gala under organic protocol in Michigan and similar climates. More research is still necessary especially to confirm these results in a longer term study.

Introduction

Organic horticulture is becoming one of the fastest growing sectors in the agriculture economy (Dimitri, 2002). There is a worldwide growing interest in the development of sustainable production systems for food production (Yussefi, 2004).

Organic agriculture limits the inputs used to those considered environmentally and economically sustainable when compared with conventional methods. It becomes then, a challenge to overcome issues such as pest, weed control, and fertilization.

There is the need to identify management systems that are productive under these constrains. In organic production the soil is considered the most important part in sustaining production and plant health. A common phrase used to characterize organic growing is "Feed the soil, not the plant".

In tree fruit production, Orchard Floor Management Systems (OFMS) are developed to create the best environment for tree growth allowing the maximization of its performance (Weibel, 2002). A successful OFMS needs to increase soil fertility, physical and biological properties, to supply nutrients to the trees, while suppressing the competitive effects of weeds without the use of traditional herbicides, and minimizing insect and disease pressure.

Orchard floor management practices have been developed and adopted by commercial fruit growers to satisfy practical needs. Mulching (with organic or inorganic material) keeps the soil free from vegetation competition, conserves soil moisture, keeps temperature constant, increases organic matter through its decomposition (in the case of organic mulches), releases nutrients to the soil, and improves the soil environment enhancing the microbial activity (Merwin and Stiles, 1994; Merwin et al., 1995; Marsh et al., 1996; Lloyd et al, 2000).

Tillage also keeps the soil free from vegetation competition but can impede internal water drainage, cause surface organic matter losses (Merwin and Stiles, 1994) and disrupt surface roots. (Cockroft and Wallbrink, 1996). Additionally, tillage can cause surface water run-off and soil erosion. It is still widely used globally even if it is expensive, uses precious petrol fuel and requires specialized machinery.

Recently a modified tilling system has been implemented in Switzerland, called the Swiss Sandwich System. It consists of a strip where spontaneous vegetation is allowed to grow on the tree row and two shallow tilled strips at each side of the tree row. This system encourages predator insects to complete their cycle in the volunteer vegetation that grow on the tree row, becoming more efficient in limiting pests and diseases, and increasing biodiversity (Luna and Jepson, 1998; Horton, 1999; Schmid and Weibel, 2000; Galoach, 2002). The resulting vegetation in the tree row can be considered as cover crops, contributing to the system their significant benefits to organic production systems aiding in the prevention of soil erosion, increased soil organic matter, facilitation in the recycling of soil nutrients, and reduction in the amount of nitrate runoff and leaching from the soil (Miles and Chen, 2001). The Swiss system is easy to manage since there is no need to reach under the tree canopy to mow weeds or till (Schmid and Weibel, 2000; Weibel, 2002; Weibel and Haseli, 2003). The two strips of shallow tilled bare soil have the effect of reducing vegetation competition for water and nutrients (Merwin and Ray, 1997).

Flaming is another effective practice in use by organic growers (Gourd, 2002; Robinson, 2003), with relative little known regarding the effects of this system, besides vegetation suppression. It has, however, drawbacks associated with its practice, such as fires, damage to the trees (Zoppolo, 2004) and the need of special equipment.

All of these systems achieve the goal to keep a certain amount of soil surface free from competitive vegetation which can have a negative impact on tree growth (Parker, 1990; Welker and Glenn, 1991; Merwin and Ray, 1997). Without the use of herbicides, vegetation management requires more thought and management skills by growers in organic production (Webster, 2000).

It is clear, that all of these OFMS have a different approach and will have different results, since they are difficult to standardize or compare, even if they somewhat achieve the same results. It will then be left to the trees to overcome eventual stressful situations created in the soil from the OFMS.

Another form of management that growers can usee to overcome this problem is the selection of appropriate rootstock, irrigation and nutrient management. There is a wide variety of specifically selected apple rootstocks that have been developed and released over many years. Each rootstock differs in its ability to adapt to soil conditions (Ferree and Carlson, 1987), disease resistance, and influenced vigor and production characteristics of the scion. There are extensive research programs that center on rootstock evaluation for the above mentioned characteristics. The evaluation is performed with conventional practices and under optimal growing conditions unless different conditions are strictly required. This factor alone reduces the utility of the rootstock outside of those conditions, thus inducing the growers to adapt their orchard conditions to the optimal one in which the rootstocks were tested. Environmental factors seem to be more influential on the uptake of nitrogen and phosphorus than the rootstock genotype (Kennedy et al., 1980) but not enough is known on the subject. There is a strong relationship between genetic (vigor) and environmental factors in determining the adaptability of the root system and consequently its capability of nutrient uptake and tree performance under adverse conditions.

Since organic OFMS do create environmental conditions that are different from the conventional practices in which rootstocks are evaluated, perhaps rootstock selection can compensate and overcome these differences.

It will then be of great value to obtain information on rootstock performance as a response to OFMS. In this study we evaluated three rootstocks of different vigor managed with three different organic OFMS (mulching, flaming and the new Swiss sandwich system).

The objectives of this work were to evaluate the responses of rootstocks to the different growing conditions present in the OFMS; to asses the effective impact of OFMS on the soil conditions; to determine the suitability for growers of the OFMS.

Materials and Methods.

An orchard of "Pacific Gala" (*Malus* x *domestica* Borkh.) was planted in May 2001 at the Clarksville Horticulture Research Station in Clarksville, MI. The orchard has been certified organic in 2003 and 2004 by Organic Crop Improvement Association (OCIA), and in 2005 by Organic Growers of Michigan (OGM).

The orchard consists of 468 trees grafted on three rootstocks depending on their vigor.

The rootstocks under evaluation are the dwarfing M9. NAKB 337 (40% of the size of a seedling. Marini et al., 2000), the semi-dwarfing M9. RN 29 (Perry, 2000a), and Supporter 4 (semi-vigorous) (Perry, 2000b).

Spacing between the trees is dependant of the rootstock vigor (Perry, 2002) and are 4.6 x 1.4 m for M9. NAKB 337, 4.6 x 1.7 m for M9. RN 29, and 4.6 x 2.0 m for Supporter 4.

Trees were trained to a vertical axe system. Rubber bands and clothes pin were used to bend branches in early years (Perry, 2000c). Minimal pruning was applied to allow the tree to grow as natural as possible mainly singularizing the leader or main branches. A two wire trellis with galvanized metal poles was installed as support system. Drip irrigation with drippers of 2.3 L/h every 0.6 m was installed in May 2001 and suspended from the lowest wire of the trellis on the tree row. All orchard floor management systems received equal irrigation throughout the season.

Soil moisture was measured by time domain reflectometry (TDR) using a Mini Trase 6050X3 (Soilmoisture Equipment Corp., Goleta, CA) with 45 cm long stainless steel rods permanently installed in the tree rows, halfway between two trees and in the middle of the tilled strip in 2002. Measurements were taken for each of the 6 plots per treatment weekly in 2002 and every other week in 2003-2005.

The predominant soil type of the orchard is Kalamazoo sandy clay loam (Typic Hapludalfs) with 53.1% sand, 23.1% silt, and 23.8% clay. The orchard presents mild slopes (less than 3%).

The site was previously farmed with conventional soybean-corn-corn-alfalfa rotation for two cycles until 1998. Subsequent soil preparation consisted of sowing of buckwheat and chicken compost (1250 kg/ha) and lime (2250 kg/ha) application in 1999 on the entire surface. At plantation (April 2000) a mixture of red mammoth clover and endophytic rye was sown in the alleys.

The orchard floor management systems (OFMS) have been applied since the plantation of the orchard. The treatments consist of Mulch of alfalfa hay, the Sandwich System (SS) and Flaming (FL) with a propane burner. The objective of the treatments is the weed management of the orchard.

The mulch treatment consists of alfalfa hay laid underneath the tree canopy in a strip of 1 m on each side of the tree and kept 15-20 cm thick. 105 round alfalfa bales/ha were used with a C:N ratio of 15:1. The mulch was hand-applied every spring and fall to keep the thickness constant in order to provide a shading effect for weed suppression, and to maintain soil moisture.

The flaming treatment consists of the burning of weeds underneath the tree canopy and 1 m each side of the tree with propane gas (estimated 56 L/ha). A custom engineered burner, consisting of 4 burners (200000 BTU) in a row, comprehensive of a metal protective shield to concentrate the heat and to prevent its escaping and damaging the canopy. On the back of the shield was also mounted a sprinkler system to extinguish eventual fires occurring during the burning. To reach the weeds underneath the canopy on the tree row a hand burner (150000 BTU) was used. The burner was mounted on the side of a tractor on a hydraulic arm to better control the application of the treatment. The treatment was applied five to six times during the year, starting at the end of April - beginning of May and ending at the end of August. The treatment was repeated every time the weeds would reach 10 cm high. Tractor speed was kept between 1.6 and 3.2 km/h depending on the density of the weeds to be controlled.

The Sandwich System is an adaptation of the Swiss system (Weibel, 2002) and consists of an area of 25-30 cm on each side of the tree, underneath the canopy, where spontaneous vegetation is allowed to grow undisturbed. On each side of this weeded area two strips of soil were kept free of vegetation by shallow tilling (5-10 cm deep). The strips were 70 cm wide from plantation till 2003 and 90 cm wide from 2004. The width of the strip has been changed to follow the growth of the trees. Timing of the treatment application was the same of the Flaming treatment. The tilling was applied by a three tooth arrow tiller mounted on the side of a tractor on a hydraulic harm till 2003, a five tooth arrow tiller during 2004, and a modified notch disk tiller during 2005. The notch disk tiller was modified to reach on the side of the tractor (Picture 1 and 2).

The alley consisted of an equal mixture of endophytic rye and mammoth clover seeded at the orchard plantation. Clover was also reseeded in 2005 to keep the proportion constant. The alleys were managed equally in all treatments by periodical mowing (3-4 times year) and the remains were left on site according to best management farming practices.

Rootstock performances were measured by growth, production, and nutritional status parameters of the trees while OFMS effect on the soil was measured by periodically checking the soil conditions.

Growth parameters measured were:

- Trunk cross sectional area (TCA) at dormancy as well as its differential since establishment (TCAI) during the years. This methodology has been proven to be highly correlated with the tree growth (Westwood and Roberts, 1970).
- Shoot growth (extension) was measured every week on three representative shoots plus the leader during all the vegetative season to measure the growth rate. Shoots were selected to represent the bottom, middle and top part of the tree. Selected shoots were comparable in size and insertion angle at the time of selection.
- Canopy volume was calculated measuring the total height as well as two orthogonal diameters of the canopy at 0.7 m from the soil.

Production parameters measured were:

- Yield (kg/tree) and number of fruits to obtain the average fruit weight (g), as well as cumulative yield during the years. Values were also corrected to the actual number of trees to obtain productions/ha.
- "Yield efficiency" (kg/cm^2), or ratio of fruit yield to trunk vigor (TCA) was calculated by dividing the yield of the year by the TCA of the previous year, as well as the cumulative yield efficiency (kg/cm^2) calculated by dividing the cumulative yield by the TCAI of the current year.

Tree nutritional status parameters measured were:

- Relative chlorophyll content of a composite sample of 10 leaves per data tree collected from the middle portion of one year old branches. Relative chlorophyll content was measured using a SPAD-502 meter (Spectrum Technologies Inc, Plainfield IL) in early August.
- Mineral nitrogen concentration of the previously described composite sample of leaves. Leaves were rinsed with distilled water, air dried at 60°C for 48 hrs, ground and sent to the MSU soil and plant nutrition lab to be analyzed for N concentration.

Soil conditions measured were:

- Soil nitrate (NO_3^-) and ammonium (NH_4^+) concentration in the soil, to check the immediate available nitrogen released from the treatments available to the trees. Soil samples were obtained for the three OFMS by mixing 20 soil core sub-samples from the tree row. Soil samples from the Alleys and the tilled strip of the SS were obtained by mixing 10 soil core sub-samples from each side of the tree row. Soil samples were collected every two months starting in April until November at 0-10 and 0-30 cm depth each year. The two depths have been chosen to represent the soil surface, where most of the microbial and root activity is greatest. Soil samples were air dried at 105°C for 24 hrs. Nitrates and ammonium were extracted from the soil with 100 ml of KCl 1 M on 10 g of dried soil, placed for 1 hour on a shaker and then filtered with filter paper. The extracted liquid was sent to the MSU soil lab for the analysis following the procedure described by (Kenney, 1982) using a Lachat automated colorimetric analyzer (Lachat Instruments Inc. Milwaukee, WI).

- Soil organic matter content was measured by loss on ignition of 3g of dry soil, from the above described soil samples, at 400 °C for 8 hours in a muffle furnace.

We also performed a limited maintenance cost comparison of the systems deployed for the 2005 growing season utilizing our experimental plot as unit.

The treatments were applied in a complete randomized split plot design with OFMS as main plots and the rootstocks as sub-plots with 6 replicates. Four trees for each rootstock were planted in each sub-plot. Only the two central trees for each rootstock were utilized as data trees for a total of 84 trees under evaluation. Each data row was alternated with buffer rows consisting of trees of same rootstocks and distances arranged in single rows. Statistical analysis was performed with SAS (Version 8, SAS Institute, Cary, NC, USA). Analysis of variance was performed using the MIXED procedure to detect treatment effects. When significant, mean separation was conducted by Least-square means test (LSMEANS) with $p \leq 0.05$. All the soil data statistical analysis was considered as repeated measures using OMFS*rootstock as the subject.

The following timetable explains the history of the plot, sampling and measurements for the duration of the experiment.

Prior to 1998	Conventional soybean-corn-corn-alfalfa rotation (2 cycles). Last crop was corn. Minimal tillage.		
1999	Spring: tillage sowing of soybean, Chicken compost (1250kg/ha), lime (2250 kg/ha). Fall: tillage, sowing of Buckwheat		
2000	April: tillage, tree planting. August: sowing of red mammoth clover and endophytic rye in the alleys.		
2001	May: implementation of the 3 orchard floor management systems.	April, June, August, November: soil sampling for NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD
2002-05	Maintenance of the OFMS and tree training	April, June, August, November: soil sampling for SOM and NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD

Results

The orchard floor management systems (OFMS) treatments impacted the soil organic matter (SOM) and Nitrogen (N) concentration of the soil, effectively changing the growth conditions for the rootstocks. Within each year, SOM content was always higher in the Mulch (MU) than in the other treatments, except in 2002 where it was similar to the tilled strip in the Sandwich (STS) for the depth of 0-10 cm (Fig. 1A). Soil organic matter increased during the years in MU, remained constant in the Sandwich vegetated area (SVA) and decreased in Flame (FL) and in STS. For the deeper sampling (0-30 cm) there is no difference between treatments within the year. However, SOM increased during the years in MU and STS while it remained constant in FL and SWA (Fig. 1B). No treatment effect was measured in the alleys at any depth during the experiment period.

Since 2003, at both depths, total mineral nitrogen (NO_3^- - N + NH_4^+ - N) concentration in the soil of the MU treatment was significantly higher than the other two treatments (Figure 2 A-B), however all the treatments had a significant increase in 2005.

In 2005, for all the growth parameters considered, there was no effect of the treatments and no interaction between the treatments and rootstocks (Figure 3; Table 1). Only during training years (2001-2003) did the treatments present some effect on branch growth, trunk cross sectional area (TCA) and its increase (TCAI) with mulch (MU) showing the highest values (Zoppolo, 2004). However, since the trees entered in full production (2004) the treatment effect has ceased to be noticeable.

Among rootstocks, Supporter 4 had the highest values in most of the growth parameters considered, presenting the same trend as Figures 3, with no differences between the other two rootstocks (M.9 RN 29 and M.9 NAKB 337) except for branch growth in 2004 (data not shown) and 2005 where no differences were noticed. Branch growth in 2005 ranged between 38 cm (M.9 RN 29 in mulch) and 43 cm (M.9 NAKB 337 and Supporter 4 in sandwich).

Rootstock did not influence the nitrogen status of the leaves. Since 2003 MU presented the highest values in leaf nitrogen concentration (Table 2).

Cropping was not influenced by OFMS but differences among rootstock exist (Table 3). Rootstock did not impact cropping in mulch treatment, while M.9 RN 29 was most productive (with no differences between the other two rootstocks) in both of the other treatments (Figure 4). Yield efficiency, as the ratio of fruit yield to trunk vigor, presented the same trend as the yield values (Figure 4).

The same production parameters behaved differently when corrected for the number of trees to obtain values per hectare. There was still no influence of the treatments on any of the parameters, but there was an influence from the rootstocks and their interaction with the treatments (Table 3). All the parameters considered had the same trend as the cumulative yield (t/ha) in which there was no difference between the rootstocks in the treatments flame (Figure 5). Supporter 4 presented the lowest production in both mulch and sandwich while M.9 NAKB 337 had the highest yield/ha in mulch and M.9 RN 29 in sandwich (Figure 5).

The cost evaluation for the applications of the Orchard floor management systems suggested that sandwich was the least expensive ($ 91), followed by the flame ($ 218) and mulch ($ 788), (Table 4).

Soil water content.

Measurements performed with TDR (Figure 6) demonstrated that most of the time there were no differences between OFMS. When some difference was present MU had always the highest values while the SVA had the lowest. Flame and the tilled strip in the sandwich did not differ from the other two.

Discussion

During the experiment the orchard floor management systems did have an impact on the soil conditions. Mulch increased the percentage of soil organic matter (SOM) at both measured depths (from 2.7 to 3.3 % at 0-10 cm and from 2.0 to 2.4 % at 0-30 cm) and it was higher than the other two treatments. This is due to the continuous break down (Cookson et al., 2002) of the mulch itself by the microorganisms in the soil and its continuous addition (twice yearly) for the duration of the experiment (Merwin et al., 1994; Sanchez et al., 2003, Zoppolo, 2004). Differences between the two measured depths are probably due to the fact that the alfalfa mulch was layered on the soil surface without disturbance. Also, when differences occurred, mulch had the highest soil water content.

On the vegetated area of the sandwich system the constant level of SOM was probably kept from the decaying dry matter produced by the dead vegetation laying on the soil. When differences occurred, mulch had the lowest soil water content. In the tilled strip however, we noticed a decrease in SOM at the soil surface (0-10 cm) but an increase deeper in the soil profile (0-30 cm). This behavior has been reported as normal since tilling increases aeration and loss in organic matter (Brady and Weil, 2002).In the flame treatment, the superficial loss in SOM is likely associated with the constant burning of the vegetation that leaves only ashes on the soil surface.

