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Short communication

Effect of soil condition on apple root development and plant resilience in intensive orchards

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ABSTRACT

The sustainability of intensively managed orchards relies on the endogenous plant mechanisms of resilience. The plasticity of plants in their responses to external stimuli determines their tolerance to stress, and has to be promoted by growers. High-density orchard management has the advantage of the use of a root system that can promptly respond to changing conditions. Thus, it has become of pivotal importance to explore the soil–plant relationships and to highlight management practices that promote root development. This applies especially to the root fibrous fraction, which is mostly active in absorption, as well as the root activity and lifespan. Moreover, for intensive orchards that are highly exposed to replanting diseases, sustainable management should promote accumulation of homospecific residues, possibly by accelerating the cycles of degradation of allelopathic compounds. This report summarises a set of studies that were conducted to determine the effects of soil fertility and amendments on apple root morphology and physiology, and it highlights the relevance of soil management practices in promoting efficient root development.

1. Introduction

Modern intensive apple production is strongly characterised by early fruit bearing and high crop loads, with short orchard life-span and frequent replanting. The achievement of constant and high yields is dependent on sustainable management of the different components of soil fertility. The environmental sustainability of high-density systems is mainly related to soil management practices (Stirling et al., 2016), which need to focus on increasing the soil organic carbon levels (Kong et al., 2005) and enhancing the soil biological activity. These can include reduced tillage (St. Laurent et al., 2008), multispecies ground cover, and supply of amendments.

The plant root system is the organ that is mainly exposed to any stimulus or stress that arises from the growth substrate, and it can be greatly influenced by soil management practices. Roots react to several endogenous and exogenous factors with plastic modifications that affect their morphology, as well as their metabolism and architecture (Bengough et al., 2005). Indeed, the plasticity of a root system determines its competitiveness and efficiency (Eissenstat et al., 2000), and influences the tolerance of the plant to stress. Numerous root traits are highly plastic, such as root diameter, tissue density, nitrogen (N) concentration, mycorrhizal fungal colonisation, and accumulation of secondary phenolic compounds. These traits can also be greatly affected by the supply of resources (e.g., N, phosphorous [P], water). These root morpho-physiological variables, in turn, affect root longevity and activity, and define the cost/benefit ratio of the below-ground resources allocation. Root development can be described by the total biomass, which is influenced, in turn, by the growth rate and longevity of the single root structures. Furthermore, as well as the standing biomass, the root activity is largely defined by its architecture (Berntson 1994; Li et al., 2016) and the selective allocation of resources among the fibrous (i.e., highly absorptive) and pioneer (i.e., explorative) stress-tolerant and long-lived structures (Zadworny and Eissenstat, 2011) (see Box 1).

Any agronomic intervention that can increase soil ‘rootability’ by reduction of the soil bulk density and concentration of allelopathic compounds would strengthen plant resilience by allowing the plant to promptly modify the allocation pattern of the roots (Eissenstat et al., 2000). The soil physical fertility is considered to be among the main parameters that can influence this rootability (Dexter, 2004), and correct soil management can stimulate root growth as well as their potentiality for uptake, by selectively promoting the fibrous root component (Pierret et al., 2006).

Physical fertility in cultivated soil is influenced by agronomical practices, and it can progressively decrease over the years because of

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Box 1
The effects of growth substrate on apple plant development and root architecture and longevity.

Materials and methods

Well-feathered, 1-year-old, bare root apple scions of cultivar Gala grafted onto M9 rootstock were transplanted into 45-L pots. Three growth substrates were compared: silt loam soil; sandy loam soil (see Table 1); and sphagnum peat (pH 4.28; electric conductivity [1:5 dilution], 0.03 mS/cm). The roots were analysed 4 months after transplanting.

Results

✓ Peat substrate increased root biomass compared to silt loam soil.

✓ Silt loam soil with limited physical fertility reduced plant development, especially at the root level, and increased shoot-to-root ratio. Total fibrous root biomass was particularly low with silt loam soil.

✓ Root cells exposed to stress in silt loam soil showed the highest electrolyte leakage (see Table 2) (Polverigiani et al., 2015a).

Table 1
Chemical properties of silt loam and sandy loam soils.

	pH($CaCl_2$)	OM (mg/g)	C_{org} (mg/g)	N tot. (%)	C/N	Exch. K_2O (meq/100 g)	Av. P_2O_5 (mg/kg)	Total $CaCO_3$ (g/kg)
Silt loam	5.2	38	21.9	2.10	10.4	0.63	73	0
Sandy loam	7.0	17	10.1	1.00	10.1	0.41	30	2

Table 2
Plant biomass, root biomass allocation pattern and root electrolyte leakage level. Means in a row followed by different letter are significantly different according to Tukey's HSD mean separation test ($p < 0.05$).

Parameter	Silt Loam	Sandy Loam	Peat
Leaf d.w. (g)	68.1 ± 7.6 c	104.7 ± 6.9 b	155.8 ± 11.7 a
Leaf specific mass (g cm^{-2})	1.50 ± 0.03 a	1.39 ± 0.01 b	1.34 ± 0.03 b
Tot.root biomass d.w. (g)	27.9 ± 5.6 b	57.8 ± 10.6 ab	74.6 ± 25.9 a
Shoot/root ratio	38.3 ± 8.0 a	18.1 ± 1.6 b	17.52 ± 2.3 b
Fibrous/pioneer roots d.w.	0.19 ± 0.04 b	0.38 ± 0.05 a	0.30 ± 0.02 ab
Electrolyte leakage (%)	28.8 ± 1.6 a	21.6 ± 1.2 b	12.3 ± 1.2 c

compaction due to mechanical actions, and because of impoverishment of the organic matter content and quality (Haynes, 2005). To partially combat this reduction in fertility, it is possible to replace the soil locally with alternative substrates (e.g., peat) at the transplanting stage, to positively influence soil colonisation by the roots, to thus improve plant setting and early bearing.

The present report summarises several studies that were conducted to define the effects of soil fertility and the use of amendments on root morphology and physiology, and on some of the rhizosphere characteristics. Agronomic interventions that can be used to promote root plasticity and plant resilience under replanting conditions are also indicated.

2. Growth substrate

A high standard of soil physical fertility generally leads to an increase in total biomass at the root level. Root growth in the field is often slowed by a combination of soil physical stresses, which can include mechanical impedance, water stress, and oxygen deficiency (Bengough et al., 2005). The stability of the soil physical structure and of the water and oxygen availability are key determinants of root exploration and their durable exploitation of the soil resources (Hinsinger et al., 2009). The geometry of the soil pore spaces defines soil permeability to gases and solutes to and from the roots, such that increased soil structural pores, and the consequent reduction in soil bulk density, positively correlates with soil rootability (Römkens and Miller, 1971) and plant allocation of resources to root growth and metabolism. The study reported in Box 1 confirmed increased root proliferation when grown with a peat substrate. With root electrolyte leakage used as an indicator of stress (Huang et al., 2005) to determine cell membrane stability and integrity (as described by Martin et al., 1987), increased integrity of the membranes of the root cells was also seen for the peat substrate (see Box 1; Table 2). This finding indicates lower levels of stress for the root tissues under growth with the peat substrate. Previous studies have shown that fine-root electrolyte leakage as negatively correlated with root lifespan (Bauerle et al.,