Root growth and survivorship in cow manure and compost amended soils

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ABSTRACT

The effect of the application of compost and cow manure on nectarine (*Prunus persica* L.) root growth and survivorship was investigated in a commercial orchard during the growing seasons 2003, 2004 and 2005. Our main objective was to determine whether compost affects root dynamics differently than cow manure. The experiment was a complete randomized block design with four replicates of two treatments: cow manure and compost applied at planting in 2001 at 10 t dry weight (DW)/ha and from 2004 at the rate of 5 t DW/ha. The compost fertilization represented a yearly rate of 120 kg N/ha, while cow manure was approximately 80 kg N/ha/year. Both root growth and survival were evaluated at 20-day intervals during the growing season by the minirhizotron technique. Cow manure increased the production of new roots compared with compost ($P \leq 0.001$). Roots were mainly produced at a depth of 21–40 cm for compost and 61–80 cm for cow manure. The root lifespan was longer in compost than in cow manure treated trees ($P \leq 0.05$) and was strongly affected by depth. No differences were observed in root length and diameter.

Keywords: *Prunus persica*; minirhizotron; organic fertilization; root lifespan; root dynamics

Due to farm specialization and reduction of cattle farms, the availability of cow manure in the Po valley in Italy in the last years strongly decreased with a consequent reduction of organic matter (OM) application. This led to a drop of OM concentration in the soil from 2.8%, measured in 1935 to 1.5% in 2004 (Tabaglio et al. 2004, Ungaro et al. 2005). To replenish adequate OM concentration in the soil, an alternative to the supply of manure could be the application of compost, an organic fertilizer obtained by a 3-month aerobic stabilization of different organic material. Compost represents a source of high quality OM that, beside the fertilization value (Gallardo-Lara and Nogales 1987), is a good way to recycle municipal solid and food industry related wastes.

The effect of organic fertilization on soil properties (Barzegar et al. 2002, Baldi et al. 2010a, Diacono and Montemurro 2010,) and on the aboveground traits of fruit trees (Gallardo-Lara and Nogales 1987) is well known, however, there is little understanding on how compost and cow manure affects belowground traits such as root production and root lifespan. Recently, in the same orchard, it was observed that the yearly application of compost at the rate of 10 t/ha increased the production and lifespan of roots when compared with mineral fertilization and unfertilized plots (Baldi et al. 2010b). However, the use of such a high rate is uncommon in orchard management. The application of OM to the soil may affect root growth by increasing inorganic ions and humic substances that induce a proliferation of lateral roots and root hairs and cause a higher differentiation rate of root cells (Concheri et al. 1996, Canellas et al. 2002), with effect on nutrient acquisition, tree growth and yield.

The aim of the present study was to evaluate, in a commercial nectarine orchard, the impact of compost and cow manure on root growth and survivorship.

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MATERIAL AND METHODS

The study was conducted from 2003 to 2005 in a nectarine (*Prunus persica* Batsch var. *nectarina* (Ait) Maxim.) orchard, located in the southeastern part of the Po valley in Northeastern Italy (44°27'N, 12°13'E). Trees of the variety Stark RedGold, grafted on GF677 (*Prunus persica* × *Prunus amigdalus*) rootstock, were planted in August 2001 at a distance of 5 m between the rows and 3.8 m between trees on the row on a Calcaric Cambisol (FAO 1990) soil, characterized by sand 6.7%, silt 67%, clay 26.3%, pH 7.8, electrical conductivity 200 μS/cm, total N 1.1‰, organic matter 1.7%, P (Olsen) 18.5 mg/kg dry weight (DW); K (extractable) 182.2 mg/kg DW and Ca carbonate 30.5%. All soil properties were determined by an external laboratory (ARPA, Ravenna, Italy) as per the Italian Ministry of Agriculture, Food and Forestry and the International Union of Soil Sciences (Violante 2000).

