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A spatially explicit approach to assess the suitability for rice cultivation in an inland valley in central Benin

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ABSTRACT

The selection of optimal areas for specific cultivation systems is an important step in achieving increased, sustainable rice production in Benin. This study aims to determine suitable areas for rice production in the inland valley of Tossahou using a GIS-based approach that evaluates and combines biophysical factors such as climate, hydrology, soil and landscape, following the FAO parameter method and guidelines for land evaluation. Soil and landscape suitability was assessed for three different rice cultivation systems: rainfed bunded (RB), cultivation under natural flooding (NF), and irrigated cultivation (RI). The results show that in the inland valley (mostly including the hydromorphic zones and the valley bottom) 52% of the area is suitable for irrigated cultivation, 18% for cultivation under natural flood and 1.2% for rainfed bunded rice. Precipitation and temperature were limiting factors for all cultivation systems. Flooding was the most limiting factor for NF while RI and RB were mostly limited by steep slopes and soil texture respectively. As a first attempt in Benin, this study can play an important role in achieving optimised rice production in inland valleys, and additional studies including socio-economic aspects, carried out in the same area, or in areas under similar conditions, are relevant to close the yield gap and improve the selection approach.

1. Introduction

An inland valley is defined as a landscape that comprises a complete toposequence from the interfluves to the valley bottom with its seasonally waterlogged depression (Windmeijer and Andriesse, 1993). Often known under various regional names, such as *bas-fonds*, *fadamas* or inland swamps in West Africa, *mbuga* in East Africa and *vleis*, *dambos*, *mapani*, *matoro*, *inuta* or *amaxhaphozi* in Southern Africa (Acres et al., 1985), in practice, the term refers only to the waterlogged area and its hydromorphic fringes (Giertz et al., 2012; IVC, 2005; Thenkabail and Nolte, 1996). In West Africa, inland valleys have important potential for rice-based production systems due to their being largely unexploited, higher water availability, lower soil fragility and higher fertility (Giertz et al., 2012; Rodenburg et al., 2014; Schmitter et al., 2015). However, in Benin, the productivity of rice systems in such wetlands is low due to biophysical and socio-economic constraints (Djagba et al., 2013), including sub-optimal functioning markets for acquiring fertilisers and for the commercialisation of rice products; a lack of financial services to make the necessary investments for intensification; poor management and maintenance of irrigation infrastructures; and inadequate national policies (Saito et al., 2015; Schmitter et al., 2015). In Benin, agriculture contributes to 31.6% of the country's gross domestic product (FAO Stat, 2011). Rice is usually grown to be sold and is not used in subsistence farming due to its high value (Igué, 2000). As the country aims to be self-sufficient in rice in the near future, the government has been actively promoting agricultural development of rice since 2008 (NRDS, 2011). Indeed, local rice production has increased (from 73,853 t in 2008 to 167,000 t in 2011) because of improved input facilities (e.g. seed, fertiliser) made available to farmers through a range of programmes and projects that were set up after the food crisis of 2008. These include the Emergency Program to Support Food Security (PUASA), the NERICA Project, the Development Project of Small Irrigated Perimeters (PAPPI) and the Agricultural Services Restructuring Project (PASR) (Totin et al., 2013). Currently, 90% of the rice

