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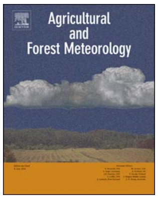

Research Paper

Evaluating AquaCrop model for simulating production of amaranthus (*Amaranthus cruentus*) a leafy vegetable, under irrigation and rainfed conditions

Z.A. Bello*, S. Walker

Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein 9300, South Africa

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ABSTRACT

Amaranthus (*Amaranthus* spp.), a leafy vegetable in South Africa, has the potential to be cultivated as a crop, but is rarely cultivated because it easily grows naturally on any waste land. The crop tolerates adverse environmental conditions, but performs better with application of water and soil organic or inorganic fertilizers. The AquaCrop crop model was calibrated and validated for amaranthus under irrigation and rainfed conditions for this study. Field experiments were carried out during the 2008–09 and 2009–10 seasons under line source sprinkler system while pot experiment was carried out during the 2010–11 season. The pot and field data sets were used for parameterisation, calibration and validation of the model. The model was adequately calibrated for biomass and cumulative evapotranspiration (ET) for amaranthus under irrigation and rainfed conditions. However, pooled data across irrigation and rainfed conditions showed canopy cover (CC) was moderately simulated (root-mean-square error (RMSE) = 20.8%; model efficiency (ME) = 0.11; R^2 = 0.577; d index of agreement (d) = 0.746; mean absolute percentage error (MAPE) = 43.4%). During validation, the model was able to adequately predict biomass and cumulative evapotranspiration (ET) for amaranthus for pooled data of irrigation (Full irrigation = W5 & Moderate irrigation = W3) and rainfed (W1) with RMSE of 1.96 t ha^{-1} and 75.64 mm, ME of 0.89 and 0.76, R^2 of 0.92 and 0.91, d index of agreement of 0.91 and 0.91 and MAPE of 24.1 and 37.6% respectively. The prediction of soil water content by the model was moderate (RMSE = 50.62 mm; ME = 0.19; R^2 = 0.30; d = 0.67; MAPE = 40.09) and needs improvement. It is recommended that datasets from other agro-ecological regions be used to improve calibration and validation for this crop.

1. Introduction

In order to bridge the gap between the increasing world population and low food production, there is need to find a sustainable and secure way of increasing food production. One of the ways of achieving this is through diversification away from over-reliance on staple crops such as maize, wheat and rice (Mayes et al., 2011). Staple crops have lost their financial benefit due to static producer prices and continuous increase in input costs (Allemann, 2004). Future challenges facing staple crop production include among others, climate change, water shortage and availability of adequate land. Therefore, there is a need for efficient crop production systems and alternative crops. Other crops are needed as an alternative to established staple crops in terms of nutritional and financial values (Allemann, 2004). Many different types of crops are consumed by humans, but their importance and potential has not been well exploited. Alternative crops have the advantages of contributing to food security and alleviating poverty by providing a means of income generation. Apart from creating new markets, another important advantage of alternative crops includes sustainable production with low inputs (Anon, 1996; Bavec and Bavec 2006; Anon, 2009). Many of alternative crops have the ability to adapt to a wide range of adverse environmental conditions such as drought, high temperature and soil with low nutrient status (van Wyk, 2011).

Amaranthus (*Amaranthus* spp.) is one of the underutilised crops out of the large rich plant biodiversity of South Africa (Cunningham et al., 1992; Jansen van Rensburg et al., 2007) which can be cultivated as an alternative crop. As an underutilized crop, it can serves as a source of livelihoods, stabilization of ecosystems and creating new markets (Anon, 2009) without displacing established staple crops (Allemann et al., 1996). Amaranthus is popular and consumed on a wide scale in South Africa due to its nutritional values and high palatability. Mostly, amaranthus is rarely cultivated because it grows easily naturally on any waste land and or during the first rains of summer (Jansen van Rensburg et al., 2007). Amaranthus becomes scarce after the first rains

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* Corresponding author.
E-mail addresses: belloz@ufs.ac.za, kunle202ng@yahoo.com (Z.A. Bello).

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due to the intensive harvest by the communities. The fact that there is little or no awareness of its ease of cultivation does not help the availability of this crop. Meanwhile, cultivation of amaranthus requires few input and less labour (Anon, 2009). In addition, amaranthus has high nutritional values (Cunningham et al., 1992; Allemann et al., 1996; Faber et al., 2010). The leaves of amaranthus have high protein, vitamin and mineral content (Makus and Davis, 1984). This is seen as a potential of the crop to serve as a source of vitamin A for nutritionally vulnerable communities in South Africa (Allemann et al., 1996; Faber et al., 2010). Amaranthus is an annual C4 plant that grows optimally under warm conditions (van den Heever and Coertze, 1996; Maboko, 1999: Schippers, 2000). Amaranthus is considered a promising crop for semi-arid regions, because of the ability to adapt to adverse environmental conditions (Cunningham et al., 1992; Allemann et al., 1996; Grubben, 2004; Maundu and Grubben, 2004). It can grow on a wide range of soils and can tolerate soil pH from 4.5 to 8.0 (Palada and Chang, 2003). The ability to tolerate salinity stress helps the plant to survive in semi-arid regions or on lands prone to high soil salinity (Omami, 2005). Irrespective of the ability of the crop to survive under adverse conditions, application of water and soil organic or inorganic fertilizer will increase fresh and dry mass production (Akparobi, 2009). Due to drought adaptation attributes, amaranthus is suitable for cultivation under South African climatic conditions. South Africa is a water scarce country with annual precipitation of around 500–600 mm (Nieuwoudt et al., 2004). To achieve high crop productivity in this water scarce region, understanding good water management with respect to types of crops to be cultivated, irrigation management and environmental sustainability are very important. These will help to develop good strategies to promote efficient water use in semi-arid regions. Crop modelling is another means of promoting efficient water use in the region. However, there is little literature information on crop modelling of alternative crops such as amaranthus. Walker et al. (2013) also observed that few of the currently available crop models have been calibrated for alternative crops.