The effect of the treatments the SOM reflected on the effects of nitrogen concentration in the soil (Powlson and Jenkinson, 1990; Díaz Rossello, 1992b; Bloksma, 2000). In fact, MU, especially at 0-10 cm depth, generated almost double the amount of total mineral nitrogen when compared with the other two treatments, as expected from its high protein concentration (Donahue et al., 1970; Sarrantonio, 2003). It seems however, that the different systems are reaching a sort of balance, since the amount of N in the soil is increasing during the years (especially evident in 2005).

The mulch treatment created the most favorable soil conditions for the tree growth having higher concentration of SOM, N and water in the soil while the other two treatments had similar soil conditions. This was reflected in the foliar N concentration, as has been reported by Nielsen and Hogue (1985), and Merwin and Stiles (1994). It is not clear which is the optimal N concentration in the leaves to determine eventual deficiency, since it has not been measured for each available variety but only in general. In our study, in fact, branch growth, TCA, TCAI and canopy volume have not been affected from the OFMS treatments, suggesting that foliar N was still sufficient.

Despite the effect of the treatments on the soil conditions, they did not have an effect on any of the growth parameters measured (TCA, TCAI, branch growth, and canopy volume) except in early years (2001-2003) where sandwich presented the least growth probably due to the vegetation competition exerted by the vegetated area underneath the canopy (Welker and Glenn, 1989; Parker 1990; Merwin and Ray, 1997; Giovannini et al., 1998; Zoppolo, 2004). An expansion of the width of the tilled strip from 2004 probably compensated and reduced vegetation competition.

Trees on Supporter 4 were more vigorous than the M.9 clones used in the experiment, as noted in previous studies (Marini, 2000).

While there has been no effect of OFMS on the vigor, there is an interaction between treatments and rootstocks regarding cropping. In the mulch, which had the most favorable growing conditions, there were no differences measured between the rootstocks while in both flame and sandwich M.9 RN 29 was the rootstock with the highest yield and "yield efficiency", with no differences between the other two rootstocks. Generally, trees on vigorous rootstocks are less precocious than less vigorous rootstocks. M.9 RN 29 appears to be a rootstock that adapts better to the less favorable growing conditions presented by SS and FL (lower SOM, N, and water content in the vegetated area of the sandwich) as expressed from the higher "yield efficiency" measured in these two treatments when compared with MU.

When we consider cropping per hectare, we have to adapt the results to relative tree density. The lowest cumulative yield per hectare is the flame treatment with no differences among the rootstocks. Yield and Yield efficiency per tree as well as the cumulative production per hectare (even if somewhat diminished by the reduced number of trees) make M.9 RN 29 and the low cost sandwich system a very interesting combination that should be considered by growers that wish to plant Pacific Gala under organic protocol in Michigan and related climates.

Conclusion

The orchard floor managements systems implemented had an impact on the soil conditions. Soil organic matter and nitrogen was highest in the mulch treatment. Flame and sandwich systems provided lower but similar nitrogen and SOM content. The effect of the treatments was more noticeable at 0-10 cm depth where a reduction of SOM was measured in both flame (due to the continuous burning of the vegetation) and the tilled strip in the sandwich system (due to tillage). The increase in nitrogen concentration, especially in 2005, suggests that the treatments are reaching a sort of equilibrium in sustainability. However, more research is needed to balance each system with plant nutrition needs and soil reactions. For example it appears that nitrogen is excessive with the alfalfa mulch.

The treatments did not have an effect on the growth, but leaf nitrogen concentration was lowest in sandwich and flame. Plant vigor appears adequate in this trial, but leaf nitrogen values are approaching the lowest acceptable range for Michigan apple orchards (Hanson, 2000).

Among the rootstocks, Supporter 4 was the most vigorous as expected. There was an interaction between treatment and rootstock regarding yield and yield efficiency with Gala on M.9 RN 29 being the highest per tree in flame and sandwich while no differences were noticed between the rootstocks in mulch despite its better growing conditions. This suggests that M.9 RN 29 is a rootstock that is better adapted to the conditions that the sandwich and flame treatments generate. This is probably due to its comparative greater vigor than M.9 NAKB 337 and its influence on earlier bearing than Supporter 4.

When considering the values per hectare and especially the cumulative production, the flame treatment was least productive having no differences between the rootstocks. This finding is surprising considering that this treatment maintained a significant weed-free zone over the years. The flame system also had a low SOM and N concentration and with the various management concerns, this OFMS appears to be the least desirable for organic growers. The mulch and sandwich treatments presented similar cumulative production per hectare with Supporter 4 having the lowest values with no differences between the other two rootstocks.

The mulch and sandwich OFMS also have some drawbacks. Alfalfa hay mulch is expensive and difficult to apply, and it poses a high risk of damage by rodents. Soil in the sandwich system appears more nitrogen and water stressed with less favorable growing conditions (lower SOM and water content on the vegetated area) than mulch. Also the desirable width of the tilled strip needs more definition especially for different soil types. The sandwich system is relatively easy to implement, avoids tree-trunk injury, is relatively inexpensive to establish and maintain, and it requires only an easily modified notch disk tiller.

Overall, the sandwich system coupled with the M.9 RN 29 rootstock seems to be a suitable choice for growers that want to grow Pacific Gala under organic protocol in Michigan and similar climate and soil conditions. More research is still necessary especially to confirm these results in a longer term study with other disease resistant rootstocks.

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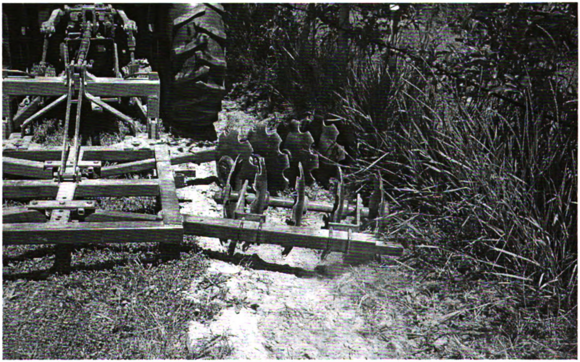
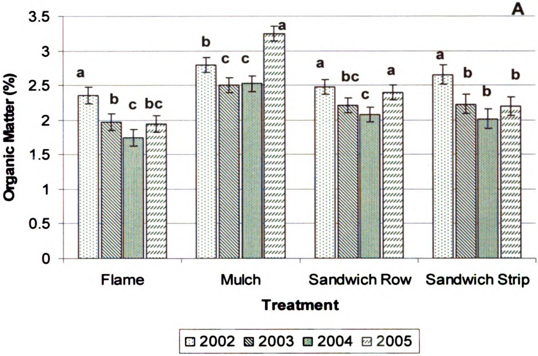
Picture 1: Modified notch disk tiller for the implementation and maintenance of the Sandwich tilled strip.



Picture 2: Particular of the modification in the disk set up for the notch disk tiller.



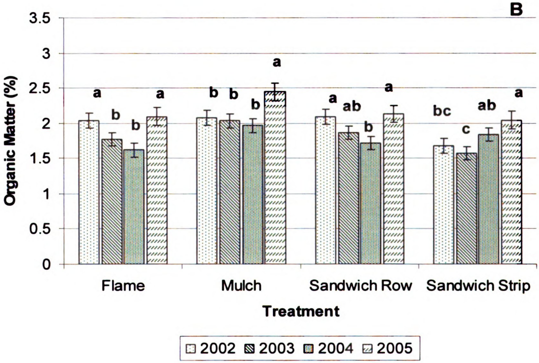


Fig. 1: Effect of the treatments on Percentage of Organic Matter content in the soil during the duration of the experiment (2002-2005) at 0-10 (**A**) and 0-30 (**B**) cm depth. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between years inside of each treatment and should be read separately. Bars represent standard error.

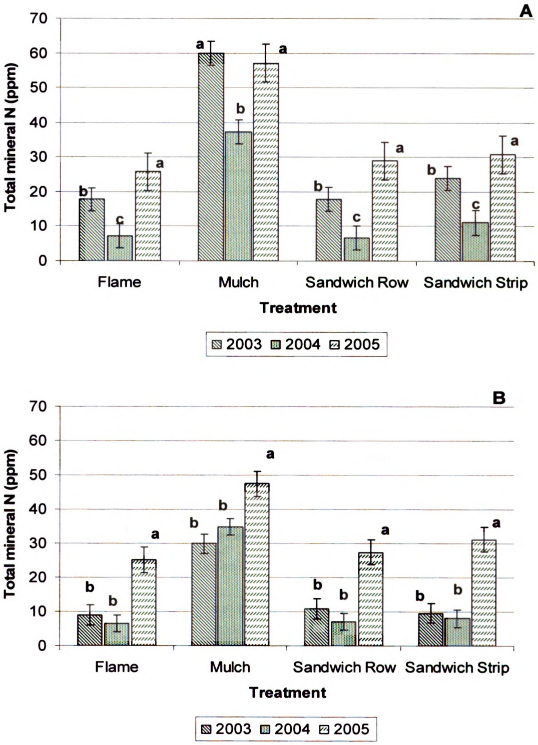


Fig. 2: Effect of the treatments on Total mineral N (N-NO_3^- + N-NH_4^+) content in the soil during the duration of the experiment (2003-2005) at 0-10 (**A**) and 0-30 (**B**) cm depth. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$) between years inside of each treatment and should be read separately. Bars represent standard error.

Table 1: Pr >F values for the tree growth parameters measured during 2005

	Trunk cross sectional area (2005)	Trunk cross sectional area Increase (2000-2005)	Volume	Branch extension
Treatment	0.5273	0.9780	0.5305	0.7672
Rootstock	<0.0001	0.0010	<0.0001	0.4368
Tretament*Rootstock	0.4069	0.3494	0.4069	0.6592

Table 2: Nitrogen content (ppm) in leaves from 2001 till 2005. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$).

	2001	2002	2003	2004	2005
Mulch	2.1	2.4 a	2.7 a	2.2 a	2.1 a
Sandwich	2.1	2.2 b	2.2 c	1.8 b	1.8 b
Flame	2.1	2.4 a	2.4 b	1.9 b	1.8 b

Table 3: Pr > F values for the production parameters measured during 2005. Cumulative parameters represent data 2003-2005.

	Avg. Fruit Weight (g)	Yield (kg/tree)	Cumulative Yield (kg/tree)	Yield Efficiency (kg/ cm^2)	Cumulative Yield efficiency (kg/cm^2)	Yield (t/ha)	Cumulativ e Yield (t/ha)
Treatment	0.0652	0.9688	0.6813	0.7572	0.4304	0.9370	0.6014
Rootstock	0.1078	0.0001	0.0007	<0.0001	<0.0001	<0.0001	<0.0001
Tretament* Rootstock	0.4360	0.0304	0.0454	0.0474	0.0414	0.0303	0.0414

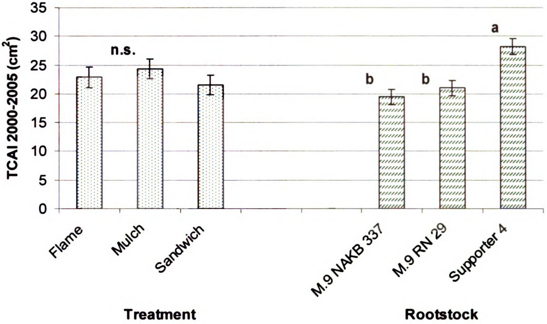


Figure 3: Trunk Cross Sectional Area Increase (TCAI) from 2000 till 2005 for both Treatments and Rootstocks. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$), n.s. means no statistical difference. Bars represent standard error.

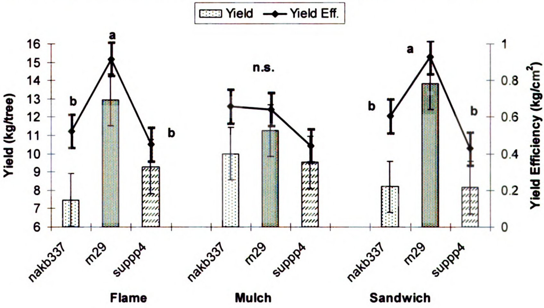


Figure 4: Rootstock productivity (kg/tree), expressed by the columns, and yield efficiency (kg/cm^2), expressed by the line, in 2005 divided in treatments and rootstocks. Different letters represent statistical difference (LSMEANS with $P \leq 0.05$), n.s. means no statistical difference. Same letters apply to both yield and yield efficiency. Bars represent standard error.

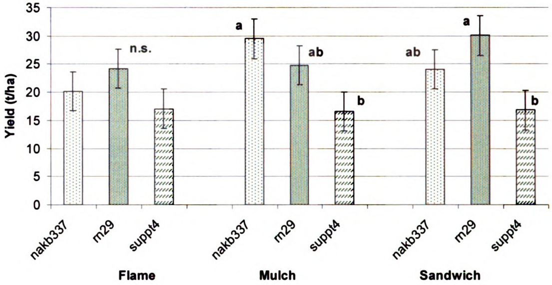


Figure 5: Cumulative yield (t/ha) 2003-2005 divided in treatments and rootstocks. Different letters represent statistical difference at (LSMEANS with $P \leq 0.05$). Bars represent standard error.

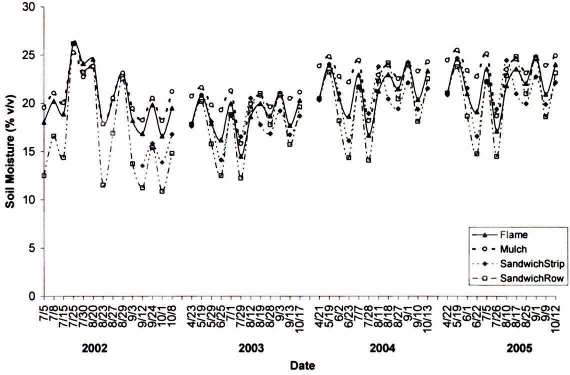


Figure 6: Volumetric soil moisture content (as %) measured with TDR for the average 0-45 cm depth, for the different treatments during 2002-2005.

Table 4: Cost evaluation of the application of the different ground floor management systems during 2005.

Mulch	Cost $
14 round bales of alfalfa	420
labor for application by hand 30 hrs * $ 12.25/hr	367.5
Total	**788**

Flame	
30 gal LPG * $1.33/gal	39.9
labor 9hr 45' * $12.25/hr	119.44
tractor 25 hp 9hr 45' * $6.0 hr	58.5
Total	**218**

Sandwich	
labor 4hr 05' * $12.25/hr	50
tractor 55hp 4hr 05' * $10/hr	40.83
Total	**91**

Abstract

CHAPTER 3. Effect of Orchard Floor Management Systems on Root Architecture of "Pacific Gala" on M.9 NAKB 337 under Organic Protocol.

By Dario Stefanelli

Plant root systems have a high plasticity, mostly due to their short life span, when compared with the canopy. This continuous growth and mortality of roots allow the plants to change their root architecture, probing the soil profile for favorable conditions. Fruit growers can change the soil conditions by using different orchard floor management systems. It is important to implement sustainable systems that will provide profitable productivity without disrupting soil-root processes. The objective of the experiment was to evaluate apple root distribution in response to three orchard floor management systems (OFMS) under organic protocol by trench profile mapping.

The experiment was conducted in an organically certified orchard of apple "Pacific Gala" on M.9 NAKB 337 (dwarfing) established in 2001. The three OFMS used were mulch of alfalfa hay (MU), propane flaming (FL), and strip tilling at each side of the tree row while natural vegetation was allowed to grow undisturbed on the tree row (Swiss Sandwich System, SS). We measured SOM and N concentration at 2 depths (0-10 and 0-30 cm) for 4 years. Root architecture was assessed after growing season and harvest 2005 with the trench profile mapping method. Trenches, 50 cm wide were dug 45 cm from the trunk perpendicular to the tree row in each OFMS. Trenches were approximately 336 cm long and 132 cm deep. A 158 cm by 130 cm metal frame divided by strings into 28 cm by 22 cm grid was placed against the profile faces to facilitate the

counting and mapping of the rooting frequency. Roots on each profile face were counted and recorded in two diameter size classes: small (≤ 2 mm) and large (> 2 mm).

Orchard floor management systems did have an impact on root number and distribution both vertically and horizontally. More roots were found in mulch than the other two systems without showing any difference in the above ground part of the tree suggesting that there was a greater allocation of carbohydrates in the roots. Mulch and flame showed a higher concentration of roots closer to the soil surface and mostly restricted to the weed free area created by the treatments. Roots in the sandwich system were found to be greatly extended through the soil profile both vertically and horizontally. Suggestions are made in this report as to the significance of these findings regarding the growing and managing of apples in an organic system.

Introduction

Plant root systems have a high plasticity, mostly due to their short life span, when compared with the canopy (DeWitt et al., 1998). This continuous growth and mortality of roots allow the plants to change their root architecture probing the soil profile for favorable conditions (Andrews and Newman, 1970). They respond differently to most of the factors that influence soil conditions, both imposed (Beckenbach and Gourley, 1932) or natural (Atkinson D. and Holloway, 1976a), by changing their life span or their entire root system architecture, expanding/contracting it vertically and/or horizontally depending on the soil conditions.

Plants tend to expand their root system (both vertically and horizontally) in response to drought conditions (Schenk and Jackson, 2002). This finding is also confirmed in fruit trees on which research has been done on the response to irrigation and drought stress (Perry et al., 1983; Layne et al., 1986; Bassoi et al., 1998; Smart et al., 2006). Soil type also affects root distribution. Fruit trees tend to have deeper root systems in coarse soils. However, if there is an impermeable layer in soils, roots will not be able to pass it (Smart et al., 2006). Higher soil fertility tends to induce a more superficial root system and/or concentrated in the more fertile area (Lyons et al., 1962; Smith, 1965). Root architecture also responds to competition from other species, reducing the amount of roots in the competitive area expanding it both horizontally and vertically (Atkinson and White, 1976b; Glen and Welker, 1989; Parker, 1993; Merwin and Stiles, 1994; Merwin et al., 1995).

It is clear that the root system, as a whole, is able to interact and to respond to soil conditions (Ryser and Eek, 2000). Fruit growers can change the soil conditions by using different ground floor management systems. It is important to develop systems that will provide profitable productivity based on soil-food web-root processes.

Efforts have then been put in developing OFMS that will create the best environment for tree growth, allowing the maximization of its performance with minimal external inputs (Weibel, 2002).

