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Organic matter amendments and their potential benefits to modern orchards in the southeastern United States

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Abstract

Commercial southeastern fruit orchards follow management practices which are often not conducive for organic matter (OM) to develop or persist. Soil OM is known to improve soil quality and health, but limited research has explored the ramifications of increasing OM using various amendments in the context of southeastern orchards. Potential changes to soil and plant nutrient and water status, horticultural performance, and possible biological interactions are reviewed while possible sources of regional OM and needs for potential research are discussed.

Improving agricultural soils through organic matter (OM) amendments such as compost, mulch, cover crops, or animal manure is uncommon in modern intensive southeastern orchards. While the philosophy and practices of the Green Revolution brought greater food production and food security worldwide, they fundamentally stressed that yields can be improved through the addition of agrochemicals, such as synthetic fertilizers for nutrient deficiencies or herbicides for competitive weeds. The modern fruit tree industry generally follows a familiar list of intensive agriculture practices typically used in commercial, non-organic farms. Growers focus primarily upon maximizing yields in monoculture settings and rely on external or auxiliary inputs such as chemical fertilizers and irrigation along with heavy machinery to reach production goals. However, undesirable environmental consequences including frequent soil disturbance, soil compaction, and reduced biodiversity often occur (Granatstein 2021). By using intensive methods that have been profitable to growers, the southeastern states of Georgia and South Carolina became well known for fresh market peach (*Prunus persica* L. Batsch) production. However, there are increasing ecological concerns from historic and current management in this important fruit growing region. For example, intensive management practices which remove soil cover and compact the soil can lead to high soil erosion rates (Figure 1) and future production is jeopardized by a changing climate, decreasing soil quality, increasing fertilizer costs, and general ecological imbalance – such as invasive pests or acquired resistance to biocides. One possible tool for growers to counter future challenges and improve the orchard ecosystem is the addition of OM, although the best methods of OM generation, application, retention, and researching the numerous ways OM can influence the orchard system are required prior to large-scale grower adoption.

Historical use of OM amendments in orchard management

Labeled “the life of the soil” (McWhorter et

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Figure 1. One of the authors stands in 0.5 m deep gully created by recent erosion in a 4-year-old peach orchard with little to no soil cover.

al. 1945), OM improves the physical, chemical, and biological functions of the soil (Mia et al. 2020; Forge et al. 2015), and the benefit of OM to soil health and crop production have been identified by agriculturalists for centuries (Reganold et al. 2001; Diacono and Montemurro 2011; Paine and Harrison 1993). Maintaining soil cover to protect or generate OM using intercrops or cover crops has also long been utilized worldwide (Paine and Harrison 1993), but there has been a shifting mentality regarding orchard floor management and use of OM over the past century. Before growers shifted to using synthetic fertilizers such as ammonium nitrate after WWII, management practices of soil coverage (cover crops), and reduced tillage, were common practices in fruit orchards (Murneek 1945; McWhorter et al. 1945). Furthermore, increased cropping diversity along with livestock integration was practiced. For example, a USDA publication by Waite (1903) reported peach growers planted various region-specific annual crops to maintain soil cover between tree rows. Planted crops included annual vegetable, grain, or leguminous crops which did not interfere with the cultivation timing for peach production and generated additional income either as nurse crops or used entirely to produce OM for the orchard soil. However, the intercropping benefit was understood to be profitable only during the years of orchard establishment as older trees would create too much shade (McWhorter et al. 1945). Adding OM through additional crops, cover crops, compost, or manure became uncommon once growers began using synthetic fertilizers, although additions of manure along with cover cropping are occasionally practiced during orchard establishment in the southeast today (Figure 2). Although OM has been consid-

Figure 2. Various cover crops such as rye grass and crimson clover could add organic matter and nutrients between rows of young trees but are not often planted in older orchards for numerous reasons including shade, competition for water and nutrients, and harboring insects which can damage fruit.

ered important for generations prior, research is only beginning to reveal the complexity of adding OM as part of southeastern orchard management.

Current soil management in southeastern orchards

Many southeastern orchards are grown on soils which are classified as Ultisols, which often have low OM from prior land use and the continuous weathering of minerals as a consequence of the humid and warm climate, and could potentially benefit by increasing OM (Wells 2011; Neilsen et al. 2014). The warm and humid climate can also reduce soil aggregate stability (Conant et al. 2011), making both accumulation and retention of OM challenging. The standard practice to maintain bare soil beneath trees with a sod strip in the alleyway to minimize water and nutrient competition from weeds (Merwin et al. 1994), and for frost protection (Perry 1998) does little to generate or retain OM. Common current management practices which maintain an absence of soil cover by mulch or plant residue within the tree rows also incentivize the reduction of OM content overtime (Merwin et al. 1994; Laird and Chang, 2013; Zhang et al. 2018), and repeated herbicide spray and residue often enter waterways or persist in the orchard (Merwin et al. 1994; Qiao et al. 2020). Furthermore, high frequency of tree replanting, which often includes tillage, increases soil compaction and soil erosion (Novara et al. 2021), and reduces stable soil aggregates (Kalia and Gosal 2011; Keesstra et al. 2016). As a result, current management practices and the intensification of orchards focus primarily on plant yield to maximize immediate profit rather than improving the agroecological environment and orchard sustainability (Giacalone et al.

