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Can sustainable management models for olive groves adequately satisfy their nutritional needs?

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ABSTRACT

Two sustainable management models were studied, in order to investigate if they were successful in satisfying the nutritional needs of mature olive groves (20 year-old olive trees- *Olea europaea*, cv. 'Koroneiki'), situated in two geographical regions of Greece (Thessaloniki, Central Macedonia, Northern Greece, and Corfu, Ionian Islands, Western Greece). Nutrient supply in both olive orchards was based, during the last 20 years, on pruning material recycling, as well as on cow manure (8 t/ha/year, in the grove of Corfu) and patent kali (5 kg/tree/year, in the grove of Thessaloniki) application. Soil analysis revealed that pH was slightly alkaline in the olive grove of Thessaloniki and acidic (6.00–6.34) in the olive orchard of Corfu; organic matter content was approximately two times greater in the grove of Corfu. Exchangeable Ca concentrations in deeper soil layers (20–40 and 40–60 cm) of the olive orchard of Thessaloniki were approximately two times greater, compared to those found in the grove of Corfu. In contrast, 2–14.5 times greater K exchangeable concentrations, but only in deeper layers (20–40 and 40–60 cm), were found in the grove of Corfu. DTPA extractable Fe, Mn and Zn concentrations were 9–14, 3–5, and 3–5.5 times greater (depending on soil layer) in the olive orchard of Corfu, compared to those found in Thessaloniki. Leaf K concentrations were significantly greater in the grove of Corfu (1.2–1.4% d.w.), while Fe concentrations in the same olive orchard exceeded 120 ppm. Generally, most of the leaf nutrient concentrations for both groves were within the normal levels of sufficiency, or within the over-sufficiency range (e.g. those of N and K in the grove of Corfu, and P in both olive orchards). Only leaf B concentrations in January (17–19 p.p.m.), in both orchards, and leaf Mn levels in the grove of Corfu were slightly (but not seriously) deficient to marginal. Consequently, it can be concluded that both studied sustainable management models for mature olive groves (no soil tillage, pruning material and weed cuts recycling, in addition to: (i) patent kali, or (ii) manure supply) were successful. Thus, the two models are commercially and environmentally sustainable for olive cultivation, especially in marginal, degraded, and/or hilly Mediterranean areas. Finally, they are of great socioeconomic importance in specific rural areas (where olive-growers combine olive oil production with domestic animal breeding).

1. Introduction

Many agricultural soils in the Mediterranean basin are marginal, eroded and poor in organic C. Thus, it is important to increase organic matter, in order to maintain soil productivity and to reduce erosion and desertification (Beltran et al., 2003). For this purpose, many vegetal or animal by-products are used as organic amendments (e.g. the different kind of manures, composts, pruning materials, olive mill pomace co-compost) (Aranda et al., 2015) and other by-products. Especially, olive mill wastewaters (OMW) have been largely used as organic fertilizer in many crops (Barbera et al., 2011), in order to improve soil physical properties and to enhance nutrient availability.

Nitrogen is the most limiting nutrient, essential for optimum plant growth and crop yield. Naturally available N in agricultural soils is not usually sufficient to ensure high productivity and therefore, the application of N fertilizers is practiced worldwide (Rodrigues et al., 2011). In olive orchards, N is the most frequent nutrient applied as fertilizer; however, excessive N fertilization appears to be common among olive growers (Fernandez-Escobar, 2001). The excessive application of N fertilizers (usually KNO_3) may

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not be only unnecessary for olive trees' growth and yield, but also environmentally harmful. Environmental damage resulting from such application has been documented (Fernandez-Escobar et al., 2012). According to Fernandez-Escobar et al. (2009), N fertilization had no significant effects on yield, plant growth and fruit characteristics of olive trees for the 13 years of their study, even when leaf N concentration increased with supplemental N. In addition, leaf N concentration did not drop below 1.2% dry weight after 13 years without N application, possibly related to N inputs from rainfall and mineralization of organic N (Fernandez-Escobar et al., 2009). In Greece, a large percentage of olive orchards (especially those on hilly, sloping lands and eroded areas) are traditionally managed and organically fertilized (i.e. mineral fertilizers are not applied), with no serious nutritional issues of olive trees reported in the literature. This may indicate that the mineralization of organic N fulfills N requirements of olive trees. In these organic olive orchards soil organic matter is usually enhanced through recycling (and not burning, or removal) of pruning material. At the same time, manures are also applied (since many olive-growers own small animal farms, and hence have sufficient quantities of manure for organic fertilization).

