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A physiological production model for cocoa (*Theobroma cacao*): model presentation, validation and application

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Abstract

In spite of the economic importance and extensive agronomic literature on cocoa, no physiological production model has been developed for cocoa so far. Such a model would be very useful to compare yields in different climates and cropping systems, and to set the agenda for future agronomic research. Here, we present and apply such a physiological growth and production model for cocoa (SUCROS-Cocoa), based on the SUCROS-family of physiological crop growth models. Our model calculates light interception, photosynthesis, maintenance respiration, evapotranspiration, biomass production and bean yield for cocoa trees grown under shade trees. It can cope with both potential and water-limited situations, and is parameterised using existing information on cocoa physiology and morphology. A validation study showed that the model produces realistic output for bean yield, standing biomass, leaf area and

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size–age relations. Simulations were carried out using climatic information of 30 locations in 10 cocoa-producing countries, three different soil types and varying shade levels.

The model was applied to answer four questions that are currently relevant to cocoa production. (1) Which are the most important yield-determining parameters? Sensitivity analyses revealed that these parameters were chiefly related to the morphology of fruits, photosynthesis and maintenance respiration. (2) To what extent can cocoa yield be predicted by rainfall and irradiance data? Regression analyses showed that over 70% of the variation in simulated bean yield could be explained by a combination of annual radiation and rainfall during the two driest months. (3) How large is the cocoa yield gap due to water limitation? Yield gaps were large – up to 50% – for locations with a strong dry season combined with an unfavourable (clayey or sandy) soil. The calculated yield gaps decreased exponentially with the amount of rain during the two driest months. (4) What are the consequences of shading on cocoa yield? Our simulations showed that moderate shade levels hardly affected bean yield, whereas heavy shading (>60%) reduced yields by more than one-third.

Keywords: Crop production; Cocoa; Cacao; *Theobroma cacao*; Simulation models; SUCROS

1. Introduction

Physiological growth and production models have shown to be very useful for guiding improvements in cropping systems of various annual crops (e.g., wheat, rice, potatoes; Van Laar et al., 1997; Bouman et al., 2001; Wolf, 2002). Such simulation models have been constructed for a large number of short-lived crops (e.g., Marcelis et al., 1998; Van Ittersum and Donatelli, 2003; Van Ittersum et al., 2003). They provide insight in the functioning of cropping systems, by applying a system's approach (De Wit et al., 1978; Leffelaar, 1999). For perennial crops much less work on production models has been carried out (Cannell, 1985; Van Kraalingen et al., 1989; Mohren et al., 1984; Wagemakers, 1995), probably due to data limitation, relatively high research costs and the difficulties of accumulated errors in long-term simulations.

Cocoa (*Theobroma cacao*) is one of the most important perennial crops worldwide, with an estimated world production of 2.8 million tons in 2002 (FAO, 2003). Although the body of cocoa research is very large (e.g., Ahenkorah et al., 1974; Alvim, 1977; Wood and Lass, 1985; Somarriba et al., 2001), the results of cocoa studies have never been integrated into a physiological production model. The cocoa production models that have been established so far are either regression-based models with limited applicability for locations other than the ones for which data were collected (e.g., Fassbender et al., 1991; Beer et al., 1990), or are conceptual models which are not suitable for yield simulations (e.g., Hutcheon, 1976; Alvim, 1977; Balashima, 1991; Yapp and Hadley, 1994 but see Ng, 1982). For cocoa, physiological simulation models may be valuable to compare attainable cocoa production between locations, soil types and cropping systems, to obtain insight in the main factors determining yield and to identify gaps in knowledge on cocoa production.