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Effects of olive shoot residues on shoot and root growth of potted olive plantlets

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ABSTRACT

Decomposition of olive shoot residue (OSR) from leaf shedding and pruning may provide nutrient to olive orchards, although beyond a phytotoxic threshold it can also hamper plant growth. We studied OSR decomposition effects on plant growth, biomass partitioning and soil fertility. Four levels of OSR (0%, 3%, 10% and 30% [v/v]) were mixed into the substrate and placed close to the roots compared on two olive potted cultivars over 240 days using a destructive sampling approach. Organic matter, polyphenol and nitrogen contents in the substrate, fine root respiration and electrolyte leakage, leaf pigment content, chlorophyll *a* fluorescence, biomass partitioning, fine root nutritional status were determined. OSR increased the content of organic matter, polyphenols and nitrogen in the soil. In the first 150 days, OSR beyond 3% induced autotoxic effects, and altered fine root respiration, and electrolyte leakage and biomass allocation. After 240 days, OSR induced a stimulatory effect on fine roots and shoot growth and increased shoot and fine root nitrogen content. Application OSR did not significantly altered leaf pigment content and chlorophyll *a* fluorescence. As a conclusion, above the threshold of 3%, olive cannot prevent autotoxicity during the early decomposition of OSR, but later soil fertility and plant growth can be increased.

1. Introduction

Addition of litter to the soil can influence both the nutrients and the phytotoxins. Litter decomposition governs the nutrient levels and the carbon cycle, and consequently influences the physico-chemical properties of the soil, which are the key components to maintain the productivity of natural and agro-ecosystems. In the natural ecosystem, the greater portion of the net primary production is shed as plant litter and enters the decomposition pathway. Humification to a stable organic form and mineralization of plant litter into its elemental components is thus responsible for the replenishment of the pool of plant-available nutrients, thereby maintaining the productivity of these ecosystems (Swift et al., 1979; Zucconi, 2003).

However, when the accumulation of residues from a single crop is overcoming a physiological threshold, it disrupts the humification process, inducing odd decompositions that delay stabilization and release toxic metabolites (Zucconi et al., 1984). These in turn can induce specific dispathic (detrimental or negative) effects that account for 'soil sickness' (Zucconi and De Bertoldi, 1987; Zucconi, 1993). The sensitivity of roots to the phytotoxic substances means that in addition to root competition (external function), phytotoxins might be also reduces root functioning, spacing of roots belonging to the same plant (internal function) (Falik et al., 2005). Root absorption, in particular, can be hindered by these phytotoxins (Zucconi et al., 1984; Zucconi, 2003), which promote dystrophies, root die-back, and eventually disease and abnormal root transmigration and ramification in the crop, or crops, being cultivated (Neri et al., 1996, 2005; Bonanomi et al., 2006; Giorgi et al., 2008; Polverigiani et al., 2014).

Litter decomposition rate and its role in nutrient dynamics according to environmental conditions, litter chemical characteristics and biotic factors, have all been widely studied (Coûteaux et al., 1995; Hättenschwiler and Gasser, 2005). Within any ecosystem, the plant litter quality and diversity are the main factors that affect the rate of litter decomposition (Aerts, 1997; Cadisch and Giller, 1997; Harguindeguy et al., 2008; Bonanomi and Incerti, 2010; Gangatharan and Neri, 2012). However, in tropical climates, the major regulator of litter decomposition is the rainfall pattern (Anderson and Swift, 1983), whereas temperature is the most limiting factor in temperate climates. Most frequently, in tropical ecosystems, the dry season is the time when the plants shed their

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Table 1
Changes in total organic matter, organic carbon, total N content, C/N ratio and polyphenols of growth substrate during the study period.

Uprooting time (days)	Olive shoot residue (%)	Total organic matter (g/kg)	Organic carbon (g/kg)	Total nitrogen (g/kg)	C/N ratio	Polyphenols (μg/kg)
0	Control	197.5	114.6	4.4	26.1	858.7*
	3	237.0	137.5	4.5	30.6	
	10	281.7	163.4	4.5	36.4	
	30	319.9	185.6	5.7	32.0	
	**SE	±20.7	±15.4	±0.3	±2.1	
30	Control	259.3	150.4	3.9	38.6	52.2
	3	296.2	171.8	5.0	34.4	86.3
	10	305.4	177.2	5.8	30.6	89.5
	30	315.8	173.3	7.2	24.1	110.8
	**SE	±12.3	±6.0	±0.7	±3.1	±12.1
150	Control	236.4	136.3	3.4	40.1	45.3
	3	237.0	137.5	4.2	32.8	57.3
	10	240.3	139.4	4.5	31.0	59.5
	30	320.9	186.1	7.4	25.2	88.9
	**SE	±20.8	±12.1	±0.8	±3.0	±9.2
240	Control	246.8	143.2	3.6	39.8	39.6
	3	260.0	150.8	4.8	31.4	46.8
	10	283.1	164.2	5.3	3.0	49.3
	30	286.6	168.6	6.8	24.8	61.6
	**SE	±9.4	±5.9	±0.7	±1.8	±4.6

* Polyphenols content of OSR.
** SE: standard error of the four treatments.

leaves. However, the dry hot conditions inhibit leaf decomposition, and a large amount of dead leaf litter accumulates on the forest floor, with decomposition starting with the onset of rain.

