Organic Fertilization of Fruit Trees as an Alternative to Mineral Fertilizers: Effect on Plant Growth, Yield and Fruit Quality

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Organic fertilization of fruit trees as an alternative to mineral fertilizers: effect on plant growth, yield and fruit quality

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Abstract

Soil is an essential non-renewable resource for plant growth and yield; it undergoes rapid degradation rates in intensive agricultural areas but it has extremely slow formation and regeneration processes. Consequently, soils from agroecosystems are severely depleted of their nutrients and organic matter pools. The excessive use of mineral fertilizers to supply tree with macro (N, P, K, Ca, Mg, S) and micro nutrients (Cu, Fe, Mn, Zn, B, Cl) may raise a concern since they may contain potentially toxic elements, are often expensive and can have negative impact on the environment. Furthermore, the production of urban and industrial organic wastes is increasing worldwide and environmental friendly strategies for their disposal, as for example compost production, have been developed. Consequently, the necessity to reconcile economic and ecological issues has led to the increase of the use of recycled waste organic fertilizers that can synchronize plant need with nutrient release and, at the same time, improve soil fertility.

The enhancement of soil organic matter provides storage of nutrients and water, stimulates soil biological activity and improves C sequestration. Several authors reported beneficial effects of organic matter on orchard soil quality and tree performance.

In the present chapter, we will discuss the use of organic matter as an alternative to mineral fertilizers evaluating the effect on plant growth, nutritional status and yield performances.

Key words: soil organic matter, amendments, fruit quality, plant nutritional status, biofertilizers

Contents

1. Introduction

Soil is defined as a component of terrestrial ecosystems and constitutes the outer layer of the Earth's crust; it is a living medium with an ecological role and functions linked to human activity (Council of Europe, 2003). Soil is essential to humankind since it supplies food, renewable energy and raw materials to animals and humans. In addition, soil provides biomass, is a reservoir of groundwater and a biological habitat for many plant and animal organisms (Council of Europe, 2003). However, despite its great importance, soil is rapidly deteriorating because of human activities (cities expansion, mining, intensive farming techniques) and natural causes (erosion, salinization, acidification). Unfortunately, the reconstitution process for a soil is very slow and, depending on the nature of the degradation, the damage may also be irreversible.

Agriculture plays a central role in land degradation because of intensive farming systems and consequently soil fertility loss; the conventional agronomic techniques such as tillage (Angers et al. 1997) and long term use of chemical fertilizers (Kleineidam et al. 2010) can negatively affect soil biodiversity having negative effects on soil health and productivity. The decrease of soil organic matter (SOM) content is though one of the main process of soil deterioration (Diacono and Montemurro 2010).

2. Organic amendment

Soil organic matter includes organic residues deriving from animal and vegetal organisms in different stages of decomposition that cohabit in the soil and that are subjected to complex processes of mineralization and buildup of non-humic primary and humic secondary components. Organic matter has a fundamental role in defining soil quality since it improves soil chemical parameters (Scotti et al. 2013), structure and water holding capacity (Abiven et al. 2009), increases natural resistance to soil-borne pathogens (Bonanomi et al. 2010), reduces heavy metal toxicity (Park et al. 2011), and enhances microbial biodiversity (Forge et al. 2008). The main benefits and concerns related to organic amendment supply to soil are summarized in Table 1.

The application of organic amendments is a sustainable strategy to restore soil fertility as integration or replacement of chemical fertilizers. This practice dates back to thousands of years ago as the first proof of the use of organic amendments in agriculture is reported in China (Goss et al. 2013). Greeks and Romans used animal manure or human sewage to improve soil fertility and crop yield; moreover, they knew that wheat yield increased in fields previously cultivated with leguminous plants (Goss et al. 2013). At the end of the Medieval time, farmers understood the use of animal manure as a tool to replace the nutrients removed by crops (Gross et al. 2013). Starting from 1842, fertilizers were produced industrially and in the early 1950s there was a dramatic diffusion of nitrogen (N)-based fertilizers all over the world (Gross et al. 2013); however, in poor countries organic amendments are still nowadays the only form of organic fertilizers used.

