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Europ. J. Agronomy 24 (2006) 296–303
European Journal of Agronomy
www.elsevier.com/locate/eja

Modelling potential growth and yield of olive (*Olea europaea* L.) canopies

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Received 3 February 2005; received in revised form 28 September 2005; accepted 31 October 2005

Abstract

The wide variability and complexity of olive orchards makes it difficult to provide solutions to the numerous management questions using a pure experimental approach. In this paper we calibrate and validate a simple model of olive orchard productivity based on the Radiation-Use Efficiency (RUE) concept of Monteith. A calibration experiment was performed in Cordoba from 1998 to 2001 with drip-irrigated olive trees cv. 'Arbequina'. Destructive samples of 18 trees and non-destructive measurements on 80 trees were used to determine RUE and dry matter partitioning coefficients. Validation experiments were performed in 18 drip-irrigated orchards of seven locations in Southern Spain, including two cultivars ('Arbequina' and 'Picual'). Average RUE was 0.86 g dry matter $(\mathrm{MJ\,PAR})^{-1}$ which is equivalent to 1.56 g glucose $(\mathrm{MJ\,PAR})^{-1}$. Aboveground accumulated biomass was allocated equally to fruits and vegetative growth, which in turn was partitioned into 30% for leaves and 70% for stems, branches and trunk. The fraction of oil in fruits was 0.38 which implies that the average ratio oil yield/intercepted PAR, which is an equivalent RUE for oil production (ε_o), is 0.17 g oil $(\mathrm{MJ\,PAR})^{-1}$. The prediction of oil yield as the product of 0.17 and total intercepted PAR was tested successfully in the validation experiments (relative RMSE = 0.26). Errors of this simple model were partly due to alternate bearing and partly to a decrease in ε_o as canopy size increases, which deserves further research. The concept of ε_o may be also useful for the evaluation of alternate bearing in olive trees.

Estimated potential carbon sequestration by intensive irrigated olive orchards in Southern Spain was 7 t CO_2 ha^{-1} year^{-1} which is much higher than that of other agricultural systems in Europe.

The simple model of growth and yield presented herein is the core of a complete model of olive growth and yield and may be useful not only for evaluating productivity at different scales but also for solving different management problems (nutrient requirements, plant protection, etc.)

Keywords: Radiation-Use Efficiency; PAR; Radiation interception; Carbon sequestration

1. Introduction

Olive (*Olea europaea* L.) trees are grown all over the Mediterranean basin, with around 9.5 million ha. Spain is the largest olive oil producer (2.4 million ha and more than 1 million t oil) (Civantos, 2004) with areas like the Jaen province where more than 90% of the agricultural area is dedicated to olive production. Olive cropping systems, which include agroforestry stands, traditional groves and new intensive orchards, are therefore of enormous importance in both economic and ecological aspects. Despite their relevance, eco-physiological information on olive orchards is scarce, partly due to the traditional low investment in research in the main producing countries and partly to the diversity and complexity of these systems.

Several major technological changes have occurred in the olive industry during the past two decades. The traditional rain fed orchard with low density (less than 100 olive trees/ha), intensive tillage, low inputs in fertilizer and pesticides and manual harvest is being substituted by new intensive (200–400 olive trees/ha) drip-irrigated plantations, with reduced tillage, high inputs and mechanical harvesting. This transition has caused a major increase in productivity from less than 1 to more than 2 t ha^{-1} of oil and generated a large number of questions for optimizing the management of olive orchards in relation to irrigation, fertilization and prunning. The classical experimental approach is inefficient and expensive in this case, due to the large variability in environmental conditions and orchard characteristics and to the perennial nature of the species. A possible alternative is

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1161-0301/$ – see front matter
doi:10.1016/j.eja.2005.10.008

the development and use of a crop simulation model which, in combination with experimental work, allows the evaluation of responses of crop growth and yield to changes in management and environmental factors. This type of tool has been widely used in field crops (e.g. Ceres-Maize; Jones and Kiniry, 1986) and much less in forest (e.g. Hunt et al., 1991) and fruit trees (Grossman and DeJong, 1994).

The central element of most crop models is the simulation of biomass accumulation which usually follows the proposal of Monteith (1977) of the concept of Radiation-Use Efficiency (RUE) which is the ratio of biomass accumulation and radiation interception (a function of leaf area). Then biomass is allocated to the different plant organs using fixed or dynamic partitioning coefficients.