2021; Granatstein 2021), and create an unbalanced ecosystem which increase weeds, insect pests, parasitic nematodes, and diseases (Granatstein 2021; Landi et al. 2022; Tworkoski and Glenn 2008).

Despite historical use of cover crops and manures to improve OM and soil qualities, orchard floor management practices using various amendments have not been extensively studied in the southeast (Jones et al. 2020). There are examples of small acreage orchards in the region which add OM to trees or shrubs, such as blueberries, from mow and blow methods or by directly adding organic materials within the planting rows, but larger acreage growers do not grow on-site biomass. Larger growers already face numerous economic challenges including increasing costs and wages for seasonal workers, and despite some cover cropping during orchard establishment, the vast majority of planting locations are maintained with wide herbicide strips and a sod middle. Thus, hesitation to change management practices is ultimately driven by economics, as OM generated from living cover crops within the orchard can be competition to applied nutrients and irrigation, while acquisition of OM from outside the farm can be expensive, inaccessible, or perceived as a risk to food safety or efficient nutrient management (Khalsa and Brown 2017; Mia et al. 2020).

Effect of OM amendments on orchard soil health and tree health

Despite grower hesitation and difficulty of shifting current orchard floor management practices, there is considerable research interest in improving or maintaining orchard soils using OM for future fruit production. The challenge for growers and researchers is to identify best practices for long-term OM use and to accurately predict the influence various amendments may have in southeastern orchards. Considering OM can be added to the soil through living covers, such as cover crops, or non-living covers such as mulches, amendments can change the orchard soil environment differently. Currently, research in other locations can provide some evidence of how OM could improve soil health and the physical, chemical and biological fractions of the soil in the southeast. All three fractions of the soil interact with one another, which often doesn't allow a single-variable explanation after adding OM. For example, adding OM can increase the number of tree roots due to biological or chemical changes in the soil (Baldi et al. 2010a), and as such, the soil physical structure for macrofauna, water infiltration, and aeration may change (Sofo et al. 2020). Additionally, the use of cover crop biomass can generate OM through root decomposition and surface mulch can protect the soil surface. Cover crops in apple (*Malus domestica Borkh.*) and nectarine (*Prunus persica var. nucipersica*) orchards have been shown to improve soil quality and can maintain or enhance fruit production (Demir et al. 2019; Sánchez et al. 2007; Reganold et al. 2001). Cover crops are often used in young orchards, although they are maintained away from the rootzone to avoid water and nutrient competition with the trees, which could potentially reduce tree size and yield (Giacalone et al. 2021; Novara et al. 2021; Tworkoski and Glenn 2008; Glenn and Welker 1989). However, growing cover crops to generate OM in mature, commercial orchards in the southeastern U.S. is uncommon as the predominant open vase system limits the amount of light interception within rows and they can harbor insect pests (Meyer et al. 1992; Shane et al. 2010). Several studies compared different living ground covers in southeastern orchards nearly three decades ago and concluded that nimblewill (*Muhlenbergia schreberi J.F. Gmel.*) was the least competitive option for tree performance and root growth to maintain soil coverage and reduce erosion, while not encouraging orchard insect pests compared to bare soil (Parker and Meyer 1996; Meyer et al. 1992). Despite the conclusions of the studies, few growers adopted the use of the species in mature orchards. Nonetheless, opportunities to understand best practices with soil coverage exist in the southeast region as ecosystems functions such as water infiltration and retention (Lepsch et al. 2019; Oliveira and Merwin 2001), prevention of runoff and soil erosion (Keesstra et al. 2016), or nutrient immobilization, mobilization, and retention (Cui et al. 2020; Culumber et al. 2019), can all be improved compared to standard practice when using alternative groundcover management (Demestihas et al. 2017).

The chemical fraction of the soil also changes following OM increase in the soil. After many years of synthetic fertilizer use in degraded soils, the natural function of nutrient acquisition by trees can become impaired, requiring more fertilizer inputs to maintain historical yields (Montanaro et al. 2017). Although maintaining high yields is seemingly possible with increased external inputs, intensive practices which reduce OM rather than maintain and restore soil quality can partially explain the decrease of micronutrients in harvested crops (Montgomery et al. 2022). Nitrogen (N) is considered one of the most important nutrients to manage for desired yield and fruit quality (Carranca et al. 2018). Applications of OM can provide sufficient N without accumulating in the soil (Baldi et al. 2010b; Toselli et al. 2019), but availability can be delayed or limited due to immobilization from high C:N ratios and incomplete decomposition (Diacono and Montemurro 2011; Hoagland et al. 2008). A review of long-term fertility studies suggests increasing OM improves soil cation exchange capacity, improving plant acquisition of potassium (K) and phosphorus (P) from the soil (Diacono and Montemurro 2011). An initial increase of available K in the soil was observed after repeated mulch applications to an apple orchard while soil nitrate, P, calcium, and manganese were higher after 10 years compared to bare soil (Atucha et al. 2011). Soils in replant orchards often have elevated (toxic) levels of elements, such as copper and zinc from previous pesticide use, and increasing OM by adding compost or manure can reduce the bioavailability of harmful compounds (Centofanti et al. 2016; Gasparatos et al. 2011).