The big challenge for a safe and sustainable use of organic matter is the choice of products with elevated quality standards able to satisfy soil and plant needs. The release of nutrients deriving from organic material mineralization at rates sufficient to meet crop needs with a minimal loss in the environment is an important component of soil quality for agro-ecosystems and an important issue to take into consideration when a fertilization plan is defined. Organic matter mineralization depends on several factors like soil biological diversity, soil redox status, environmental conditions and soil properties (Calderón et al. 2005; Gioacchini et al. 2007; Mohanty et al. 2011). In addition, the chemical composition of the organic material used has a basic influence on its mineralization timing. The carbon (C)/N ratio is considered a good parameter to predict organic C mineralization rate and the dynamics patterns of nutrient (mainly N) release (Parton et al. 2007; Masunga et al. 2016; Möller 2018). Organic substrates with C:N lower than 30 mineralize more rapidly than those with higher values (Cordovil et al. 2005; Masunga et al. 2016). This mechanism is related to the behavior of soil microorganisms since for their metabolism they require a C/N ratio ~25-30. Consequently, if organic fertilizers have a C/N ratio above this threshold, the microbial feeding rate, as well as the organic matter decomposition rate, rapidly decrease, allowing long-term C storage. However, in this case mineral N can be temporarily immobilized within microbial biomass, thus impairing plant growth and crop yields (Hodge et al. 2000).

The knowledge of C/N ratio provides good hint when preparing a fertilization plan since a proper mixture of matrices with different origin permits to obtain fertilizers with a different release of N suitable for different agronomic conditions and plant requirements.

Another important issue related to organic amendment supply is the relevant role that soil plays as a C source and reservoir, thus helping the mitigation of the climate change. Soils from agroecosystems are able to sequester high quantity of C, since CO_2 from the atmosphere is transferred into the soil through plant residues (Lal et al. 2015), consequently organic amendment soil incorporation actively contributes to SOC sequestration. Therefore, it is essential, for a sustainable management of organic fertilization and soil quality to choose organic amendments with specific biochemical quality that are able to balance organic C stock recovery and nutrient mineralization. In a recent experiment (Scotti et al. 2015a), organic materials with different C/N ratio were combined; the application of compost (C/N=13) combined with wood scraps (C/N=375) resulted in an increase of soil organic matter around 60%.

In a long term experiment on a commercial peach orchard it was demonstrated a positive effect of compost application on the amount of C fixed into the soil (Baldi et al. 2018). The increase in C stock, not only depends on organic amendment quality, but also on soil characteristics such as texture fractions as well as carbonate and organic C content (Clough and Skjemstad 2000).

Since 50-60 years ago, the most common soil organic amendments were animal manure; however, due to the reduction of animal husbandry, this type of organic matter is less used in comparison to other organic fertilizers such as municipal solid waste compost, etc. There are several types of organic material that can be applied as a source of organic matter: animal manure, municipal biosolids, cover crops, food residues, waste from manufacturing processes and composts, etc. The different source of each organic material reflects the peculiar chemical properties of each amendment (Table 2) and the knowledge of these information is fundamental when setting fertilization plans.

2.1 Animal manure

Animal manure is a combination of animal feces, urine and bedding (wheat straw, sawdust or other wood by-products) accumulated in piles and composted until complete maturation. It can derive from beef, dairy, pork, poultry and turkey and can be liquid or solid. The composition of manure (Table 3) depends on animals, type of breeding and the composting time. In addition, the composition of the animal feed and its changes during digestion in the gastrointestinal tract cause great differences between different types of manure (Velthof et al. 2000).

Manure maturation is an aerobic process that if occurs in soil and it can induce root anoxia since O_2 is consumed for the composting process. The stabilization of manure is therefore essential for its safe use, considering that the temperature inside the pile are able to kill most of the pathogens, reducing the risk of biological contamination. Ruminants, for example, have been identified as the major reservoir of *Escherichia coli*, with cattle as the most important source of human infections followed by sheep and goats (Doyle et al. 2006). Some bacteria were also found in swine, poultry (Heuvelink et al. 1999) and rabbit feces and may contaminate a variety of crops especially when the manure is fresh or not properly stabilized. Another important issue is the presence of antibiotics since it was estimated that around 90% of antibiotics fed to animals end up in manure since they are poorly absorbed by animals' gut and mostly excreted in urine and feces (Phillips et al. 2004; Kumar et al. 2005; Grote et al. 2007). Moreover, it was demonstrated that antibiotics remain stable during manure storage and end up in agricultural fields on manure applications (Migliore et al. 1995). The presence and persistence of antibiotics in manure can lead to environmental problems such as toxicity for soil biota; in addition, they can potentially increase pathogen antibiotic resistance (Smith et al. 2005). Moreover, antibiotics could be absorbed by crops and the consumption of fresh vegetables grown in soil amended with manures can lead to potential risks for human health.

