Scientia Horticulturae 234 (2018) 236–244

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Olive tree response to applied phosphorus in field and pot experiments

Isabel Q. Ferreira[a], M. Ângelo Rodrigues[a], José M. Moutinho-Pereira[b], Carlos M. Correia[b], Margarida Arrobas[a,*]

[a] Mountain Research Centre – Polytechnic Institute of Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal
[b] Centre for the Research and Technology of Agro-Environmental and Biological Sciences (CITAB), University of Trás-os-Montes e Alto Douro, Apt. 1013, 5000-801 Vila Real, Portugal

ARTICLE INFO

Keywords:
Olea europaea
Soil P status
Olive P status
Root P
Root/shoot ratio
Acid phosphatase activity
Chlorophyll fluorescence

ABSTRACT

Phosphorus (P) application in olive orchards is very common in the Mediterranean basin although experimental evidence of crop response to applied P is practically non-existent. In this work soil P and tree P nutritional status of the olive groves of NE Portugal were assessed from a population of 1808 soil and 2252 leaf samples. Plant response to applied P was evaluated from two field and two pot experiments carried out with the cultivar 'Cobrançosa'. The analyses of soil and leaf samples of the olive orchards of the region indicate that P fertilizer recommendations should be based on leaf rather than on soil analyzes, since the latter seems to overestimate the need for P. The field and pot experiments hardly showed any positive response to P applications, which is a sign that the use of P fertilizer in olive can be substantially reduced. Nonetheless, in one pot experiment, P application significantly increased total dry matter yield during three consecutive years, in a strict association with higher tissue P concentrations and enhanced photosynthetic activity, as revealed by gas exchange and chlorophyll fluorescence traits. The experimental results also showed that the roots can uptake and store P when available in the soil, which may buffer the levels of P in the shoots. The acid phosphate activity can provide useful information but deserves caution in the interpretation of results since it depends not only on the availability of inorganic P in the soil, but also on the available organic substrate and pH.

1. Introduction

Phosphorus has prominent roles in plants as a constituent of nucleic acids and phospholipids of biomembranes and in the energy transfer reactions involving adenosine triphosphate (ATP) (Hawkesford et al., 2012; Havlin et al., 2014). P is the second most limiting element to crop growth and yield on a global scale (Li et al., 2016). The availability of P to plant roots is estimated to be limited to approximately 2/3 of the world's soils, causing a major constraint on agricultural productivity (Batjes, 1997; Sepehr et al., 2012). A number of studies have shown the effect of the application of P on the productivity increase of several crops, such as wheat (Brennan and Bolland 2001, Wang et al. 2010), soybean (Watt and Evans, 2003), canola (Brennan and Bolland, 2001) and lupine (Brennan and Bolland, 2001; Watt and Evans, 2003; Wang et al., 2010).

The use of P in agriculture has become of increasing concern due to the fact that it is a finite resource. It is estimated that the phosphate rocks from which P fertilizers are manufactured will be depleted within the next 50 to 100 years if consumed at the current rates (Gilbert, 2009; Hawkesford et al., 2012). On the other hand, the excessive use of P in agriculture can lead to the eutrophication of groundwater (Bai et al., 2016; Dodd and Sharpley, 2016). Thus, for several good reasons, it is necessary to moderate the use of P in agriculture. Different species may need different P fertilization programs since they differ greatly in the ability to use sparingly soluble P. Some species exudate organic acids to the rhizosphere which reduce pH and solubilize P (Wang et al., 2007;Veneklaas et al., 2003) and/or develops cluster roots or proteoid roots which provide enhanced zones for P uptake (Uhde-Stone et al., 2003; Schulze et al., 2006). In trees, for instance, symbiotic relationships between plant roots and arbuscular mycorrhizal fungi can be established, enhancing P uptake in ways that are not readily available to most plants (Smith and Read, 2008; Pereira et al. 2012; Havlin et al., 2014).

