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Development of an oil palm cropping systems model: Lessons learned and future directions☆

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ABSTRACT

Oil palm has become one of the most important crops in the world with questions being raised about its economic and environmental sustainability. Agricultural systems models are regularly employed in studying sustainable crop management but no detailed model is currently available for oil palm systems.

We developed a production systems model for oil palm within the Agricultural Production Systems Simulator (APSIM) framework and tested it using data across a range of environments within Papua New Guinea (PNG). The model captured key growth responses to climate and management. This demonstrates that modern modelling frameworks do allow for rapid model development for new agricultural systems.

However, whilst application of the model is promising, the availability of key data is likely to restrict its use. Local soil and weather data are not available in adequate detail for many of the major oil palm production areas, although some methods exist to address this.

Software availability

Software name: APSIM-Oil Palm
Developer: Neil Huth
Contact address: CSIRO (Toowoomba, Australia) (neil.huth@csiro.au)
Year first official release: 2014
Software requirements: APSIM version 7.6 or higher
System requirements: Microsoft Windows (XP or later)
Availability: www.apsim.info
Licence: APSIM is freely available for non-commercial use which includes public-good research & development and educational activities
Documentation and support for users: APSIM online training and documentation, example simulations, APSIM User Forum (www.apsim.info).

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) has become one of the world's major crops, being cultivated on more than 16 million hectares (FAO, 2013). The industry is expanding rapidly due to consumer demand and will continue to do so into the foreseeable future, providing both increasing benefits and risks for communities and the environment (Sayer et al., 2012). To optimise benefits and sustainability, it is necessary to maximise yields within the constraints imposed by genetic and environmental factors, while minimising detrimental impacts to the surrounding environment. Areas of concern and in need of further research include balances of carbon, water, energy and nutrients and related soil losses and how these processes can be measured and managed (Nelson et al., 2010; Sheil et al., 2009). However, the amount of work required to adequately investigate these areas is large because of the wide range of environments (soils, climate, and landscape) and possible management interventions (e.g. fertiliser, palm or understory management).

Agricultural systems modelling approaches are often used in sustainability studies, in concert with field measurements, to estimate the likely environmental impacts of management strategies. For example, Vogeler et al. (2013) used systems modelling to

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evaluate the impact of greenhouse gas mitigation strategies on nitrogen leaching losses in New Zealand pasture systems and Nelson et al. (1998) used the same modelling environment to test the economic viability of farming systems designed to minimise erosion losses in the Philippine uplands. Analyses such as these can help explain field observation and allow the investigation of large numbers of management scenarios across a range of environments. However, for the relatively new oil palm production systems, such a modelling capacity has not been readily available. In this paper we seek to address this and learn how modern environmental modelling processes facilitate model development for new agricultural systems.

The construction of a systems modelling capacity for any agricultural system requires four things: detailed data and understanding of the system, a framework for integrating model components, methods for testing or evaluating the model, and data describing the environments for which the model is to be employed. Detailed datasets for oil palm growth and development (Breure, 1988a,b; Henson and Dolmat, 2003; Henson et al., 2007) and water and nutrient fluxes (Banabas et al., 2008a,b) are available following standard methodologies used throughout the industry (Corley et al., 1971). The availability of large amounts of data of high quality is of great benefit and this paper will demonstrate how these can be used to develop a model for oil palm growth.

To date, an adequate integrated agricultural systems modelling framework has not been developed for oil palm production systems. However, the components to create such a system are currently available. Several oil palm growth models have been developed and tested in the major production areas. These include OPSIM (van Kraalingen et al., 1989), OPRODSIM (Henson et al., 2007), WaNuLCAS (Van Noordwijk et al., 2011) and ECOPALM (Combres et al., 2013). Models for soil and environmental processes are also available (Coleman et al., 1997; Del Grosso et al., 2009; Huth et al., 2012; Probert et al., 1998), as are integrating frameworks (e.g. David et al., 2002; Knapen et al., 2013; Moore et al., 2007) that combine various models into a single agricultural systems model for a particular problem domain. In this paper, we combine approaches from existing oil palm models and other knowledge of oil palm growth and development to create a model of oil palm production within the APSIM framework (Holzworth et al., 2014; Keating et al., 2003). This integration with existing APSIM soil models will allow, for the first time, the specification of a model for crop growth and carbon, nutrient and water cycling in an oil palm production system.