Animal manure dry matter should be at least 20% and usually horse and sheep manures are those with the lower moisture, while pig manure is the wettest. The C:N ratio depends on the bedding and the stabilization time. Compared to compost, cow manure increased the cumulative root production between 40 and 80 cm of depth. However, it decreased root survivorship from 192 to 123 days (Baldi and Toselli 2013).

2.2 Municipal biosolids

The sludge from municipal wastewater or bio digester can be used in agriculture only after several treatments that aim to stabilize organic matter. The stabilization process reduces unpleasant smell and eliminates pathogens (Goss et al. 2013). Biosolids can be applied to agricultural soils only under regulatory controls that set limits for heavy metals, weeds, human and plant pathogens.

The high concentration of organic matter and the presence of nutrients in biosolids represent agronomic advantages. The application of this type of amendment has resulted in an increase of SOM and nutrients (Brofas et al. 2000; Korboulewsky et el. 2002) with positive effects on plant growth and yield (Viator et al. 2002). Municipal biosolids, besides being a source of macro and micro nutrients (Petersen et al. 2003), can also contain organic and inorganic contaminants that could constitute a danger to the environment. Heavy metal presence is one of the major concerning limiting the application of sewage sludge to agricultural lands; it was demonstrated that the long term use of sewage sludge can cause a significant accumulation of zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr) and cadmium (Cd) in soil and plants (Mulchi et al. 1991). This is the reason why municipal biosolid application should be used for a relatively limited period of time (i.e. 8-year in apple trees) to maintain levels of heavy metals (Zn, Mn and Cu) under the toxicity threshold for plants (Neilsen et al. 2007).

2.3 Cover crops

The use of cover crops is an agronomic technique that consists in incorporating into the soil selected species while green or soon after flowering to increase of SOM, reduce nutrient leaching, limit nutrient run off and soil erosion, improve soil physical and chemical properties and reduce nematode infestation (Goss et al. 2013; Toselli et al. 2019). The main benefit of green manure and cover crop is the addition of nutrients and organic matter to the soil, but also the stimulation of microbial activity and water retention capability (Goss et al. 2013). Legumes, such as soybean (*Glycine max*), clover (*Trifolium* spp.), broad bean (*Vicia faba minor*) and vetch (*Vicia sativa*) are frequently used since they are able to fix N_2 from atmosphere working with bacteria at root level. Leguminous plants, however, often have a deep root system that competes with crops during vegetative season; consequently, their cultivation should be limited to winter time. Because of their high density and superficial root system, the use of graminaceous species, like rye grass (*Lolium perenne*), oat (*Avena sativa*), sorghum (*Sorghum vulgare*) or barley (*Hordeum vulgare*) is recommended to prevent erosion and nutrient run off. In addition, some graminaceous can help to reduce lime-induced Fe deficiency symptoms (Zuo and Zhang 2011). To combine the tolerance to low winter temperature of graminaceous with the positive effect on N_2 fixation of legumes, different species can be sown together in late winter or early spring and tilled into the soil few days before full bloom. *Brassiceae* species are usually grown to provide biomass and to contrast pest thanks to the ability to produce isothiocyanates, volatile compounds toxic for nematode and pathogens (Brown et al. 2008; Wentzell and Kliebenstein 2008). Recently, the use of seed meals (from *Brassica carinata* and *Helianthus annuus*) was proposed as organic amendment (Zaccardelli et al. 2013). Soil application of seed meals or by-product deriving from oil or biofuel production is a source of organic matter, with effectiveness in pest control after the *mirosinase*-driven transformation of glucosinolate to isothiocynates. The use of defatted seed meals deriving from *Brassicaceae* supplied nutrients for plants, organic matter and soil microbial biomass, with a potential activity against soil pathogen (Kirkegaard et al. 1993; Manici et al. 1997; Baldi et al. 2015), a positive effect on leaf N concentration (Baldi et al. 2015) and shoot growth (Table 4).

2.4 Agro-industry wastes

This category includes organic by-products coming from manufacturing processes such as those related with exhausted seeds, hoof and horn meal, animal feathers and fur, residues from sugar or oil extraction, biochar, distillery waste, and biosolids from paper mill (Goss et al. 2013). The large amount of waste produced by the food industry raises serious disposal problems, both from the economic and environmental points of view. Many of these residues, however, could be a source of valuable materials and have the potential to be re-used in agriculture. It was demonstrated, for example, that the use of by-products from orange processing improved soil fertility in an orange orchard (Intrigliolo et al. 2005) and in durum wheat (Tuttobene et al. 2009). Another example could be the mixture of exhausted olive-cake and poultry manure that improved soil fertility and yield in potato (Sellami et al. 2008).

