Field Crops Research 210 (2017) 20–32

Contents lists available at ScienceDirect

Field Crops Research

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

Yield and nitrogen losses in oil palm plantations: Main drivers and management trade-offs determined using simulation

Lénaïc Pardon[a,c,*], Neil Ian Huth[b], Paul Netelenbos Nelson[c], Murom Banabas[d], Benoît Gabrielle[e], Cécile Bessou[a]

[a] CIRAD, UPR Systèmes de pérennes, pôle ELSA, F-34398 Montpellier, France
[b] CSIRO, Toowoomba, Australia
[c] College of Science and Engineering, James Cook University, Cairns, Australia
[d] Papua New Guinea Oil Palm Research Association, Dami, Papua New Guinea
[e] AgroParisTech, INRA, Université Paris-Saclay, UMR EcoSys, 78850 Thiverval-Grignon, France

ARTICLE INFO

Keywords:
APSIM-Oil palm
Morris sensitivity analysis
Perennial crop
Environmental impact
Nutrient use efficiency

ABSTRACT

Oil palm cultivation has environmental impacts, including those associated with nitrogen (N) losses. Improving management practices to optimise yield and N losses is critical. In order to identify the key management and site parameters driving yield and N losses, over a 25-year cycle, we undertook a Morris's sensitivity analysis of the Agricultural Production Systems sIMulator oil palm model (APSIM-Oil palm), using 3 sites in Papua New Guinea. We selected 12 parameters and 3 outputs: yield, nitrous oxide (N_2O) emissions and N leaching. The influence of the 12 parameters on the outputs depended on site characteristics, age of the palms, and climate. The most influential parameters for losses were N mineral fertiliser rate, drainage and fraction of legume in groundcover vegetation. The simulations suggested that APSIM-Oil palm is a useful tool for assessing management options for optimising yield and environmental outcomes in different environments. The results can also guide future measurements needed to improve N loss estimates, and further development of models and risk indicators.

1. Introduction

Oil palm is an important crop for global production of vegetable oil and the economies of tropical countries. The area of land under oil palm cultivation, currently approximately 19 M ha, has been rising at 660 000 ha^{-1} yr^{-1} over the 2005–2014 period (FAOSTAT, 2014) and is likely to continue rising until 2050 (Corley, 2009). This expansion raises environmental concerns, not only regarding land-use change and its consequences, but also concerning potential impacts of losses of nitrogen (N) from fields during cultivation. Addition of N via fertilisers and biological fixation (by legume cover crops) is a common practice to help achieve the yield potential of the crop (Corley and Tinker, 2015; Giller and Fairhurst, 2003). However, this addition is associated with potential risks of N losses into the hydrosphere and atmosphere, and subsequent environmental impacts such as terrestrial acidification, fresh water eutrophication, or climate change. For instance, a life cycle assessment study estimated that the addition of N fertiliser was responsible for 48.7 % of the greenhouse gases emitted during the cultivation period to produce 1 t of oil palm fruit bunches (Choo et al., 2011).

Reducing N losses requires identification of their drivers throughout the oil palm growing cycle, which spans about 25 years. A recent literature review showed that N losses remain the most uncertain and least documented of N fluxes in oil palm systems (Pardon et al., 2016a). The largest and most environmentally significant losses are N leaching and N_2O emissions, both of which are influenced by environmental conditions and management practices (Pardon et al., 2016a). At the global scale, the main climatic driver for both N leaching and N_2O emissions is known to be rainfall. Regarding soil properties, N leaching losses are driven largely by soil N content and texture (Mulla and Strock, 2008) and N_2O emissions are driven mainly by soil texture, content of water, N and organic C, pH and temperature (Stehfest and Bouwman, 2006). However, the main drivers of N losses in oil palm systems are likely to differ from those applying to annual crops under temperate climates. First, tropical soils often have an acidic pH, and their temperature variability is often lower than in temperate areas. Furthermore, water-related factors are usually important in tropical contexts, due to higher rainfall. Second, the substantial amounts of N and C entering the soil in oil palm systems may have a particular impact on N losses (Pardon et al., 2016a). Third, the legume cover usually

* Corresponding author at: TA B-34 / 02 - Avenue Agropolis, 34398 Montpellier Cedex 5, France.
E-mail addresses: lenaic.pardon@cirad.fr (L. Pardon), neil.huth@csiro.au (N. Ian Huth), paul.nelson@jcu.edu.au (P. Netelenbos Nelson), murom.banabas@pngopra.org.pg (M. Banabas), benoit.gabrielle@agroparistech.fr (B. Gabrielle), cecile.bessou@cirad.fr (C. Bessou).

http://dx.doi.org/10.1016/j.fcr.2017.05.016
Received 22 November 2016; Received in revised form 19 May 2017; Accepted 23 May 2017
0378-4290/

established under young palms may influence N dynamics and losses (Pardon et al., 2016a).