It therefore becomes necessary in organic production to assess the responses of the root system to the OFMS implemented. In organic production it is necessary to achieve a balance between above and below ground processes while implementing OFMS, since growers can rely primarily on soil processes to make nutrient available for the plants (Yao et al., 2005). If we know the root system response to certain OFMS, it could be a great step toward a better understanding and utilization of the system, thus benefiting the growers.

The objective of the experiment was to evaluate apple root distribution in response to three GFMS under organic protocol by trench profile mapping.

Materials and Methods

The experiment was conducted at the Clarksville Horticultural Experiment Station of Michigan State University, MI. An orchard of "Pacific Gala" (*Malus* x *domestica* Borkh.) was established in May 2001. The orchard was certified organic by the Organic Crop Improvement Association (OCIA) in 2003 and 2004 and Organic Grower of Michigan (OGM) in 2005. The trees are grafted on three rootstocks, but for this experiment we considered only those on M.9 NAKB 337 with 4.6 x 1.4 m spacing between the trees.
Trees were trained to a vertical axe system with relatively little pruning over the years (Perry, 2000). Minimal pruning was applied to allow trees to grow as natural as possible maintaining a single leader. A two wire trellis with galvanized metal poles was installed as a support system. A drip irrigation with drippers of 2.3 L/h every 0.6 m was installed in May 2001 and suspended from the lowest wire of the trellis on the tree row. All orchard floor management systems received equal irrigation throughout the season.
Soil moisture was measured by time domain reflectometry (TDR) using a Mini Trase 6050X3 (Soilmoisture Equipment Corp., Goleta, CA) with 45 cm long stainless steel rods permanently installed in the tree rows, halfway between two trees and in the middle of the tilled strip in 2002. Measurements were taken for each of the 6 plots per treatment weekly in 2002 and every other week in 2003-2005.
The site was previously farmed with conventional soybean-corn-corn-alfalfa rotation for two cycles until 1998. Subsequent soil preparation consisted of sowing of buckwheat and chicken compost (1250 kg/ha) and lime (2250 kg/ha) application in 1999 on the entire

surface. At plantation (April 2000) a mixture of red mammoth clover and endophytic rye was sown in the alleys.

Three orchard floor management systems (OFMS) were established in the beginning of the second growing season (2001) and maintained for the entire study. The treatments consist of mulch of alfalfa hay (MU), the Sandwich System (SS) and Flaming (FL) with a propane burner. The alfalfa hay mulch was laid underneath the tree canopy in a strip of 1 m on each side of the tree and kept 15-20 cm thick. 105 round alfalfa bales/ha were used with a C:N ratio of 15:1. The treatment was hand-applied every spring and fall to keep the thickness of the mulch constant in order to provide a shading effect for weed suppression, and to maintain soil moisture.

The flaming treatment consists of the burning of weeds underneath the tree canopy and 1 m on each side of the tree with propane gas (estimated 56 L/ha). A custom engineered burner, consisting of 4 burners (200000 BTU/burner) in a row, and covered with a metal protective shield to concentrate the heat and to prevent its escaping and damaging the canopy. On the back of the shield was also mounted a sprinkler system to extinguish eventual fires occurring during the burning. The burner was mounted on the side of a tractor on a hydraulic arm to better control the application of the treatment. To reach the vegetation underneath the canopy on the tree row, a hand burner (150000 BTU) was used. The treatment was applied five to six times during the year, starting at the end of April - beginning of May and ending at the end of August. The treatment was repeated every time the weeds would reach 10 cm high. Tractor speed was kept between 1.6 and 3.2 km/h depending on the density of the weeds to be controlled.

The Sandwich System is an adaptation of the Swiss system (Weibel, 2002) and consists of an area 25-30 cm on each side of the tree, underneath the canopy, where spontaneous vegetation is allowed to grow undisturbed. On each side of this weeded area two strips of soil were kept free of vegetation by shallow tilling (5-10 cm deep). The strips were 70 cm wide from planting till 2003 and expanded to 90 cm wide in 2004. Timing of the treatment application was the same as the flaming treatment. The tilling was accomplished from 2001 through 2004 with a spring-tooth (three teeth 2001-2003, 5 teeth 2004) harrow mounted on a side-bar of a tractor. To improve tillage effectiveness, a modified notch-disk tiller, mounted on the tractor side-bar, was deployed during the 2005 growing season.

The alley consisted of an equal mixture of endophytic rye and mammoth clover established soon after planting the orchard in 2000. Clover was also reseeded in 2005 to keep the proportion constant. The alleys were managed equally in all treatments by periodical mowing (3-4 times year).

Tree growth parameters (TCA at dormancy, shoot growth, and canopy volume) and fruit production (Yield and average fruit weight) were measured to monitor the effect of the OFMS on the above ground part of the tree.

The effect of the OFMS on the soil conditions were monitored through:

- Soil organic matter concentration was measured by loss on ignition of 3g of dry soil, from the above described soil samples, at 400 °C for 8 hours in a muffle furnace.

The predominant soil type of the orchard is Kalamazoo sandy clay loam (Typic Hapludalfs) with 53.1% sand, 23.1% silt, and 23.8% clay. The orchard presents mild slopes (less than 3%).

Root architecture was assessed at the end of the sixth growing season and after harvest 2005 with the profile wall method described by Bohm (1979). Trenches 50 cm wide were dug in the middle between two trees (45 cm from the trunk) for each GFMS. Trenches were approximately 336 cm long and 132 cm deep (Fig 1A and 1B) perpendicular to the tree row. Trenches were dug with a backhoe. The distance from the surface of each soil profile was also measured.

A 158 cm by 130 cm metal frame divided by strings into 28 cm by 22 cm grid was placed against the profile faces to facilitate the counting and mapping of the root distribution. Roots on each profile face were counted and sub-divided in smaller than 2 mm diameter and larger than 2 mm. The number of roots in each grid was transformed in percentage of the visible root system and also represented as # roots / dm^2 of soil.

The GFMS were applied in a complete randomized block design with six replicates. The trenches were dug between the two central trees under evaluation for a total of twelve profile faces for each ground floor.

Statistical analysis was performed with SAS (Version 8, SAS Institute, Cary, NC, USA). Distances from the trunk and depth in the soil profile (determined from the string positions) were considered as continuous components to determine the statistical differences between the GFMS through polynomial analysis at the desired distance and depth. The Least-square means test (LSMEANS) with $p \leq 0.05$ was utilized to determine statistical differences between the treatments after the polinomium was constructed.

The following timetable explains the history of the plot, sampling and measurements for the duration of the experiment (conducted Sept-Oct 2005).

Prior to 1998	Conventional soybean-corn-corn-alfalfa rotation (2 cycles). Last crop was corn. Minimal tillage.		
1999	Spring: tillage sowing of soybean, Chicken compost (1250kg/ha), lime (2250 kg/ha). Fall: tillage, sowing of Buckwheat		
2000	April: tillage, tree planting. August: sowing of red mammoth clover and endophytic rye in the alleys.		
2001	May: implementation of the 3 orchard floor management systems.	April, June, August, November: soil sampling for NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD
2002	Maintenance of the OFMS and Tree training	April, June, August, November: soil sampling for SOM and NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD
2003-05	Maintenance of the OFMS	April, June, August, November: soil sampling for SOM, NO_3^- and NH_4^+	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD, yield

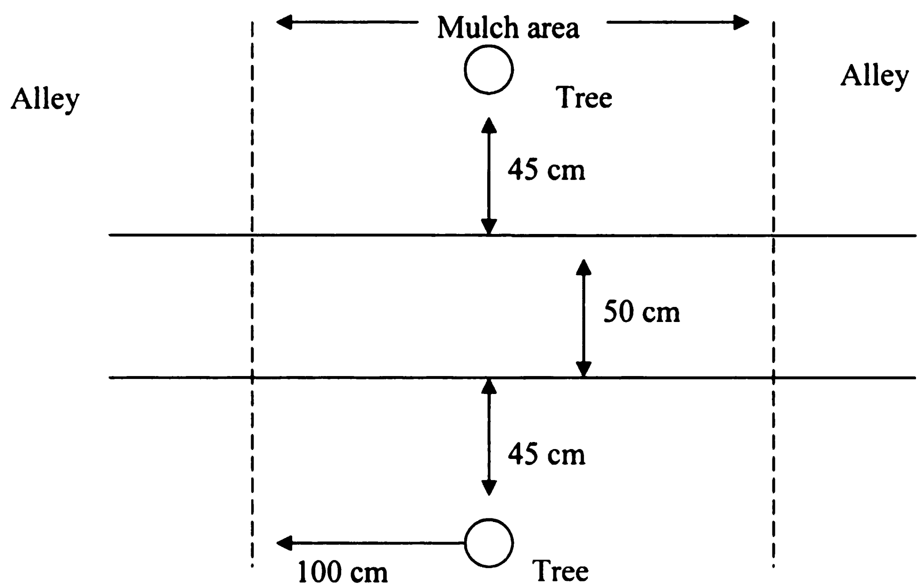


Fig 1A. Top view diagram of trench location for apple tree root distribution study in the mulch treatment.

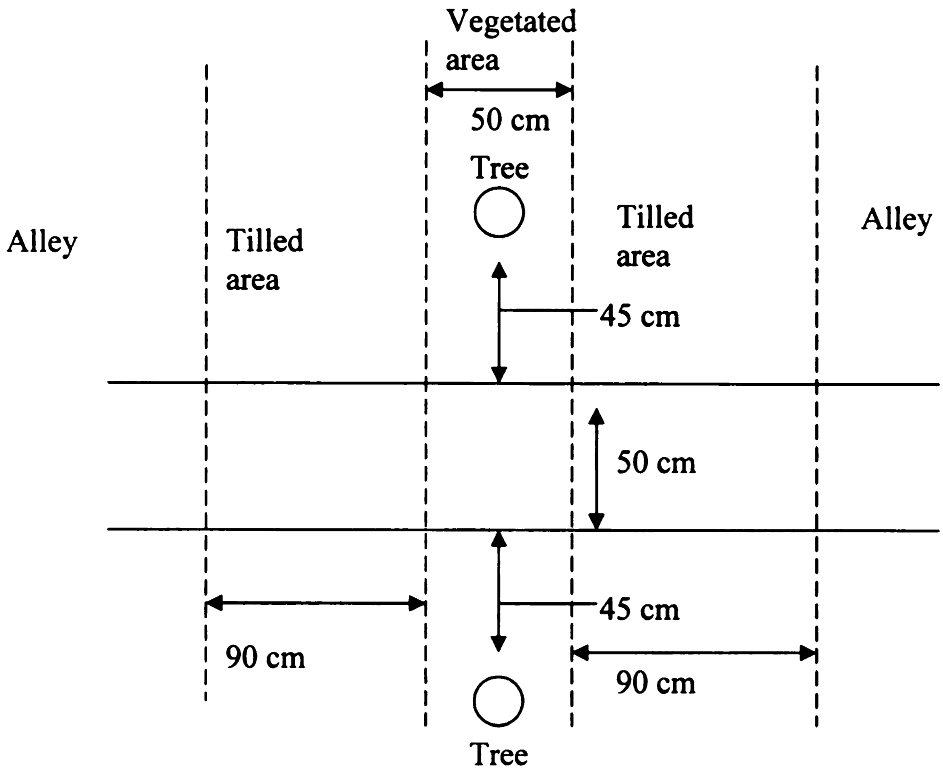


Fig 1B. Top view diagram of trench location for apple tree root distribution study in the sandwich treatment.

Results

There was no difference between treatments in the percentage of soil organic matter (SOM) in the soil at either of the depths under evaluation (0-10 and 0-30 cm). However, if we consider the position inside of each treatment, we notice some differences, except for the treatment mulch (MU) at 0-10 cm depth. For the treatments flame (FL) and Sandwich System (SS) the percentage of SOM in the alley was always higher than where the treatments were applied (Table1). We did not find any difference in SOM percentage neither between treatments, nor between positions inside of the treatment at 0-30 cm depth (Table 2).

Tree vigor and cropping of Gala on M.9 NAKB 337 were not significant among treatments (data not shown).

The separation between the A and B horizon in the soil occurred at approximately 20 cm depth, thus the data representing the effects of depth on the root distribution are expressed in 20 cm increments. Since there was no statistical significance on the interaction between the horizon and the treatments we evaluated the rooting only based on the depth in the soil profile discarding the horizon effect.

The mulch treatment had a higher total number of small ($\leq$2 mm) roots/dm^2 (6.9) compared with the treatment flame and sandwich (5.7 and 5.6). No difference was determined between treatments regarding total number of large (>2 mm) roots/dm^2 (Table 3).

Effect of depth on number of roots

Rooting frequency of small roots was greatest under the mulch system and for large roots, under MU and FL at the shallow depth. (Table 4 and 6). Rooting progressively declined in depth within each OFMS (Table 5 and 7).

Effect of distance from the tree trunk on number of roots.

Distances from the tree trunk were evaluated every 20 cm. Every distance discussed below represents each side of the tree trunk. Between 0 and 20 cm from the tree trunk treatment MU presented the highest number of small (<2 mm) roots/dm^2 (1.18), followed by FL (1.0) and SS (0.8). Between 20 and 60 cm from the trunk MU again had the highest number of small roots, SS presented the smallest and FL was in the middle not differing from either of the other treatments (Tab. 8). Between 60 and 100 cm from the trunk no difference between the treatments was found. Between 100 and 160 cm from the trunk the treatment SS had the highest number of small roots/dm^2 while no differences were found between the other two treatments (Tab. 8).

When we consider the effect of distance from the tree trunk inside of each treatment we can see slightly different results. In the MU treatment we noticed a significant steady decrease in the number of small roots/dm^2 from 0 to 100 cm from the trunk (the area where the mulch was applied) (Tab. 9). Flame treatment also presented a similar decrease at the same distances, but differences were not as accentuated (Tab. 9). Farther than 100 cm, where the alley is situated (100-160), no difference in number of small roots was noticed in MU or FL treatments. In the SS treatment the decrease in number of small roots, depending on the distance from the trunk, is even less accentuated than the other two treatments. Sandwich system still had that the highest number of small roots is closer to the tree trunk (0-40 cm); however the decrease is more gradual. In fact, between 20 and 100 cm from the trunk (most of the tilled strip) the number of small roots is the same, as well as between 80 and 160 cm from the trunk (Tab. 9).

The distance from the tree trunk did not have any effect on large (>2 mm) roots among the treatments (Tab. 10). The number of large roots steadily and significantly decreased in each treatment between 0 and 80 cm from the trunk. No differences were found in any of the treatments greater in distance than 80 cm from the tree trunk (80 to 160 cm) (Tab. 11).

Percentage of rooting

Percentage of rooting is another method to represent the distribution of the roots in the face wall of the soil profile. It represents the percentage of roots present at each distance from the trunk and at each depth on the total amount of roots present. From Fig. 1&2 we can see that MU and FL show the same percentages along the soil profile both in distance from the trunk and in depth in the soil profile. For these two treatments, percentage of rooting steadily decreases along the depth of the soil profile till 80 cm, with the highest percentages closer to the soil surface, below that it is similar. They also show a steady decrease in rooting percentage the farther from the trunk till 100cm distance, which is the area covered from the treatment and weed free, with the highest percentage closer to the trunk. Farther than 100 cm the percentage of rooting is similar. In treatment SS (Figure 3) percentage of rooting is more evenly distributed along the soil profile both in distance from the trunk and in depth in the soil profile. It still shows a decrease in rooting percentage the farther we move from the trunk but it is less pronounced, in fact from 0 to 40 cm from the trunk SS shows the same percentages as well as from 40 to 100 cm. Farther than 100 cm (100-160 cm) the percentages are similar. While MU and FL presented the highest percentages closer to the soil surface rapidly declining along the entire profile (Figure 1), SS shows the same percentage of rooting at 60 cm deep and then it starts decreasing (Figure 1). The depth, at which the percentage of roots starts decreasing, increases with the distance from the trunk (Figure 1). The sandwich system practically promotes rooting deeper and farther from the trunk compared with FL and MU where the roots are shallower and closer to the trunk. The same pattern described for small roots was noticed for the large roots as well (Figures 2).

If we consider the treatments in their weed free areas, we notice that there are differences in percentages of small roots between the treatments. The mulch and FL treatments had 90.1% and 89.9% of the roots respectively are in the weed free area (0-100cm from the trunk), having only more or less 10% of the small roots that reache in the alley. The sandwich system instead, had 20.9% of the small roots in the weeded area underneath the canopy, 63.6% in the tilled area and 15.5% that reache in the alley.

Soil water content.

Measurements performed with TDR (Figure 3) demonstrated that most of the time there were no differences between OFMS. When some difference was present MU had always the highest values while the SVA had the lowest. Flame and the tilled strip in the sandwich did not differ from the other two.

Discussion

The treatments had an effect on the soil organic matter concentration only in the superficial sampling (0-10 cm) with mulch showing the highest numbers. This is probably due to the continuous addition and consequent decomposition during the season and years of alfalfa hay. The fact that only the superficial layer was affected is probably due to the fact that the mulch was added on top of the previous one and left undisturbed. The different concentrations of SOM will reflect on the available nitrogen in the soil as well (Powlson and Jenkinson, 1990; Díaz Rossello, 1992b; Bloksma, 2000). However, considering that the deepest sampling we tested was 30 cm, it is difficult to assess if there were different concentrations of SOM in deeper soil profiles and consequently if they exerted any effect on deeper root distribution. This factor should probably be better investigated. When a difference occurred, MU had the highest soil water content.

The different soil composition of the B horizon did have an effect on the number of roots as reported by Fernandez et al. (1995), but since there was no interaction between treatments and soil type it was discarded from the analysis as inconsequential in this investigation.

We measured no differences in tree vigor and cropping between the treatments, however the mulch treatment had a higher number of roots/dm^2 than the other two treatments. Mulch also presented the highest number of roots/dm^2 closer to the soil surface where the treatment was able to exert some effect on the soil conditions (higher SOM and nitrogen concentration). Morlat and Jacquet (1993) did in fact find a higher number of roots in soil with higher organic matter concentration for grapevine. The consideration of these two factors suggests that there is a higher carbon allocation in the root system under mulch than in the other two treatments (Lakso et al., 1999 and Comas et al., 2005). However, several other factors could be responsible, besides the carbon allocation, for the different response that the Orchard floor management systems had on root number and distribution.