Other key components of crop models include water balance, nitrogen balance, phenology and responses of growth to water or N stress.

In the case of olive the only evaluation of RUE and partitioning has been the work of Mariscal et al. (2000b) with young trees before the onset of flower production. Other model components have been developed. The water balance of olive orchards has been the subject of much research. Olive transpiration has been studied by Villalobos et al. (2000) and Testi et al. (2004, 2006). Direct evaporation from the soil surface may be a significant fraction of total evapotranspiration and may be predicted following Bonachela et al. (1999) for rainfed orchards and Bonachela et al. (2001) for drip-irrigated plantations.

Simulation of phenological development of olive orchards may be performed using the model of Melo-Abreu et al. (2004) for flowering.

The objectives of this work were (a) to develop a simple model of potential growth and yield for olive orchards and (b) to test the model for yield prediction.

2. Materials and methods

2.1. Model description

Oil yield (g m^{-2}) may be calculated as:

$$Y = R_{sp} Q_e \, \varepsilon \, \mathrm{HI} \, F_o \quad (1)$$

where R_{sp} is the annual incoming PAR (MJ m^{-2}), Q_e the fraction of PAR intercepted by the canopy, ε the Radiation-Use Efficiency for above ground biomass production (g MJ^{-1}), HI the Harvest Index (ratio of fruit yield and total biomass) and F_o is the fraction of oil in fruit dry matter.

This equation might be simplified to the following:

$$Y = R_{sp} Q_e \varepsilon_o \quad (2)$$

where ε_o is the equivalent RUE for oil production, that is, the amount of oil produced per unit of intercepted PAR.

2.2. Calibration experiment

The experiment was performed from 1997 to 2001 on a 4 ha flat uniform olive orchard (cv. “Arbequino”) located in the Agricultural Research Center of Cordoba, Spain (37.85°N, 4.8°W, altitude 110 m). The climate in the area is typically Mediterranean, with rainfall concentrated from autumn to spring (Table 1), and an average annual reference evapotranspiration (ET_0) of around 1400 mm. The orchard was planted in summer 1997 with a 3.5 m × 7 m spacing (408 olive trees/ha), which is typical for modern intensive plantations in this zone. The orchard was drip irrigated, without water restrictions: the amount of irrigation applied ranged from 4 to 6 mm per week (applied from 9 June to 16 October) in 1998, from 4.5 to 8 mm per week (applied from 3 March to 15 October) in 1999 and from 6.5 to 10 mm per week from April to October in 2000 and 2001. The irrigation system consisted of two emitters per tree with a flow rate of 4 l h^{-1}. The fraction of soil wetted by the irrigation drippers varied from 7 to 14% depending on the amount of irrigation applied. Weed control was performed using herbicides. The soil is classified as Typic Xerofluvent of sandy-loam texture, with upper drained limit soil water content of 0.23 m^3 m^{-3} and lower limit soil water content of 0.07 m^3 m^{-3} (Testi et al., 2004).

Ten subplots of eight trees (two lines of four trees each) were marked within the orchard for non-destructive measurements such as fruit yield, trunk diameter at 0.3 m height, canopy dimensions (diameters in the *x*, normal to the row, *y*- and *z*-directions) and Leaf Area Density (LAD), i.e. leaf area per unit canopy volume.

Table 1
Average monthly weather conditions during the calibration experiment (1998–2001, Córdoba, Spain)

Month	R_s (MJ m^{-2} day^{-1})	T_{max} (°C)	T_{min} (°C)	Rainfall (mm)	Wind speed (m s^{-1})	Vapor pressure (kPa)
1	8.6	15.2	4.8	58	1.54	1.08
2	12.9	18.9	5.4	35	1.49	1.13
3	17.1	22.1	8.4	72	1.77	1.28
4	21.4	22.8	9.6	62	2.01	1.24
5	23.3	27.0	13.6	77	1.71	1.65
6	28.5	34.3	16.8	8	1.86	1.64
7	27.6	36.5	19.0	4	2.15	1.81
8	24.9	37.1	19.6	4	2.08	1.84
9	18.9	31.5	17.5	20	1.99	1.86
10	13.8	25.5	13.3	33	1.72	1.67
11	9.6	18.4	7.4	47	1.57	1.24
12	7.2	15.8	5.4	85	1.72	1.09
Total	17.8	25.4	11.7	505	1.80	1.46