Since orchard plantation the application of cow manure and compost was compared as in a randomized block design with four replicates and 4 trees in each block. Both fertilizers were supplied at planting at a rate of 10 t DW/ha resulting in a supply of 160 kg N/ha for cow manure and 240 kg N/ha for compost, and then from 2004, amendants were applied every spring in May at a rate of 5 t DW/ha with an application of 80 and 120 kg N/ha for cow manure and compost, respectively. The application was done by tilling the matrix into the soil at the depth of 25 cm on the 2 m wide tree row. Compost was obtained from the domestic organic wastes (50%) mixed with plant material from urban ornamental trees and gardens (50%) after a 3-month stabilization and was characterized by 82.1% dry matter; 2.4% DW N, 22.8% organic carbon, a C/N ratio of 10 and humic + fulvic acid (HA + FA) of 7.9% DW. Manure was obtained by cow stable dung and wheat straw bedding after 6-month stabilization provided by a local cow livestock and was characterized by 32.7% dry matter, 1.6% DW N, 37.4% organic carbon, a C/N ratio of 17 and HA + FA of 12% DW.

As typical of commercial practices in this region, soil was tilled three times a year to a depth of 25 cm in the tree rows (manually around the tube), while the alleys were untilled and covered with spontaneous grass mown 3 times a year. Tree canopies were trained in a ‘delay-vase system’ and from June to September, were daily watered using drip irrigation to replenish daily evapotranspiration (based upon pan evaporation at the farm meteorological station, 1 km from the field site). Average annual air temperature was 13.7°C and annual precipitation was 594 mm (1967–1997, Geophysical Station of Modena University, Italy).

Root growth and parameter were determined using the minirhizotron technique. One clear Plexiglas® tube (6 cm in diameter × 100 cm in length) per tree was inserted into the soil in October 2002, 50 cm from the trunk and at a 30° angle from vertical, to avoid any preferential water drainage and root growth along the tube walls (Bragg et al. 1983). Tubes were inclined towards the center of the row. Each minirhizotron bottom was sealed to prevent water from entering the tube; the tops were closed with a rubber stopper and the portion of the tube above the ground was painted black to prevent light intrusion. Each tube was covered with a can to prevent radiant heating. On the side of each tube a graduated scale was drawn to have a reference for depth. Images were collected with a video camera system (Bartz Technology, Santa Barbara, USA) every 20 days during the growing seasons (2003, 2004 and 2005) from March to November. Videos were then converted into digital images (Studio DC 10 Plus, Pinnacle Studio version 8, Mountain View, USA) that were catalogued according to ICAP (Bartz) nomenclature in order to have a sequence of the same minirhizotron window positions over the time of investigation. Images were analyzed using a specialized software (WinRHIZO Tron MF, Regent Instrument, Quebec, Canada) for number of roots and survivorship. Root birth was considered the date when a root was first observed, while root death was identified by disappearance from the window or evidence of root shriveling and decay. Root lifespan was calculated, in days, as the difference between date of death and birth. Root survival probability was generated using the baseline statement of PROC PHREG in SAS with treatment or depth used as the stratifying variable.

Statistical analysis. All data were statistically analyzed using a completely randomized block design with 4 replications (trees) using soil fertilization (2 levels: cow manure and compost) and depth (4 levels: 0–20, 21–40, 41–60 and 61–80) as factors. When analysis of variance showed statistical differences ($P \leq 0.05$), means were separated by the Student-Newman-Keuls (SNK) test; when interaction between two factors was significant 2 time standard error of means (SEM) was used as the minimum difference between two means statistically different at $P \leq 0.05$.