In olive, studies showing a positive response of the tree to P fertilizers are practically non-existent (Freeman and Carlson, 2005; Gregoriou and El-Kholy, 2010; Fernández-Escobar et al., 2017). The absence of response may be due to the very low amount of P removed in harvest, with values below 1 kg P per ton of fresh fruit (Rodrigues et al.,

* Corresponding author.
E-mail addresses: isabelaqferreira@gmail.com (I.Q. Ferreira), angelor@ipb.pt (M.Â. Rodrigues), moutinho@utad.pt (J.M. Moutinho-Pereira), ccorreia@utad.pt (C.M. Correia), marrobas@ipb.pt (M. Arrobas).

https://doi.org/10.1016/j.scienta.2018.02.050
Received 23 December 2017; Received in revised form 17 February 2018; Accepted 19 February 2018

2012; Fernández-Escobar et al., 2017). Despite the recognized lack of response by the olive tree to applied P, national P fertilizer programs are usually generous in the rates of P fertilizer they recommend. Gregoriou and El-Kholy (2010) reported a summary of the national olive fertilization programs for several countries of Western Asia and North Africa showing annual recommendations frequently exceeding 100 kg P_2O_5 hm^{-2}. In Portugal, an official publication of the Ministry of Agriculture (LQARS, 2006) recommends P rates at an olive orchard installation of 200, 150 and 100 kg P_2O_5 hm^{-2} to soils respectively classified as very low, low and medium in P. For mature trees, LQARS (2006) recommends 40–60 kg P_2O_5 hm^{-2} yr^{-1} when leaf P concentrations are found to be at adequate levels. Notwithstanding, there are no studies in the country showing olive tree response to the application of P.

This work was motivated by the lack of data on olive tree response to P fertilization. Taking into account the large area that olive occupies in the Mediterranean basin, and with phosphate rock being a finite resource, it seems of great importance to use this nutrient more responsibly. The work comprises two parts: i) evaluation of soil P and tree P nutritional status of the olive groves of NE Portugal from high number of soil (1808) and leaf (2,522) samples; and ii) experimental work, consisting of the evaluation of olive tree response to applied P in two field trials and two pot experiments. The hypothesis tested is that P being a primary macronutrient it should be expected that a positive response in tree crop growth and yield to the applied P will be found.

2. Material and methods

2.1. Evaluation of soil and plant P status of olive orchards of NE Portugal

Soil P status of the olive groves was obtained from a population of 1808 soil samples voluntarily delivered by farmers to the soil testing and plant analysis laboratory of the Polytechnic Institute of Bragança in the last 4 years. The P nutritional status of the olive trees was also obtained from 2252 leaf samples sent to the lab by the olive growers in the same period.

2.2. Field and pot experiments

The study included two field trials and two pot experiments. Field trial 1 (Ftrial1) was installed in March 2013 in a three-year-old 'Cobrançosa' olive grove, with the trees spaced 7 × 6 m, and rainfed managed (41.807665, -6.733173). The second field trial (Ftrial2) began with the plantation of 'Cobrançosa' young trees spaced 6 m between lines and 1 m within the line (41.808259, -6.733402). Planting took place in May 2014. The experimental designs of both Ftrial1 and Ftrial2 included two treatments, P fertilization (+P) and control, without P application (−P), and three replicates. In Ftrial1 the experimental unit consisted of four homogeneous trees, which total 12 trees per treatment and 24 marked trees in the total experiment. In Ftrial2, the experimental unit was composed of 10 trees totaling 60 trees in the experiment. P fertilizer in the + P treatment of Ftrial1 was broadcast in squares of 4 × 4 m around the tree. P was applied at a rate of 70 g P $tree^{-1}$, as superphosphate (18% P_2O_5), which represents 38 kg P2O5 hm^{-2}, a value within the usual recommendations to young orchards in the region when soils present medium P levels. In Ftrial2, P in the fertilized treatment was broadcast in rectangles of 10 × 4 m (2 m both sides of the row), at a similar rate of Ftrial1, which means 175 g P per experimental unit (40 m^2). In both M +P and –P treatments, nitrogen (N), potassium (K), and boron (B) were applied as a basal fertilization plan. K was applied at similar rates of P when expressed as K2O and P2O5, which means 133 and 332 g K, respectively per tree in Ftrial1 and experimental unit in Ftrial2. The fertilizer used was potassium chloride (KCl, 60% K_2O). Due to their higher mobility in the soil, N and B were applied in smaller areas, respectively in 4 m^2 (2 × 2 m, with the tree in the center of the square) and in rectangles of 20 m^2 (1 m for each side of the line) in Ftrial 1 and Ftrial2. N rates were 48 and 200 g applied as ammonium nitrate (34.5% N) in the above mentioned areas in Ftrial1 and Ftrial2. B was applied at the rates of 1.2 and 6.0 g as borax (11% B), respectively per tree and experimental unit in Ftrial1 and Ftrial2. In the year of the installation of the field trials the fertilizers were incorporated in the soil. Thereafter, the soil was no longer tilled and weeds were managed by a non-selective glyphosate-based herbicide (360 g L^{-1} of active ingredient; 4 L of herbicide hm^{-2}) applied once a year in April between rows and complemented by manual weeding close to the trees.