In general the treatments responded as reported from Cowart (1938), Lyons and Krezdorn (1962), and Parker (1993) who demonstrated a decrease in root number with the increase of depth and/or distance from the trunk. However, the pattern of this decrease was different depending on the treatments. In fact, when considering the root frequency (as % of root in a particular position on the total number of roots in the wall profile), we noticed that mulch and flame had the same distribution while sandwich was different. Sandwich had a lower concentration of roots closer to the surface and at the same time a more extensive root system that reached well into the alley. In contrast to Cockroft and Wallbrink (1966), and Parker (1993) in peaches, there was a greater concentration of roots deeper in the soil profile. As expected, there were more roots in the weed free zones (mulch and flame) compared with vegetated areas as reported from Atkinson and White (1976), Glen and Welker (1989) and Parker (1993). This was relatively true for SS as well. It still had higher root percentage closer to the trunk than in the weed free area. This could be caused from the position of the irrigation that was established on the tree row. If we had the irrigation on the tilled strip it would have probably have shown higher percentage than what we found in that area. When differences occurred, the vegetated area had the lowest water content, while the tilled area had similar water content to MU and FL. This factor should be probably investigated more deeply. Bechenbach and Gourley (1932), Cockroft and Wallbrink (1966), and Richards (1983) reported that mulching encourages rooting in the mulch and in the soil surface for apple, peach, pear, and grapes. However, the expansion of the sandwich root system into the alley zone was not expected. This could be due to the combination of greater competition underneath the tree canopy (Schenk and Jackson, 2002) coupled with the effect of the tillage in the weed free area that prompted the sandwich root system to expand both vertically and horizontally. It is, in fact, known that tilling disturbs and reduces roots closer to the soil surface (Cockroft and Wallbrink, 1966; Richards, 1983). The same pattern of distribution was observed for both small (<2 mm) and large (>2 mm) roots.

Conclusion

Orchard floor management systems did have an impact on root number and distribution along the soil wall both vertically and horizontally. Mulch presented a higher number of roots compared with the other two systems without showing any difference in the above ground part of the tree leading to a higher allocation of carbohydrates in the roots.

Mulch and flame had a higher concentration of roots closer to the soil surface and mostly restricted to the weed free area created by the treatments. The sandwich root system was prompted by the treatment to explore more soil extending both vertically and horizontally. Considering the higher difficulties that organic horticulture encounters in creating more balanced soil conditions for the tree uptake (mostly through fertilization), a more expanded root system is beneficial to the tree because it encourages greater probing, helping in the uptake of nutrients and water. It will also reduce eventual leaching since the root free area will be lower in the soil profile than a more superficial root system.

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Table 1: Percentage of Organic Matter in the soil in the treatments at 0-10 cm depth.

	Treatments		
Position	Flame	Mulch	Sandwich
Alley	2.7 a	3.5 a	3.0 a
Tree row	1.8 b	3.1 a	2.1 b
Tilled strip			1.9 b

Different letters represent statistical differences (LSMEANS with $P \leq 0.05$).

Table 2: Percentage of Organic Matter in the soil in the treatments at 0-30 cm depth.

	Treatments		
Position	Flame	Mulch	Sandwich
Alley	2.2 a	2.3 a	2.5 a
Tree row	1.9 a	2.0 a	1.9 a
Tilled strip			1.9 a

Different letters represent statistical differences (LSMEANS with $P \leq 0.05$).

Table 3: Total number of roots/dm^2 in each treatment.

Treatments	Small roots (≤2 mm)	Large roots (>2 mm)
Mulch	6.9 a	0.09 a
Flame	5.7 b	0.07 a
Sandwich	5.6 b	0.07 a

Different letters represent statistical differences (LSMEANS with $P \leq 0.05$).

Table 4: Number of small (≤2 mm) roots/dm^2 at each depth in the soil profile depending on the treatments.

	Depth in the soil profile (cm)					
Treatments	0-20	20-40	40-60	60-80	80-100	100-120
Flame	0.78 b	0.59 a	0.45 a	0.35 a	0.27 a	0.20 a
Mulch	1.00 a	0.71 a	0.50 a	0.37 a	0.24 a	0.16 a
Sandwich	0.66 b	0.65 a	0.59 a	0.51 a	0.38 a	0.22 a

Different letters represent statistical differences (LSMEANS with $P \leq 0.05$) between treatments at each depth in the soil profile.

Table 5: Number of small ($\leq$2 mm) roots/dm^2 for each treatment depending on the depths in the soil profile (cm).

Depth in the soil profile (cm_)	Flame	Sign[1].	Mulch	Sign[1].	Sandwich	Sign[1].
0-20	0.78	a	1.00	a	0.66	a
20-40	0.59	b	0.71	b	0.65	a
40-60	0.45	bc	0.50	c	0.59	a
60-80	0.35	cd	0.37	cd	0.51	ab
80-100	0.27	d	0.24	de	0.38	bc
100-120	0.20	d	0.16	e	0.22	c

[1]Different letters represent statistical differences (LSMEANS with P$\leq$0.05) between depths in the soil profile inside each treatment.

Table 6: Number of large (>2 mm) roots/dm^2 at each depth in the soil profile depending on the treatments.

	Depth in the soil profile (cm)					
Treatments	0-20	20-40	40-60	60-80	80-100	100-120
Flame	0.16 a	0.09 a	0.05 a	0.02 a	0.01 a	0.00 a
Mulch	0.18 a	0.10 a	0.05 a	0.02 a	0.01 a	0.00 a
Sandwich	0.11 b	0.09 a	0.06 a	0.04 a	0.02 a	0.00 a

Different letters represent statistical differences (LSMEANS with P$\leq$0.05) between treatments at each depth in the soil profile.

Table 7: Number of large (>2 mm) roots/dm^2 for each treatment depending on the depths in the soil profile (cm).

Depth in the soil profile (cm_)	Flame	Sign[1].	Mulch	Sign[1].	Sandwich	Sign[1].
0-20	0.16	a	0.18	a	0.11	a
20-40	0.09	b	0.10	b	0.09	ab
40-60	0.05	c	0.05	c	0.06	bc
60-80	0.02	cd	0.02	d	0.04	cd
80-100	0.01	d	0.01	d	0.02	d
100-120	0.00	d	0.00	d	0.00	d

[1]Different letters represent statistical differences (LSMEANS with P$\leq$0.05) between depths in the soil profile inside each treatment.

Table 8: Number of small (≤2 mm) roots/dm^2 at different distances from the tree trunk depending on the treatments.

	Distances from the trunk (cm)							
Treatments	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160
Flame	1.00 b	0.81 ab	0.65 ab	0.49 a	0.32 a	0.18 b	0.07 b	0.01 b
Mulch	1.18 a	0.97 a	0.77 a	0.53 a	0.32 a	0.18 b	0.04 b	0.00 b
Sandwich	0.80 c	0.68 b	0.58 b	0.49 a	0.42 a	0.37 a	0.34 a	0.33 a

Different letters represent statistical differences (LSMEANS with P≤0.05) between treatments at each distance from the tree trunk.

Table 9: Number of small (≤2 mm) roots/dm^2 for each treatment depending on the distance from the tree trunk (cm).

Distance from the trunk (cm)	Flame	Sign[1].	Mulch	Sign[1].	Sandwich	Sign[1].
0-20	1.00	a	1.18	a	0.80	a
20-40	0.81	ab	0.97	b	0.68	ab
40-60	0.65	bc	0.77	c	0.58	b
60-80	0.49	c	0.53	d	0.49	bc
80-100	0.32	d	0.32	e	0.42	bc
100-120	0.18	de	0.18	ef	0.37	c
120-140	0.07	e	0.04	f	0.34	c
140-160	0.01	e	0.00	f	0.33	c

[1]Different letters represent statistical differences (LSMEANS with P≤0.05) between distances from the tree trunk inside each treatment.

Table 10: Number of large (>2 mm) roots/dm^2 at different distances from the tree trunk depending on the treatments.

	Distances from the trunk (cm)							
Treatments	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160
Flame	0.16	0.11	0.08	0.05	0.03	0.01	0.01	0.00
Mulch	0.17	0.12	0.09	0.06	0.04	0.02	0.01	0.00
Sandwich	0.16	0.11	0.08	0.05	0.02	0.00	0.00	0.00

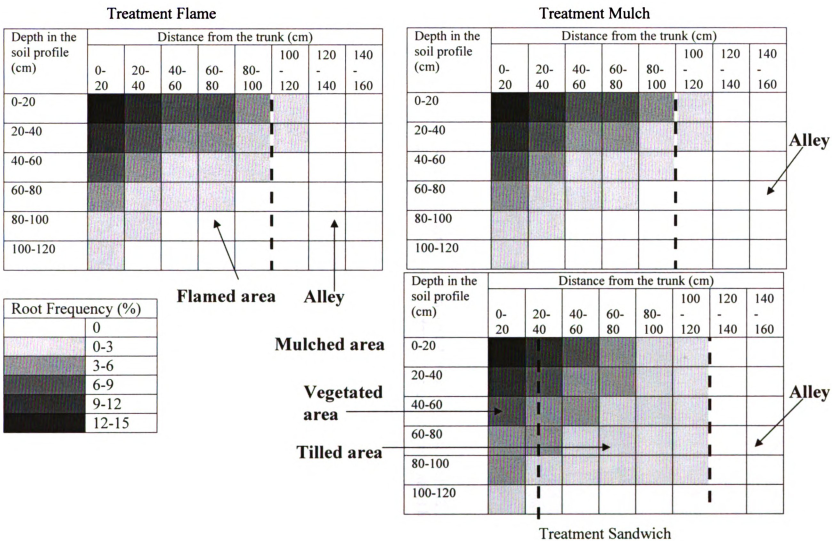
No differences were found between treatments (LSMEANS with P≤0.05).

Table 11: Number of large (>2 mm) roots/dm^2 for each treatment depending on the distance from the tree trunk (cm).

Distance from the trunk (cm)	Flame	Sign[1].	Mulch	Sign[1].	Sandwich	Sign[1].
0-20	0.16	a	0.17	a	0.16	a
20-40	0.11	b	0.12	b	0.11	b
40-60	0.08	c	0.09	c	0.08	c
60-80	0.05	cd	0.06	cd	0.05	d
80-100	0.03	d	0.04	d	0.02	de
100-120	0.01	d	0.02	d	0.00	e
120-140	0.01	d	0.01	d	0.00	e
140-160	0.00	d	0.00	d	0.00	e

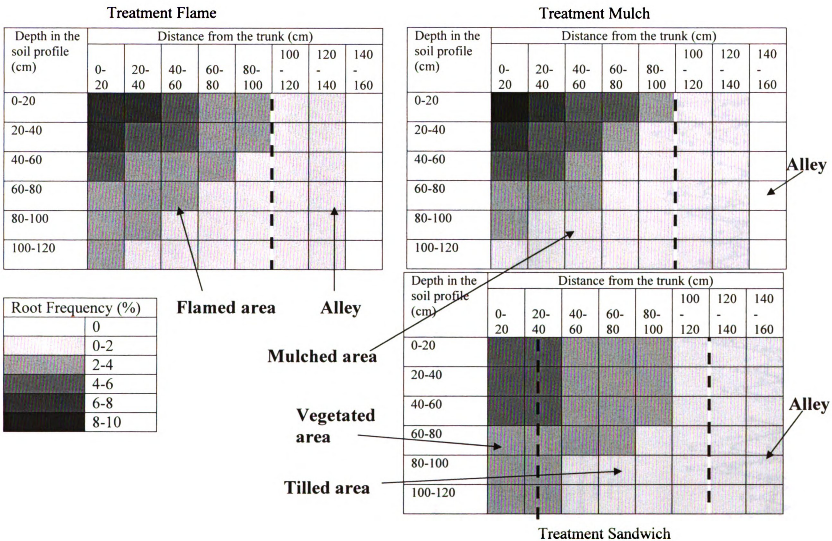
[1]Different letters represent statistical differences (LSMEANS with $P \leq 0.05$) between distances from the tree trunk inside each treatment.

Figure 1: Frequency (% on the total number of roots) of small roots ($\leq$ 2 mm in diameter) related to the distance from the trunk and depth in the soil profile.



Treatment Flame
Treatment Mulch
Depth in the soil profile (cm)
Distance from the trunk (cm)
0-20
20-40
40-60
60-80
80-100
100-120
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
Flamed area
Alley
Root Frequency (%)
0
0-3
3-6
6-9
9-12
12-15
Mulched area
Vegetated area
Tilled area
Treatment Sandwich

Figure 2: Frequency (% on the total number of roots) of large roots (>2 mm in diameter) related to the distance from the trunk and depth in the soil profile.


Treatment Flame
Depth in the soil profile (cm)
Distance from the trunk (cm)
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
0-20
20-40
40-60
60-80
80-100
100-120
Flamed area
Alley
Root Frequency (%)
0
0-2
2-4
4-6
6-8
8-10
Treatment Mulch
Depth in the soil profile (cm)
Distance from the trunk (cm)
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
0-20
20-40
40-60
60-80
80-100
100-120
Alley
Mulched area
Vegetated area
Tilled area
Depth in the soil profile (cm)
Distance from the trunk (cm)
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
0-20
20-40
40-60
60-80
80-100
100-120
Alley
Treatment Sandwich

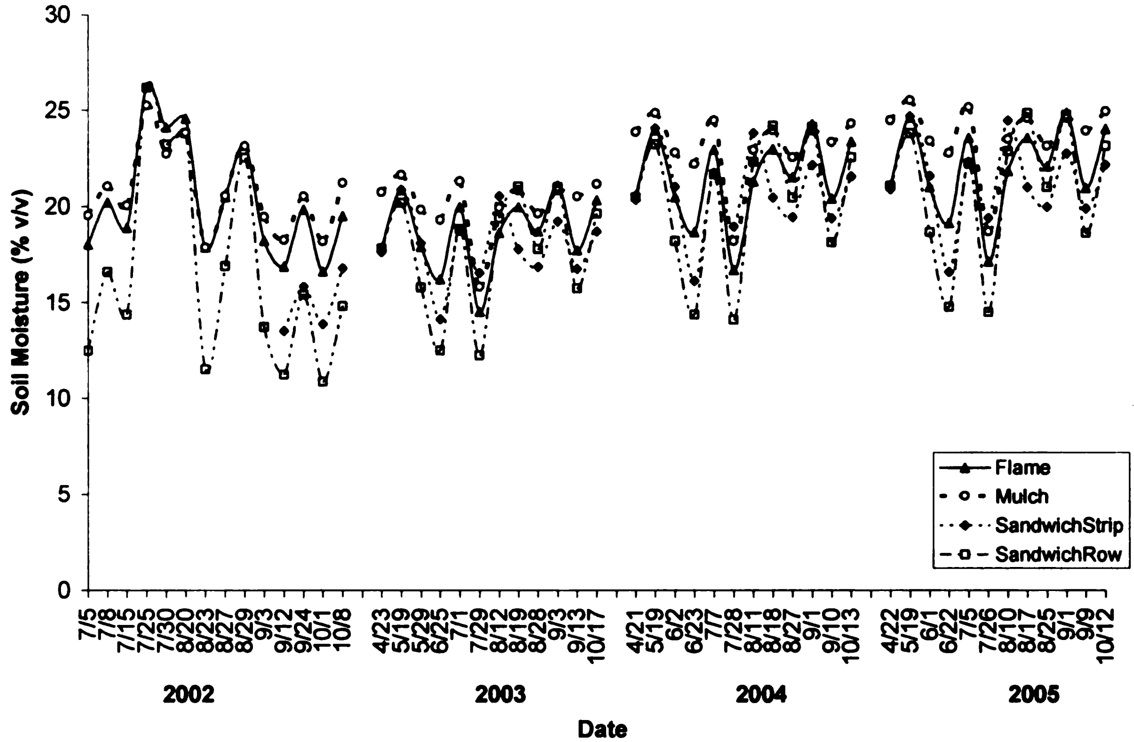


Figure 3: Volumetric soil moisture content (as %) measured with TDR for the average 0-45 cm depth, for the different treatments during 2002-2005.

Abstract

CHAPTER 4. Root Development of Apple as Affected by Orchard Floor Management Systems under Organic Protocol.

By Dario Stefanelli

One of the major challenges in organic fruit production is the implementation of a successful orchard floor management system (OFMS) to maintain productivity. Many plant root systems can adjust nutrient uptake capacity to meet variation in shoot demand caused by environmental changes. Root turnover is an important indicator of plant productivity and a measurement of carbon return to the soil. In general, an increased N concentration in soil accelerates the process of fine root turnover. It becomes then, important to determine root response to the different conditions that an OFMS will create. In adverse soil conditions, negative impact on root development and generation could be detrimental for tree production, thus making that OFMS less suitable.

The aim of this experiment was to evaluate fine root development as affected by two different OFMS using the minirhizotron technique.

The experiment was conducted in an orchard of "Pacific Gala" (*Malus* x *domestica* Borkh.) on M.9 NAKB 337, planted in May 2001. The OFMS used were mulch of alfalfa hay (MU) and strip tilling at each side of the tree row while natural vegetation was allowed to grow undisturbed on the tree row (Swiss Sandwich System, SS). We measured SOM and N concentration at 2 depths (0-10 and 0-30 cm) for 4 years. Root development was monitored by minirhizotrons. Root characteristics (number, length, diameter, area, volume, number of branches, and angle of branch insertion) were monitored and measured utilizing a custom software program.

Orchard floor management systems did have an effect on fine root development. The different soil conditions created from the systems (higher N concentration in mulch) were likely responsible for the increase in fine root life span measured in the sandwich system (50-60 days against 30 for the mulch). Fine root production initiated earlier in SS vegetated area than MU and more fine roots were found in SS vegetated area than MU.

Introduction

One of the major challenges in organic fruit production is the implementation of successful orchard floor management systems (OFMS). The lack of herbicides in organic horticulture requires OFMS that limit or restrict ground cover competition so tree performance does not suffer.

Whichever the OFMS selected, organic growers rely primarily on soil microbial processes to obtain the nutrients for plants; thus, OFMS are extremely important because they have an effect on soil conditions and consequently on nutrient availability, tree growth and yield (Yao et al, 2005). Orchard floor management systems will change the microbial composition and food web of the soil (Yao et al, 2005). The absorption of nutrients within an ecosystem depends on temporal and spatial synchrony between nutrient availability and nutrient uptake (Bassirirad, 2000; Tierney et al., 2001).

Plant roots can alter their water and nutrient acquisition capacity by adjusting their physiological longevity, morphological and/or architectural characteristic to meet changes in shoot nutrient demand (Chapin, 1980; Clarkson and Hanson 1980; Clarkson 1985). Therefore, it is useful to evaluate root characteristics that play a role such as lifespan and turnover, as indicators of growth potential of the plant and its actual nutrient acquisition (Bakker, 1999).