2.5 Compost

Compost is the result of the biological aerobic transformation of any organic by-products into different products that can be added to the soil without detrimental effects on crop growth (Eghball et al. 1997). The composting process is one of the oldest techniques used for stabilizing natural wastes and biological fertilization of the soil and the main objective of this practice is to obtain a stable, chemically and biologically rich product with micro and macro nutrients (Coker 1996). The stabilization process lasts around 90 days, during which the fresh material loses CO_2, NH_3, and water while produces heat and consumes O_2. At the end of this process there is a reduction of more than 50% of weight and the obtained material is stable. The chemical composition of compost depends on the starting material (Table 5).

For all types of compost, agronomic and hygienic-sanitary parameters are established in order to define quality limits for environmental protection; these parameters are related to the presence of heavy metals, non-organic matter (glass, plastic and metal), stone and other biological parameters and the limits are different among European countries (AA.VV. 2004; Ciavatta et al. 2019).

The use of compost allows reducing the costs of green/urban waste disposal, recycling nutrient elements useful for crop growth and increasing soil organic matter. The benefits provided by the use of compost as fertilizer are broad and can be of physical, chemical, biological, or environmental nature. Multiple benefits derive from the use of compost as fertilizer, for example an increase of soil organic C content (Scotti et al. 2015b; Baldi et al. 2018), microbial activity (Scotti et al. 2015b; Baldi et al. 2010; 2018), plant nutrients availability and of micronutrient chelation (Sorrenti et al. 2012). In addition, compost supply induces an improvement of soil porosity (Bronick and Lal 2005) with a consequent increase of water available for plants (Scotti et al. 2013) and a reduction of water irrigation rate (Sorrenti and Toselli 2016). An important feature of compost is the capability to influence soil microflora by enhancing soil biodiversity (Valarini et al. 2009) and consequently suppressing many soilborne pathogens diseases (Bonanomi et al. 2007; Noble and Coventry 2005).

However, the application of compost carries the associated risk of possible pollution due to nitrate leaching and contamination of surface and groundwater (Sorrenti and Toselli 2016; Jorge-Mardomingo et al. 2015) and the release of hazardous nutrients such as heavy metals, chloride, and sulfur (Pérez-Gimeno et al. 2016).

The research conducted in our laboratory indicates that the most appropriate rate of application of municipal solid waste compost (with a C/N ratio of 10) should be between 10 and 20 t ha^{-1} $year^{-1}$ (Fig. 1); otherwise the availability of mineral N exceeds the tree requirement and becomes a pollution risk, potentially leached throughout soil profile with rainfalls. This response is clear at bloom, when the tree usually accounts on reserves stored at the previous season and root N uptake is negligible (Fig. 1). At bloom, values of mineral N higher than 5 mg kg^{-1} are considered too elevated for most of temperate fruit trees. At fruit set, a mineral N concentration of 15 mg kg^{-1} is provided by application of 10-20 t ha^{-1} of compost, while 40 t ha^{-1} exceeds this threshold. At harvest the 20 mg kg^{-1} of mineral N are provided by application of 20 t of compost ha^{-1} y^{-1}, while 5 is lower and 40 is higher than this threshold. Finally, in postharvest, 10 mg kg^{-1} are found only for application of 10 t ha^{-1} (Fig. 1). Higher application rates can be done involving a green compost (C/N > 20), so that the concentration of mineral N is decreased by the development of microbial biomass.

3. Effect of organic matter on plants

3.1 Effect on nutritional status and growth

The enhancement of soil microbial biomass as a consequence of long term compost addition (Baldi et al. 2010; Baldi et al. 2018), for example, stimulated nutrient mineralization in soil improving plant nutritional status and total nutrient removal at the end of the orchard life (Tab. 6). In detail, the yearly application of compost at 10 t ha^{-1} for 14 years has increased macro nutrient in plant with values similar to mineral fertilization (Tab. 6).

The increase of soil microbial biomass not only rises nutrient soil availability, but also contributes to preventing the loss of mineral N and other nutrients by slowing the release of nutrients. A long-term field experiment on peach demonstrated that in the soil profile of 0.00 - 0.80 m depth, mineral N (sum of nitrate and ammonium) pool concentration ranged between 1 and 28 mg kg^{-1} showing a similar trend for all treatments. Only occasionally the application of compost at 10 t ha^{-1} and mineral fertilization caused significant peaks of mineral N; however, it is interesting to note that the maximum N concentration were in those period (late spring, early and late summer) of intense N absorption by plants (Toselli et al. 2019).