Table 1
Fertilizer treatments of pot experiments 1 (Pexp1) and 2 (Pexp2), rates of nutrients of the fertilizer treatments and basal fertilization plans and fertilizers used.

		Pexp1				Pexp2		
[a]Year	Nutrient	P0	P1	P2	P3	P0	P1	Fertilizer
		g pot^{-1}				g pot^{-1}		
2013	P	0.00	0.35	0.70	1.05			Super (18% P_2O_5)
	K	0.66	0.66	0.66	0.66			KCl (60% K_2O)
	N	0.80	0.80	0.80	0.80			[b]AN (34.5% N)
	Lime	5.0	5.0	5.0	5.0			[c]Lime
2014–2016	P	0.00	0.35	0.70	1.05	0.00	1.05	NP (2:8:0)
	N	0.00	0.20	0.40	0.60	0.00	0.60	NP (2:8:0)
	N	0.80	0.60	0.40	0.20	0.80	0.20	AN (34.5% N)
	K	0.66	0.66	0.66	0.66	0.66	0.66	KCl (60% K_2O)
	Micro	0.08	0.08	0.08	0.08	0.08	0.08	[d]Mixture

[a] Data of 2016 refers only to Pexp2; the rates of 2014–2016 were split into five applications.
[b] Ammonium nitrate.
[c] (88% $CaCO_3$ and 5% $MgCO_3$).
[d] (10% MgO, 0.3% B, 18.5% SO3, 0.3% Cu, 2% Fe, 1% Mn, 0.02% Mo, 1.6% Zn).

The pot experiment 1 (Pexp1) consisted of a completely randomized experimental design with four fertilizer treatments (P0, P1, P2 and P3) and 10 replicates (10 pots) per treatment. The pots were filled with 3 kg of dry and sieved (2 mm mesh) soil mixed with the fertilizer of the experimental design and those of a basal fertilization plan. The rates of nutrients as well as the fertilizers used are presented in Table 1. Semi-hardwood rooted 'Cobrançosa' cuttings, ~20 cm high, were planted in June 2013. In April 2014 a new pot experiment (Pexp2) was installed where the nutrients were applied from liquid fertilizers during the growing season. In that time, it was decided to manage the Pexp1 in a similar way by using the same liquid fertilizers (Table 1). From 2014 the fertilizers were split into five annual applications to reduce salt effect. There was also used a fertilizer consisting of a mixture of macro and micronutrients whose rates were also split into 5 annual applications during the summer growing season. Pexp2 was installed as a randomized complete block design with two fertilizer treatments, with (P1) and without (P0) P application, four different soils (the same as Pexp1 and three new soils) as blocks and six replicates (6 pots) per treatment. Each pot also received 3 kg of dry soil sieved in 2 mm mesh. Previously rooted 'Cobrançosa' cuttings of ~20 cm high were used. The pots of both the experiments were kept in a greenhouse and the fertilizers applied simultaneously with watering. The cover of the greenhouse consists of a double-wall polycarbonate panel. Aeration and heat dissipation in summer relies on lateral and zenithal openings and reflective screen.

Selected properties of the soils of the field trials and those used in pot experiments are presented in Table 2. The climate of the region is of Mediterranean type, with some influence of the Atlantic regime. The average air temperature and the precipitation of the region are respectively 12.7 °C and 772.8 mm.