Roots, and fine roots in particular, play a central role (Schulze et al., 1997) in soil chemicals (pH, O_2, CO_2 and other ions), physical (moisture and aeration), and biological (soil pathogens, beneficial microorganisms and allelopathy) composition (El-Shatnawi and Makhadmeh, 2001) with important consequences for plant growth and productivity, plant competition, biological activity, and carbon and nutrient cycling at an ecosystem scale by releasing in the soil a wide variety of exudates (Makhadmeh and El-Shatnawi, 2001; Bertin et al., 2003; Walker et al., 2003). Plants expend a substantial proportion of photosynthate below ground in the annual production of fine roots (Eissenstat et al., 2000) and release of exudates (Walker et al., 2003). In many cases, more than 50% of annual net primary production (NPP) is allocated below ground, and nutrient return to the soil by tree fine root death may exceed that by the above ground litterfall (Kasuya N., 1997). Tree root turnover may return four to five times more carbon to the soil than above ground litter (Zech and Lehrmann, 1998). Consequently there is a need to include the effects of root turnover in models of carbon and nutrient cycling (Cox et al., 1978; Vogt et al., 1986; Hendricks et al., 1993; Jackson et al., 1997; Norby and Jackson, 2000).

Moreover, through the exudation of a wide variety of compounds, roots regulate the soil microbial community in their immediate vicinity, cope with herbivores, and encourage beneficial symbioses (Nardi et al., 2000, Walker et al., 2003).

Assessing root turnover becomes then, very important as an indicator of plant productivity and a measurement of carbon return to the soil. In the last decade the most common technique to measure fine root turnover is by minirhizotrons installed in the ground. They can be used to characterize fine root production, phenology, growth, mortality and lifespan, and are useful in developing ecosystem carbon budgets (Hendrick and Pregitzer, 1996; Majdi, 1996). Their reliability depends on the accuracy of assessing physiological status of the roots (alive or dead) (Wang et al, 1995; Tingey et al, 2000) mostly based on color (Hendrick and Pregitzer 1992a, b; Comas et al, 2000).

However, the determination of fine root physiological status is a common problem (Comas et al., 2000). Also, there is a certain inconsistency in the definition of the proper diameter for fine roots. Several authors reported that fine roots, for woody perennials, should be $\leq$ 1 mm in diameter (McCrady and Comerford, 1998; Eissenstat et al, 2000; Comas and Eissenstat 2001).

Processes and responses vary not only with root diameter but with other root characteristics as well (Norby and Jackson, 2000). It is necessary to couple the total size of the root system with physiological information on the response of root specific nutrient uptake efficiency (Norby and Jackson, 2000). The size of the root system and its efficiency to deploy roots at the time and place nutrients are present (Fitter et al., 1991), as well as the efficiency by which a particular root segment can take up a nutrient from the soil solution (Norby and Jackson, 2000), are fundamental for the plant uptake capacity (Tjeerd et al., 2001). The degree to which kinetics of nutrient uptake or other potential adjustments are expressed would ultimately depend on soil nutrient availability (Tjeerd et al., 2001) and soil factors that determine transport to the root surface (Bassirirad, 2000). Nutrient adsorption, and eventually absorption within an ecosystem, depend on temporal and spatial synchrony between nutrient availability and nutrient uptake, and disruption of fine root development (Tierney et al., 2001).

In general, increased N concentrations in the soil decrease fine root turnover because of their increased lifespan (Pregitzer et al., 1993; Ostonen et al., 1999; Burton et al., 2000; Hendricks et al., 2000; King et al., 2002) allowing the plant to reduce carbon costs. However, several authors reported that with increased N concentration in soil, root turnover rates increase, reducing fine root lifespan (Aber et al, 1985; Nadelhoffer et al., 1985; Persson and Ahlström, 2002). Burton et al. (2000), in an experiment on fine roots (<1 mm) dynamics within and across forest species with different N availability, found that, across species root lifespan decreases with increased N availability, while within species there is the opposite trend. Tjeerd et al. (2001) found that in P depleted soils citrus fine roots life span was diminished.

In any case, all the authors agree on the importance of the interaction between N availability and fine root dynamics, especially for the effects on organic matter (McClaugherty et al, 1982), on the organic N pool in the soil (Ehrenfeld et al., 1997), and on the control of the substrate quality (Hendricks et al., 2000).

Root turnover has been extensively studied in grasslands and forests ecosystems but there is not much literature on fruit trees and none in organic tree production.

The established interaction between OFMS, food web, and root processes could create a different response from the roots that needs to be studied and compared between conventional and sustainable conditions.

The aim of this experiment was to evaluate fine root development as affected by two organic OFMS utilizing the minirhizotron technique.

Materials and Methods.

The experiment was conducted in an orchard of "Pacific Gala" (*Malus* x *domestica* Borkh.) on M.9 NAKB 337, planted in May 2001 at the Clarksville Horticultural Extension Station at a spacing of 4.6 x 1.4 m between the trees. The orchard has been certified organic in 2003 and 2004 by Organic Crop Improvement Association (OCIA), and in 2005 by Organic Growers of Michigan (OGM). Trees were trained to a vertical axe system with relatively little pruning over the years (Perry, 2000). Minimal pruning was applied to allow the tree to grow as natural as possible maintaining a single leader. A two wire trellis with galvanized metal poles was installed as support system. Drip irrigation with drippers of 2.3 L/h every 0.6 m was installed in May 2001 and suspended from the lowest wire of the trellis on the tree row. All orchard floor management systems received equal irrigation throughout the season.

Soil moisture was measured by time domain reflectometry (TDR) using a Mini Trase 6050X3 (Soilmoisture Equipment Corp., Goleta, CA) with 45 cm long stainless steel rods permanently installed in the tree rows, halfway between two trees and in the middle of the tilled strip in 2002. Measurements were taken for each of the 6 plots per treatment weekly in 2002 and every other week in 2003-2005.

The site was previously farmed with conventional soybean-corn-corn-alfalfa rotation for two cycles until 1998. Subsequent soil preparation consisted of sowing of buckwheat and chicken compost (1250 kg/ha) and lime (2250 kg/ha) application in 1999 on the entire surface. At plantation (April 2000) a mixture of red mammoth clover and endophytic rye was sown in the alleys.

The two orchard floor management systems (OFMS) under study were established in a complete randomized block design at the beginning of the second growing season (2001) and maintained for the entire study. The treatments consist of mulch of alfalfa hay (MU), the Sandwich System (SS). The alfalfa hay mulch was laid underneath the tree canopy in a strip of 1 m on each side of the tree and kept 15-20 cm thick. 105 round alfalfa bales/ha were used with a C:N ratio of 15:1. The treatment was hand-applied every spring and fall to keep the thickness of the mulch constant to provide a shading effect for weed suppression, and to maintain soil moisture. The Sandwich System is an adaptation of the one reported by Weibel (2002) and consists of an area 25-30 cm on each side of the tree, underneath the canopy, where spontaneous vegetation is allowed to grow undisturbed. On each side of this vegetated area two strips of soil were kept free of vegetation by shallow tilling (5-10 cm deep). The strips were 70 cm wide from planting till 2003 and expanded to 90 cm wide in 2004. Timing of the treatment application was the same as the flaming treatment. The tilling was accomplished from 2001 through 2004 with a spring-tooth (three teeth 2001-2003, 5 teeth 2004) harrow mounted on a side-bar of a tractor. To improve tillage effectiveness, a modified notch-disk tiller, mounted on the tractor side-bar, was deployed during the 2005 growing season.

The alley consisted of an equal mixture of endophytic rye and mammoth clover established soon after planting the orchard in 2000. Clover was also reseeded in 2005 to keep the proportion constant. The alleys were managed equally in all treatments by periodical mowing (3-4 times year).

The predominant soil type of the orchard is Kalamazoo sandy clay loam (Typic Hapludalfs) with 53.1% sand, 23.1% silt, and 23.8% clay. The orchard presents mild slopes (less than 3%).

Tree growth parameters (TCA at dormancy, shoot growth, and canopy volume) and fruit production (Yield and average fruit weight) were measured to monitor the effect of the OFMS on the above ground part of the tree.

The effect of the OFMS on the soil conditions were monitored:

- Soil nitrate (NO_3^-) and ammonium (NH_4^+) concentration in the soil, to check the immediate available nitrogen released from the treatments available to the trees. Soil samples were obtained for the two OFMS by mixing 20 soil core sub-samples from the tree row. Soil samples from the Alleys and the tilled strip of the SS were obtained by mixing 10 soil core sub-samples from each side of the tree row. Soil samples were collected every two months starting in April until November at 0-30 cm depth each year. The 0-30 cm depths have been chosen to represent the most frequently explored part of soil from roots. Soil samples were air dried at 105°C for 24 hrs. Nitrates and ammonium concentration was measured by extraction with 100 ml of KCl 1 M on 10 g of dried soil, placed for 1 hour on a shaker and then filtered with filter paper. The extraction liquid was sent to the MSU soil lab for the analysis following the procedure described by (Kenney, 1982) using a Lachat automated colorimetric analyzer (Lachat Instruments Inc. Milwaukee, WI).

- Soil organic matter (SOM) concentration was measured by loss on ignition of 3g of dry soil, from the above described soil samples, at 400 °C for 8 hours in a muffle furnace.

Root development was monitored using minirhizotrons installed during summer 2002. Minirhizotrons consisted of clear butyrate plastic tubes 13 cm in diameter and 182 cm long. Four tubes for each tree in trial were installed at a 45° angle facing the tree at 40 cm from the tree trunk parallel to the tree row, and 122 cm deep. To evaluate the effect of the OFMS on root development the tubes were installed at the same fixed intervals from the tree trunk in each treatment (2 at 13 cm on each side the tree trunk perpendicular to the tree row, 1 at 53 cm, and the last one at 68 cm) (Fig. 1 A and 1 B). Two trees for each treatment were utilized in the experiment with four replicates for a total of 32 tubes for each treatment.

Images of roots were recorded at fixed time intervals (2-3 weeks) during the growing season with a digital camera developed by Bartz Technology Corp., CA. Thirteen images were collected for each tube and recorded every 10 cm along the length of the tube starting at 10 cm depth. Data were collected in 2003 and 2004.

Root parameters (number, length, diameter, area, volume, number of branches, and angle of branch insertion) were measured through a software program especially designed from our department. The software utilizes an algorithm (claimed in U.S. Patent Number 6,690,816 which has been assigned to the University of North Carolina at Chapel Hill. Used with permission) specifically modified for root studies. The program is copyrighted by the MSU Board of Trustees, and is currently not commercially available.

Root data from each image was segregated into four classes (0-30 cm, 30-60 cm, 60-90 cm, and below 90 cm) to evaluate development within the soil horizons. Distances from the tree trunk were kept separated to evaluate the effect of distance on root development.

Data were log transformed to maintain homogeneity. Statistical analysis was performed with SAS (Version 8, SAS Institute, Cary, NC, USA). Analysis of variance was performed using the MIXED procedure to detect treatment, distance from the trunk, and depth in the soil profile effects, as well as their interactions. Where appropriate, means were separated using the Least-square means test (LSMEANS) with $p \leq 0.05$.

The following timetable explains the history of the plot, sampling and measurements for the duration of the experiment (conducted May-Sept 2004 & 2005).

Prior to 1998	Conventional soybean-corn-corn-alfalfa rotation (2 cycles). Last crop was corn. Minimal tillage.			
1999	Spring: tillage sowing of soybean, Chicken compost (1250kg/ha), lime (2250 kg/ha). Fall: tillage, sowing of Buckwheat			
2000	April: tillage, tree planting. August: sowing of red mammoth clover and endophytic rye in the alleys.			
2001	May: implementation of the 3 orchard floor management systems.	April, June, August, November: soil sampling for NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD	
2002	Maintenance of the OFMS and tree training	April, June, August, November: soil sampling for SOM and NO_3^-	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD	July-August: installment of minirhizotrons
2003	Same as above	April, June, August, November: soil sampling for SOM, NO_3^- and NH_4^+	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD and yield	
2004	Same as above	Same as above	Same as above	
2005	Same as above	Same as above	TCA, TCAI, shoot growth, canopy volume, leaf N %, SPAD and yield,	

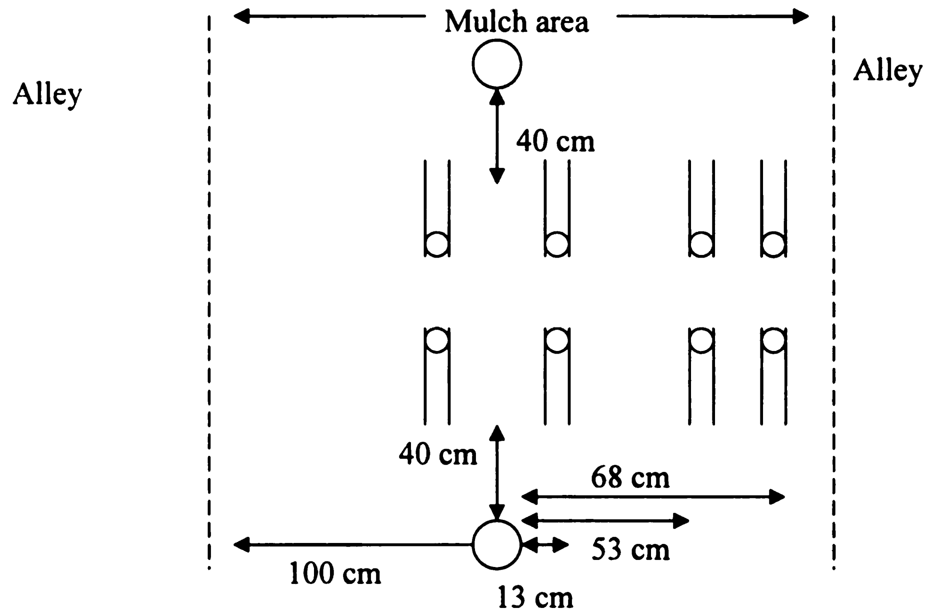


Fig 1A. Minirhizotron location for apple tree root development study in the mulch treatment.

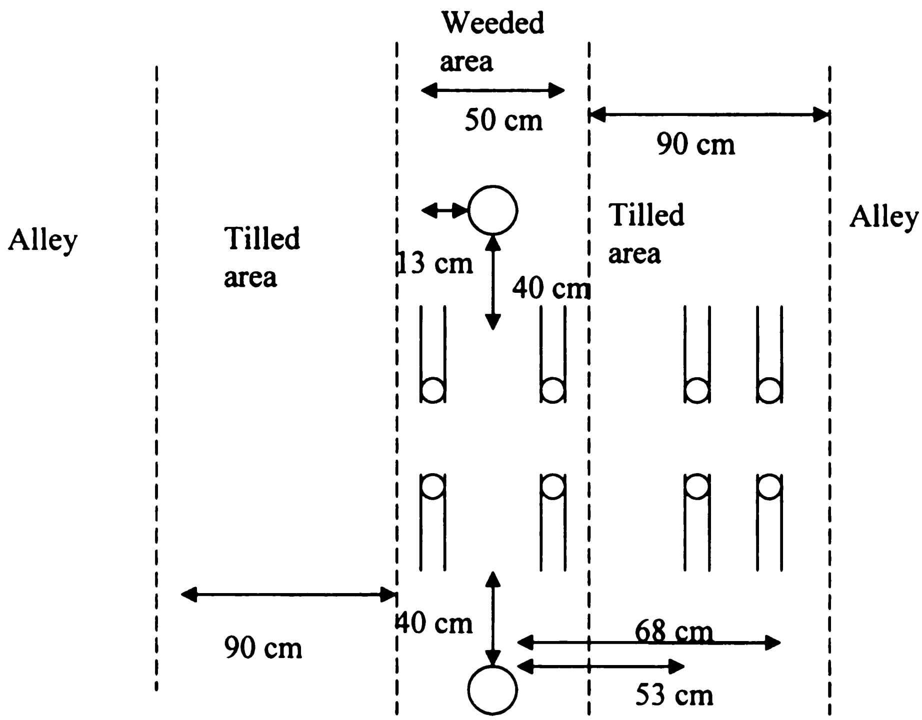


Fig 1B. Minirhizotrons location for apple tree root development study in the Swiss Sandwich treatment.

Results

The treatments did have an impact on the organic matter (SOM) and nitrogen concentration, effectively changing the chemical, physical and biological conditions of the soil (Chapter 1). We did not notice any effect of SOM or N on any of the fine root parameter measured (data not shown).

In general there were no differences between the two years of observation (2003-2004) in any of the fine root parameters measured. Also, the only fine root parameters that were affected from the treatments were the fine root numbers, area, and the rate of growth.

Effect on fine root number

There were more fine roots per image in SS than MU in both years (Figure 2). Fine root number in SS declined during the growing season and approached values of MU towards the beginning of July and then no differences were measured between the treatments for the rest of the measurements (Figure 2).

Fine root number was not affected by depth in the soil profile but was affected by distance from the trunk in SS, which had a higher number of fine apple roots closer to the trunk in the vegetated area than MU (Figure 3).

When the fine root number was segregated by classes of diameter and checked for their frequency (expressed as the percentage of fine roots in each diameter class), there was significant difference among the diameter classes, with a greater proportion of apple roots being 0.4 to 0.8 mm (Figure 4). Orchard floor management systems did not affect root diameters. Roots generated near the trunk (13 cm) are larger in MU than SS (Figure

5). Sandwich presented the opposite in the middle position that is closer to the transition between the vegetated area and the tilled strip, and a much higher percentage of very fine roots (0.2-0.4 mm) farther from the trunk (corresponding to the middle of the tilled strip) (Figure 5).

Larger roots were found developing deeper in the soil profile in MU (Figure 6).

Effect on fine root area

The amount of fine root area for both treatments varied, depending on the distance from the trunk and soil depth. Closer to the surface (0-30 cm) SS presented a higher fine root area closer to the trunk (in the vegetated area) than mulch for most of the duration of the experiment, both in 2003 and 2004 (Figure 7). No differences were measured between the treatments in any other position in both years.

Below 30 cm there was a lot of variation during the experiment that nullified differences between positions inside of the treatments and between them in both years (Figure 8). Differences did not exist deeper in the soil profile (below 60 cm) (Figure 9; 10).

Effect on growth rate

The growth rate (expressed as number of roots/day $^{-1}$) was different between the two treatments. In the literature, root length is normally used to establish root turnover rates and life span. According to Tracey et al. (2003), root number can be substituted for root length if there is a direct correlation between the two. The correlation found in this experiment allowed us to use root number as an indicator of fine root turnover and lifespan (Figure 11).