Beside the effect of increased microbial activity, also the presence of humic acids in organic amendments is able to increase the availability of micronutrients (Nardi et al. 2002) and promote Fe acquisition (Chen and Aviad 1990; Pinton et al. 1999; Nardi et al. 2002) and nutrient uptake (Nardi et al. 2002) by plants.

As a matter of fact, in the soil of the river Po Valley (Italy), leaf concentration response to increasing compost application rate changes according to the nutrients. Leaf Ca (Fig. 2D), Cu (Fig. 3A), Fe (Fig. 3B) and Mn (Fig. 3C) increased linearly with rate; leaf K (Fig. 2C) increased until 20 t ha^{-1}, then it stabilized with higher application rate. Leaf N (Fig. 2A) and Mg (Fig. 2E) and Zn (Fig. 3D) did not respond to rate of compost, while leaf P decreased with increasing compost rate (Fig. 2B).

A number of reports show that application of organic matter induces a positive effect on plant growth. For instance, compost significantly enhanced strawberry (Wang and Lin, 2002) and nectarine growth (Bravo et al. 2012; Sorrenti et al. 2019; Baldi et al. 2018); sludge induced a significant enhancement of apple plant growth (Bozkurt et al. 2010); compost and compost+biochar positively influenced apple tree growth with more evident effect in the combination of the two amendments (Safaei Khorram et al. 2019). The application of compost, olive mill waste water and cover crop with legumes increased olive growth (Chehab et al. 2019). The use of dried fungal biomass, vinasse and animal sewage promoted apple tree above and below ground growth and enhanced the final number of fruit (Polveriggiani et al. 2014). Compost, vermicompost and peat-compost mixture at planting increased apple tree growth in a clay soil from Israel (Gur et al. 1998) and in a sandy soil from USA (Peryea and Covey 1989). Similar results at planting were also observed when cow and chicken manures were applied (Van Schoor et al. 2009).
Nonetheless, many research evidenced the positive effects of compost; there are also several studies that reports negative effects of compost application on seed germination (Tiquia 2010; Aslam and VanderGheynst 2008) and plant growth (von Glisczynski et al. 2016), mainly due to N immobilization by microbial competition (Hodge et al. 2000) and to the release of phytotoxic compounds (Tiquia 2010). Organic amendments can, indeed, release a wide range of inhibitory compounds, like short-chain organic acids, tannins and phenols, mainly when not properly stabilized (Bonanomi et al. 2011); consequently it is vital to supply amendments opportunely stabilized during the production process.

3.2 Effect on yield and fruit quality

The supply of mineral nutrients (De Brito et al. 1995), the improvement of soil structure and water retention capability (Serra-Wittling et al. 1996), the enhancement of soil microbial and enzymatic activities (Garcıa-Gil et al. 2000), and the control of soilborne pathogens (Bonanomi et al. 2010) are considered the main reasons of the improvement of plant yield, as a response of organic matter applications. This response is often observed even in the absence of differences in leaf nutrient concentration, supporting the hypothesis that nutrient status is not the main cause of different yields (Roussos et al. 2017). Increase of fruit yield as a consequence of organic matter addition was observed in strawberry (Wang and Lin

2002; Mahadeen 2009), apple (Bozkurt et al. 2010), sour cherry (Angin et al. 2012; Aslantas et al. 2013) wine grape (Liu et al. 2016) and strawberry (Arancon et al. 2004). In the latest case the authors hypothesize that growth responses reflected the ability of humic acids, present in vermicompost, to act as plant growth regulators.

Contrasting results on the effect of organic fertilization on fruit quality and nutraceutical value are reported in literature (Prange 2015). Several evidences report a positive effect of organic fertilization on crop quality, including fruit color, weight, size, total sugars and anthocyanin contents in dates fertilized with chicken manure and cow dung (Marzouk and Kassem 2011). Strawberry fertilized with compost increased fructose, glucose, sucrose, total sugars and organic acid concentration (Wang and Lin 2002). Sweet cherry (Tan et al. 2018) and apple (Amarante et al. 2008; Peck et al. 2006) fertilized with organic amendment increased soluble sugar and total acidity. However, opposite results were reported in apple (Amiri and Fallahi 2009) and kiwi fruit (Amodio et al. 2007). An excess of N available for plants was considered the main reason for the reduction of vitamin C concentration in fruits (Lee and Kader 2000). A similar response can describe the second degree function response of fruit firmness and soluble solid concentration in nectarine to increasing compost application rate with the highest values found as a response to 20 t ha^{-1} (Fig. 4). While the fruit firmness is related to fruit maturation, that can be delayed by the increase of N availability, soluble solid concentration is the result of a balance between fruit and shoot competition for C. The best results in term of C partitioning to the fruit can be achieved with a compost application rate of 20 t ha^{-1}.