Concerning K, which is the most important nutrient for olive trees' fruiting (Therios, 2009), it seems that the application of manures in organically fertilized olive orchards is a valuable tool, that both enhances soil K availability and K mineral nutrition (Therios, 1996). In addition, manures greatly contribute to the improvement of soil physical properties. Recent experimental data showed that olive trees receiving only K fertilization (during 7 years of experiments) grew well. Previous season foliar analysis showed levels of all macro- and micro-nutrients above deficiency (Fernandez-Escobar et al., 2015). It is conceivable that with suitable and sufficient K supply (of organic origin, compatible with biological groves), the nutritional needs of olive trees in K could be sufficiently satisfied. The different kinds of manures used by farmers significantly differ in nutrient composition, especially in N and K concentration, as well as in micronutrient content. For example, goat manure contains 2.88% K_2O, while sheep manure contains 1% K_2O, horse manure 0.60%, cow manure 0.50%, pig manure 0.38% and poultry manure contains 0.35% K_2O (Therios, 1996). On the other hand, patent kali (30% K_2O, 10% MgO, 42% SO_2) is a rich in K fertilizer, which may be used for K supply in biological agro-ecosystems (due to its origin from natural salt disposals). Its applied quantities in field should be based on soil exchangeable K and Mg concentrations, as well as on the expected production level. Generally, for olive trees a quantity of 3–5 kg/tree of patent kali is usually advised (Agrotypos-Patentkali). Our hypothesis was based on the premise that, with a combination of organic fertilization with suitable sustainable management actions (no soil tillage, composts and manures supply, patent kali, pruning material recycling), the nutritional requirements of two olive orchards (one in the experimental farm of the Aristotle University of Thessaloniki, central Macedonia, northern Greece, and the other in Corfu, Ionian Islands), of the same cultivar ('Koroneiki') and age (both 20 years old), could be adequately satisfied.

Prices of mineral fertilizers have increased in the last two decades, leading to increased production costs. In addition, there has been an increasing interest among farmers and consumers for organic foods and sustainable agriculture. Furthermore, olives may be easier adapted to organic management systems, compared to other tree crops. The best to our knowledge, no study has been published addressing the suitability and adaptation of olive tree for organic management systems. Therefore, it is important to investigate whether olive tree culture only with organic fertilization (e.g. with manures or patent kali supply, pruning material recycling e.t.c.), and no application of mineral fertilizers, can produce satisfactory crop yields. Many regions in Greece, as well as in other Mediterranean countries, are suitable for sustainable and organic olive oil production due to special socioeconomic conditions (for example, in many hilly, marginal, eroded or degraded lands, or also in other areas, where olive growers often have great quantities of manures at their disposal; this happens because they also breed domestic animals in order to achieve a better income). However, only few recently published papers from Fernandez-Escobar et al. (Fernandez-Escobar et al., 2009, 2012, 2015) documented that, in many cases, over-fertilization (especially with N) is a common practice in olive orchards. In addition, the best to our knowledge, there are only two published papers, those of Aranda et al. (2011) and Gomez-Munoz et al. (2015), discussing the effects of conventional and organic management systems for olive groves on soil organic matter and N mineralization, respectively (but not on olive trees' nutrition). In addition, only Palese et al. (2013) proposed a sustainable model for the management of olive orchards in semi-arid marginal areas, but from a socioeconomic point of view. Moreover, there are not published data studying the effectiveness of patent kali (as organic fertilizer) in sustainable management systems for olive groves.

The purpose of our study was to investigate if it was feasible to satisfy the nutritional needs of two olive orchards (cv. 'Koroneiki'), managed with sustainable models and organically fertilized during the last 20 years (with a suitable combination of pruning material and weed cuts recycling, combined with manure or patent kali supply). Since nutrient contents and removals vary according to biomass and fruit production, as well as climatic conditions (Charfi-Masmoudi and Ben Mechlia, 2009), we included two groves from different Greek regions (Thessaloniki, Central Macedonia and Corfu, Ionian islands), which significantly differ in annual precipitations and average monthly temperatures. Finally, 'Koroneiki' was chosen for study, since is the most commercially important Greek olive cultivar (widely cultivated in Greece, as well as in other Mediterranean countries), producing high oleuropein content olive oil.

2. Materials and methods

2.1. Description of the grove of Corfu

This grove is situated in northern Corfu (39°46′35.96″N and 19°56′15.38″E), 29 m above sea level and consists of 100 (20 year-old) trees (cv. 'Koroneiki'), established in a 5 × 5 m planting system. Supplementary irrigation is not in place, since annual precipitation in Corfu is sufficient (Fig. 1). The grove is fully productive with fruit collection realized in early December and with pruning following harvest. Branches with diameter >6 cm are removed from the orchard, while those having diameter <6 cm are crashed and shattered (using suitable machine), remaining on the soil surface. No soil tillage is applied, according to sustainable management practices. In order to combat pathogens, only Cu products are used. Cow manure (8 t/ha/year) is dispersed and incorporated into the soil, while poultry manure is also applied as supplementary organic fertilizer. Weed cutting is performed 4 times per year: in the middle of March, in the middle of April, in the middle of May, and at the beginning of June. Weed material is left on the soil surface.

2.2. Description of the experimental grove of the Aristotle university of Thessaloniki

The experimental grove of the Aristotle University of Thessaloniki (40°32′04.16″N and 22°59′41.33″E) is situated 8 m above sea level and consists of mature trees (20 year-old) of cv. 'Koroneiki', planted in a 6 × 6 m system. The grove is fertilized once annually, at the end of winter, with patent kali (5 kg/tree), which is a compatible fertilizer with the systems of organic agriculture (since it