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Higher yield and economic benefits are achieved in the macadamia crop by irrigation and intercropping with coffee

Marcos J. Perdoná[a], Rogério P. Soratto[b,*]

[a] São Paulo Agency of Agrobusiness Technology (APTA), Midwest Regional/SAA, Av. Rodrigues Alves, 4040, 17030-000 Bauru, SP, Brazil
[b] São Paulo State University (UNESP), College of Agricultural Sciences, Department of Crop Science, P.O. Box 237, 18610-307 Botucatu, SP, Brazil

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ABSTRACT

The main difficulty in expanding macadamia (*Macadamia integrifolia* Maiden & Betche) cultivation is the high payback period, which is caused by low yields and the long juvenile period. The use of technologies such as intercropping and irrigation has been suggested as a solution for this problem. For seven years, an experiment was conducted in the São Paulo State, Brazil, to evaluate the growth and yield of a macadamia crop and to analyze the profitability and payback period of the investment represented by these technologies. Treatments consisted of two cropping systems (macadamia monocropping and macadamia-Arabica coffee (*Coffea arabica* L.) intercropping) and two water regimes (without (rainfed) or with drip irrigation) and were replicated ten times. Drip irrigation and intercropping with coffee provided the greatest growth and an earlier production of macadamia. Compared with that of rainfed macadamia monocropping, the kernel yields were 51, 176, and 251% higher in the rainfed macadamia-coffee intercropping, irrigated macadamia monocropping, and irrigated macadamia-coffee intercropping treatments, respectively. Irrigation also increased the yield of coffee intercropped with macadamia; thus, the income from this cropping system was more increased. Irrigation and intercropping with coffee reduced the payback period of the macadamia crop investment. The highest profitability was achieved using both irrigation and the intercropping of macadamia with Arabica coffee.

1. Introduction

The worldwide production of macadamia (*Macadamia integrifolia* Maiden & Betche) is 140,000 tons of nuts-in-shell per year, and worldwide demand has increased by 7–8% per year in the last decade, offering good opportunities for the marketing of this nut (AMS, 2014). In Brazil, the consumption of macadamia nuts has increased rapidly; however, the industry works at half capacity due to a shortage of feedstock (nuts-in-shell) (Perdoná et al., 2013). Brazil is among the countries with the greatest potential for macadamia nut production. Large areas, including almost the entire areas of the states of São Paulo, Rio de Janeiro, and Espírito Santo and most of the states of Mato Grosso do Sul, Minas Gerais and Paraná, are favorable for the cultivation of this species (Schneider et al., 2012). Currently, Brazil produces only 3% of the worldwide macadamia production (AMS, 2014).

The long payback period, which occurs due to the low yields that are obtained in Brazil (<3000 kg ha^{-1}) and the long juvenile period of the species (5–6 years), is the main factor limiting profitability and restricting the expansion of macadamia cultivation in Brazil (Sobierajski et al., 2006; Pimentel et al., 2007). This phenomenon is also true in many other countries that grow macadamia (Hamilton and Fukunaga, 1959; Stephenson et al., 1986; Gitonga et al., 2009).

According to Sobierajski et al. (2006), orchard maintenance costs can be reduced and income can be achieved in advance by intercropping macadamia with other crops, such as coffee. van Asten et al., 2011 and Snoeck et al. (2013) obtained higher economic returns for crops of banana (*Musa* spp.) and rubber (*Hevea brasiliensis* Muell. Arg.) trees, respectively, when these species were intercropped with coffee (*Coffea arabica* L. or *C. canephora* Pierre). The use of macadamia-coffee intercropping has been attempted with success in many countries (Elevitch et al., 2009; Pezzopane et al., 2010; Steiman et al., 2011) because this nut crop grows well in traditional coffee regions (Hamilton and Fukunaga, 1959; Gitonga et al., 2009; Schneider et al., 2012). These local farmers intercrop coffee and macadamia for various purposes, including (1) maximizing coffee yield and mitigating

* Corresponding author. Tel.: +55 14 3880 7161; fax: +55 14 3880 7000.
E-mail addresses: marcosperdona@apta.sp.gov.br (M.J. Perdoná), soratto@fca.unesp.br (R.P. Soratto).

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adverse weather conditions through afforestation; (2) establishing a permanent intercropping cultivation in which both crops are produced over several years, and (3) establishing a temporary intercropping cultivation to improve the economic feasibility of implementing a macadamia orchard (Perdoná et al., 2012).

Coffee is an important crop in Brazil and is cultivated over an area of 2.3 million hectares; Brazil, representing approximately 35% of the world production, is the largest producer and exporter of coffee in the world (FAOS, 2014). In Brazil, although the main coffee and macadamia crops are monocrops, coffee-macadamia intercropping has been used with some success since the 1970s. This intercropping has had beneficial effects on coffee trees, and the expansion of this type of cultivation is favored due to the possibility of global warming. Pezzopane et al. (2010) observed a decrease of 72% in the incidence of wind and a 2.2 °C decrease in the average air temperature in intercropping systems and concluded that macadamia trees improved the microclimate for coffee growing. In Hawaii, Elevitch et al. (2009) reported advantages for coffee cultivation produced by macadamia intercropping, such as decreased temperature, higher yield and improved health. However, Steiman et al. (2011) reported that Arabica coffee yields were decreased by intercropping and did not recommend intercropping macadamia and Arabica coffee.

