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Climate, soil and land-use based land suitability evaluation for oil palm production in Ghana

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ABSTRACT

In the past decade, oil palm (*Elaeis guineensis* Jacq.) has become the world's most important oil crop. The large demand for palm oil has resulted in a rapid expansion of oil palm cultivation across the globe. Because of the dwindling availability of land in Southeast Asia, most expansion of the industry is expected in Central and South America and sub-Saharan Africa, where land with suitable agro-ecological conditions is available. Using Ghana as a case study, a method for evaluating areas that are both suitable and available for oil palm production is presented. Our assessment used spatial data and GIS techniques, and showed that areas with suitable climatic conditions (annual average water deficit <400 mm) is about 20% greater than was previously identified. The observed differences are the result of using different methods to determine suitability, and climate change. A major climatic factor limiting suitability for oil palm production in Ghana is the annual water deficit, with the most suitable areas located in the rainforest and semi-deciduous forest zones with higher rainfall in southern Ghana. Opportunities for large-scale oil palm plantation development is limited, however, because of the lack of availability of large and contiguous tracts of land that are required for commercial plantation oil palm development. A feasible strategy for oil palm expansion is therefore smallholder production, which can make use of smaller parcels of land. Alternatively, oil palm production in Ghana can be increased by yield intensification on land already planted to oil palm. This can also reduce the requirement for further land clearance for new plantations to meet the growing demand for palm oil. Such assessments will be essential for guiding government policy makers and investors considering investments in oil palm development.

1. Introduction

In the past decade, oil palm (*Elaeis guineensis* Jacq.) has become the world's most important oil crop, contributing nearly 30% of the world's edible vegetable oil requirements (Corley, 2009; Hansen et al., 2015). The large demand for palm oil has resulted in a rapid expansion of oil palm cultivation across the globe. Because of the dwindling availability of suitable land in Southeast Asia, most future expansion is expected in Central and South America and sub-Saharan Africa (SSA), where large areas with agricultural potential are available (Laurance et al., 2014).

In West Africa (WA), the consumption of palm oil and derived products is expected to increase as the population grows. Strong demand for vegetable oil in Africa has resulted in the expansion of the oil palm sector in WA. This has a large economic impact in producer countries by providing employment for millions of workers. In addition, palm oil is now a major source of income and trade along border districts (Ofosu-Budu and Sarpong, 2013). In the

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Ghanaian economy for example, oil palm is the second most important perennial crop after cocoa (Angelucci, 2013; Ofosu-Budu and Sarpong, 2013). The yield of fruit bunches (FB) in Ghana is poor, however, and has decreased from 6.5 t ha^{-1} in 1990 to 5.4 t ha^{-1} in 2012 (FAO, 2014a). By contrast, FB yields in the major producing countries in Southeast Asia and Latin America, where the climate is more favourable, are more than three times greater at 18.5–19.0 t ha^{-1} (FAO, 2014a). In response to increasing local demand for palm oil and the present requirement for costly palm oil imports (for example, Ghana imported 74,431 t palm oil at a cost of US$ 83 million in 2011) (FAO, 2014a), the governments of some West African countries are encouraging both national and foreign investors to plant more oil palm (Ofosu-Budu and Sarpong, 2013). Area expansion is therefore proposed to increase local production and to reduce imports of crude palm oil.

An analysis of the availability of suitable land for oil palm plantations and the obtainable yields is essential information for government policy makers and investors. Some 45 years ago, van der Vossen (1969) identified areas in Ghana with suitable climatic conditions for oil palm based on 400 and 250 mm mean annual water deficit isolines. As in much of SSA, climatic conditions in the oil palm belt in Ghana have changed since the 1960s (Lemoalle and de Condappa, 2012). Rainfall isohyets and water-deficit isolines have been displaced to the south by about 1° latitude (i.e., about 110 km), possibly due to climate change and the impact of deforestation. Furthermore, total annual rainfall has also become more variable over the past three decades (Manzanas et al., 2014; Owusu, 2009; Stanturf et al., 2011). Whilst total annual rainfall has remained similar, rainfall distribution has changed, with more rainfall now occurring in what was formerly the dry season (Abdul-Aziz et al., 2013; Owusu, 2009). At a local scale, the amount of land with climatic conditions suitable for oil palm production may have either expanded or diminished due to changes in rainfall patterns (Gilbert, 2013).

In this paper, we provide an up to date and more accurate assessment of land suitability and availability for oil palm based upon geographic information systems (GIS) using spatial data that was not available when van der Vossen (1969) developed his suitability map. Using Ghana as a case study, we describe the agro-ecological conditions and, using information from the literature, derive environmental parameters that define whether or not areas are suitable for oil palm cultivation. We used these parameters together with the spatial data on climate to develop a land suitability classification and estimate the amount of suitable land that is available for oil palm development.

