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Research paper

Effect of combined deficit irrigation and grass competition at plantation on peach tree root distribution

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A R T I C L E I N F O

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A B S T R A C T

Agroforestry systems success is predicated on the assumption of root spatial separation between the tree and the crop species. Such a feature, where tree roots prospect subsoil horizons whereas intercrop roots prospect top soil horizon is thought to eventually happen as the system ages and trees get older. However, since roots are very plastic, we can hypothesise that it is possible to shape the tree root system when trees are young, i.e. after plantation. In this experiment, we tested the hypothesis that combining a moderate water deficit to change the carbon allocation pattern in favour of root over shoot growth combined with the top soil competition brought about by the intercrop will force tree roots to grow deeper, thus leading to the vertical separation of the trees and the intercrop root systems. To test this hypothesis, a peach tree orchard was established in 2014 with three water regime treatments: (i) a fully irrigated control without intercrop (C), (ii) a moderate water deficit treatment without intercrop (RDI) and (iii) a moderate water deficit treatment intercropped with a grass + legume mixture (RDI + G). Roots were manually excavated at the end of the first and the second growing seasons and root length and biomass per soil horizon and distance to the tree trunk were measured. The juvenile tree root system in all treatments was mainly plagiotropic, reaching 1.5 m from the tree trunk (middle of the inter row) horizontally as opposed to 0.7 m vertically, without difference between treatments. The combination of water deficit and intercrop competition reduced tree root biomass fourfold in 2014 and by 3 in 2015. Tree roots in RDI + G were also excluded from the topsoil horizon (0–10 cm) due to grass + legume competition, but because of the strong reduction in their total biomass, they did not grow in deeper soil horizons than the control tree roots (C). Secondary vertical tap roots were only starting to grow by the end of the second year, suggesting that root growth at depth could not take place the year after plantation especially in grafted scions.

1. Introduction

For agroforestry systems to be beneficial and successful, complementarity in the use of above and below-ground resources between the trees and the crop must outcompete competition between species. In other words, agroforestry may produce more than monoculture only if trees acquire resources that the crop would not otherwise acquire (Cannell et al., 1996). For belowground resources such as water and nutrients, this means that the tree and the crop root systems must not overlap and be segregated in time and/or space. Vertical stratification of root systems, i.e. the tree root system exploiting the subsoil below crop roots, is indeed a desirable feature in agroforestry. However, it is not an inherent property and can possibly not be produced (Odhiambo et al., 2001; Schroth, 1999; Smith et al., 1999), mainly because most trees have their maximum root length density in the attractive nutrient rich top soil (Schroth, 1995), especially during the early stages of their development. Therefore, tree roots overlap with crop roots (Ong et al., 2002) by preferentially developing long horizontal scavenging roots (Drénou, 2006). But since trees live longer than annual crops, they eventually develop deep root systems reaching the water table (Noordwijk et al., 2015), which suggest that agroforestry trees will be more prone to deeper root growth if the soil is not too shallow and the water table not too deep. Thus, vertical stratification has been reported in agroforestry systems (Isaac et al., 2014; Yocum, 1937) and silvopastoral systems (Lai et al., 2014) and some processes able to produce such a feature have been proposed: the species specific growth habit controlled by root system architecture (Schroth, 1995), the species differential response to abiotic factors such as climate or nutrients availability (Lehmann et al., 1998), farmer's practices, i.e. shoot or root pruning (Noordwijk et al., 1991), or the root competition between two

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species (Livesley et al., 2000). In situ root architecture being the result of a tightly coupled interplay between developmental processes and environmental constrains, it can greatly vary within a species depending on the local soil context and interspecific interactions (Hodge et al., 2009; Malamy, 2005; Schroth, 1999). Abiotic factors of the local soil environment will also impact the tree root system establishment, since roots exhibit a species dependant optimum temperature growth range, cannot grow if the soil impedance is too high (Bécel, 2010) and will preferentially grow in water and nutrient rich soil patches (Hodge, 2006). Therefore, it seems that there is no such thing as an ideal agroforestry tree that will grow a deep taproot in any pedoclimatic conditions. This suggests that in a specific soil context, root pruning and/or interspecific root competition would be the best options to create vertical segregation of the root systems.

In order to create a vertical segregation of root systems by interspecific root competition and favour deep tree-root growth, Schroth (1999) identified four conditions: (i) The intercrop must be sufficiently competitive to displace the tree root system so that the root systems of the intercropped partners don't intermingle (ii) the intercrop root system must be sufficiently shallow so that the tree still have room for lateral root spread below the intercrop roots (iii) the soil conditions must permit root growth in deep soil layers (subsoil not too compact, dry or infertile) and (iv) the tree root system must be capable of responding to the restriction in surface soil layers with compensatory root growth at depth.

