Europ. J. Agronomy 66 (2015) 1–7

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

# Light interception, leaf nitrogen and yield prediction in almonds: A case study

Jose L. Zarate-Valdez[a,b,*], Saiful Muhammad[c], Sebastian Saa[d], Bruce D. Lampinen[b], Patrick H. Brown[b]

[a] *Centro Regional Universitario del Noroeste, Universidad Autónoma Chapingo, Colima 163 Norte, Cd. Obregón, Sonora, Mexico*
[b] *Department of Plant Sciences, University of California, Davis, CA 95616, USA*
[c] *Institute of Horticultural Sciences, University of Agriculture Faisalabad, Jail Road, Faisalabad, Pakistan*
[d] *Facultad de Agronomía, Pontificia Universidad Católica de Valparaíso, Casilla 4-D, Quillota, Chile*

ARTICLE INFO

*Article history:*
Received 26 June 2014
Received in revised form 3 February 2015
Accepted 8 February 2015
Available online 18 February 2015

*Keywords:*
Yield
Light interception
Canopy nitrogen
Nitrogen allocation
*Prunus* spp.

ABSTRACT

Crop yield prediction is important for the optimization of irrigation water, fertilizers, and other inputs and resources on the farm. In perennial crops, yield prediction is influenced by multiple factors regulated within the tree such as carry over effects from previous years, source-sink interactions and resource allocation and remobilization, but the bases for those regulation mechanisms are not well understood. This study reports the analysis of intensive sampling of light interception, leaf and nut nutrient concentration and yield of 768 almond trees subjected to fertilization and irrigation treatments within a mid-age commercial orchard. Nitrogen fertilization had a significant effect on individual tree fPAR, LAI, leaf nitrogen content and nut yield. While light interception and leaf area index (LAI) were poor predictors of kernel yield ($R^2 = 0.16–0.36$ for light interception and 0.21–0.40 for LAI), leaf nitrogen pool (LNP) was able to predict 71–76% of the tree yield variability observed in two and three years. Near harvest, the LNP was highly correlated with fruit nitrogen pool (FNP) ($R^2 = 0.87$). The results indicate that tree yield and nitrogen demand can be predicted based on leaf nitrogen content.

## 1. Introduction

Knowing the factors that most affect and determine yield, as well as being able to early predict yield of crops are of paramount importance. Yield prediction allows the grower to optimize the use of inputs and other resources (machinery, time, labor) required by the crop. Second, it helps the grower and the processing industry to plan the logistics related with harvest, transport and processing of the collected product. And third, yield forecasting is important in the determination of the product's price.

Crop yield may be affected by a number of genetic and environmental factors. Among the latter, ambient temperature, radiant energy, water supply, soil conditions (aeration, texture, structure, pH), biotic factors and mineral nutrition are the most important (Call, 1999).

Crop yield predictions are generally based on the accumulation of above ground biomass, which depends on a number of climatic and edaphic factors in addition to light conditions. The rate of biomass accumulation through the growth period is estimated using weather variables that affect photosynthesis, respiration and leaf development, such as radiation, temperature and precipitation. Plant biomass at a specific time can be estimated using a number of variables such as light interception, leaf area, leaf area index (Marcelis et al., 1998) or by other variables estimated through remote sensing, such as normalized difference vegetation index (NDVI), normalized difference water index (NDWI), soil adjusted vegetation indexes (SAVI) or other multispectral indices (Gommes, 1998). Yield prediction also relies upon knowledge of how much of the biomass is partitioned to the harvestable portion of the crop. For annual crops, the ratio of harvested product to above ground biomass is species dependent and can be roughly estimated using a harvest index.

Crop yield is highly correlated with canopy light interception, LAI and above ground biomass in vegetables, soybeans, maize, sorghum, cotton, rice (Gommes, 1998; Mo et al., 2005) and perennial crops (Marcelis et al., 1998; Zarate-Valdez et al., 2012). Lampinen et al. (2012) found that canopy light interception in

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[*] Corresponding author at: Centro Regional Universitario del Noroeste, Universidad Autónoma Chapingo, Colima 163 Norte, Cd. Obregón, Sonora, México. Tel.: +52 644 4137171; fax: +52 644 4137171.

*E-mail address:* jlzarate@gmail.com (J.L. Zarate-Valdez).

http://dx.doi.org/10.1016/j.eja.2015.02.004
1161-0301/

almonds, walnuts and other tree crops correlates well with maximum potential yield. They reported that the maximum sustainable yield in commercial almond orchards of California is 56 kernel kg $\mathrm{ha}^{-1}$ per each unit percent light intercepted by the canopy. The prediction of the actual yield, however, has not been evaluated at the orchard or sub-orchard level.

Nitrogen fertilization and leaf nitrogen concentration show a high correlation with biomass and yield in most agricultural crops, including almonds. Research during the last decades has focused on the improvement of crop yield by the application of nitrogen and other nutrients and by improving water supply to the plants.

Worldwide cereal fertilization rates explain more than 80% of grain yield variability (Greenwood, 1990). Nitrogen is the most limiting nutrient factor for crop growth and yield, and the assessing of plant nitrogen status to allow for maximum growth and yield, while reducing environmental impact, is a key factor in agricultural production. For nut crops such as almonds and pistachios, it has been found that most of the absorbed nutrients end up in the nuts, and thus are removed from the orchard at harvest (Brown and Rosenstock, 2006; Brown, 2010; Muhammad, 2013). One of the strategies to improve the management of nitrogen and other nutrients has been to predict yield early in the growing season to supply the nutrients at the rate and time required to reach the potential yield (Saa et al., 2014). Unlike nitrogen, the effect of other nutrients on yield has not been extensively studied.