We determine the main constraints to oil palm production in Ghana based on an analysis of land characteristics that limit productivity, and conclude by providing recommendations for the sustainable development of the oil palm sector in Ghana.

2. Material and methods

2.1. Agro-ecological conditions in Ghana

Ghana is located in the middle of the West African coast along the Gulf of Guinea (4.5–11.5°N, 3.5°W–1.3°E), and is bordered by Côte d'Ivoire to the west, Burkina Faso to the north, and Togo to the east. The climate of Ghana is strongly influenced by the movement of the tropical rain belt, known as the inter-tropical convergence zone (ITCZ). The ITCZ oscillates between the northern and southern tropics in the course of a year, transporting a dry continental air mass to the north, and a tropical, maritime air mass to the south (Hayward and Oguntoyinbo, 1987). As a result, northern and southern regions of Ghana have distinct climates (McSweeney et al., 2010a, 2010b). Six distinct agro-ecological zones have been identified in Ghana, with a gradient of increased aridity from south to north (Antwi-Agyei et al., 2012). In order of increasing aridity they are: rainforest, semi-deciduous forest, coastal savanna, forest-savanna transition, Guinea savanna, and Sudan savanna (Antwi-Agyei et al., 2012) (Fig. A1). Rainfall decreases from the southwest (> 2000 mm $year^{-1}$) to the northeast (< 1000 mm $year^{-1}$) (Environmental Protection Agency (EPA) and Ministry of Environment, 2011). In the south, the annual mean relative humidity (RH) is ±80% (except for some days during the 'Harmattan' in the dry season), while in the north RH is lower at ±40% (Oppong-Anane, 2006). Northern Ghana has a single wet season between May and November, while the southern regions of Ghana have two wet seasons with long rains usually from March–July and short rains from September–November.

With the exception of the Kwahu Plateau, which runs along the southern edge of the Volta River Basin, the topography in Ghana is relatively flat and low-lying, with more than half the area <150 masl. Because Ghana is in the equatorial belt, mean monthly temperatures below 25 °C are seldom recorded. Mean annual temperature ranges from 26 °C in the south to 29 °C in the north (FAO, 2005). Minimum temperatures less than 18 °C only occur in the highlands above 400 masl (e.g., on the Kwahu Plateau) (van der Vossen, 1969). The diurnal temperature range is small in the south (5–9 °C) due to maritime influence from the Atlantic, and greater in the north (7–14 °C) due to hot and dusty air brought in from the Sahara desert during the Harmattan (McSweeney et al., 2010a, 2010b). As a result, climatic conditions are hot and seasonally dry along the southeast coast, hot and humid in the southwest, and hot and dry in the north.

Little solar radiation data is available for West Africa, and Ghana, because of the lack of solar radiation recording stations in the region (Stout, 1990). As a surrogate, sunshine hours are used as an estimate of solar radiation because it is easier to measure and data are more readily available. While solar radiation and sunshine hours are generally well-correlated, the effects of the Harmattan and atmospheric pollution under West African conditions prevents accurate recording of sunshine, even when conditions are cloudless. As a result, much solar radiation is reflected by the atmosphere, and reaches the earth's surface predominantly as diffuse radiation (Corley and Tinker, 2003; Hayward and Oguntoyinbo, 1987). Nevertheless, taking these factors into account, the total hours of sunshine per annum in WA is considerably less than in other oil palm growing regions such as Southeast Asia or Central and South America (Corley and Tinker, 2003; van der Vossen, 1974). In WA, sunshine hours increase with latitude from the Guinea Coast up to the Sahel and the margins of the Sahara, albeit not in a regular pattern. In Ghana, for example, a large land pocket with less sunshine occurs in the west central region (Hayward and Oguntoyinbo, 1987). In general, there are more sunshine hours during the dry season and less during the rainy season because of the effect of cloud cover. However, sunshine hours during the dry season are periodically reduced due to the effect of dust in the atmosphere during the Harmattan.

Soils in the higher rainfall zones in the south of Ghana are generally strongly weathered and highly leached with low pH, and poor soil fertility status (Swaine, 1996). Soil type is strongly related to topography and slope position. The topography in the oil palm belt is undulating to rolling, with slopes ranging from 2 to 9°. Some relatively flat areas are found with moderate slopes (<5°) but rolling to hilly terrain (5–17°) is more common, with low-lying and poorly drained swamps enclosed by upland areas. In the oil palm belt, the predominant soils are free-draining Acrisols and Ferralsols (Fig. A2). These two soil types are often found together, with Acrisols on eroded slopes of low hills, Ferralsols on nearby stable pediments and uplands. Soils in enclosed, low-lying swamps are commonly Gleysols (FAO, 2014b).