4. Biofertilizers

Plant performances not only on soil available nutrients, but also on microorganism that live in agricultural soils; while some of them are detrimental, others have positive effects on plant, in term of growth (roots and aerial parts), root uptake, and tolerance to pathogen diseases (Glick et al., 1998). Recently, the use of bio-fertilizers, together with the supply of organic matter has gained more importance due to the higher concern on crop sustainability and the preservation of soil quality. The term “bio-fertilizer” has been recently introduced to define a fertilizer (organic or mineral) that contains living cells of different types of beneficial microorganisms (Mohammadi and Sohrabi, 2012). including bacteria, cyanobacteria, fungi (yeast, molds, mycorrhizae) and actinomycetes (Bora et al., 2016) with indirect or direct effects on growth promotion (Vessey, 2003). Indirect mechanisms occur when they reduce or prevent the negative effects of abiotic and biotic stresses, through antibiotic production, nutrient and space competition and synthesis of lysing enzymes against phytopatogenic organisms (Lucy et al., 2004; Principe et al., 2007). Direct mechanisms include the synthesis of easily available compounds for plants (phytohormones, ammonia, etc.) and the solubilization of nutrients (Glick et al., 1998; Vessey, 2003; Lucy et al., 2004; Principe et al., 2007; Ahmad et al., 2008).

The mechanisms of action of bio-fertilizers can be divided in five classes, according to different effects on plant growth: 1) increase of root surface area; 2) increase of the availability of nutrients in the rhizosphere through N_2 fixation, nutrient solubilisation and production of siderophores (Glick et al., 1998); 3) establishment of a symbiotic relationship among microorganisms and host plant; 4) reduction of the proliferation of pathogens; 5) combination of actions (Persello-Cartieaux et al., 2003; Vessey, 2003; Van Loon, 2007).

Biofertilizers can fix yearly 20-200 kg N ha^{-1}, can solubilize phosphorous (Richardson, 2001; Artursson et al., 2006), in the range of 30-50 kg P ha^{-1}, and K (Khumar et al., 2016), and mobilize P, Zn and Fe to varying extent (Bora et al., 2016). One of the mechanisms developed is the release of organic acids (such as oxalic, citric, butyric, malonic, lactic, succinic, malic, gluconic, acetic, glyconic, fumaric, adipic, and 2-ketogluconic), and the decrease of rhizosphere pH (Kim et al., 1998; Richardson, 2001).

In the literature, there are a number of papers dealing with the employment of bio-fertilizers in fruit crops. Root-applied combinations of *Bacillus* spp. and *Microbacter* increased cumulative yield, fruit weight and nutrient acquisition of apple Granny Smith in Turkey (Karlidag et al., 2007). The use of yeast in combination with beneficial bacteria promoted an increase of yield in Topaz apple variety (Mosa et al., 2016). Beneficial microbial, including *Azotobacter chroococcum*, *Pseudomonas* spp. and mycorrhizal fungi (*Glomus fasciculatum*) improved kiwifruit crop (Khachi et al., 2015). Leaf-applied N-fixing-bacteria-*Azotobacter*, *Azospirillum* and *Beijerinkia* were effective in promoting mulberry leaf yield for silkworm rearing and cocoon production (Sudhakar et al., 2000). A positive effect on cherry and apricot yield, vegetative growth and leaf nutrient concentration was also found in response to flower and/or foliar application of *Pseudomonas* (strain BA-8) and *Bacillus* (strain OSU-142) alone or in combination (Esitken et al., 2006). Similar results of floral and foliar application of *Pseudomonas* and *Bacillus* were also obtained on apple cv. Starkrimson and Granny Smith grown in Turkey (Pirlak et al., 2007). The positive effect was related to N_2-fixing capacity of both bacteria strains along with specific positive activity on auxine (OSU-142) and zeatin (BA-8) hormone production. The foliar fixation of N enhanced shoot growth and induced a greater uptake of nutrients from the soil (Esitken et al., 2006). Growth promoting hormones such as auxin and cytokines, on the other hand, are effective in stimulating cell division and fruit growth (Esitken et al., 2006).

