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Impact of evergreen oaks on soil fertility and crop production in intercropped dehesas

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Abstract

Dehesa, open oak woodland, is the most extended agroforestry system in Europe, with more than 3 million hectares existing in the south-western Iberian peninsula. However, today, thousands of trees are still being lost every year and soils that are more fertile have already been completely deforested. A better understanding of the effects of oak trees on crops could help in designing management practices to ensure sustainability of this traditional agroforestry system. The aim of this study was to examine the effect of Holm-oak (*Quercus ilex* L.) on soil nutrient concentration and its consequent effect on the production of understorey crops (oats: *Avena sativa* L.) in intercropped dehesas of central-western Spain. Crop production, crop plant characteristics (weight and size), the nutritional status of crop plants (N, P, K and Mg) and soil nutrient content in the topsoil layer (0–30 cm: texture, pH, soil organic matter (SOM), total and mineral N, available P, cation exchange capacity (CEC) and base cations) were determined. Samples were taken around 6 trees per plot at distances ranging from 2 to 30 m from the tree trunk, in 16 intercropped plots differing in soil fertility and fertilisation rate. Soil fertility increased near the trees, with a significant increase of SOM, total N, available P, CEC and exchangeable Ca^{2+} and K^{+}. By contrast, pH and soil particle size did not vary significantly with the distance from the tree. In unfertilised plots, trees had a positive effect on crop production, with higher crop production occurring beneath trees than beyond tree canopy projection. Fertilisers outweighed the positive effect of trees in fertilised plots, where crop production was reduced near to the trees. This could be explained mainly by management practices (biased distribution of seeds and fertilisers by broadcast spreaders), whereas light reduction probably played a minimal role (explained only 2% of the crop yield variability).

Keywords: Agroforestry; *Avena sativa*; Open woodland; *Quercus ilex*; Tree–crop interactions

1. Introduction

The presence of trees was a common feature of most of croplands in the past, where trees were believed to be beneficial for the system productivity. However, these trees were mostly eliminated in the last century in Europe (Eichhorn et al., 2006). In recent years, an increasing interest in the introduction of trees into temperate croplands and pasturelands has been emerging (Nair et al., 2004), due to the multiple environmental benefits that are generally attributed to agroforestry systems, that is, reduction of fertiliser application, control of soil erosion and nutrient leaching, increase of biodiversity and C accumulation (Garrity, 2004).

The ecological principles that define the competitive and complementary interactions among trees and crops have received considerable research attention in recent years (Jose et al., 2004). Multiple positive effects of trees in agroforestry systems have been described (Ong et al., 1996), such as a positive role of trees on soil fertility through improved utilisation and recycling of soil nutrients (Dahlgren et al., 1997; Brandle et al., 2004). Increases of crop yield in the presence of trees have also been described in temperate regions, but the presence of trees usually reduces crop yield (see Jose et al., 2004, for a review).

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Although considerable progress has been made in our understanding of the interactions between trees and crops, it is limited to only a few practices in certain regions. Much more baseline information is still needed in order to establish guidelines for tree–crop interactions and to determine the sustainability and profitability of specific systems (Jose et al., 2004).

In Europe, the most extended agroforestry system is the dehesa, with about 3 million hectares in south-western Spain and Portugal (Eichhorn et al., 2006). A dehesa is a multipurpose system of widely spaced, scattered oak trees (Holm-oak, *Quercus ilex*; cork oak, *Quercus suber*; a deciduous oak, *Quercus pyrenaica*), which forms an open permanent upperstorey, mixed with pastures or intercropped with cereal and/or fodder. Livestock is the main product of dehesas, but other products such as cereal, cork, firewood and game have been common since at least the Middle Ages (Gómez-Gutierrez and Pérez-Fernández, 1996).