The purpose of this study was thus to test the following hypotheses: (1) trees growing under moderate water deficit (i.e. not inhibitory to photosynthesis) will favour root over shoot growth and increase their relative root length (Root length/Soil volume) and biomass density (Root biomass/Soil volume) as compared to the control, at least in the top soil horizon and (2) trees growing under moderate water deficit and intercropped with grass will be subjected to a competitive downward displacement of their root systems and will grow deeper than trees solely growing under the same moderate water deficit. We designed our experiment so that the three first conditions proposed by Schroth (1999) would be met, by setting up a fertilized and irrigated peach trees orchard intercropped with shallow rooted grass on a clay loam soil in the Southern France Mediterranean region. Peach trees are very sensitive to pests and water demanding (Hostalnou, 2008). The development of agro-ecological methods such as grass inter-cropping is a way of reducing herbicides use and a peach tree deep rooting a way of reducing irrigation water. Thus, the peach trees intercropped with grass agrosystem can be considered as a model, developing in France, of an agroforestry system to study the competition/facilitation relationships after plantation that may lead to the segregating of root systems sought in all agroforestry systems. Regarding the capability of peach tree root system to grow at depth, we hypothesized that the root system can be helped by stimulating root growth through manipulation of the carbon allocation between shoots and roots by a moderate water deficit (hypothesis 1). This could be done by applying a moderate water deficit, since it has been shown that a moderate water deficit inducing only a small reduction in net photosynthesis would reduce shoot growth (Forey et al., 2016), thus living more carbon to roots. We also hypothesise that young trees will be more plastic than older trees and that root of young peach tree intercropped with grass at plantation will be more easily manipulated (hypothesis 2).

2. Material and methods

2.1. Study site, plant material and experimental layout

The experiment was conducted during two years (2014 and 2015) at the INRA experimental centre in Montpellier Southern France (43.610533 N, 3.981312 E). The soil was a clay loam with a stony soil horizon at approximately a depth of 50 cm. The subsoil was decompacted down to a depth of 0.5 m before planting to remove any soil compaction (plough pan). The peach scion used was "Summerlady" (*Prunus persica*, L.) grafted on "Monctlar" rootstock (*Prunus persica,* L.). The rootstock started as seeds and once the seedling reached 5 cm in height, it was uprooted by cutting its taproot and transplanted into the nursery for grafting at the end of the growing season. After grafting, trees grew for another season and as a result, the rootstocks were two years of age at plantation. Plantation occurred in January 2014 and 475 trees were planted in a 2000 m^2 plot (2375 trees ha^{-1}), with 1.5 × 3 m spacing and a north-south line orientation on a clay-loam soil. Tree density was four times higher than in commercial plantations in order to have a more homogeneous colonization of soil by the roots around the soil water measurement probes. A Latin square design composed of three treatments replicated three times (9 elementary plots) was used: (i) C, a full irrigation control treatment with no intercropping (soil covered with a canvas which permits water flux between soil and air), (ii) RDI, a deficit irrigation treatment scheduled with tensiometers with no intercropping (soil covered with a canvas) and (iii) RDI + G, the same deficit irrigation treatment with a groundcover of grass-legume mixture (30% *Festuca ovina* + 60% *Festuca rubra* + 4% *Trifolium repens* + 6% *Trifolium subterraneum*) continuous on the whole orchard floor (that we will call hereafter "grass"). Each elementary plot held 35 trees and plots were delimited by one adjacent tree row.

Micro-irrigation was applied with four 4 $l h^{-1}$ drip emitters per tree, two emitters on each side of the Tree 40 cm away from the tree trunk. Meteorological data were collected from the automatic weather station of the INRA centre located 300 m from the study site. Trees were managed according to commercial practices for pest control and standard fertilisation in order to ensure that there were no other limiting factors than water shortage. An amount of 40 g of ammonium nitrate (33% N) per tree was applied manually under each emitter for all treatments each year at the beginning of the season, in order to avoid nitrogen stress for the trees. A second application was done in treatment RDI + G, in both years to compensate for the cover crop nitrogen uptake. The canvas (130 $g m^{-2}$) used in C and RDI was used for weed control and was made of a green woven weed barrier allowing rain water and soil evaporation to go through. The green colour was aimed to have a similar albedo than in RDI + G. Tree flowers were manually removed in all treatments in both years in order to remove any carbon competition from reproductive sinks (future fruits) and allow us to test our hypothesis of carbon allocation between two sinks (shoots and roots).

2.2. Soil water status monitoring and irrigation

Soil water potential at 40 cm depth within the tree root zone was monitored with tensiometers (SM 2000, SDEC France) 40 cm apart from the tree trunk and irrigation was applied according to tensiometers readings (manual readings every 1–3 days), in order to maintain soil water potential between −0.01 and −0.02 MPa (no soil water deficit experienced by the plant) in C and between −0.04 and −0.06 MPa (moderate soil water deficit) in RDI and RDI + G (Wery, 2005). Thus, soil water content was maintained at field capacity in the C treatment and below field capacity in RDI and RDI + G in order to create a moderate soil water deficit sufficient to limit shoot growth without impacting net photosynthesis (Pellegrino et al., 2005). The value of soil water potential at field capacity measured at a depth of 0.4 m was observed 48 h after an extreme rainfall event having ensured the refill of soil micro-porosity with water in the root zone. The amount of irrigation water differed among treatments, the objective being to manage a moderate soil water deficit experienced by the trees of similar intensity with and without grass intercropping. As shown by Forey et al. (2016), this management allowed to obtain the desired differences between treatments to test our two hypotheses: a control (C) without any stress for shoot growth and photosynthesis, and the same level of moderate water deficit in RDI and RDI + G with stronger effect on shoot growth than on photosynthesis (Table 1). Water deficit was