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Fertilization with N and K increases oil and water content in olive (*Olea europaea* L.) fruit via increased proportion of pulp

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ABSTRACT

N and K fertilization usually increases olive fruit oil content as well as fruit size and pulp to pit ratio. The objective of this work was to investigate whether the increase in fruit oil content occurs via increased oil concentration in the pulp, or via increased fraction of pulp in the fruit. In 2009 Leccino olive trees were fertilized with the equivalent of 180 kg of urea-N, split in three equal doses (April, June, September). In April, K_2O fertilizer (potassium sulphate) was also applied for an equivalent amount of 100 kg of K_2O per hectare. Control trees were not fertilized. Fresh and dry weight of fruit, pulp and pit, fruit and pulp oil and water content, pulp firmness and fruit maturity index were measured throughout fruit growth, on fruit samples from both fertilized and control trees. At all sampling dates, fertilized plants had significantly greater fruit weight, both on a fresh (+23% on average) and dry (+17% on average) basis. Pulp/pit ratio also increased significantly with fertilization (+23%, both on fresh and dry basis). Fruits of fertilized plants also had significantly higher oil content on dry matter basis (+9% on average). However, pulp oil content did not differ significantly between treated and control plants. The same was found for water content, which was significantly higher in the fruit of fertilized plants (+5% on average), but not in the pulp. Fertilization did not affect fruit maturation (i.e., color and pulp firmness).

1. Introduction

Fertilization practices in olive-growing are widely used; nitrogen (N), phosphorus (P), potassium (K) and boron (B) are the most important nutrients applied (López-Granados et al., 2004). Nitrogen is the most limiting nutrient and the most frequently used as a fertilizer (Hartmann et al., 1966; Fernández-Escobar, 2001; Fernández-Escobar et al., 2006). Nutrient application is usually carried out as soil and/or foliar application (Sánchez-Zamora and Fernández-Escobar, 2002). An adequate level of available nutrients, based on a correct evaluation of tree nutritional status, crop demand, and nutrient availability, usually improves plant growth, fruit production, oil yield (Jasrotia et al., 1999) and fruit set (Erel et al., 2008).

Toplu et al. (2009) found that soil fertilization (i.e., urea, potassium sulphate and mono-ammonium phosphate) increases fruit and oil yield, mean fruit weight and pulp/pit ratio. Fruit oil content may increase with supplemental N–K fertilization (Toplu et al., 2009; Malek and Mustapha, 2013) or it may not increase (Talaie et al., 2001; Inglese et al., 2002; Morales-Sillero et al., 2007).

Potassium fertilization during pit hardening also increases oil content, probably since K requirements at this stage are higher (Jordao et al., 1994; Toplu et al., 2009). An increase in fruit weight, pulp weight, pit weight, pulp/pit ratio, oil content and fruit size is also reported with a combination of micro and macronutrients through foliar application (Abbasi et al., 2012).

Irrigation is also known to produce similar effects. For instance, irrigation during the enlargement of mesocarp cells increases fruit weight, percent flesh, and fruit and oil yield (Baratta et al., 1986; Lavee et al., 1990; Dettori and Russo, 1993; D'Andria et al., 2004). However, in some cases irrigation decreases oil concentration in the fruit, due to a significant increase in water content (Spiegel, 1955; Lavee et al., 1990). For instance, Chehab et al. (2013) found that individual fruit size and pulp/pit ratio increased proportionally with applied water, while oil content was negatively affected by irrigation. Attalla et al. (2011) reported increased fruit diameters, flesh thickness, pulp and pit weight, pulp/pit ratio and fruit water content under several irrigation treatments compared to the control, in mature olive trees of "Manzanillo" cultivar. In "Ascolana Tenera" irrigation resulted in higher fruit weight, volume, and pulp/pit ratio as a consequence of increased pulp water content (Proietti

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and Antognozzi, 1996). Toplu et al. (2009) found that a combination of irrigation and fertilization provided the highest yield indicating that additional irrigation along with suitable fertilization treatment could increase yield in olive trees.

The above mentioned literature shows that fertilizers and irrigation often increase both the pulp/pit ratio as well as the fruit oil content. Since pulp oil content is much higher than the pit oil content, an increase in the pulp/pit ratio implies an increase in the fruit oil content even when the oil concentration in the pulp does not change. It is possible, therefore, that the increase in fruit oil content often reported with fertilization/irrigation is at least partly explained by the parallel increase in the pulp/pit ratio, without necessarily implying increased oil concentration in the pulp. Understanding whether a given treatment actually affects the oil metabolism (i.e., the oil concentration) or whether it simply affects the proportional growth of the different tissues (mesocarp vs. endocarp) is of significant scientific and practical importance. Unfortunately, oil content is usually expressed as a percentage of the fruit mass and not of the pulp, making it impossible to ascertain whether pulp concentration is actually affected. The objective of this work was to test the hypothesis that, at least in some cases, the increase in fruit oil content with fertilization may be due to an increase in pulp/pit ratio, rather than to an actual increase in oil concentration in the pulp. To this aim, we applied a fertilization treatment with N and K fertilizers, since these two elements are among those most often reported to increase oil content in olive fruits.