Testing of such an integrated systems model requires appropriate methods for evaluating model performance (Jakeman et al., 2006; Prisley and Mortimer, 2004; Rykiel, 1996). This evaluation needs to include a wide range of detailed model tests that exercise a model at various levels and investigate responses to the range of environments likely to be specified by users (Holzworth et al., 2011). Furthermore, appropriate statistical methods for quantifying model performance against these tests are required (Moriasi et al., 2007) including estimates of model uncertainty and parameter sensitivity (Hamby, 1994; Refsgaard et al., 2007; Saltelli et al., 2004). In this paper, we perform an initial comparison of the newly developed model against data from a range of environments using a range of established statistical measures.

Finally, good quality data are required to characterise the various environments being modelled and large datasets for soils (Batjes, 2009; Romero et al., 2012) and climate (Jeffrey et al., 2001; Weedon et al., 2011) are now becoming available. Databases such as these are important in countries where data are limited. However, some modelling uncertainty will derive from the quality of these input data. Previous studies have shown differences in model output for simulations of a given environment when parameterised using different data sources (Pogson et al., 2012; Ramarohetra et al., 2013). The paucity of existing environmental data is an important issue for many oil palm production regions and so this study provides an initial evaluation of these datasets for detailed environmental modelling in Papua New Guinea.

2. Model development

The APSIM oil palm model described here (APSIM-Oil Palm) was developed and is maintained within the APSIM Community Source Framework (www.apsim.info). The APSIM modelling framework has been developed to simulate biophysical process in farming systems where there is interest in the economic and environmental outcomes of management practice in the face of climatic risk, climate change or changes in policy (Keating et al., 2003). APSIM has been used in on-farm decision making, farming systems design, assessment of seasonal climate forecasts, analysis of agribusiness supply chains, development of waste management guidelines, risk assessment for government policy and as a guide to research and educational activities. APSIM's component-based design allows models to interact via a communications protocol (Moore et al., 2007). Models are available for over thirty crop, pasture and tree species as well as for the main soil processes affecting agricultural systems (e.g. water, C, N and P dynamics, and erosion). APSIM also provides a flexible agricultural management capability enabling the user to specify complex crop rotations and land management regimes (Moore et al., these proceedings). The role of APSIM-Oil Palm within an APSIM simulation is to calculate the growth, development, resource use and organic matter flows for the plant and to communicate this information to other models within the simulation.

APSIM-Oil Palm was developed using the Plant Modelling Framework (PMF) (Brown et al., these proceedings). The PMF provides the model developer with a library of objects describing commonly-used functions or algorithms for plant modelling. These are configured by the modeller into a model description using the eXtensible Markup Language (XML). APSIM-Oil Palm has been configured to simulate the growth of fronds, stem, roots and bunches in oil palm. The models for each of these are briefly described below. Fronds and fruit bunches are simulated in age-based cohorts created at the initiation of each successive frond and their subsequent development is traced via the rank of each cohort within the palm (Fig 1). Both the lowest (oldest) frond and lowest (oldest) bunch are removed at the harvest of a cohort.

2.1. Canopy

Frond initiation is calculated using an age-dependent plastochron (Fig 1e) which increases until age 10 years (von Uexküll et al., 2003). This value represents the shortest time interval between the initiation of successive fronds. The impact of temperature on plastochron is captured via a daily relative developmental rate (RDR) which is calculated in a manner similar to that of Combres et al. (2013). The four cardinal temperatures (Fig 1d) were fitted to frond appearance data from the three sites used in model testing. The model assumes that plastochron and phyllochron are equivalent. After emerging as the ‘spear leaf’, the frond undergoes expansion for a further 5 phyllochrons. Each frond expands in a logistic fashion using the equations developed by Schultz (1992) for modelling leaf expansion in grapes. The maximum frond size increases to 14 m^2 at age 14 years (Fig 1c).

Whilst seasonal variation in clear sky solar radiation is low in most regions located near the equator, variation from clouding in high rainfall environments is significant. Photosynthesis is calculated using a radiation use efficiency (RUE) of 1.22 g MJ^{-1} of