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ORIGINAL PAPER

Autumn fertilization of *Quercus ilex* ssp. *ballota* (Desf.) Samp. nursery seedlings: effects on morpho-physiology and field performance

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Abstract

• ***Background*** The Holm oak (*Quercus ilex* ssp. *ballota* [Desf.] Samp.) is an evergreen tree widely distributed in the western Mediterranean Basin. Forest restoration programs using this species have enjoyed only limited success, and knowledge concerning the effect of fertilization on plant quality and post-transplantation response is sparse.

• ***Methods*** We assessed the effect of autumn fertilization using different doses of nitrogen, phosphorus, and potassium (70.0 mg N, 30.5 mg P and 58.1 mg K during the growing phase for all plants; and 30.0 vs 1.5 mg N, 13.1 vs 0.3 mg P and 24.9 vs 0.5 mg K during the hardening phase, depending on the fertilization treatment) on the seedling characteristics and field performance of Holm oak.

• ***Results and Conclusions*** Autumn fertilization, especially with N, did not decrease plant quality but improved overall growth, root growth capacity, cold hardiness, and the nutritional content of nursery-grown seedlings. However, autumn fertilization had only a small effect on field performance, which was affected only by K fertilization, probably because of the adequate N and P nutrient status of all the plants and the mild weather conditions of the field plot. In our site, which had a mild winter climate, late autumn out-planting was more successful than was mid-winter out-planting.

Keywords Holm oak · Nursery fertilization · Cold hardiness · Nutritional status · Field performance

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1 Introduction

Quercus ilex L. (Holm oak) is a late successional evergreen tree that dominates many types of woodlands in the western Mediterranean Basin (Ruiz de la Torre 2006), and is widely used for forest restoration in such ecosystems (Rodà et al. 1999). Nevertheless, this species shows a poor early out-planting performance compared to other Mediterranean species, particularly in sites with unfavorable climatic conditions (Pausas et al. 2004). This has been attributed to water stress (Villar-Salvador et al. 2004a, b), low site fertility (Pardos et al. 2005; Sanz-Pérez et al. 2007; Valdecantos et al. 2006), and poor seedling quality (del Campo et al. 2010). This indicates that Holm oak is very vulnerable to environmental stress during early life; this is especially true for the form *Q. ilex* ssp. *ballota* (Desf.) Samp., which occurs mainly in continental and inland areas (Ruiz de la Torre 2006).

Nursery practices, environmental conditions, and genetic factors affect the functional characteristics of seedlings and field performance after transplantation (Birchler et al. 1998). Manipulation of nutrient availability is one of the most powerful tools modifying plant characteristics (Puttonen 1997). However, its effect on seedling quality and field performance of Mediterranean *Quercus* spp. still remains uncertain (Broncano et al. 1998; Villar-Salvador et al. 2004a, 2005; Oliet et al. 2009a; Trubat et al. 2010).

During the hardening phase in the nursery, environmental factors (including chill temperature, short photoperiod, irrigation, and fertilization) can induce plant dormancy and improve hardiness (Colombo et al. 2003; Fernández et al. 2008). For instance, Holm oak seedlings have reached a typical cold hardiness (temperature causing 50 % leaf tissue damage) between −13° and −19°C, depending on the