Southeastern orchards have a higher incidence of pests and diseases compared to other growing regions due to hot and humid conditions (Jones et al. 2020). Soils which receive fewer pesticides, herbicides and synthetic fertilizers often have greater diversity, abundance, and activity of biological life, including species of arbuscular mycorrhizae fungi (AMF) (Turrini et al. 2017), and association of orchard tree roots with AMF can increase available cations, micronutrients, and partially alleviate orchard replant disease (Lǚ et al. 2019). A study in a sub-tropical orchard in China showed that OM development under cover cropping after AMF inoculation improved P acquisition and soil qualities including pH and bacterial diversity and richness (Cui et al. 2015). Although many orchard trees are known to associate with AMF, there is a need to understand nutrient acquisition and retention in different types of southeastern soils improved with OM and their associated AMF partnership, which could reduce or eliminate the need for frequent applications of synthetic fertilizers.

Additionally, there is evidence that changing the biological fraction of the soil by increasing soil microbiology after adding OM can be antagonistic to pathogens and may improve plant health (Downer and Faber 2019; Granatstein 2021; Sun et al. 2016) but methods to predict disease suppression using OM remain undeveloped (Hadar 2011). A growing concern among growers regarding long-term sustainability of the southeastern peach industry is Armillaria root rot (*Desarmillaria caespitosa*), which is a common pathogen on replant sites (Scroggs 2022). In an Armillaria mellea study in California, tree survival increased after adding OM to planting holes (Downer and Faber 2019) and, while southeastern growers limited tree mortality from Armillaria by planting trees on soil berms (Miller et al. 2020), there is an opportunity to further study how improving the soil ecosystem after adding OM may mitigate the incidence of tree decline and death.

Effect of OM amendments on tree water and nutrient status

In addition to altering soil biology and nutrients, adding OM can improve tree water and nutrient status. Available soil moisture can increase following the use of mulch (Merwin et al. 1994) and, consequently, tree water status (Lordan et al. 2015) and irrigation use efficiency (Liao et al. 2021). In locations with limited water or where growers utilize deficit irrigation strategies, mulch can increase water use efficiency (Gholami and Zahedi 2019) while applications of OM to the soil surface may increase tree growth (Smith et al. 2000) and resilience to drought (Lepsch et al. 2019). There are some exceptions regarding the immediate benefit of adding OM to orchards depending on the type of amendment. For example, adding straw mulch to the soil surface may increase water repellency (García-Moreno et al. 2013) or wood chips may absorb much of the irrigation water or create a barrier which prevents water movement into existing soil (Gebretsadikan et al. 2023). However, increasing OM which buffers dry periods and reduces water stress may improve nutrient acquisition during the first several years of growth and help future production of peaches in the southeast, as growers often do not supply young, nonbearing orchards with irrigation water (Casamali et al 2021). Moreover, different methods of adding OM, such as incorporation and mixing with native soil prior to planting, may prove superior to surface application, and require further study regarding moisture availability.

Regarding nutrient status, most orchards are monitored using foliar tissue analysis. Several studies reported that adding OM amendments can provide similar leaf nutrient status compared to conventional management (Baldi et al. 2010b; Khalsa et al. 2022; Melo et al. 2016), while other studies showed increasing nutrients after several years of OM application, including iron in pear (Sorrenti et al. 2012), and both K and P in apple (Neilsen et al. 2014). Perennial plants naturally recycle many nutrients annually through resorption as well as reacquisition from decomposing leaves, fruit and pruning wood from the soil surface (El-Jendoubi et al. 2013). Understanding how OM applications alter nutrient resorption and reserves within perennial tissues, such as roots and shoots, may help reduce required application amounts and optimize fertilization practices to prevent the loss of applied nutrients to the larger environment (Baldi et al. 2021; Casamali et al. 2021).

Effect of OM amendments on tree growth, yield, and fruit qualities

Increasing soil OM may often buffer soil temperature and reduce soil water evaporation, both of which can enhance water availability over time and reduce tree water stress (Atucha et al. 2011; Granatstein et al. 2014; Smith et al. 2000). Improved tree water status after adding mulch often increases tree trunk cross sectional area (TCSA) and can increase yield in numerous fruit trees and growing regions including both apple and pear in the Pacific Northwest (Granatstein et al. 2010; Granatstein et al. 2014), apple in New York (Atucha et al. 2011), as well as peach (Lawrence and Melgar 2023) and pecan (Carya illinoinensis (Wangenh.) K. Koch) in the southeast (Foshee et al. 1996; Smith et al. 2000). Although TCSA can be positively correlated with cumulative yield in apples (Xu et al. 2021), yield also depends on tree density (Marini and Sowers 2000) and the economic influence of OM on various planting densities over the orchard lifespan have not been explored in the southeast. From a grower perspective, OM amendments which do not quickly result in a return on investment could be a major obstacle for adoption. However, if the average tree lifetime increases by only several years following the use of OM amendments, greater cumulative yields could justify OM amendment use. Future studies on the interaction of soil health with tree and fruit health could provide significant insights on the effect of OM additions on fruit marketability and orchard lifespan.

