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Parameterisation and evaluation of the FAO-AquaCrop model for a South African taro (*Colocasia esculenta* L. Schott) landrace

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ABSTRACT

Promotion of taro, a neglected underutilised crop, as a possible future crop under water-limited conditions hinges on availability of information describing its yield responses to water. Therefore, AquaCrop was calibrated and validated for the first time for an eddoe type taro landrace from South Africa, using data from pot, field and rain shelter experiments conducted over two seasons (2010/11 and 2011/12) at two locations (Pretoria and Pietermaritzburg) representative of semi-arid climates. Observed weather and soil physical parameters for specific sites together with measured crop parameters from optimum experiments conducted during 2010/11, were used to develop climate, soil and crop files in AquaCrop and to calibrate the model. Observations from the 2011/12 growing season and independent data were used to validate the model. Model calibration showed a good fit (R^2 = 0.789; *d-index* = 0.920; RMSE = 2.380%) for canopy cover (CC) as well as good prediction for final biomass (RMSE = 1.350 t ha^{-1}) and yield (RMSE = 1.205 t ha^{-1}). Model validation showed good simulation for CC under irrigated conditions (R^2 = 0.844; *d-index* = 0.998; RMSE = 1.852%). However, the model underestimated CC under rainfed (R^2 = 0.018; *d-index* = 0.645; RMSE = 20.170%) conditions. The model predicted biomass (R^2 = 0.898; *d-index* = 0.875; RMSE = 5.741 t ha^{-1}) and yield (R^2 = 0.964; *d-index* = 0.987; RMSE = 1.425 t ha^{-1}) reasonably well for pooled data [field (RF and FI) and rain shelter (100, 60 and 30% ETa)]. The model also predicted biomass (R^2 = 0.996; *d-index* = 0.986; RMSE = 1.745 t ha^{-1}) and yield (R^2 = 0.980; *d-index* = 0.991; RMSE = 1.266 t ha^{-1}) well for the independent data set.

1. Introduction

Taro (*Colocasia esculenta* L. Schott) is a major root crop of the Araceae family (aroid) with its centre of origin in the Indo-Malay regions (Kreike et al., 2004; Lebot et al., 2005). In South Africa, it is considered as an "indigenised" traditional crop and has undergone many years (>100 years) of cultivation. It has been suggested that, over the years, through natural and farmer selection (Schippers, 2002, 2006) and often under harsh conditions, local taro landraces may have "acquired" drought tolerance. The growing concern regarding climate change and water scarcity has led to renewed interest in identifying previously underutilised indigenous and traditional crops as possible drought tolerant crops for the future in South Africa (Mabhaudhi, 2009). Recently, Mabhaudhi (2012) and Mabhaudhi et al. (2013a,b) observed physiological and phenological traits that suggest that local taro landraces may be adapted to limited water conditions. Despite such possibility, taro remains an underutilised crop in South Africa and the region owing to limited research that has been conducted on the crop as well as the view that it is a 'water-loving crop'.

Although taro, a wetland crop, is associated with high levels of water-use; in South Africa, a great deal of taro production is rainfed and occurs inland under water-limited conditions (Modi, 2004; Shange, 2004). Successful commercialisation of the crop (Modi, 2003) has also led to increased taro production and expansion into areas with limited water availability. Lack of quantitative information describing its agronomy and water-use now proves to be a major hindrance to its further promotion in areas outside of the traditional growing areas. With the threat of climate change (Schulze, 2011; de Wit and Stankiewicz, 2006;Hassan, 2006) and in the absence of extensive, and often costly, agronomic trials, the use of well calibrated and validated crop models may prove useful to generate such information.

Crop models have proved to be useful tools for estimation of crop yields (Azam-Ali et al., 2001; Steduto et al., 2009; Singels

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et al., 2010) and for comprehensive synthesis of quantitative understanding of physiological processes as well as for evaluating crop management options. However, crop models have not been fully explored for NUS such as taro landraces. Previous efforts to model taro were based on the SUBSTOR-Aroid model (Singh et al., 1998) which is housed in DSSAT (Jones et al., 2003). However, these efforts only considered hybrids. Furthermore, the application of the model has been limited; this is possibly due to the complexity and input requirements which often make it difficult for researchers in developing countries to run these models (Mabhaudhi et al., 2014). There is therefore need to come up with a simpler model with minimum input requirement that can be used to model yield response to water and for evaluating management options for NUS such as taro landraces.

AquaCrop (Raes et al., 2009; Steduto et al., 2009) is a water-driven crop model developed by the FAO for simulating yield responses to water. The model has been previously used for several NUS such as quinoa (Geerts et al., 2009), bambara groundnut (Karunaratne et al., 2011; Mabhaudhi et al., 2014), orange fleshed sweet potato (Beletse et al., 2011) and pearl millet (Bello et al., 2011). The authors reported that AquaCrop was ideal for simulating NUS due to its ease of calibration and minimum input requirements compared with established models. Also, in most cases, there were no established models developed for these NUS. There is a need to continue with the efforts to model NUS and boost their profile in terms of availability of quantitative information.