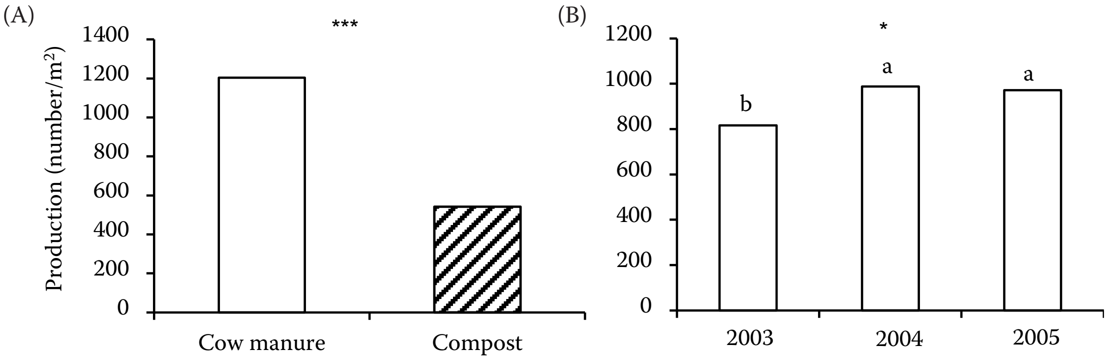


Figure 1. Effect of fertilization practice (A), and year (B) on new root production expressed per m^2 of viewing surface on the minirhizotron tube. Means represent averages of the main effects. Bars with the same letter are not statistically different (*$P \leq 0.05$, ***$P \leq 0.001$)

RESULTS

We did not observe any significant interactions between year and treatments on cumulative root production in the two fertilizer treatments. Trees fertilized with cow manure had higher total cumulative root production than compost-treated plants during the 3-year investigation (Figure 1A). Annual root production was lowest in the first year and increased in 2004, becoming stable in 2005 (Figure 1B). Soil depth and treatment significantly interacted with root population during the whole experiment; root populations, observed in the shallowest layer (0–20 cm), was not affected by treatments and was lower than in all the other depths with the exclusion of compost at 61–80 cm (Figure 2). At the depth of 21–40 cm, the number of new roots was higher in compost than in cow manure treated plots, and at this depth we found the highest number of roots in compost treated soil. Between 40 cm and 80 cm the number of roots in cow manure was higher than in compost; it reached the highest values between 61 cm and 80 cm (Figure 2).

Seasonal patterns of root production varied from year to year (Figure 3), and were similar for the two treatments; they were always higher in cow manure than in compost treated plants. In 2003, new root production increased until the end of June, decreased during summer and increased again (Figure 3A) at the beginning of September. In 2004, new root production started later in the season (May 10th) and showed a similar trend of 2003, with a decrease during summer and an increase after harvest in cow manure plots, while in compost soil it slightly decreased (Figure 3B). In 2005, it was not possible to observe a clear seasonal pattern of root production for cow manure and compost (Figure 3C).

Compost application increased root survivorship compared to cow manure fertilization (Figure 4A). Differences in treatments were greatest for roots less than 300 days old, with about 38% shorter median lifespan in cow manure (123 days) than compost-treated trees (192 days) over all three years. In addition, root survivorship was affected by depth, since it was longer at 21–40 cm compared to the other soil layers (Figure 4B) for roots younger than 180 days. For older roots no significative differences among depths were observed. The probability of survivorship was not significantly different at 0–20 cm and 41–50 cm. Median lifespans of roots in the 21–40 cm depth was 180 days, similar to those in the depth of 0–20 cm