Regarding fruit, adding various OM amendments may increase yield (Di Prima et al. 2018; Lepsch et al. 2019; Baldi et al. 2010b; Gholami and Zahedi 2019) or have similar fruit yield over time compared to conventional management (Atucha et al. 2011; Carey et al. 2009; Neilsen et al. 2014), but this is largely dependent on the fruit species, age of tree, and location of study. Fruit quality traits such as color or soluble solid concentration could improve as in sweet cherry (Prunus avium L.; Gebretsadikan et al. 2023) or not substantially change compared to conventional management, as observed with apples (Thompson and Peck 2017). One caution of growers to using OM amendments is the inability to easily quantify the immediate or slow release of nutrients during specific stages of plant growth, or from one season to another. Improper nutrient management may lead to excessive N release from amendments at the wrong time of year, which can negatively affect fruit quality by delaying maturity or reducing color (Toselli et al. 2019; Granatstein and Sánchez 2009). Due to the warm and humid climate of the southeast, decomposition of OM can be rapid, and additional research is needed to avoid nutrient imbalances.

Figure 3. Adding composted organic matter and covering the soil with mulch (left row) can improve tree size during orchard establishment in the southeast.

OM amendment sources and those specific to the southeast

One the easiest ways to generate OM in the southeast is to grow biomass in row middles or beneath trees during the offseason, when nutrient or water competition is of least concern and fruit are not present on the trees. Exploring different ground cover species and mixtures of species along with timing of seasonal growth, interactions with existing trees, and best termination methods need to be explored. Growers in the region already return pruning wood to the system but it is often chipped and returned within the row middles instead of returning them to the tree rows. Increasing OM in orchards can be achieved using on-farm practices, such as integration of cover crops or the practice of mow and blow from row middles to tree rows, but since few to no growers attempt these practices following orchard establishment and little research in the region has explored best practices, other external OM sources may be applicable. Various manure and mulch products are accessible to growers through waste programs of nearby municipalities and animal farms. The southeast is the most productive region of the United States for poultry broilers (USDA 2018) and factory farms produce large quantities of broiler bedding (manure with wood shavings). Bedding can be applied to pecan orchards as a source of N and organic matter (Wells 2011), but similar to other manure-based amendments, poultry litter can increase P and salts in the soil (Diacono and Montemurro 2011) or result in high-nutrient runoff pollution following application (Preusch and Tworkoski 2003). Alternatively, vast acres of pine-species plantations exist in the southeast (Paudel and Dwivedi 2021) and byproducts of the timber industry, including bark mulch and pine straw could potentially be used as a source of OM, as they are already used to improve blueberry production (Krewer et al. 2009). Regardless of the source, fully composted soil amendments are preferred as amendments (Baldi et al. 2010b), as stable manure-based or mulch products have the potential to supply large quantities of OM for agricultural use. The amendment quality (including pH and C:N ratio) determines N immobilization when applied (Khalsa et al. 2022; Lazicki et al. 2020) as does amendment storage prior to application, and the timing of application (Wells 2011; Preusch and Tworkoski 2003). Many other products in the region can probably be used to provide OM to growers, but can be expensive if acquired far from orchards (Mia et al. 2020). Opportunities do exist for regional industries to close green waste streams and create reliable OM products, and municipalities can contribute to green waste capture and offer growers a cost reduction for these inputs, but program and grower success will depend on the return on investment from these alternative management practices to yield and product sales.

Outlook of using OM amendments in the southeast

Although potential benefits of adding OM to orchards are possible, altering future orchard management will require changing grower perception, and no social data is available regarding possible adoption of OM amendments in the southeastern region. A survey in California revealed growers were concerned about food safety issues more so than the cost and logistics when using OM amendments (Khalsa and Brown 2017) while in the Netherlands, a similar study on OM perception revealed that many growers realize the benefit of increasing soil OM but believe increasing OM is beyond their control (Hijbeek et al. 2018). Orchard management is multifaceted, undoubtably determined by cultural and economic decisions, but growers are looking for options to sustain production while reducing both production and environmental costs. There are large research and knowledge gaps regarding how OM would influence orchard pathogens, and whether amendments could reduce fruit pathogens such as bacterial spot, bacterial canker or replace practices such as soil fumigation require further research. Continued increase of synthetic fertilizer prices, currently on the rise since 2020 (Schnitkey et al. 2022), may encourage the adoption of using locally available compost as a fertilizer source, especially if growers have evidence of similar yields and tree growth overtime while using the products.

While research on a topic as complicated as soil health can be slow, and labeling management practices which are unsustainable are more easily done than identifying those which are sustainable, studies are beginning to uncover agroecological benefits for growers. The southeast region appears behind other regions of the country and of the world which are actively engaged in research and government programs to identify sustainable options for fruit tree growers in their respective areas. From the little research performed in the southeast, the role of OM as a tool is promising. Scientists and growers moving forward should consider the many factors specific to an orchard prior to encouraging the use of OM or applying a specific form of OM. Comparing orchard systems, rootstocks, planting densities, along with nutrient, water, and pathogen interactions with OM may need to occur prior to grower adoption. Similarly, understanding orchard-specific factors which could include anything from climate, history of the orchard, tree species and ultimate tree age, soil type, and production goals will need to be taken into account. The immediate and derivative effects of adding OM to current orchard systems may be complex, but a renewed focus and identification of how to use OM in the region may lead to viable solutions and ensure production despite future economic and environmental challenges.

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References Cited

Atucha A, Merwin IA, Brown MG. 2011. Long-term effects of four groundcover management systems in an apple orchard. HortScience. 46(8):1176-1183. https://doi.org/10.21273/HORTSCI.46.8.1176.