There was a decline in fine root number greater for SS than MU. The amount of re-growth was similar between the treatments, but SS always had a higher fine root reduction than MU (Figure 12). Additionally, the turnover rate was greater in SS than MU when expressed as fine root mortality (Figure 12) following the methodology utilized by Joslin et al. (2000). The amount of time between active growth and fine root disappearance was used as an estimation of fine root life span. Sandwich had an estimated lifespan of around 30 days compared with the 50-60 for mulch (Figure 12).

Growth rate was not affected by the depth in the soil profile or by the distance from the trunk; also, there were no interactions with the treatments.

The different classes of fine root diameter considered did not differ in growth rate.

Soil water content.

Measurements performed with TDR (Figure 13) demonstrated that most of the time there were no differences between OFMS. When some difference was present MU had always the highest values while the SVA had the lowest. Flame and the tilled strip in the sandwich did not differ from the other two.

Discussion

The orchard floor managements under evaluation did have an impact on the soil conditions. Mulch increased the percentage of soil organic matter (SOM) in the soil and it was higher than sandwich. This is due to the continuous break down of the mulch itself by the microorganisms in the soil and its continuous addition (twice yearly) for the duration of the experiment, as most of the work done on similar conditions attests (Merwin et al., 1993; Sanchez et al., 2003).

We did not find a clear correlation between fine root parameters and amount of nitrogen present in the soil, except for the fine root lifespan and turnover. The literature present is contradictory regarding the effect of nitrogen on fine roots. Some authors report that with increased N concentration in soil, root production and length, as well as their life span increases (Aber et al, 1985; Nadelhoffer et al., 1985; Persson and Ahlström, 2002) while others (Pregitzer et al., 1993; Ostonen et al., 1999; Burton et al., 2000; Hendricks et al., 2000; King et al., 2002) reported the opposite. Our work aligns with the correlation of higher N concentration and increased life span, thus reducing carbon costs of the root system (Nadelhoffer and Raich, 1992).

In any case, all the authors agree on the importance of the interaction between N availability and fine root dynamics especially for the effects on organic matter (McClaugherty et al, 1982), on the organic N pool in the soil (Ehrenfeld et al., 1997), and on the control of the substrate quality (Hendricks et al., 2000).

McClaugherty et al (1982) reported that increased organic matter in the soil increased root lifespan while we found the opposite. The difference in SOM in our experiment was probably not enough to exert an effect.

The 30 days of root lifespan found in the mulch treatment is similar to the finding by Bouma et al. (2001) for apples. The same author also states that nutrient depleted systems increase not only the fine root lifespan but also their nutrient efficiency uptake, thus implying that the sandwich system is more efficient.

This theory also explains the higher number of fine roots measured in SS compared with MU early in the season when the trees are in higher demand. It also explains the higher amount of fine roots and area found closer to the trunk in the first 30 cm of soil in the sandwich system. The higher competition for nutrients and water exerted from the vegetation present in this area of the SS is probably responsible for this finding, since it will increase the system nutrient depletion (Schenk and Jackson, 2002).

It is not clear which factors are responsible for the lack of response in fine root area in the other positions and depths between the treatments.

Wells and Eissenstat (2001), reported that 55-60 % of apple roots in their study have a diameter of 0.5-1.1 mm and 30 % of 0.3-0.5 mm. Our findings, even if the division in classes of diameter are slightly different, support their observation. We did not, however, find an association between root diameter and mortality, as found in their report.

We did instead find an interaction between the diameter class frequency and both depth in the soil profile and distance. This interaction was different for the two treatments. It is not clear which factors are responsible for these results. Closer to the trunk (the vegetated area in the sandwich), MU tends to show a higher frequency of larger diameters than SS, especially both, near to and the farthest distance to the trunk. Sandwich presented the opposite in the middle position that is closer to the transition between the vegetated area and the tilled strip, and a much higher percentage of very fine roots (0.2-0.4 mm) farther from the trunk (corresponding to the middle of the tilled strip). A similar tendency was noticed for soil profile depth. Mulch tends to have higher frequency of larger root classes deeper in the soil profile, even if the most represented classes are still the two mid size roots in both treatments.

The reason why SS tends to show a higher frequency of very fine roots farther from the trunk and deeper in the soil profile than MU could be explained by lower carbon cost for very fine root, thus reducing the demand of the root system and allowing SS to be equally productive as MU.

More research should be done trying to link root diameters with efficiency of nutrient absorption, response to water content, SOM, and carbon cost of their production.

Conclusion

With this experiment we did demonstrate that fine root development was affected by the ground floor management systems implemented. The different soil conditions created from the systems (higher N concentration in mulch) were responsible for the increase in fine root life span measured in the sandwich system (50-60 days against 30 of the mulch). This treatment also had a higher fine root number early in the season than mulch.

The vegetated area underneath the canopy of the sandwich system was probably responsible for the higher fine root area found in this position compared to mulch.

We also found unique data that linked the treatment diameter class of fine roots with the depth in the soil profile and distance from the trunk. The Sandwich system had higher frequency of very fine roots (0.2-0.4 mm) closer and farthest from the trunk, as well as deeper in the soil profile when compared with mulch.

Even if we did not measure them, from the results of this study, it is possible to suggest that the sandwich system is able to implement a root system that is both more efficient in the uptake and less costly on the carbon demand. More research should be done to assess this point.

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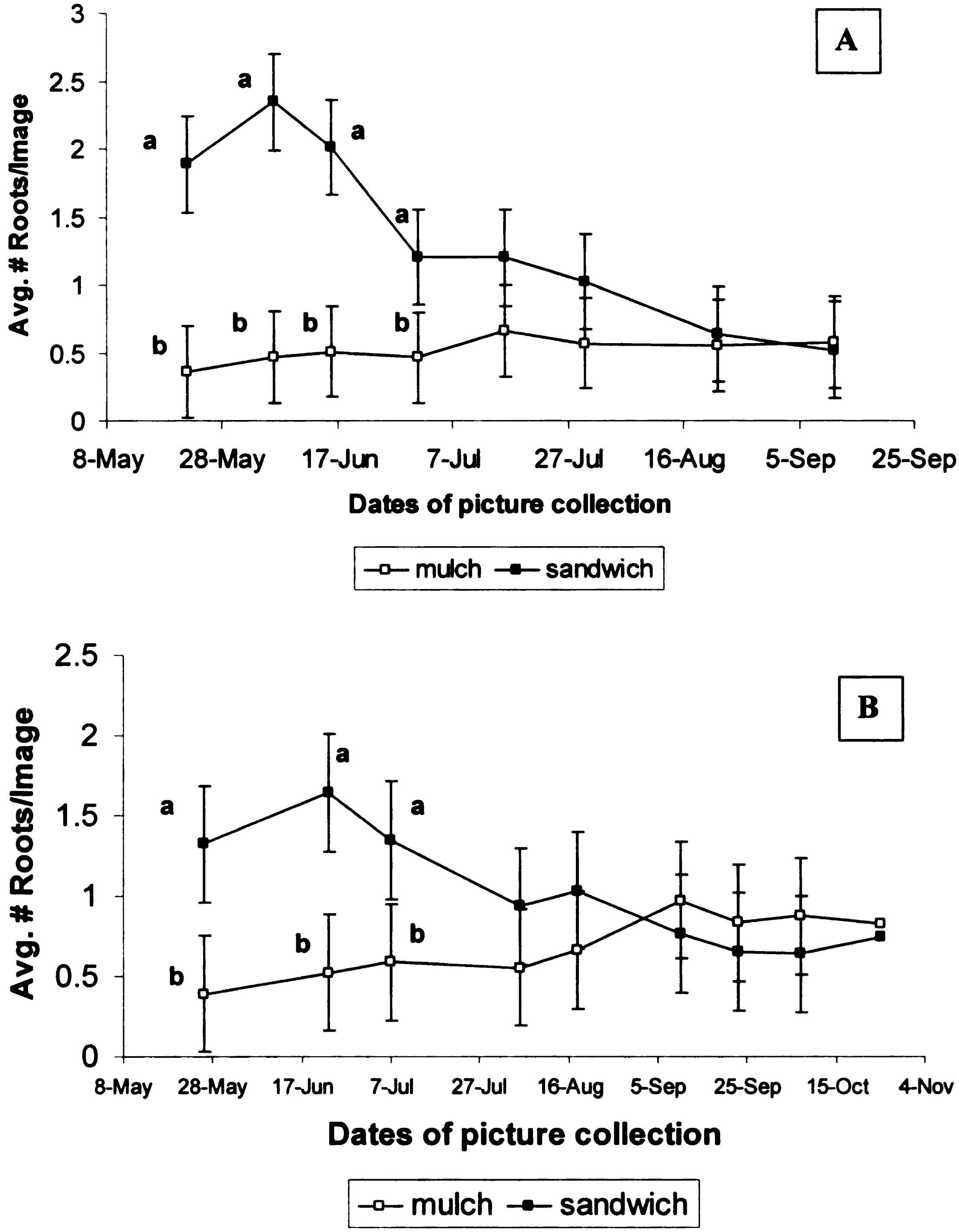
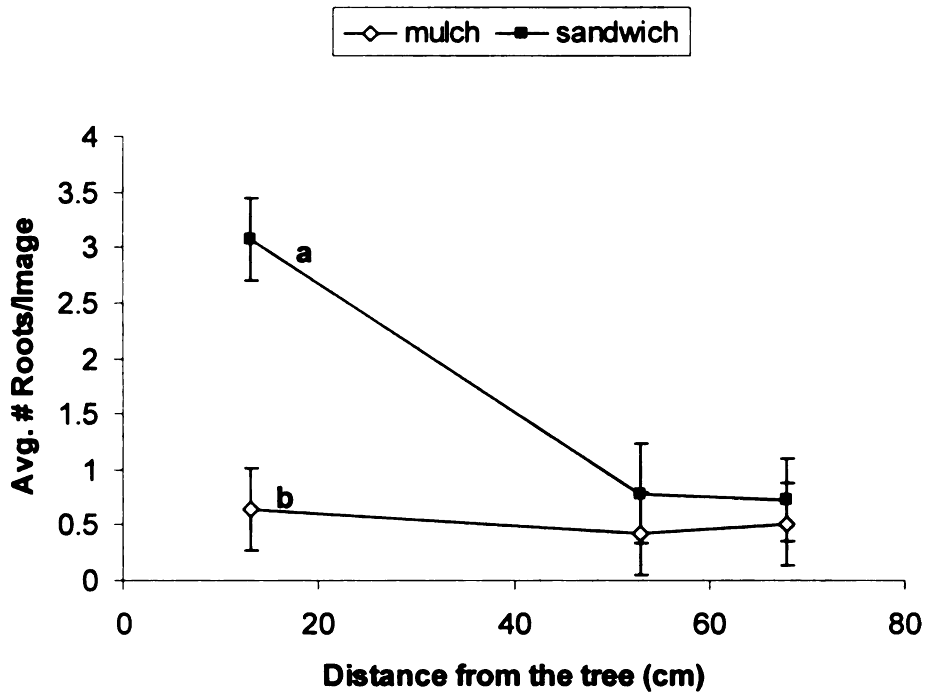


Figure 2: Average root number/image during 2003 (A) and 2004 (B) for the two treatments. Different letters represent statistical significance (LSMEANS with $P \leq 0.05$). Bars represent standard error.



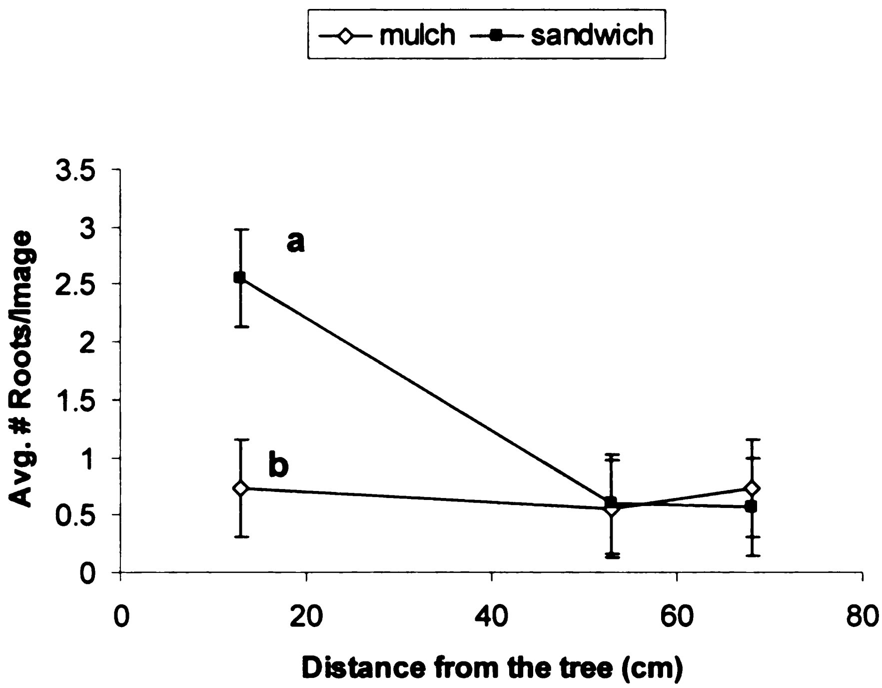


Figure 3: Average root number/image as affected from distance from the trunk (cm) for 2003 (A) and 2004 (B). Different letters represent statistical significance (LSMEANS with $P \leq 0.05$). Bars represent standard error.

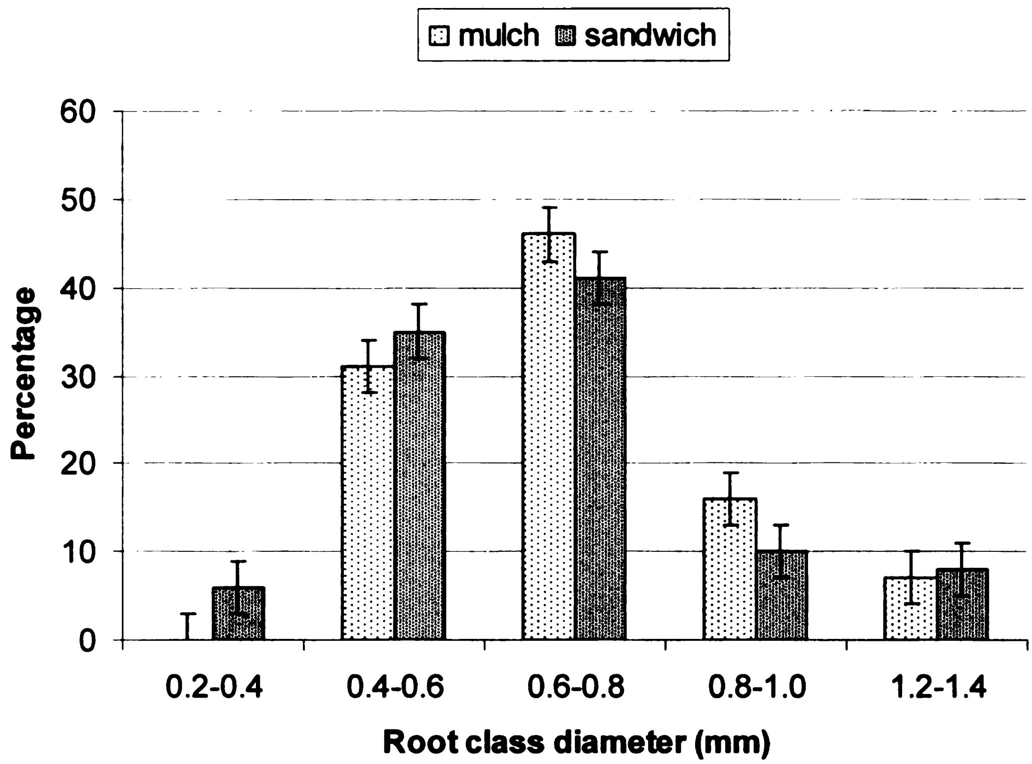


Figure 4: Frequency of roots (percentage on the total number of roots) in each root class diameter (mm) for the two treatments. Bars represent standard error (LSMEANS with $P \leq 0.05$).

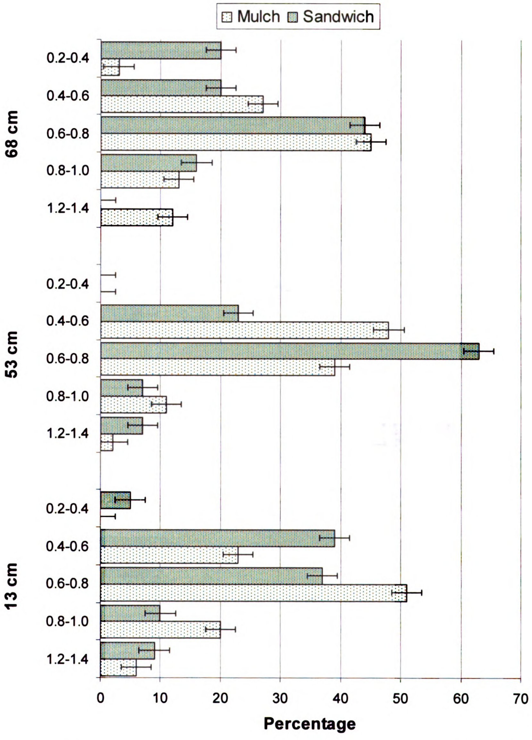


Figure 5: Effect of the distance from the trunk (cm) on the frequency (percentage on the total number of roots) of roots in each class diameter (mm) for the two treatments. Bars represent standard error.