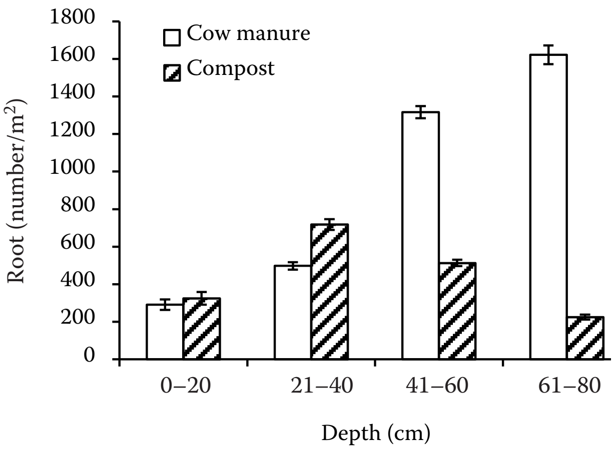
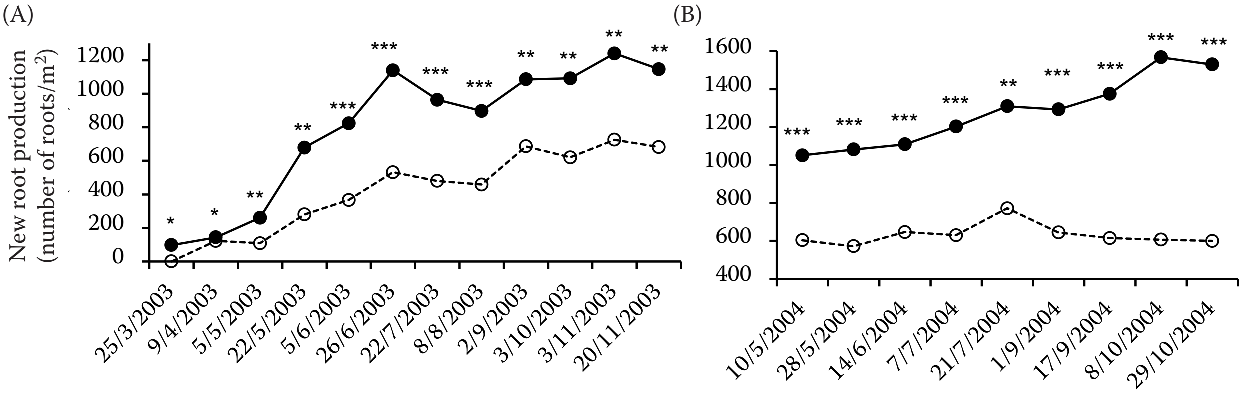


Figure 2. Effect of fertilization practice and depth on the number of roots produced over the entire experiment (2003–2005). Interaction between treatments and depth was significant at $P \leq 0.01$. Values differing by 2SEM are statistically different. Bars indicate mean ± standard error



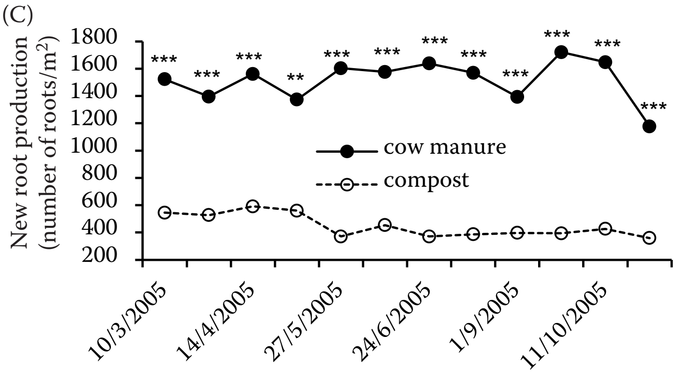


Figure 3. Effect of fertilization practice on new root production during the experiment (2003–2005). Data are expressed per m^2 of the minirhizotron tube surface examined and are an average value over all depths. $^*P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$

and higher than those in the 41–60 cm and 61–80 cm depth. Treatments and depth did not affect root length and diameter (data not reported).

DISCUSSION

The stimulating effect of cow manure on the number of new roots is probably related to soil chemical and physical properties and particularly to the different substances that results from decomposition of compost and cow manure; these compounds include humic and fulvic acids that were higher in cow manure (12%) than in compost (7.9%). Trevisan et al. (2010), for example, demonstrated that humic substances enhance root growth and elongation due to the production of auxin or auxin-like components. Moreover, it was demonstrated that organic matter have a positive effect on soil physical properties by increasing soil porosity that is favourable to root growth and function (Passioura 2002). Studies on soil porosity