Baldi E, Quartieri M, Sorrenti G, Toselli M. 2021. Evaluation of nutrients removed and recycled in a commercial peach orchard over a 14-years-production cycle. Italus Hortus. 28:1-12. https://doi.org/10.26353/j.itahort/2021.3.0112.

Baldi E, Toselli M, Eissenstat DM, Marangoni B. 2010a. Organic fertilization leads to increased peach root production and lifespan. Tree Physiol. 30(11):1373-1382. https://doi.org/10.1093/treephys/tpq078.

Baldi E., Toselli M, Marcolini G, Quartieri M, Cirillo E, Innocenti A, Marangoni B. 2010b. Compost can successfully replace mineral fertilizers in the nutrient management of commercial peach orchard. Soil Use Manag. 26(3):346-353. https://doi.org/10.1111/j.1475-2743.2010.00286.x.

Carey PL, Benge JR, Haynes RJ. 2009. Comparison of soil quality and nutrient budgets between organic and conventional kiwifruit orchards. Agric Ecosyst Environ. 132(1-2):7-15. https://doi.org/10.1016/j.agee.2009.02.017.

Carranca C, Brunetto G, Tagliavini M. 2018. Nitrogen nutrition of fruit trees to reconcile productivity and environmental concerns. Plants. 7(1):4. https://doi.org/10.3390/plants7010004.

Casamali B, van Iersel MW, Chavez DJ. 2021. Nitrogen partitioning in young "Julyprince" peach trees grown with different irrigation and fertilization practices in the southeastern united states. Agronomy. 11(2):350. https://doi.org/10.3390/agronomy11020350.

Centofanti T, McConnell LL, Chaney RL, Beyer WN, Andrade NA, Hapeman CJ, Torrents A, Nguyen A, Anderson MO, Novak JM, Jackson D. 2016. Organic amendments for risk mitigation of organochlorine pesticide residues in old orchard soils. Environ Pollut. 210:182-191. https://doi.org/10.1016/j.envpol.2015.11.039.

Conant RT, Ryan MG, Ågren GI, Birge HE, Davidson EA, Eliasson PE, Evans SE, Frey SD, Giardina CP, Hopkins FM, Hyvönen R. 2011. Temperature and soil organic matter decomposition rates–synthesis of current knowledge and a way forward. Glob Chang Biol. 17(11):3392-3404. https://doi.org/10.1111/j.1365-2486.2011.02496.x.

Cui H, Zhou Y, Gu Z, Zhu H, Fu S, Yao Q. 2015. The combined effects of cover crops and symbiotic microbes on phosphatase gene and organic phosphorus hydrolysis in subtropical orchard soils. Soil Biol Biochem. 82:119-126. https://doi.org/10.1016/j.soilbio.2015.01.003.

Cui M, Zeng L, Qin W, Feng J. 2020. Measures for reducing nitrate leaching in orchards: A review. Environ Pollut. 263:114553. https://doi.org/10.1016/j.envpol.2020.114553.

Culumber CM, Reeve JR, Black BL, Ransom CV, Alston DG. 2019. Organic orchard floor management impact on soil quality indicators: nutrient fluxes, microbial biomass and activity. Nutr Cycl Agroecosyst. 115:101-115. https://doi.org/10.1007/s10705-019-10007-2.

Demestihas C, Plénet D, Génard M, Raynal C, Lescourret F. 2017. Ecosystem services in orchards. A review. Agron Sustain Dev. 37:1-21. https://doi.org/10.1007/s13593-017-0422-1.

Demir Z, Tursun N, Işık D. 2019. Effects of different cover crops on soil quality parameters and yield in an apricot orchard. Int J Agric Biol. 21(2):399-408. https://doi.org/ 10.17957/IJAB/15.0000.

Di Prima S, Rodrigo-Comino J, Novara A, Iovino M, Pirastru M, Keesstra S, Cerdà A. 2018. Soil physical quality of citrus orchards under tillage, herbicide, and organic managements. Pedosphere. 28(3):463-477.https://doi.org/10.1016/S1002-0160(18)60025-6.

Diacono M, Montemurro F. (2011). Long-Term Effects of Organic Amendments on Soil Fertility. In: Lichtfouse, E., Hamelin, M., Navarrete, M., Debaeke, P. (eds) Sustainable Agriculture Volume 2. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-0394-0_34.

Downer J, Faber B. 2019. Non-chemical control of Armillaria mellea infection of Prunus persica. J Plant Sci Phytopathol. 3:50-55. https://doi.org/10.29328/journal.jpsp.1001031.

El-Jendoubi H, Abadía J, Abadía A. 2013. Assessment of nutrient removal in bearing peach trees (Prunus persica L. Batsch) based on whole tree analysis. Plant Soil. 369:421-437. https://doi.org/10.1007/s11104-012-1556-1.

Forge, T, Neilsen G, Neilsen D, O'Gorman D, Hogue E, Angers D. 2015. Organic orchard soil management practices affect soil biology and organic matter. Acta Hortic. 1076:77-84. https://doi.org/10.17660/ActaHortic.2015.1076.8.

Foshee WG, Goff WD, Tilt KM, Williams JD, Bannon JS, Witt JB. 1996. Organic mulches increase growth of young pecan trees. HortScience. 31(5):811-812. https://doi.org/10.21273/HORTSCI.31.5.811.