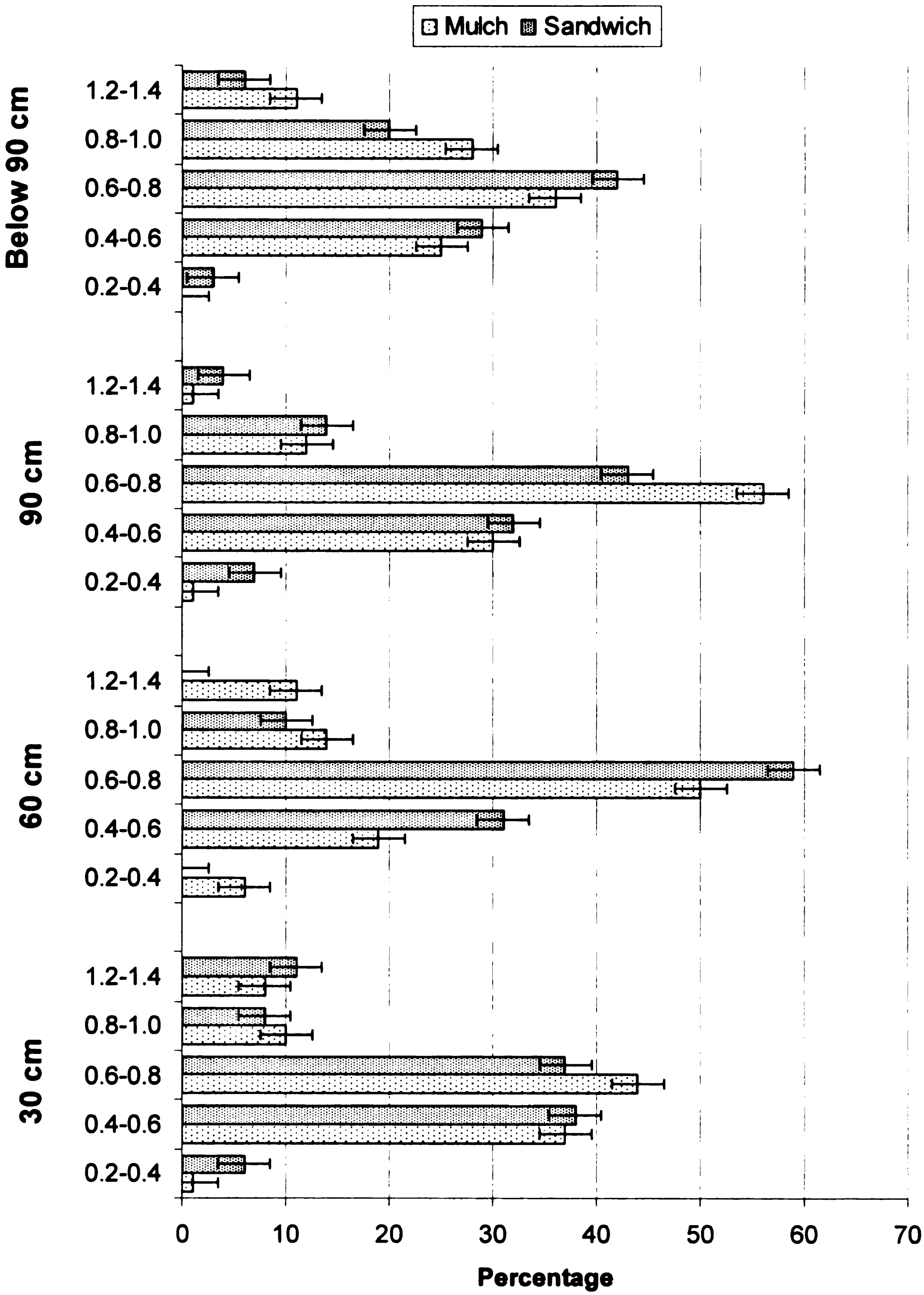


Figure 6: Effect of depth in the soil profile (cm) on the frequency (percentage on the total number of roots) of roots in each class diameter (mm) for the two treatments. Bars represent standard error.

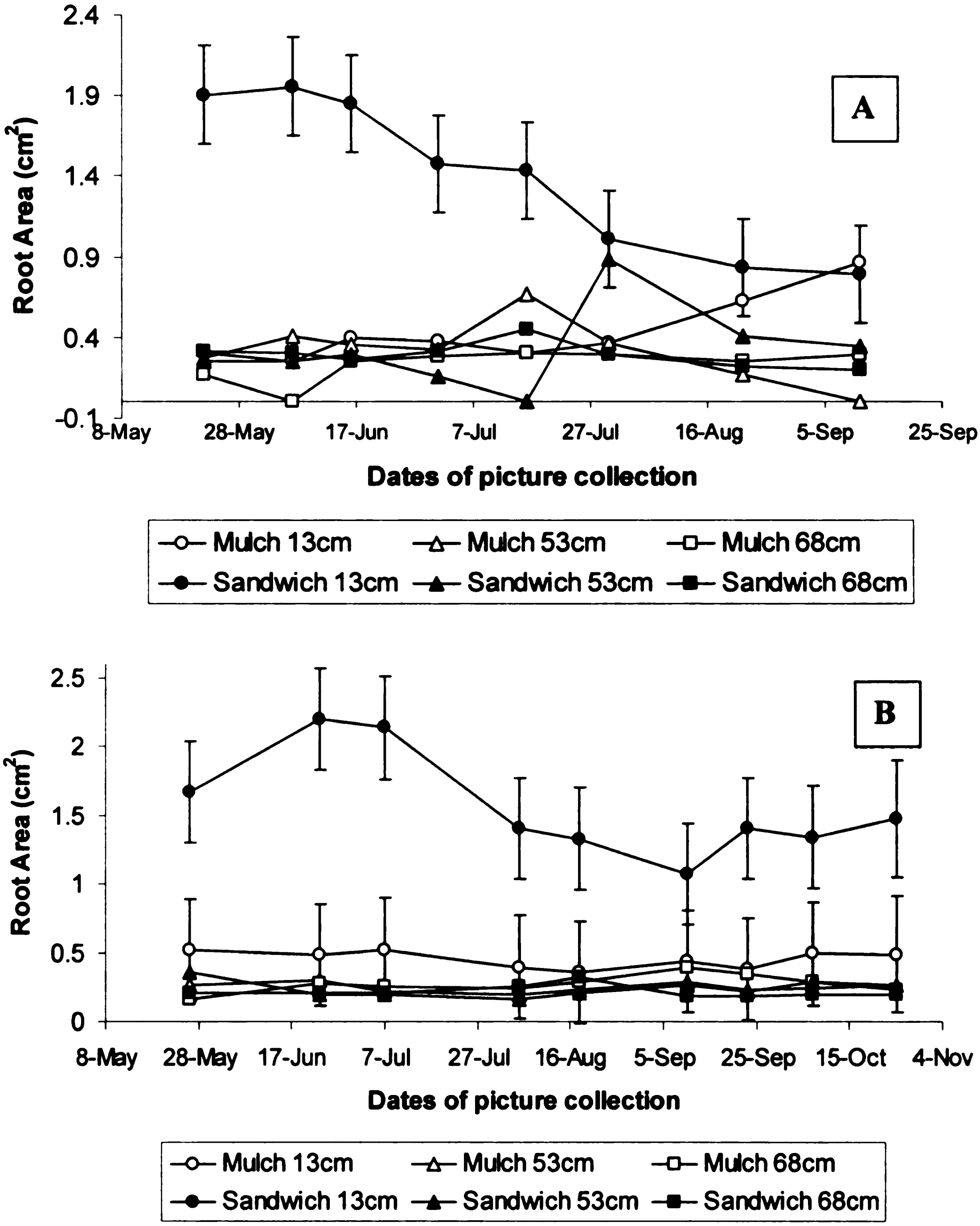
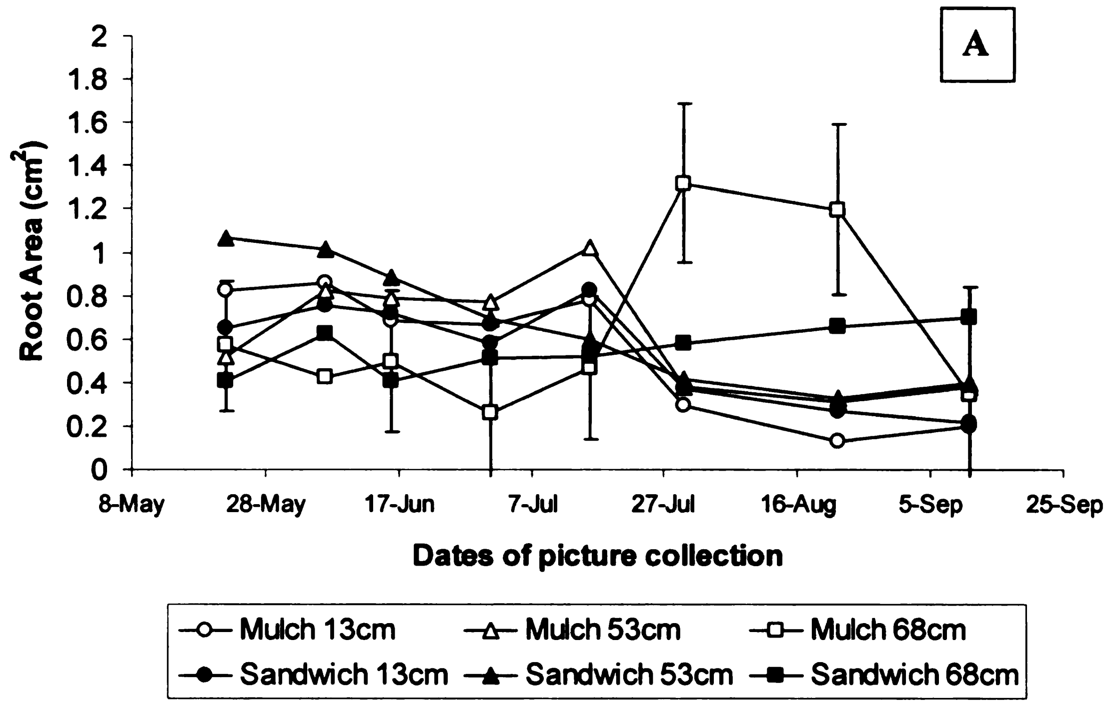


Figure 7: Root area dynamics depending on the distance from the trunk for both treatments at 0-30 cm depth in the soil profile during 2003 (A) and 2004 (B). Bars represent standard errors for significance (LSMEANS with $P \leq 0.05$).



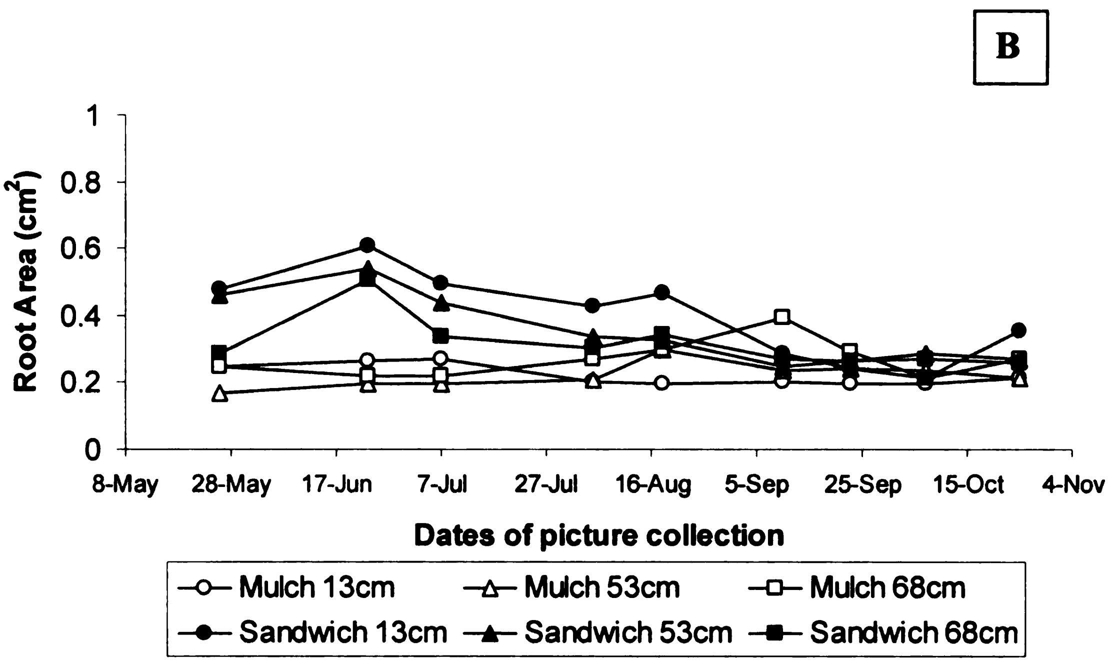
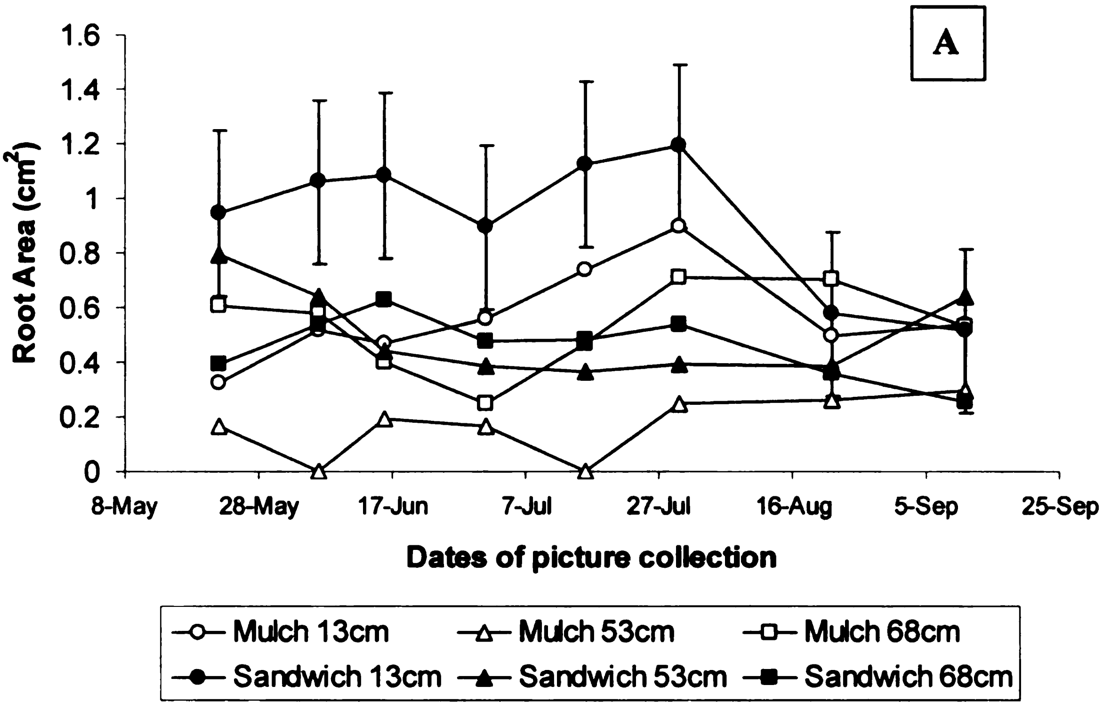


Figure 8: Root area dynamics depending on the distance from the trunk for both treatments at 30-60 cm depth in the soil profile during 2003 (A) and 2004 (B). Bars in figure A represent standard errors for significance (LSMEANS with P≤0.05). There was no difference between treatments in figure B.



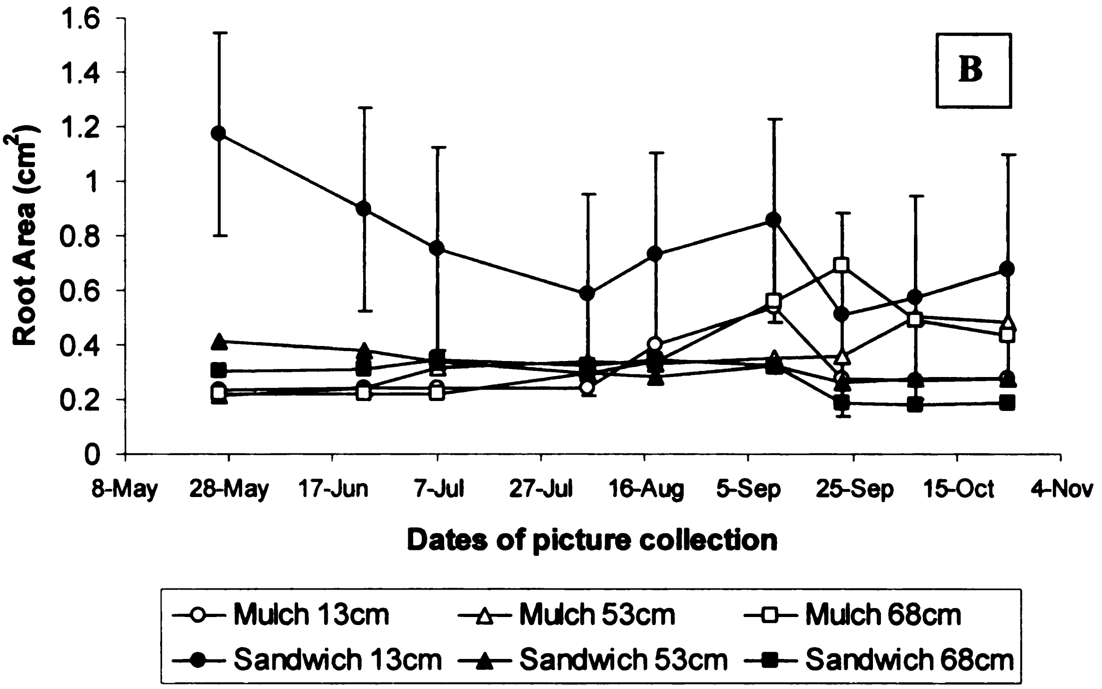
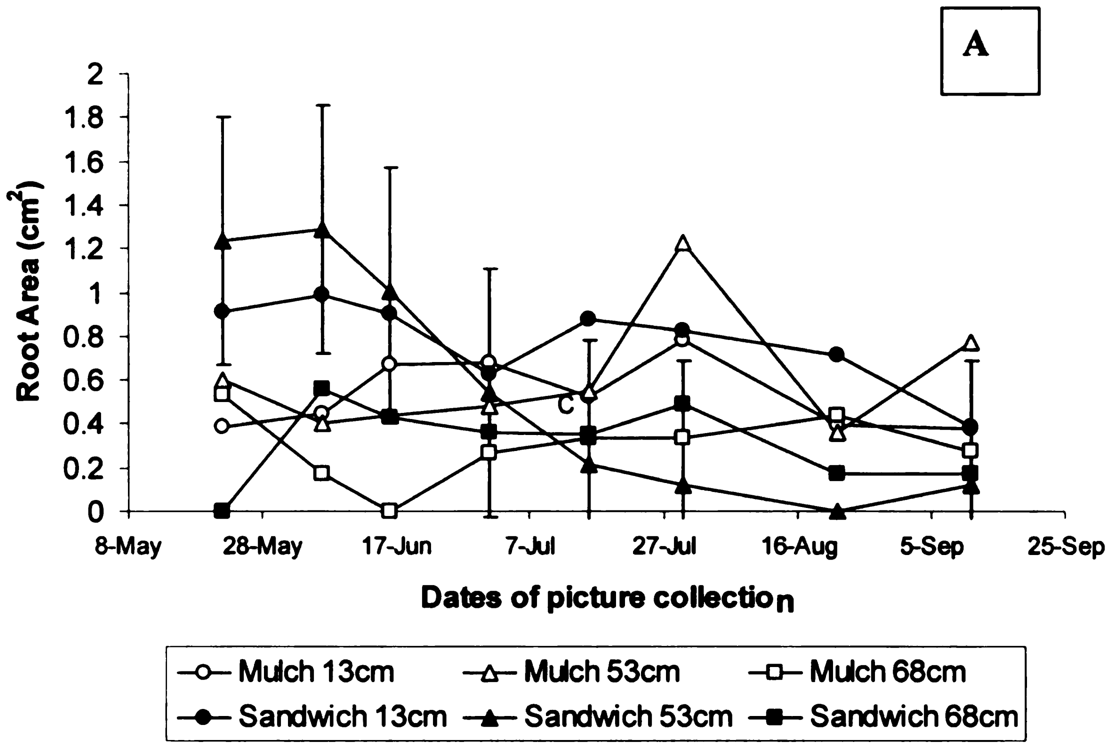


Figure 9: Root area dynamics depending on the distance from the trunk for both treatments at 60-90 cm depth in the soil profile during 2003 (A) and 2004 (B). Bars represent standard errors for significance (LSMEANS with P≤0.05).