To increase macadamia yield and kernel recovery, Sobierajski et al. (2006) and Pimentel et al. (2007) suggested the use of other technologies, such as irrigation. According to Stephenson and Gallagher (1989), Stephenson et al. (2003) and Mayer et al. (2006), macadamia yield is greatly affected by climatic conditions, particularly by water deficits. According to São José (1991), the use of irrigation during flowering and fruit growth in Brazilian macadamia cultivation can increase fruit set and reduce premature fruit drop. At Jaboticabal, in São Paulo State, Brazil, Perdoná et al. (2013) observed an approximately 50% decrease in yield due to flower abortion when precipitation was low during the months prior to and during flowering.

In major macadamia-producing countries, similar situations occur. In many areas of macadamia cultivation in Australia, South Africa and Hawaii, the amount and/or distribution of rainfall are insufficient to sustain high nut yields (Stephenson et al., 1986, 2003). According to Stephenson et al. (2003), nut yields were reduced by 45% when water deficit stress occurred during the premature fruit-drop period (early fruit growth), and kernel recovery was reduced from 34% to 25% when water deficit occurred during the oil accumulation stage. These authors concluded that short periods of water deficit stress during any reproductive stage reduce the yield of macadamia trees.

Some studies have compared the performance of coffee when intercropped with macadamia trees and in monocropping systems (Elevitch et al., 2009; Steiman et al., 2011), but none have evaluated the growth and performance of macadamia under these conditions or measured the economic benefits arising from this practice. This information is essential for producers who wish to use this cropping system. Furthermore, the use of either intercropping with coffee or irrigation alone, as well as the combination of these technologies, has the potential to increase yields and income, reduce the payback period, and increase the economic viability of macadamia cultivation, factors that are essential to facilitate its expansion.

The aim of this study was to evaluate the growth and yield of macadamia in monocropping and intercropping systems with Arabica coffee under rainfed (without irrigation) and drip-irrigation regimes and to analyze the efficiency of these technologies in shortening the juvenile period and decreasing the payback period of macadamia cultivation in the São Paulo State, Brazil.

2. Materials and methods

2.1. Site description

The experiment was conducted in Dois Córregos, São Paulo, located in southeastern Brazil (48°22′ W; 22°21′ S and 753 m above sea level), between 2006 and 2013. The region has a Cwa tropical climate according to the Köppen classification system, with dry winters and hot and rainy summers. The long-term (50-year) annual average temperatures have a maximum of 27.6 °C, minimum of 14.8 °C, and average of 21.2 °C. In addition, the region has an annual average rainfall of 1342 mm, with approximately 85% occurring between September and April (CEPAGRI, 2014). The monthly rainfall and average temperatures were measured during the experimental period (Table 1).

The soil is classified as a sandy-textured dystrophic Typic Hapludox (Oxisol) with 103 g kg^{-1} clay, 71 g kg^{-1} silt, and 826 g kg^{-1} sand. The slope of the land is less than 6%, and the site was used as a pasture (*Brachiaria decumbens* Stapf.) before the study. At the beginning of the experiment, the chemical characteristics of the topsoil (0–0.20 m), which were determined according to van Raij et al. (2001), were as follows: organic matter (OM) of 17 g dm^{-3}; pH (1:2.5 soil/0.01 mol L^{-1} $CaCl_2$ suspension) 5.2; P(resin) of 5 mg dm^{-3}; exchangeable K, Ca, and Mg values of 0.8, 9, and 7 $mmol_c$ dm^{-3}, respectively; total acidity at pH 7.0 (H + Al) of 18 $mmol_c$ dm^{-3}; cation exchange capacity (CEC) of 35 $mmol_c$ dm^{-3}; base saturation of 49%; SO_4-S of 3 mg dm^{-3}; and B, Cu, Fe, Mn, and Zn concentrations of 0.12, 0.4, 20, 3.6, and 0.6 mg dm^{-3}, respectively.

2.2. Experimental layout and treatments

A completely randomized experimental design was used, and treatments consisted of two cropping systems (macadamia monocropping and macadamia-coffee intercropping) and two water regimes (without (rainfed) or with drip irrigation) arranged in a 2 × 2 factorial arrangement. Each cropping system occupied an area of approximately 4000 m^2, and half of each plot was irrigated. These plots were established on adjacent sections with uniform soil and topography. Within each treatment plot, ten replications (sampling units) were randomly defined. Each sampling unit had an area of 51.5 m^2 (4.9 m × 10.5 m), with one macadamia tree in the macadamia monocropping system and one macadamia tree plus twenty coffee trees in the macadamia-coffee intercropping system (Fig. 1). At least two rows of macadamia or macadamia plus coffee trees were always present as a border between the different treatment plots.

2.3. Crop planting, fertilization, weed control, and pruning

Before establishing the crops, 1300 kg ha^{-1} of dolomitic limestone was distributed and incorporated into the soil at a depth of 0.25 m through the use of a harrow disk. In addition, all of the treatments received 1000 kg ha^{-1} of dolomitic limestone applied to the soil surface in 2008, 2010 and 2012.

Fifty days before transplanting the seedlings, the holes for planting the macadamia trees and furrows for planting the coffee plants were prepared. The holes had a depth of 0.5 m and diameter of 0.5 m and were opened with a hole digger that was hooked to a tractor, and the furrows were opened using a furrower at a depth of 0.30 m. The rows of crops were planted perpendicularly to the direction of the slope in a northwest–southeast orientation.

2.3.1. Macadamia monocropping

Macadamia seedlings of the cultivar IAC 9–20 grafted on the rootstock Aloha (IAC 10–14) were planted at a spacing of