Modelling is an essential tool for estimating losses and identifying key drivers, since direct measurements and experimentation are prohibitively difficult and costly, especially over the long growing cycle of oil palm. N management inevitably involves trade-offs between achieving high yields and minimising environmental impacts, and models that simultaneously simulate yield and N losses allow such trade-offs to be examined. Several models are available for estimating N losses in oil palm, but they give widely divergent estimates of losses due to their diverse structures and assumptions (Pardon et al., 2016b). There exist other models such as OPRODSIM (Henson, 2005), PALMSIM (Hoffmann et al., 2014) or ECOPALM (Combres et al., 2013) that were calibrated to simulate the growth of oil palm and its potential fruit yield, but those do not estimate emissions to the environment. Two models simulate the impact of management practices, such as organic matter application and legume cover establishment, on both yield and N losses in oil palm systems (Pardon et al., 2016b): APSIM-Oil palm (Huth et al., 2014) and WANULCAS (Noordwijk et al., 2004). APSIM-Oil palm has published validation and test data sets for yield response to N fertiliser, at several sites in Papua New Guinea, and so was chosen for this study. This model was developed using the Agricultural Production Systems sIMulator (APSIM). APSIM is a freely available and widely used open-source program incorporating modules for cycling of water, C and N that have been tested in a large variety of settings around the globe (Holzworth et al., 2014).

In this paper, we present a sensitivity analysis of the APSIM-Oil palm model, performed using a novel combination of state-of-the-art software systems. This analysis aimed at identifying the key management and site parameters driving yield and N losses estimated by this model, in order to highlight improvement tracks for both model development and practices in the field. We chose three sites in Papua New Guinea on mineral soils, where the APSIM-Oil palm model had already been validated against field data and for which we had available soil and weather data. We simulated an oil palm growth cycle of 20 years, following the standard management practices in industrial oil palm plantations. We tested the influence of twelve parameters on yield and N losses, using the Morris's sensitivity analysis method (Morris, 1991). This is a widely used and robust method that is particularly relevant in contexts of high computational costs (Saltelli and Annoni, 2010; Campolongo et al., 2007), as is the case with a complex model such as APSIM-Oil palm, and the number of parameters chosen for this study. We estimated N fertiliser rates for each site to optimise trade-offs between yield and N losses. We finally outlined the implications of the results for modelling, measurements and management.

2. Material & methods

2.1. Study sites and datasets

We chose three sites in Papua New Guinea (Fig. 1), where APSIM-Oil Palm had already been validated against field data for production (Huth et al., 2014). These sites are presented in this paper by their plantation names, being Sangara (8.73°S, 148.20°E), Sagarai (10.42°S, 150.04°E) and Hargy (5.29°S, 151.07°E). Measurements of N losses and data regarding management practices were available for some of these sites (Banabas et al., 2008; Pipai, 2014), as well as fertiliser trials from the Papua New Guinea Oil Palm Research Association (PNGOPRA) trial database. The soil profiles and long term weather data were the ones used for validation (Huth et al., 2014). The weather data at a daily time step, i.e. rainfall, solar radiation and temperature, lasted from 1986 to 2014 for Sangara, 1990–2008 for Sagarai, and 1990–2008 for Hargy.

This set of three sites presented the advantage of spanning different conditions in terms of soil properties and climate, which may affect N losses differently. At Sangara, the soil is a sandy clay loam developed in

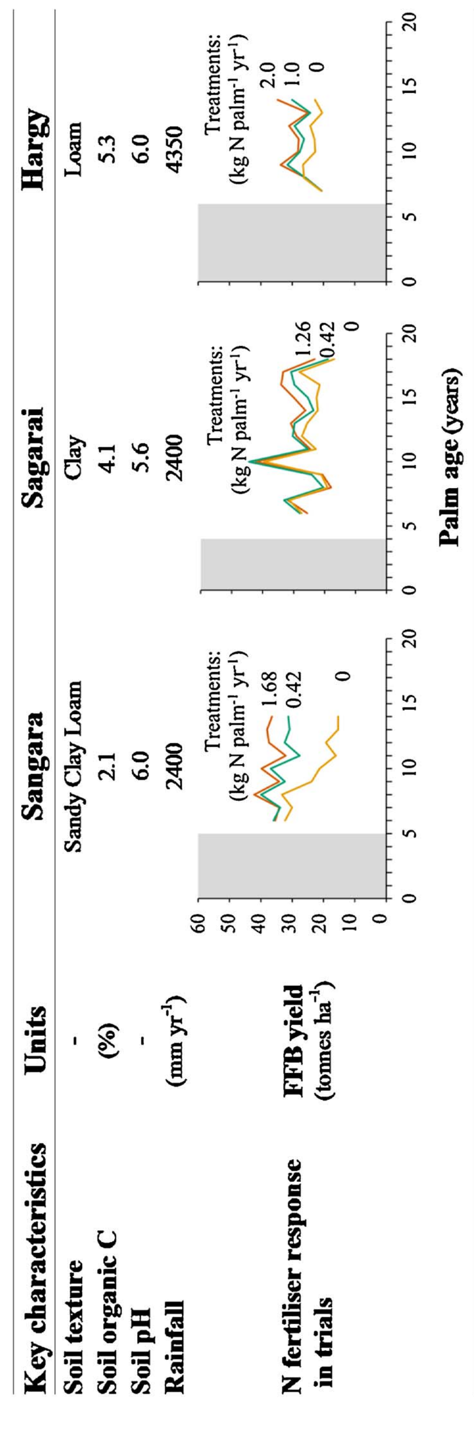

Fig. 1. Key characteristics of the sites used for oil palm modelling. In the graphs, grey shaded areas indicate the period before N fertiliser rate treatments were imposed. FFB: fresh fruit bunches.