The response of yield to nutrients and water has been extensively studied in annual crops. The prediction of yield in perennial crops is more complicated than for annual crops, since multi year photosynthate accumulation and allocation to reproductive and vegetative organs affects yield and this in turn depends on weather conditions as well as on photosynthate storage and availability (Isagi et al., 1997; Marcelis et al., 1998).

To date, no reliable method has been developed to predict almond yield for individual trees. The objective of this study was to determine how yield of individual trees is affected by canopy light interception, leaf area index, leaf nitrogen content, leaf content of other nutrients and fruit load and to know which of these variables better predicts nut yield and nitrogen contents of fruits.

## 2. Material and methods

### 2.1. Study site and fertilization treatments

This study was conducted in a commercial almond orchard located near Lost Hills, Kern County, in the southern San Joaquin Valley of California (35°30′36″N and −119°40′03″W), United States. The orchard is established on soils of fine sandy loam surface, mixed mineralogy, superactive, calcareous, Thermic Typic Torriorthents (Kimberlina), well drained, formed on nearly level Quaternary alluvium. The orchard was established in 1999 with alternate rows of Monterey (pollinator) and Nonpareil varieties at row and tree spacing of 7.3 and 6.4 m, respectively. Before 2008, water and fertilizer were both supplied uniformly (1.47 m of water to meet crop evapotranspiration and 290 kg N $\mathrm{ha}^{-1}$, 90 kg P $\mathrm{ha}^{-1}$ and no K fertilizer were applied) in the whole orchard through drip irrigation. In the spring of 2008 the orchard was divided in two blocks, one with fanjet micro-sprinkler and the other with drip irrigation. Twelve fertilization treatments (see Table 1), each replicated five to six times were randomly distributed within each irrigation system, making a total of 128 experimental units (Table 1). Fertilizer was injected through the irrigation systems. The amount of water applied was 1.2 times that of the crop evapotranspiration commonly used by local growers to schedule irrigations.

Each experimental unit included 15 Nonpareil trees of one row flanked by 30 Monterey trees in the neighboring rows. Among the 15 Nonpareil trees, only 6 tagged trees located in the middle of the experimental unit were sampled for leaf, nuts and yield, making a total of 768 monitored trees in this experiment. Almond trees in this area flower and leaf out in late February and early March with harvest occurring in August through September. Full canopy cover is reached in late April and early May.

**Table 1**
Fertilization treatments in the experimental orchard. Phosphorus application rate was 90 kg P $\mathrm{ha}^{-1}$ for all treatments.

| Treatment | N (kg $\mathrm{ha}^{-1}$) | K (kg $\mathrm{ha}^{-1}$) | Replicates per irrigation system | |
|---|---|---|---|---|
| | | | Drip | Fan Jet |
| 1 | 140 | 224 | 5 | 5 |
| 2 | 224 | 224 | 5 | 5 |
| 3 | 308 | 224 | 6 | 6 |
| 4 | 392 | 224 | 5 | 5 |
| 5 | 140 | 224 | 5 | 5 |
| 6 | 224 | 224 | 5 | 5 |
| 7 | 308 | 224 | 6 | 6 |
| 8 | 392 | 224 | 5 | 5 |
| 9 | 308 | 112 | 5 | 5 |
| 10 | 308 | 336 | 5 | 5 |
| 11 | 308 | 224 | 6 | 6 |
| 12 | 308 | 224 | 6 | 6 |

UAN, urea ammonium nitrate; CAN 17, calcium ammonium nitrate; KS, potassium sulfate; KTS, potassium thiosulfate; KCl, potassium chloride. KS was applied banded in winter, while the other fertilizers rates were split in four fertigation cycles in February, April, June and October. Indicated fertilizer rates were applied every year starting in 2008.

### 2.2. Canopy light interception measurements and LAI calculation

Photosynthetically active radiation (PAR) was intensively measured below the canopy of both sides of Nonpareil trees using a mobile platform (Lampinen et al., 2012) during July 2009, July 2010 and at the end of June 2011. The mobile platform (hereafter referred as MLB) consists of a series of 18 ceptometer segments mounted on a Kawasaki mule utility vehicle; it recorded the light under the canopy ($\mathrm{PAR}_{\mathrm{below}}$) at a height of 0.4 m from the ground as it run under the trees at a speed of 10-11 km/h. Geo-position of the PAR measurements was recorded by a differential GPS or a GPS and radar system as described by Zarate-Valdez et al. (2012). Simultaneously, a light sensor set up outside of the orchard recorded the full sun PAR (PAR above the canopy, $\mathrm{PAR}_{\mathrm{above}}$). PAR measurements were made at solar noon ±1 h and the fractional PAR intercepted by the canopy (fPAR) was calculated as

$$\mathrm{fPAR} = 1 - \frac{\mathrm{PAR}_{\mathrm{below}}}{\mathrm{PAR}_{\mathrm{above}}}$$

The MLB measured the light interception in between rows but only fPAR values corresponding to the Nonpareil trees were used for further analysis. Average fPAR values of individual trees were computed.

Leaf area index (LAI) – defined as the one sided leaf area per unit ground surface area – was calculated using fPAR and other parameters using the inverted formula for the prediction of scattered and transmitted PAR under a canopy according to the following equation (Norman and Campbell, 1989; Decagon Devices, Inc, 2008):

$$\mathrm{LAI} = \frac{[(1 - \frac{1}{2K}) * f_b - 1] * \ln\tau}{A * (1 - 0.47 * f_b)}$$

In which $K$ is the canopy extinction coefficient and is calculated as a function of the leaf angle distribution parameter – calculated as 2.3 by Zarate-Valdez et al. (2012) for the same orchard and conditions – and measured zenith angle of the sun; $f_b$ is the measured sun beam fraction of incident radiation. $A$ is the leaf absorptivity