In the Mediterranean agro-ecological zone, olive-leaf shedding and shoot pruning usually happen at the end of the cold winter season, the decomposition starts with the onset of spring, and litter layers in natural plant communities are generally made up of more than one species. Most olive agro-ecosystems are devoted to mono-cropping, with little or no chance of crop rotation because of the nature of the crop, such as olive orchards that remain for decades or for centuries in the same field. The actual changes in the system of cultivation are from traditional (100–200 trees per hectare) to intensive (400–500 trees per hectare), and to super-high density (≥1000 trees per hectare) olive orchards (Pastor et al., 2007). The incorporation of pruned shoots (leaves and branches) into the soil as organic amendments is wide spreading to reduce the external fertilization supply. Thus farming intensification, coupled with the incorporation of increasing amounts of OSR from pruning, may create a new burden on the root system by inducing phytotoxic responses (autopathy) and nitrogen (N) immobilization during litter decomposition (Zucconi et al., 1984; Pastor et al., 2007; Bonanomi et al., 2011).

The objective of the present study was to investigate the autotoxic effects of OSR on shoot and root growth of potted olive plantlets during litter decomposition, and to determine whether there is any direct relationship between root stress induced by OSR decomposition and several physiological parameters associated with plant growth.

2. Materials and methods

2.1. Plant material and growth substrate

The experiment was carried out from August 2010 until April 2011 in a controlled greenhouse of the Experimental farm of Polytechnic University of Marche. One-year-old plantlets of olive (*Olea europaea* L.) cvs. Arbequina (the most used Spanish cultivar in super-high density orchards) and Frantoio (one of the most widespread Italian cultivar) were grown in 3.0-l plastic pots (0.14 × 0.14 × 0.18 m) filled with growth substrate (20% soil, 30% blend of wheat and frozen through black sphagnum peat, 50% blond sphagnum peat), plus ground and sieved OSR. The sieved OSR were incorporated into the growth substrate at 0% (control), 3%, 10% and 30% (v/v) to provide four treatment levels. Care was taken to ensure the contact of the roots with the OSR. The chemical characteristics of the growth substrate before the start of the experiment were reported in Table 1 at time zero.

The OSR were collected from a mature olive tree orchard after pruning in December 2009, and dried in the sun for 21 days and roughly ground into smaller pieces, which were further dried in the sun for 15 days. To stimulate rapid decomposition and release of nutrients and phytotoxins, these sun-dried OSR were ground to dust and sieved (to 3 mm). The sieved OSR were stored in a dry place before the beginning of the experiment, to reduce microbial degradation (Fig. 1a and b).

Before transplanting, the roots were washed under gently flowing tap water in a laboratory sink, to avoid any effects of the primary growth substrate (Fig. 1c and d).

2.2. Experimental design and green house conditions

A total of 72 olive plantlets (36 of each of the two varieties) were used, in a randomized block design with three replicates per treatment, for three uprooting dates (30, 150, 240 days after planting). For each uprooting date, one plant from each block per treatment and cultivar (for a total of 12 plants of Arbequina and 12 plants of Frantoio) was taken for the destructive measurements.

The temperature and relative humidity of the greenhouse were recorded on an hourly basis, using 175-H2 Testo sensors and a data logger (Testo, Germany). The climatic trend in the greenhouse throughout the whole experiment period is reported in Fig. 2.

2.3. Above-ground and below-ground measurements

On each uprooting date, the basal stem diameter and plant height were measured using digital calipers and a ruler, respectively. The fresh and dry weights (with drying in oven at 70 °C for 48 h) of the above-ground (stem, branches, leaves) and below-ground biomass were determined for each plant. The below-ground biomass was further divided into three groups according to the root diameter: fine roots (≤2 mm), small roots (2 to 5 mm), and coarse roots (≥5 mm). The uproots of each plant were placed on a stack of sieves of decreasing diameter (3.0–0.25 mm) and washed thoroughly in a laboratory sink with gently flowing tap water. Then the