2. Materials and methods

This study was carried out in an olive orchard planted in 1992 with a spacing of 6 × 5 m, located in central Italy at 500 m above the sea level. The cultivar studied was "Leccino". The orchard received 30 t ha^{-1} of sheep manure at planting and no subsequent fertilization. The soil was managed with green mulch with naturally occurring vegetation, mowed twice a year in May and June, leaving the mowed vegetation in situ as a form of organic fertilization. Given the relatively high altitude and longitude, there was no need to spray for the olive fly, and no other chemical treatments were applied for disease and pest control.

In 2009, three random trees were selected and fertilized with the equivalent of 180 kg of urea-N (based on 333 trees per hectare), split in three equal doses in April, before the new flash of vegetative growth, in June, during fruit set, and in September. In the first date of fertilizer application, K_2O fertilizer (potassium sulphate) was also applied for an equivalent amount of 100 kg of K_2O per hectare. Fertilizers were applied in an area corresponding to the tree canopy projection and, immediately after their application, the soil was tilled under each tree and up to the neighboring trees.

Fruit samples were collected on 24 September, 18 October, 3 November, 15 November, 11 December, from each of the three trees which received the chemical fertilization (i.e., fertilized treatment) and from three more trees (i.e., control treatment), randomly chosen among those not bordering trees receiving chemical fertilization (to avoid border effects). Samples of 100 fruits per tree (randomly chosen from the outside of the canopy at about 2 m of height) were collected, mixed and split into two subsamples of 50 fruits each. One subsample was used to measure fresh and dry fruit, pulp and pit weights, and fruit and pulp water content was calculated. Before de-pitting the fruits, the same subsamples was used to assess the fruit maturity index (Uceda and Hermoso, 1998), and pulp firmness (g), using a penetrometer with a point of 1 mm in diameter. The second subsample of 50 fruits per tree was used to measure total fruit oil content, using nuclear magnetic resonance (the MINISPEC mq 20 NMR Analyzer, Bruker Corporation, Billerica,

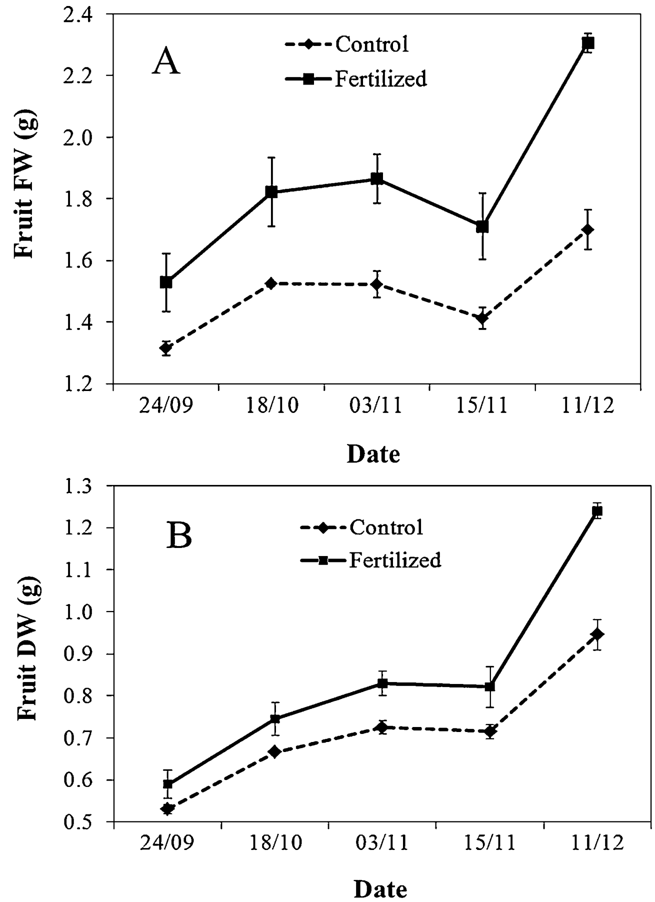

Fig. 1. Fresh (A) and dry (B) fruit weight of fertilized and control plants at different sampling dates. Data represent averages and standard errors (bars). When error bars are not visible, they are smaller than symbols. Fertilization and date effects were significant ($P < 0.01$) for both graphs, while the interaction was not significant.

Massachusetts, USA). Pulp oil content was calculated by dividing the total oil amount in the fruit by the pulp weight. This assumes that all the oil was present only in the pulp, which is a reasonable approximation since in reality 96–98% of the oil is in the pulp (Therios, 2009).

Data were statistically analyzed by a two-way ANOVA, according to a complete randomized design, and the averages were compared by the Student–Newman–Keuls Test.

3. Results and discussion

3.1. Fruit weight and pulp/pit ratio

Fertilized plants had significantly heavier fruits than control plants, both on a fresh (+23% on average) and a dry (+17% on average) weight basis (Fig. 1A and B). This was due to greater pulp size (i.e., fresh and dry weight), while pit fresh and dry weight did not differ (data not shown), resulting in significantly higher pulp/pit ratio, both on a fresh (+23% on average) and a dry (+23% on average) matter basis (Fig. 2A and B).

These results are consistent with previous reports, finding that NPK fertilizers, applied jointly, increase average fruit weight and pulp/pit ratio (Abbasi et al., 2012; Malek and Mustapha, 2013; Toplu et al., 2009). Inglese et al. (2002) reported that N and K fertilization during pit hardening increased fruit size and pulp/pit ratio. Also Ben Mimoun et al. (2004) reported that K fertilization improve yield and quality as well as fruit weight and pulp/pit ratio.