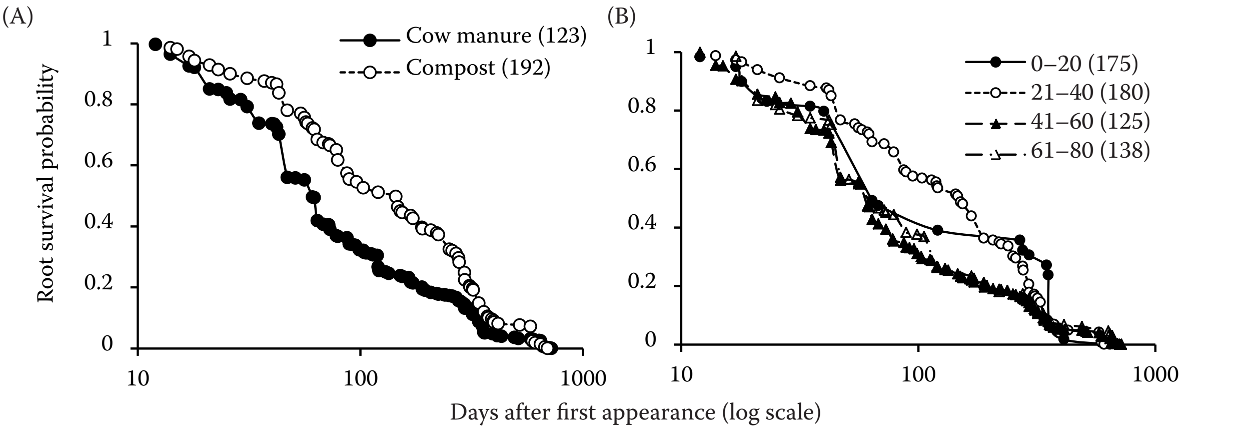


Figure 4. Survival probability of roots observed from 2003 until 2005. Survival probabilities were generated using the baseline statement of PROC PHREG in SAS with treatment (A) or depth (cm, B) as the stratifying variable. Median lifespans (days, in parenthesis) are also shown in legend

in the same experimental orchard (Vignozzi et al. 2005) showed that the number of total transmission pores was higher in cow manure (20% in 2003 and 24% in 2004) than in compost (16% in 2003 and 20% in 2004). These effects were most expressed when organic matter was applied yearly (2004 and 2005).

The different distribution of roots in relation to depth could be associated to the different release of chemicals from OM. Probably chemicals released by the decaying of cow manure accumulated in the shallower soil layers resulting toxic for roots. In the deeper layers, these chemicals are diluted and become possibly beneficial (López-Bucio et al. 2003, Giorgi et al. 2008) for roots. For compost we did not observe such a marked trend and probably the highest number of roots between 21 cm and 40 cm is the result of the optimal chemical and biological soil properties in this layer. This result is confirmed indirectly by previous observations in the same orchard (Baldi et al. 2010b) where the yearly application of compost at 10 t/ha (two times the rate here investigated) since orchard plantation stimulated the highest root production at 61–80 cm, similar to what was observed in this experiment for cow manure, probably for the same reason of toxicity previously explained. In our study the application of 120 kg N/ha/year with compost resulted in a lower root number and longer survivorship when compared with a supply of 80 kg N/ha with manure. Although several reports (Burton et al. 2000, Nadelhoffer 2000) indicate an effect of soil N availability, the differences in root number and lifespan observed in the two fertilization strategies cannot be related to N supply, since soil mineral N (NO_3^--N and NH_4^+-N) during the 3 years of investigation was not affected by treatments (Baldi et al. 2010a). Longevity of roots varied with depth and roots produced at 21–40 cm lived longer than at all other depths, probably in relation to soil gradient of water, nutrients and microbiological activity (Zak et al. 2000). The mechanical damage and heat may have negatively impacted root number, function and survival especially during summer periods of high temperatures in the shallower layers.

The differences of survival probability of root production observed in the 3 years are common in temperate fruit crops (Eissenstat et al. 2005) that typically ranges from 30 to 100 days in grape (Anderson et al. 2003), apple (Wells and Eissenstat 2001) and peach (Wells et al. 2002). Seasonal root pattern did not show a clear trend or any possible competition for carbohydrate with fruit and shoot as reported by Abrisqueta et al. (2008) this means that in our experimental conditions root production was mainly affected by environmental variation.

In conclusion, the application of cow manure stimulated root production but reduced the survival when compared to compost; however no substantial difference in root morphology was observed.

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