Mycorrhizal inoculation with *Glomus epigaeum*, *G. mosseae* and *Gigaspore calospora* increased height, root length, number of leaves and dry weight of micro propagated pomegranate (Singh et al., 2012) plantlets. Similar results were obtained in apple (Sharma and Bhutani, 1998) and peach (Wu et al., 2011). Moreover, mycorrhizal inoculation was found to improve nutritional status of peach seedling (Wu et al., 2011).
Pear plants of the cv. Gola inoculated with *Azotobacter* and *Azospirillum* showed a greater uptake of NO_3^-, $NH4^+$, H_2PO_4, K^+ and Fe^{2+} (Mohammadi and Sohrabi, 2012) and a higher vegetative growth (*Azotobacter*), fruit yield and quality (Kumar t al., 2013), indicating that chemical fertilization inputs can be reduced when plant growth-promoting rhizobacteria (PGPR) are applied to plants.
The combined effect of *Bacillus*, strain M3 in combination with strain OSU-142 increased yield, growth and nutrition of raspberry plant under organic growing conditions (Orhan et al., 2006). In addition, these two strains were able to solubilize phosphates and to increase organic matter mineralization through the process of acidification, chelation and exchange reactions in plant growth media.
Bio-fertilizer inoculation with *Pseudomonas flourescence* was found to significantly improve fruit quality, yield, weight, soluble solid concentration and juice volumes of Washington navel orange (Shamseldin et al., 2010); while inoculation with *Azospirillum brasilence* did not significantly improve yield and fruit quality. *P*. *flourescence* was also able to reduce growth and diffusion of soil nematode more than *A*. *brasilence* (Shamseldin et al., 2010).
On the other hand on strawberry none of the individual microorganisms from each species or their mixture showed growth-promoting-effects in more than two experiments and dual inoculation was not more effective than the single one (Vestberg et al., 2004).
The concentration of the beneficial microorganisms in bio-fertilizers should allow the colonization of rhizosphere at a sufficient population density to produce their beneficial effect (Bloemberg and Lugtenberg, 2001). In apple (Kardilag et al.,2007) and sweet cherry (Esitken et al., 2006), a positive effect was obtained using 109 CFU (colony forming units) ml^{-1}. However, IAA-producing-PGPR should not be applied over the 106 CFU ml^{-1}, because they can trigger ethylene-mediated negative effects (Persello-Cartieaux et al., 2003). Although the number of beneficial microorganisms declines rapidly in the rhizosphere after inoculation, their effects usually last throughout the growing season (Lucy et al., 2004). The correct management of fertilization is the first mean to increase soil beneficial microorganism; for example, the use of organic fertilizers stimulates microorganism proliferation (Mohammed and Sohrebi, 2012). In addition, the use endophytic efficient

genotypes that can easily adapt to soil conditions is able to promote plant growth (Compant et al., 2005; Forchetti et al., 2007; Príncipe et al., 2007).

5. Conclusions

The application of organic matter could, besides increasing fruit tree performances, be a useful tool to improve soil organic C stock and fertility in intensive agriculture systems. Soil acts as a C reservoir playing an important role in the mitigation of climate change. Soils of agroecosystems can have an important C sink capacity: it was estimated that an increase of soil organic carbon of 4‰ every year can balance anthropogenic CO_2 emissions (Lal et al. 2015). Most of the organic amendment derives from recycling of waste reducing, thus, the cost of disposal and landfill management. The challenge of future research will be the identification, for each soil, of the organic amendments that can maximize C stock and, at the same time, allow a sufficient release of mineral nutrients to sustain orchard yields and plant performances minimizing eventual detrimental effects.

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Table 1. Main benefits and concerns related to organic amendment supply to soil (modified from: Gross et al. 2013).

BENEFITS	CONCERNS
Source of macro and micro nutrients	Imbalance of nutrient supplied; Absence of synchronization between release and plant needs; Loss of N by volatilization or leaching; Accumulation of heavy metals.
Increase of C stocked in soil	Release of antibiotics in the soil
Raise of soil microbial biomass	Release of animal pathogen into the environment
Improvement of soil physical properties	Increased risk of preferential flow of contaminants in ground water

Table 2. Physiochemical characterization of some organic wastes (Source: Alvarenga et al. 2015; Baldi).