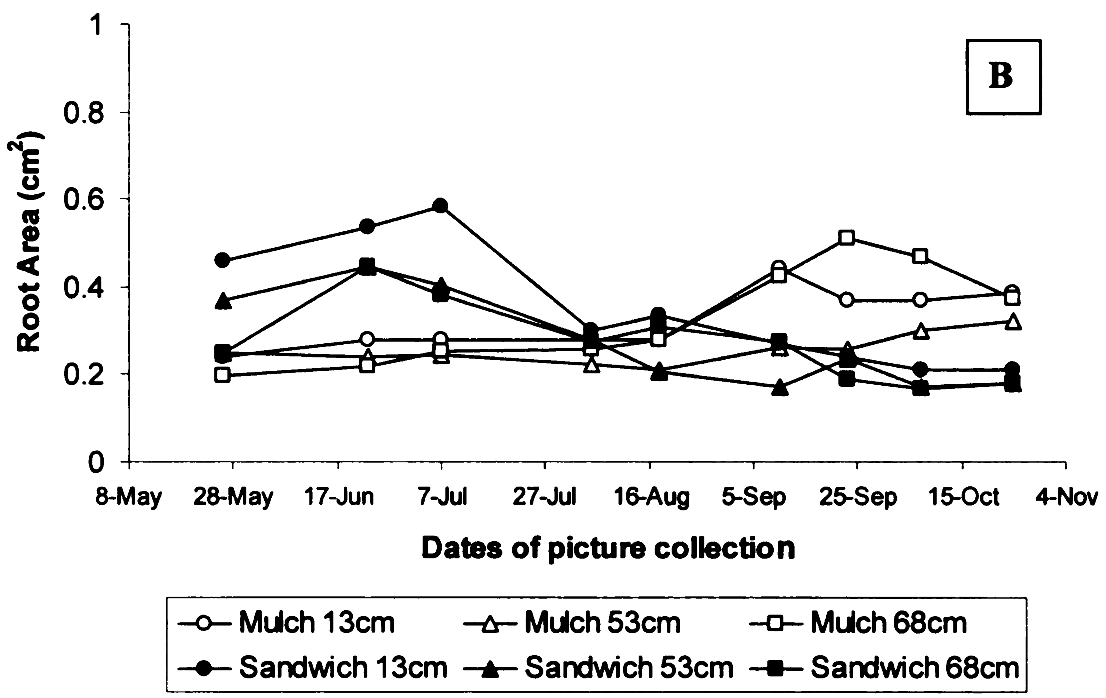


Figure 10: Root area dynamics depending on the distance from the trunk for both treatments at below 90 cm depth in the soil profile during 2003 (A) and 2004 (B). Bars in figure A represent standard errors for significance (LSMEANS with $P \leq 0.05$). There was no difference between treatments in figure B.

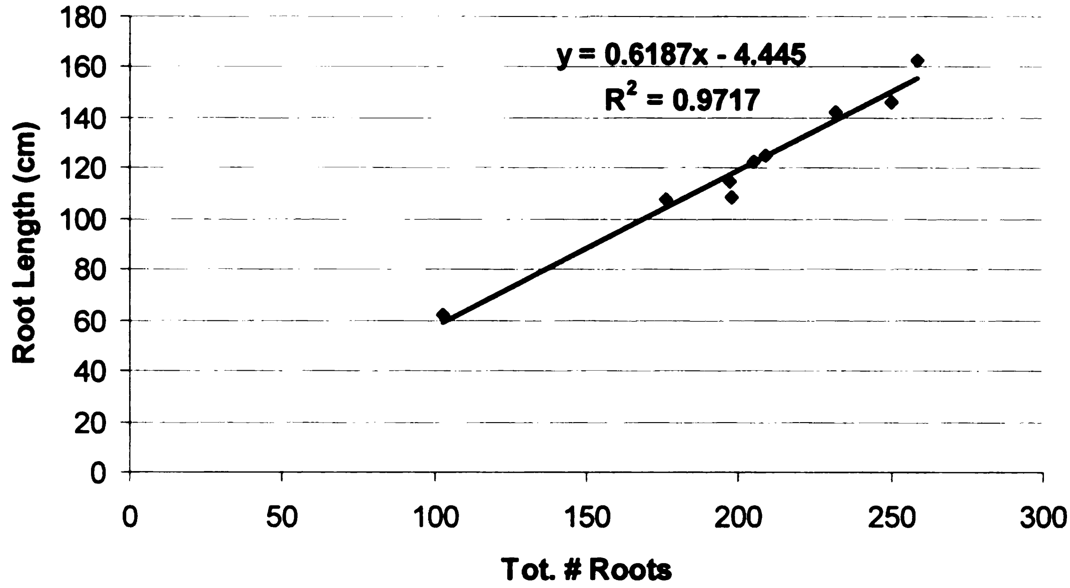


Figure 11: Correlation between root number and root length (cm).

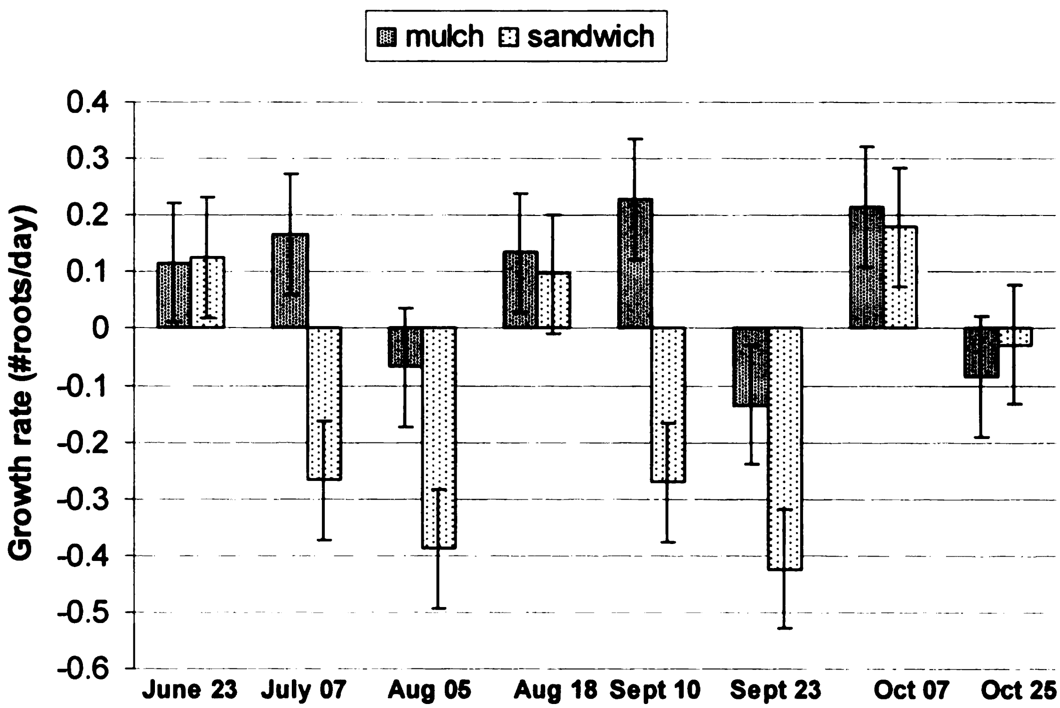


Figure 12: Root growth rate (number of roots day $^{-1}$) for treatment mulch and sandwich during 2004. Measurement starts at the second collection date. Bars represent standard errors for significance (LSMEANS with $P \leq 0.05$).

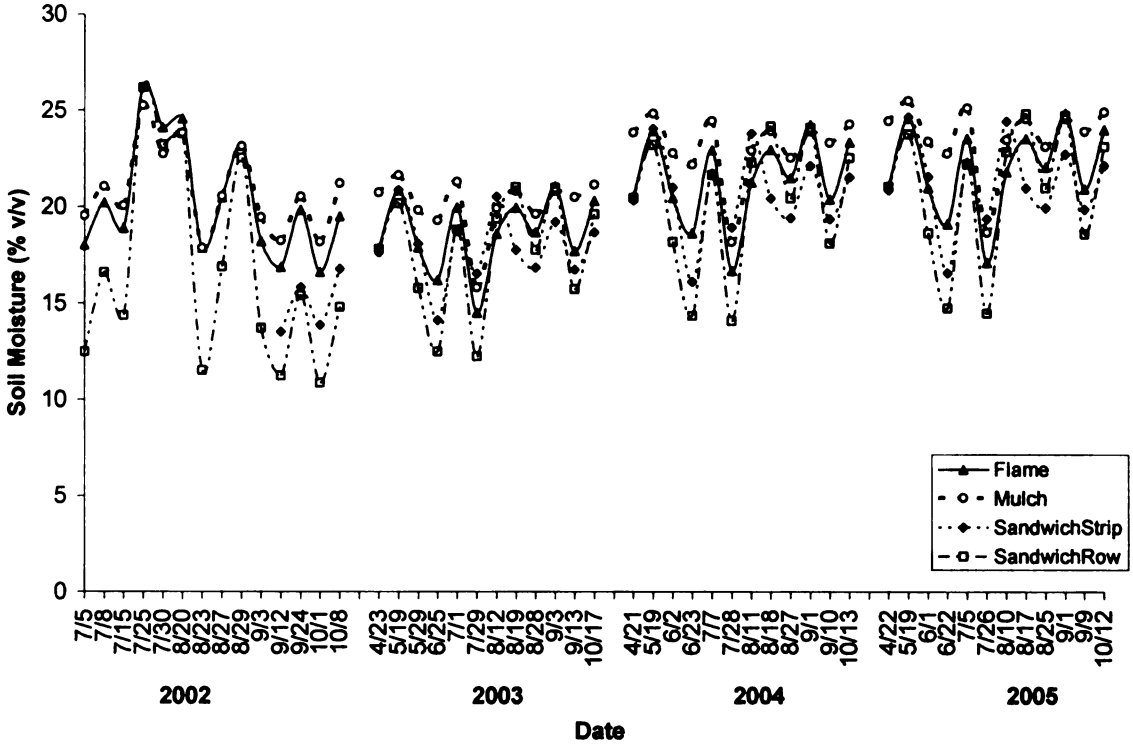


Figure 13: Volumetric soil moisture content (as %) measured with TDR for the average 0-45 cm depth, for the different treatments during 2002-2005.

CONCLUSION

With this dissertation we asserted that the Orchard Floor Management Systems (OFMS) under evaluation were able to change the soil conditions regarding organic matter, carbon sequestration and nitrogen concentration.

The highest soil organic matter (SOM) concentration was found in the mulch treatment (MU), which increased over the duration of the experiment, especially near the soil surface where litter was added twice yearly. Soil organic matter decreased near the soil surface for flame (FL) and the tilled strip of the sandwich system (SS) where there was continuous burning of the vegetation (in the flame treatment) and the effect of tillage (in the tilled strip of the sandwich, STA). Soil organic matter in the vegetated area of the sandwich system (SVA) remained constant for the duration of the experiment due to the continuous degradation of the on site vegetation. Soil organic matter was less significant deeper in the soil profile (0-30 cm), where MU increased overtime and was the highest in soil organic matter. The tilled strip of the sandwich also increased in SOM. There was no change at this depth over time for the other systems/positions sampled.

A very similar trend was found for all treatments regarding Nitrogen (N) concentration in the soil.

When some difference was present MU had always the highest water content values in the soil while the SVA had the lowest. Flame and the tilled strip in the sandwich did not differ from the other two.

The trend for carbon sequestration per hectare at orchard level was inverse in relation to SOM for the systems. The greatest potential for carbon sequestration was at 0-30 cm depth, for MU and SS.

The different nematode populations present in the soil were changed by the OFMS. There were more bacteria feeding nematodes (84%) in the mulch system which accelerated over time and eventually dominated nematode populations. In contrast, bacteria feeding nematodes stabilized (around 60%) in SS and FL, while the fungal feeding populations strengthened. Fungal feeding nematodes usually develop in depleted soil conditions but at the same time have an enhanced effect on nitrogen release in the soil. This may have occurred here where there was a measured increase in nitrogen concentration in the soil, even with decreasing or stable SOM. Also, a higher percentage of roots were infected by mycorrhizae in FL and SS, which is commonly associated with poor soil conditions. These results suggest that these two treatments found a balance to overcome the lower SOM concentration, thus increasing their efficiency. Mycorrhizal infection enhances root lifespan in woody roots (Hooker et al., 1992).

There were less root feeding nematodes in the soil in MU than FL and SS. Levels in FL and SS were similar but below damage threshold.

There was a direct correlation between mycorrhizal spores in the soil and percentage of roots infected by mycorrhizae.

It appears that trees managed in all system treatments were equally efficient regarding plant growth and development (TCA, TCAI, canopy volume, and shoot growth). Perhaps the different performances of plants under the OFMS improved root system efficiency. This was demonstrated when we measured the fine root development under MU and SS by minirhizotrons. Fine root turnover life span was increased under SS (from 30 days of MU to 50-60 days), suggesting an improved efficiency of nutrient uptake and reducing the carbon cost of new root production. The adaptation of the root system to the OFMS was not confined only to a physiological but also to a physical one.

Weed presence influenced root architecture measured by trench soil profile. Apple roots were confined to the weed free area in MU and FL and relatively closer to the soil surface. In contrast, very few roots were found in SS closer to the trunk (vegetated area), and more were found extended into the tilled strip (vegetation free), and reached farther into the alley. It was also found to have a greater frequency of roots deeper in the soil profile. The lower water content found in the vegetated area of the sandwich could have also played a role in the root distribution.

In total, there were more roots found in MU than the other two treatments. This fact coupled with the fact that no differences were measured in the tree growth parameters suggests that there is a better carbon allocation for trees in FL and SS.

The trench profile data contradicts the spatial results from the minirhizotrons regarding between MU and SS. The soil and root interface sampling in the minirhizotrons is very limited and thus data is not applicable in assessing spatial distribution. This technique is reliable in monitoring root growth development. With the trenches, a selected part of the root system is measured and it is assumed representative of the totality. The general trends of the results should still be considered valid.

During the minirhizotron experiment we found some unique results that linked the treatment diameter class of fine roots with the depth in the soil profile and distance from the trunk. The Sandwich system had higher frequency of very fine roots (0.2-0.4 mm) closer and farthest from the trunk, as well as deeper in the soil profile when compared with mulch. The reason of this finding is not clear and more research should be done on the subject.

As part of the OFMS evaluation we also measured the performance of three rootstocks (the dwarfing M.9 NAKB 337, the semi-dwarfing M.9 RN 29, and the semi-vigorous Supporter 4) to the different conditions created.

The OFMS treatments did not have an effect on tree growth, but nitrogen concentration of leaves was lowest in sandwich and flame. This suggests that the growing conditions were still sufficient but should still be monitored because the values were in the lowest acceptable range.

As expected, trees on Supporter 4 rootstock were most vigorous.

There was an interaction between treatments and rootstocks regarding the crop yield with M.9 RN 29 having the highest yield and yield efficiency per tree in flame and sandwich while no differences were noticed between the rootstocks in mulch despite its better growing conditions. This suggests that M.9 RN 29 is a rootstock that is better adapted to the more stressful conditions imposed by sandwich and flame treatments (lower SOM, N and in case of the sandwich vegetated area less water content). This is probably due to RN 29 being slightly more vigorous than NAKB 337 and more precocious than Supporter 4. It could also depend on its higher efficiency in nutrient and water absorption.

When considering the values per hectare and especially the cumulative yield, the flame treatment cropped least with no differences between the rootstocks. Mulch and sandwich treatments had similar cumulative production per hectare with Supporter 4 having the lowest values with no differences between the other two rootstocks.

The low production per hectare in FL, despite its higher "yield efficiency" per tree, and the low level of nitrogen in the leaves, suggests that this OFMS could not be sufficient anymore without implementation of fertilization. This is interesting since this system is equivalent to conventional orchards where a weed free zone is maintained with herbicides.

Implementation of each of these OFMS is quite different and should be considered during the selection and implementation for the growers.

The flame system presents high risk of fires, damage to the lowest branches due to heat convection, and requires specialized equipment. It is however, relatively inexpensive to maintain ($218). In my opinion, this treatment is not particularly desirable to organic growers.

The mulch is expensive ($788), difficult to apply, requires multiple redressing to maintain adequate thickness, subject to rodent damage and wild fires during the summer. In my opinion this treatment is slightly more desirable to organic growers than flame. More research should be done on the kind of mulching material to use, in relation to SOM and soil food web.

The sandwich system is easy to implement, it does not damage tree trunks, it is less expensive to manage ($91), and it requires only an easily modified notch disk tiller. The drawback of this system is that vegetation competes with tree growth and soils are lower in SOM and N concentration than mulch. Therefore, irrigation and soil fertility must be monitored. Also the ideal width of the tilled strip requires more research for various soil types.

Overall, the sandwich system coupled with the M.9 RN 29 rootstock appears to be a suitable choice for growers that want to grow Pacific Gala under organic protocol in Michigan and similar climates. More research is still necessary, especially to confirm these results in a longer term study and under commercial orchard operations.

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