García-Moreno J, Gordillo-Rivero ÁJ, Zavala LM, Jordán A, Pereira P. 2013. Mulch application in fruit orchards increases the persistence of soil water repellency during a 15-years period. Soil Tillage Res. 130:62-68. https://doi.org/10.1016/j.still.2013.02.004.

Gasparatos D, Roussos PA, Christofilopoulou E, Haidouti C. 2011. Comparative effects of organic and conventional apple orchard management on soil chemical properties and plant mineral content under Mediterranean climate conditions. Soil Sci Plant Nutr. 11(4):105-117. http://dx.doi.org/10.4067/S0718-95162011000400008.

Gebretsadikan T, Munro P, Forge TA, Jones MD, Nelson LM. 2023. Mulching improved soil fertility, plant growth and productivity, and postharvest deficit irrigation reduced water use in sweet cherry orchards in a semi-arid region. Arch Agron Soil Sci. 69(8):1419-1436. https://doi.org/10.1080/03650340.2022.2095621.

Gholami R, Zahedi SM. 2019. Reproductive behavior and water use efficiency of olive trees (Olea europaea L. cv Konservolia) under deficit irrigation and mulching. Erwerbs-Obstbau. 61(4):331–336. https://doi.org/ 10.1007/s10341-019-00435-3.

Giacalone G, Peano C, Isocrono D, Sottile F. 2021. Are cover crops affecting the quality and sustainability of fruit production? Agriculture. 11(12):1201. https://doi.org/10.3390/agriculture11121201.

Glenn DM, Welker WV. 1989. Cultural practices for enhanced growth of young peach trees. Am J Altern Agric. 4(1):8-11. https://doi.org/10.1017/S0889189300002563.

Granatstein D. 2021. Agroecology: a strategy for greater orchard sustainability. Acta Hortic. 1303:389-398. https://doi.org/ 10.17660/ActaHortic.2021.1303.54.

Granatstein D, Sánchez E. 2009. Research knowledge and needs for orchard floor management in organic tree fruit systems. Int J Fruit Sci. 9(3):257-281. https://doi.org/10.1080/15538360903245212.

Granatstein D, Andrews P, Groff A. 2014. Productivity, economics, and fruit and soil quality of weed management systems in commercial organic orchards in Washington State, USA. Org Agric. 4:197-207. https://doi.org/10.1007/s13165-014-0068-0.

Granatstein D, Wiman M, Kirby E, Mullinix K. 2010. Sustainability trade-offs in organic orchard floor management. Acta Hortic. 873:115-122.https://doi.org/ 10.17660/ActaHor-

tic.2010.873.11.
Hadar Y. 2011. Suppressive compost: when plant pathology met microbial ecology. Phytoparasitica, 39(4):311-314. https://doi.org/10.1007/s12600-011-0177-1.
Hijbeek R, Pronk AA, van Ittersum MK, ten Berge HFM, Bijttebier J, Verhagen A. 2018. What drives farmers to increase soil organic matter? Insights from the Netherlands. Soil Use Manag. 34(1):85-100. https://doi.org/10.1111/sum.12401.
Hoagland L, Carpenter-Boggs L, Granatstein D, Mazzola M, Smith J, Peryea F, Reganold JP. 2008. Orchard floor management effects on nitrogen fertility and soil biological activity in a newly established organic apple orchard. Biol Fertil Soils. 45:11-18. https://doi.org/10.1007/s00374-008-0304-4
Jones J, Savin MC, Rom CR, Gbur E. 2020. Soil microbial and nutrient responses over seven years of organic apple orchard maturation. Nutr Cycl Agroecosyst. 118:23-38. https://doi.org/10.1007/s10705-020-10080-y.
Kalia A, Gosal SK. 2011. Effect of pesticide application on soil microorganisms. Arch Agron Soil Sci. 57(6):569-596. https://doi.org/10.1080/03650341003787582.
Keesstra S, Pereira P, Novara A, Brevik EC, Azorin-Molina C, Parras-Alcántara L, Jordán A, Cerdà A. 2016. Effects of soil management techniques on soil water erosion in apricot orchards. Sci. Total Environ. 551:357-366. https://doi.org/10.1016/j.scitotenv.2016.01.182.
Khalsa SDS, Brown PH. 2017. Grower analysis of organic matter amendments in California orchards. J Environ Qual. 46(3):649-658.
Khalsa SDS, Hart SC, Brown PH. 2022. Nutrient dynamics from surface□applied organic matter amendments on no□till orchard soil. Soil Use Manag. 38(1):649-662.
Khalsa SDS, Rivers DJ, Holtz BA, Brown PH. 2022. Effects of organic matter amendments on soil nutrient availability and tree nutrient status in California almond. Acta Hortic. 1333:51-58.
Krewer G, Tertuliano M, Andersen P, Liburd O, Fonsah G, Serri H, Mullinix B. 2009. Effect of mulches on the establishment of organically grown blueberries in Georgia. Acta Hortic. 810:483-488.
Laird DA, Chang CW. 2013. Long-term impacts of residue harvesting on soil quality. Soil Tillage Res. 134:33-40.
Landi S, d'Errico G, Papini R, Cutino I, Simoncini S, Rocchini A, Brandi G, Rizzo R, Gugliuzza G, Germinara GS, Nucifora S. 2022. Impact of super-high density olive orchard management system on soil free-living and plant-parasitic nematodes in central and south Italy. Animals. 12(12):1551.
Lawrence BT, Melgar JC. 2023. Annual compost amendments can replace synthetic fertilizer, improve soil moisture, and ensure tree performance during peach orchard establishment in a humid subtropical climate. Front Plant Sci. 14:1172038. https://doi.org/10.3389/fpls.2023.1172038.
Lazicki P, Geisseler D, Lloyd M. 2020. Nitrogen mineralization from organic amendments is variable but predictable. J Environ Qual. 49(2):483-495. https://doi.org/10.1002/jeq2.20030.
Lepsch HC, Brown PH, Peterson CA, Gaudin AC, Khalsa SDS. 2019. Impact of organic matter amendments on soil and tree water status in a California orchard. Agric Water Manag. 222:204-212. https://doi.org/10.1016/j.agwat.2019.06.002.
Liao Y, Cao HX, Liu X, Li HT, Hu QY, Xue WK. 2021. By increasing infiltration and reducing evaporation, mulching can improve the soil water environment and apple yield of orchards in semiarid areas. Agric Water Manag. 253:106936. https://doi.org/10.1016/j.agwat.2021.106936.
Lordan J, Pascual M, Villar JM, Fonseca F, Papió J, Montilla V, Rufat J. 2015. Use of organic mulch to enhance water-use efficiency and peach production under limiting soil conditions in a three-year-old orchard. Span J Agric Res. 13(4):e0904. https://doi.org/10.5424/sjar/2015134-6694.
Lŭ LH, Zou YN, Wu QS. 2019. Mycorrhizas mitigate soil replant disease of peach through regulating root exudates, soil microbial population, and soil aggregate stability. Commun Soil Sci Plant Anal. 50(7):909-921. https://doi.org/10.1080/00103624.2019.1594882.
Marini RP, Sowers DS. 2000. Peach tree growth, yield, and profitability as influenced by tree form and tree density. HortScience. 35(5):837-842. https://doi.org/10.21273/HORTSCI.35.5.837.
McWhorter OT, Jackman ER, King A. 1945. Orchard soil covers. Oregon State College Ext Bul. 650.
Melo GWBD, Sete PB, Ambrosini VG, Freitas RF, Basso A, Brunetto G. 2016. Nutritional status, yield and composition of peach fruit subjected to the application of organic compost. Acta Sci Agron. 38:103-109. https://doi.org/10.4025/actasciagron.v38i1.25638.
Merwin IA, Stiles WC, van Es HM. 1994. Orchard groundcover management impacts on soil physical properties. J Am Soc Hortic Sci. 119(2):216-222. https://doi.org/10.21273/JASHS.119.2.216.