Material type	Moisture (%)	pH	EC (mS cm^{-1})	C/N	OM	Total N (% dw)	P_2O_5	K_2O	Ca (g kg^{-1} dw)	Mg	Na
Municipal sewage sludge	84.6	7.4	1.23	5.9	74.3	6.2	6.9	14.5	27.6	7.9	1.6
Agro-industrial sludge	65.7	12.2	9.76	10.4	37.6	2.0	5.9	1.6	213	8.7	1.3
Mixed municipal solid waste compost	33.8	7.8	7.19	9.3	39.5	2.1	3.6	10.5	83.4	14.0	32.1
Agriculture waste compost	22.5	8.3	6.12	11.8	41.3	1.8	3.5	45.6	30.2	37.5	29.8
Pig slurry digestate	62.1	6.4	7.95	12	60.8	2.6	19.2	26.3	108	18.1	4.4
Paper mill wastes	52.4	12.5	19.4	15.3	17.8	0.6	3.8	1.1	180	16.8	1.8
Sewage sludge compost	47.0	8.43	-	14.0	55.5	2.3	1.25	12.9	-	-	2.72
Compost from mushroom residues	45.8	-	-	11.1	17.4	0.91	0.41	10.4	-	-	-

Table 3. Average composition of some animal manures.

Manure type	Dry matter (g kg^{-1})	Organic C (g kg^{-1})	Total N (g kg^{-1})	NH_4-N (g kg^{-1})	pH
Cattle – liquid	15-123	3.8-3.6	2.0-7.0	1.0-4.9	7.1-8.4
Cattle – solid	140-300	65-126	4.2-8.1	0.3-2.0	8.6
Pig – liquid	4.9-152	1.0-65	0.6-7.8	0.3-6.6	6.7-8.9
Pig – solid	150-330	42-132	3.5-11	0.5-6.0	8.1
Poultry – liquid	10-367	11-112	2-21	1.9-9.4	7.9-8.8
Poultry – solid	220-700	103-597	10-58	2.4-18	7.6

Source: Bernal et al. 2009 and literature here cited.

Table 4. Effect of defatted seed meal application rate on microbial biomass and nitrate in the soil 15 days after treatment (done at bud break) and on shoot growth 4 month after treatment (Source: Baldi et al. 2015).

Application rate (t ha^{-1})	Microbial biomass (μg C kg^{-1} DW)	NO_3^--N (mg kg^{-1} DW)	Shoot growth (cm)
0	331 c	3.84 b	53 b
2.5	573 b	70.2 ab	63 b
5.0	850 a	116 ab	66.0 a
7.5	984 a	155 a	37 c
Significance	***	**	***

2.5 t ha^{-1} is the rate usually applied in commercial fields.
Within the same column, values followed by the same letter are not statistically different according to Student Neuman Keul test ($P \leq 0.05$). **, ***: effect not significant or significant at $P \leq 0.01$ and $P \leq 0.001$, respectively. DW, dry weight,

Table 5. Average composition of compost deriving from different material.

Material type	Humidity (%)	N (% DW)	P_2O_5 (% DW)	K_2O (% DW)	TOC (% DW)	pH	C.E.S. (μS cm^{-1})
Food waste	40-55	1.79	1.38	1.26	25	8.15	3730
Sewage sludge	40-55	1.78	2.13	0.67	24	7.21	2470
Livestock	35-50	3.01	8.93	1.06	30	8.01	1890
Green waste	40-55	1.07	0.47	0.42	22	7.81	980

Database Soil Improvers and growing – DFCA. FW, fresh weight.

Table 6. Effect of compost application on total nutrient content in peach trees (g $plant^{-1}$) after 14 years of amendment application.

TREATMENT	N	P	K	Ca	Mg
Untreated control	360 b	133 b	325	996 b	107 b
Mineral	587 a	149 b	417	1262 a	135 a
Compost low rate	403 b	142 b	343	947 b	107 b
Compost high rate	568 a	167 a	435	1224 a	137 a
Significance	**	*	*n.s.*	*	*

Within the same column, values followed by the same letter are not statistically different according to Student Neuman Keul test (P≤0.05). n.s., *, **: effect not significant or significant at P≤0.5 and P≤0.01, respectively.

Figure 1. Relation between compost rate and soil mineral N in peach orchards during the vegetative season. R^2 = Pearson correlation coefficient. DW, dry weight.

Figure 2. Effect of compost application rate on leaf macronutrient concentration in commercial nectarine trees. R^2 = Pearson correlation coefficient. DW, dry weight.

Figure 3. Effect of compost application rate on leaf micronutrient concentration in commercial nectarine trees. R^2 = Pearson correlation coefficient. DW, dry weight.

Figure 4. Effect of compost application rate on soluble solid concentration and fruit firmness. R^2 = Pearson correlation coefficient.