AquaCrop is a water driven crop model developed by the FAO for simulating crop yield responses to water (Raes et al., 2009; Steduto et al., 2009). It segregates the crop responses to water stress into four separate components, namely, canopy growth, canopy senescence, transpiration and harvest index (Steduto et al., 2009). The whole concept and underlying principles of AquaCrop model is described in Steduto et al. (2009). This model was developed to help agronomists, consultants, irrigation engineers, and farm managers to increase crop water productivity under rainfed and irrigated conditions (Raes et al., 2009). Under water limiting conditions, AquaCrop can simulate water requirements, water use efficiency and crop productivity. Apart from being easy to operate when compared to other models, it also requires a limited set of input parameters for predictions. Calibration and validation of the model for cereals and root staple crops has been reported, but not for leafy vegetables. In view of this, the objective of this study was to calibrate and validate the AquaCrop crop model for amaranthus, a leafy vegetable, under irrigation and rainfed conditions.

2. Materials and methods

2.1. Site descriptions and experimental procedures

Two sets of experiments were performed for the study, namely pot and field experiments. The sets of experiments were used for calibration and validation of the AquaCrop crop model. Both sets of experiments were carried out with a genotype of amaranthus (*Amaranthus cruentus* ex Arusha) provided by the Agricultural Research Council Vegetable and Ornamental Plant Institute (ARC-VOPI, Roodeplaat). The pot experiment was carried out in a glasshouse facility of the Department of Soil, Crop and Climate Sciences, main campus, University of the Free State, Bloemfontein (latitude and longitude of 29.11°S, 26.19°E, and altitude of 1395 m). The field experiment was conducted at the Experimental field of the same department (Department of Soil, Crop and Climate Sciences), Kenilworth, 20 km North West of the main campus, near Bloemfontein (latitude and longitude of 29.02°S, 26.15°E and altitude of 1354 m). Bloemfontein has a mean annual temperature of 15.9 °C, with an average maximum and minimum of 30.8 °C and 15.3 °C during January and 16.8 °C and −2.0 °C during July respectively. The mean annual rainfall is 559 mm and the maximum is received in February with 111 mm precipitation. The patterns of daily mean air temperatures at the experimental farm for the two seasons (2008/2009 & 2009/2010) were similar (Fig. 1a). The daily mean temperatures ranged between 15.2 °C and 28.6 °C for first season and ranged from 14.2 °C to 26.8 °C for the second season. Reference evapotranspiration (ETo) for the two seasons declined with months while the sharpest decline (1.1 mm) was found in January (Fig. 1a). The ETo for the month of December was higher in the 2009/2010 season than that of the 2008/2009 season. Rainfall distribution for the two seasons indicated that the 2009/2010 season was wetter (575 mm) than the 2008/2009 season (415 mm) (Fig. 1b).

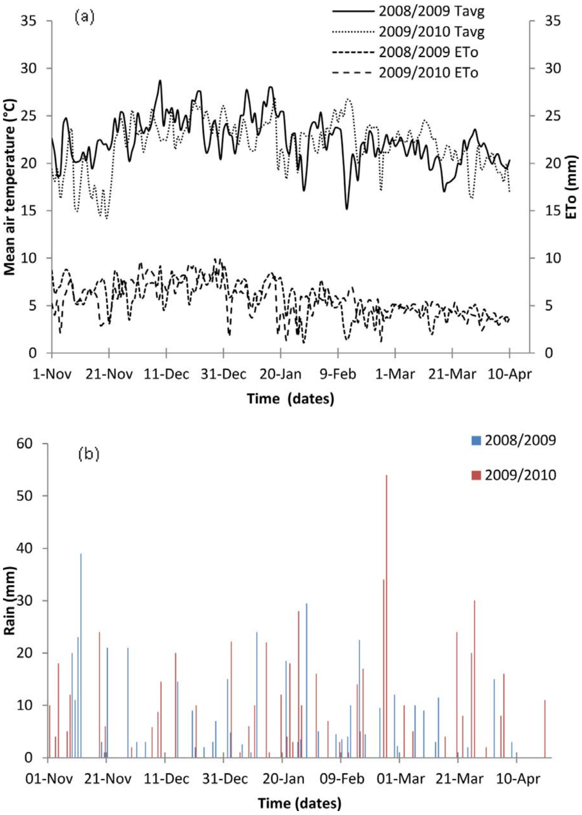

Fig. 1. (a) Daily mean temperature (T_{avg}), reference evapotranspiration (ETo) and (b) rainfall at the experimental site, Kenilworth, Bloemfontein for the two cropping seasons (2008/2009 and 2009/2010).

2.2. Experiments

2.2.1. Pot experiment

The pot dimensions were 36 cm in diameter and 28 cm high with a volume of 28.5 L. Forty pots were filled with top soil from the experimental site where field trials were conducted. The soil was oven dried at 105 °C for 24 h to determine the initial water content of the soil. All the pots were filled and then saturated with water and left to drain, and weighed daily until a constant mass was observed and recorded. Differences between the dried soil mass and drained soil mass were taken as the water content at full water holding capacity. The pots were covered with quartz gravel to minimize soil surface evaporation and two pots were left bare to serve as reference for determining the