Dehesas have been created mainly through the clearance of natural oak forests. Trees are maintained by selective protection of natural regeneration rather than by planting, maintaining a tree density of between 20 and 60 trees per ha, depending on its main use (lower densities in intercropped areas and higher densities in areas reserved for hunting). Apart from their direct function as ‘fodder trees’ (acorn and leaves), oaks are also maintained in the belief that they improve soil chemical fertility (Gallardo, 2003), physical fertility (Joffre and Rambal, 1988), microclimate (Moreno et al., 2005a) and pasture production in terms of yield, quality and diversity (Marañón, 1986; Puerto et al., 1990; Vázquez de Aldana et al., 2000). Additionally, herbaceous vegetation under the tree cover can lengthen its growing season in dehesas (Puerto et al., 1990).

All the aforementioned studies have been carried out in grazed dehesas, whereas no attention has yet been paid to intercropped dehesas. Many dehesas are periodically intercropped, and around 225,000 ha are cultivated each year in Spain (INE, 2002), mainly with cereals and to a lesser extent with legumes. Dehesas are cropped in a rotational cycle every 4–10 years, which aims to control shrub encroachment, to benefit the grass layer and to obtain a fodder complement for livestock, which is very useful in both dry and cold seasons. In this way, cropping is part of dehesa management for livestock.

However, in the best soils, many dehesas have been mainly (even exclusively) used for cropping. In this case, trees have been seen as detrimental for farm productivity (loss of cropped areas, competition for crops, hindered mechanisation) and millions of trees have been eliminated in the past decades (Fernández Alés et al., 1992), especially in more productive lands, where there has been an almost complete removal of tree cover.

A comprehensive, scientifically sound knowledge of the effects of trees on crop production in dehesas could contribute to avoiding the progressive elimination of this traditional and environmentally friendly agroforestry system, and it could be taken as an example of the afforestation of vast treeless croplands in Mediterranean countries. In order to understand the nature of interactions between trees and crops in dehesas, the aims of this study were:

1. To describe the soil nutrient distribution around scattered Holm-oak trees by studying soil nutrient content at different distances around trees in dehesas with different fertility and fertiliser applications.
2. To determine the effect of trees on crop plant characteristics and crop production.
3. To ascertain the relative importance of the different effects of trees on crop production: soil fertility improvement (positive interaction), below-ground competition and light reduction (negative interaction) and management practices.

2. Material and methods

2.1. Study area

The study was carried out in intercropped oak open woodlands (‘dehesas’) in central-western Spain (region of Extremadura: 38–39°N and 6–7°W), located on flat or gently sloping areas with oligotrophic, slightly acid soils, mostly classified as Cambisols and Luvisols, with the presence of some Leptosols and Fluvisols (Table 1). The climate is Mediterranean, with dry, hot summers and cool, rainy winters, a mean annual rainfall of between 500 and 600 mm, and a mean annual temperature of between 16 and 17.5 °C. Dehesas were dominated by mature Holm-oak trees (*Q. ilex* L.), ranging from 80 to 120 years old and 7–12 m of canopy width. Tree density varies from 10 to 30 trees per hectare. Plots studied were intercropped with oats (*Avena sativa* L.), which were sown by the end of October and harvested by the beginning of June. Common native weeds were *Trifolium campestre*, *Medicago polymorpha*, *Geranium molle* and *Lolium rigidum*.

2.2. Experimental layout

The study has been carried out in 16 intercropped plots, which varied in soil fertility (4 types) and in fertilisation rate (4 levels of NPK), following a multilocal design, with a plot for each combination of soil fertility and fertilisation rate (Table 1). Each plot consisted of 4 ha, selected in the middle of the cropped area of each farm (10–100 ha per farm). The study did not follow a manipulative experiment but was carried out on farm fields. This is the reason why the four plots included in the same ‘fertiliser rate’ group did not receive the same amount/type of fertiliser. Soil fertility was characterised by texture, which correlated significantly with many other soil parameters: $r > 0.30$ for soil organic matter (SOM), total N, CEC and exchangeable K^+, Ca^{2+} and Mg^{2+}.