Meyer JR, Zehr EI, Meagher Jr RL, Salvo SK. 1992. Survival and growth of peach trees and pest populations in orchard plots managed with experimental ground covers. Agric Ecosyst Environ. 41(3-4):353-363. https://doi.org/10.1016/0167-8809(92)90121-Q.

Mia MJ, Massetani F, Murri G, Neri D. 2020. Sustainable alternatives to chemicals for weed control in the orchard–A review. Hortic Sci. 47(1):1-12. https://doi.org/10.17221/29/2019-HORTSCI.

Miller SB, Gasic K, Reighard GL, Henderson WG, Rollins PA, Vassalos M, Schnabel G. 2020. Preventative root-collar excavation reduces peach tree mortality caused by Armillaria root rot on replant sites. Plant Dis. 104(5):1274-1279. https://doi.org/10.1094/PDIS-09-19-1831-RE.

Montanaro G, Xiloyannis C, Nuzzo V, Dichio B. 2017. Orchard management, soil organic carbon and ecosystem services in Mediterranean fruit tree crops. Sci Hortic. 217:92-101. https://doi.org/10.1016/j.scienta.2017.01.012.

Montgomery DR, Biklé A, Archuleta R, Brown P, Jordan J. 2022. Soil health and nutrient density: preliminary comparison of regenerative and conventional farming. PeerJ. 10:e12848. https://doi.org/10.7717/peerj.12848.

Murneek AE. 1945. Nitrogen fertilizers for fruit trees. University of Missouri. Agr. Expt. Sta. Bul. 489.

Neilsen G, Forge T, Angers D, Neilsen D, Hogue E. 2014. Suitable orchard floor management strategies in organic apple orchards that augment soil organic matter and maintain tree performance. Plant Soil. 378:325-335. https://doi.org/10.1007/s11104-014-2034-8.

Novara A, Cerda A, Barone E, Gristina L. 2021. Cover crop management and water conservation in vineyard and olive orchards. Soil Tillage Res. 208:104896. https://doi.org/10.1016/j.still.2020.104896.

Oliveira MT, Merwin IA. 2001. Soil physical conditions in a New York orchard after eight years under different groundcover management systems. Plant Soil. 234:233-237. https://doi.org/10.1023/A:1017992810626.

Paine LK, Harrison H. 1993. The historical roots of living mulch and related practices. HortTechnology. 3(2):137-143. https://doi.org/10.21273/HORTTECH.3.2.137.

Parker ML, Meyer JR. 1996. Peach tree vegetative and root growth respond to orchard floor management. HortScience. 31(3):330-333. https://doi.org/10.21273/HORTSCI.31.3.330.