Currently, AquaCrop has not been parameterised for any plant species in the aroid family. It is also not clear whether AquaCrop's generic crop file for root and tuber crops is capable of being parameterised for taro which has a unique growth pattern. Therefore, the aim of the current study was to parameterise and evaluate the FAO's AquaCrop model for a taro landrace from South Africa. Such a model would have huge applicability in future studies on promoting the cultivation of the crop under limited water conditions as well as contribute towards policy formulation on NUS.

2. Materials and methods

2.1. Study site descriptions

Field and rain shelter experiments (Table 1) were conducted at the Agricultural Research Council-Roodeplaat, Pretoria (25°60′ S; 28°35′ E; 1168 m a.s.l) and Ukulinga, Pietermaritzburg (29°37′ S; 30°16′ E; 775 m a.s.l), during the 2010/11 and 2011/12 summer seasons. Soil in rain shelter trials at Roodeplaat was classified as sandy clay loam (USDA taxonomic system) (Table 2). The average, within season rainfall (November to April) of Roodeplaat is about 500 mm, and is highly variable with maximum precipitation in December and January. Daily maximum and minimum temperature averages are 34 °C and 8 °C in summer (November–April). Ukulinga represents a semi-arid environment and is characterised by clay-loam soils (USDA taxonomic system) (Table 2).

2.2. Experiments

Controlled (pot), field and rain shelter experiments were conducted over two season (2010/11 and 2011/12) across different locations for taro in order to develop crop specific parameters to calibrate and validate the FAO AquaCrop model.

2.2.1. Plant materials

Three taro landraces – Dumbe Lomfula, KwaNgwanase and Umbumbulu, were collected from different areas in KwaZulu-Natal, South Africa. Dumbe Lomfula is a wild type; KwaNgwanase is semi-domesticated while the Umbumbulu landraces is well-domesticated and widely cultivated inland.

2.2.2. Pot trials

The objective of the pot trials was to evaluate emergence, canopy expansion and stomatal closure and their sensitivity to water stress. These trials were conducted during 2010 under simulated drought conditions, in tunnels at the University of KwaZulu-Natal, Pietermaritzburg. The experimental layout was a completely randomised design (CRD) with two factors: landrace type (3) and water stress (no stress, intermittent stress and terminal stress), replicated six times. Details of experimental designs, procedures and measurements taken are described in Mabhaudhi et al. (2013a).

2.2.3. Rain shelter trials

The objective of the rain shelter experiments was to evaluate growth, yield and water-use of taro landraces in response to a range of water regimes. With regards to modelling, the experiments were designed to contribute in developing parameters for maximum canopy cover and effect of stress on canopy expansion as well as stomatal conductance. Details of experimental designs, procedures and measurements taken are described in Mabhaudhi et al. (2013b).

The experiments were conducted during 2010/11 and 2011/12 growing seasons at Roodeplaat, Pretoria. The experimental design was a factorial experiment laid out in a randomised complete block design with two factors: irrigation level and landrace type (3), replicated three times. The three irrigation levels were 30, 60 and 100% of crop water requirement (ETa), delivered using drip irrigation system. The rain shelters have a total area of 288 m^2, with individual plot size of 6 m^2. Plant spacing was 0.6 m × 0.6 m translating to 27 758 plants per hectare. The rain shelters operate on electric power and automatically cover the experimental crop when it is raining, but otherwise remain open, positioned at least 5 m from the field. Therefore, except when it was raining, the crops experienced normal field conditions. Irrigation scheduling was based on ET_o and a crop factor (K_c) delivered daily.

2.2.4. Field trials

The objective of these trials was to determine the mechanisms involved in taro landraces' drought tolerance under field conditions. Data collected from these experiments contributed in developing parameters for time to emergence, initial cover, and times to maximum canopy cover, senescence and maturity as well as harvest index. Details of experimental designs, procedures and measurements taken are described in Mabhaudhi (2012).

Taro landraces were planted during the 2010/11 and 2011/12 growing seasons at Ukulinga, Pietermaritzburg, in a split-plot design arranged in a randomised complete block design. Irrigation [full irrigation (FI) vs rainfed (RF)] was the main factor with landrace type (3) as sub-factors, replicated three times. The total size of the field trial was 499.8 m^2. Main plots (FI and RF) measured 207.4 m^2 each, with 15 m spacing between them and sprinklers were designed to have a maximum range of 6 m radius to prevent water sprays from reaching RF plots. Sub-plot size was 17 m^2 with an inter-plot spacing of 1 m, and plant spacing of 1 m × 0.5 m, translating to 20 000 plants per hectare. Irrigation scheduling for the FI treatment was based on ET_o and a crop factor. During the 2010/11 growing season, 912 mm of rainfall were received compared to 622 mm received during 2011/12 growing season. Supplementary irrigation amounted to 879 mm and 740 mm during 2010/11 and 2011/12 growing seasons, respectively. Less supplementary irrigation was applied during 2011/12 growing season because the taro crop was harvested earlier than in the preceding season.