Paudel K, Dwivedi P. 2021. Economics of southern pines with and without payments for environmental amenities in the US south. Front For Glob Change. 4:610106. https://doi.org/10.3389/ffgc.2021.610106.

Perry KB. 1998. Basics of frost and freeze protection for horticultural crops. HortTechnology. 8(1):10-15. https://doi.org/10.21273/HORTTECH.8.1.10.

Preusch PL, Tworkoski TJ. 2003. Nitrogen and phosphorus availability and weed suppression from composted poultry litter applied as mulch in a peach orchard. HortScience. 38(6):1108-1111. https://doi.org/10.21273/HORTSCI.38.6.1108.

Qiao C, Wang C, Pang R, Tian F, Han L, Guo L, Luo J, Li J, Pang T, Xie H, Fang J. 2020. Environmental behavior and influencing factors of glyphosate in peach orchard ecosystem. Ecotoxicol Environ Saf. 206:111209. https://doi.org/10.1016/j.ecoenv.2020.111209.

Reganold JP, Glover JD, Andrews PK, Hinman HR. 2001. Sustainability of three apple production systems. Nature. 410(6831):926-930. https://doi.org/10.1038/35073574.

Sánchez EE, Giayetto A, Cichón L, Fernández D, Aruani MC, Curetti M. 2007. Cover crops influence soil properties and tree performance in an organic apple (Malus domestica Borkh) orchard in northern Patagonia. Plant Soil. 292:193-203. https://doi.org/10.1007/s11104-007-9215-7.

Schnitkey G, Paulson N, Zulauf C, Swanson K, Colussi J, Baltz J. 2022. Nitrogen fertilizer prices and supply in light of the Ukraine-Russia conflict. farmdoc daily (12):45, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, April 5, 2022.

Scroggs C. 2022. Mechanizing the removal of soil between peach trees planted on berms. Clemson Univ. Masters Thesis. 3845.

Shane B, Epstein D, Wise J. 2010. Managing western flower thrips in peaches and nectarines. Michigan State University Extension, Department of Entomology. 15 Oct, 2022. <https://www.canr.msu.edu/news/managing_western_flower_thrips_in_peaches_and_nectarines>.

Smith MW, Carroll BL, Cheary BS. 2000. Mulch improves pecan tree growth during orchard establishment. HortScience. 35(2):192-195. https://doi.org/10.21273/HORTSCI.35.2.192.

Sofo A, Mininni AN, Ricciuti P. 2020. Soil macrofauna: A key factor for increasing soil fertility and promoting sustainable soil use in fruit orchard agrosystems. Agronomy. 10(4):456. https://doi.org/10.3390/agronomy10040456.

Sorrenti G, Toselli M, Marangoni B. 2012. Use of compost to manage Fe nutrition of pear trees grown in calcareous soil. Sci Hortic. 136:87-94.

https://doi.org/10.1016/j.scienta.2011.12.033.

Sun R, Dsouza M, Gilbert JA, Guo X, Wang D, Guo Z, Ni Y, Chu H. 2016. Fungal community composition in soils subjected to long□term chemical fertilization is most influenced by the type of organic matter. Environ Microbiol. 18(12):5137-5150. https://doi.org/10.1111/1462-2920.13512.

Thompson AA, Peck GM. 2017. Alternative fertility management for establishing new apple orchards in the Mid-Atlantic. HortScience. 52(9):1313-1319. https://doi.org/10.21273/HORTSCI11916-17.

Toselli M, Baldi E, Cavani L, Mazzon M, Quartieri, M, Sorrenti G, Marzadori C. 2019. Soil-plant nitrogen pools in nectarine orchard in response to long-term compost application. Sci Total Environ. 671:10-18. https://doi.org/10.1016/j.scitotenv.2019.03.241.

Turrini A, Agnolucci M, Palla M, Tomé E, Tagliavini M, Scandellari F, Giovannetti M. 2017. Species diversity and community composition of native arbuscular mycorrhizal fungi in apple roots are affected by site and orchard management. Appl Soil Ecol. 116:42-54. https://doi.org/10.1016/j.apsoil.2017.03.016.

Tworkoski TJ, Glenn DM. 2008. Orchard floor management systems, p. 332-351. In: D.R. Layne and D. Bassi (eds.). The Peach: Botany, production and uses. CABI, Wallingford.

USDA. 2018. Broilers: Inventory by State. <https://www.nass.usda.gov/Charts_and_Maps/Poultry/brlmap.php>

Waite MB. 1903. Cultivation and fertilization of peach orchards. US Department of Agriculture.

Wells ML. 2011. Nitrogen availability in pecan orchard soil: implications for pecan fertilizer management. HortScience. 46(9):1294-1297. https://doi.org/10.21273/HORTSCI.46.9.1294.

Xu H, Ediger D, Singh A, Pagliocchini C. 2021. Rootstock–scion hydraulic balance influenced scion vigor and yield efficiency of Malus domestica cv. Honeycrisp on eight rootstocks. Horticulturae. 7(5):99. https://doi.org/10.3390/horticulturae7050099.

Zhang YL, Wang L, Yuan Y, Xu J, Tu C, Fisk C, Zhang W, Chen X, Ritchie D, Hu S. 2018. Irrigation and weed control alter soil microbiology and nutrient availability in North Carolina Sandhill peach orchards. Sci Total Environ. 615:517-525. https://doi.org/10.1016/j.scitotenv.2017.09.265.