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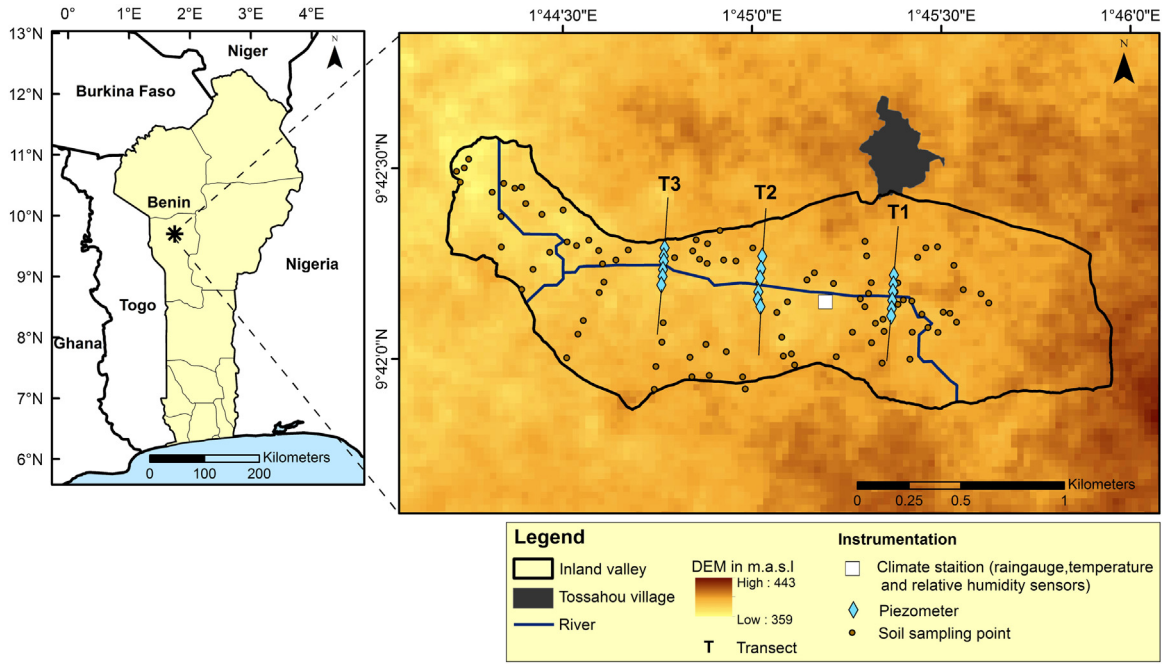

Fig. 1. Location of research area and instrumentation.

outputs are produced by small-scale farmers using only 7–10% of the total arable land available (United States Department of Agriculture, 2013), with the average rice farm size for the users and non-users of credit being approximately 0.82 and 0.63 ha, respectively (Kinkingninhoun-Medagbe et al., 2015). Despite this recent increase in rice production, following the implementation of technologies and techniques developed and offered by the government and agricultural development projects, traditional smallholder production is still dependent on the physical conditions of the land. This is due to the insufficient coverage of the input facilities, and also to the lack of capital to compensate for natural constraints in terms of rainfall variability, low chemical fertility and unfavourable physical characteristics of soils (Janssens et al., 2010). Moreover, due to the increasing population pressure, farmers move to more marginal areas and expose themselves to environmental risks. Consequently, they often produce low yields as they are not willing to make more investments. Thus, our method should be of interest to development agencies and NGOs that are interested in assessing suitable areas for development and investment.

Knowing that not all inland valleys are necessarily suitable for crop production (Kotze, 2011; Sakané et al., 2011), several biophysical and socio-economic factors should be investigated during the land evaluation process. Recent studies have developed different quantitative and qualitative methods and approaches to planning land suitability, either for agriculture in general (Krishna and Regil, 2014; Liu et al., 2006; Mokaram and Aminzadeh, 2010) or for specific crop production, such as paddy rice, wheat, maize, mustard, mango and sugarcane (Halder, 2013; Martin and Saha, 2009; Singh, 2012), within a given watershed. Generally, these methods integrate remote sensing or a multi-criteria evaluation, coupled with GIS, and combine, depending on the research, layers of factors such as climate, drainage density, geology, hydrology, landform, land use, soil, topography and vegetation, via a weighted overlay approach (Krishna and Regil, 2014) or a pairwise comparison matrix (Kihoro et al., 2013). Some studies rate the factors based on the proposed method of Sys et al. (1993) and define the suitability ranked classes using the qualitative approach described by the FAO (FAO, 1976; Halder, 2013; Martin and Saha, 2009; Mustafa et al., 2011), and others rely on expert opinion, local agronomists and researchers' knowledge (Kihoro et al., 2013). Among other older studies in West Africa, a GIS-based model developed by Fujii et al. in 2010 was recently applied to select suitable rice cultivation areas in inland valleys in the Mankran and Jolo-Kwaha watersheds from different agro-ecological zones in Ghana that have high potential for rice production (Fujii et al., 2010). However, very few studies address land use planning for rice-based systems in inland valleys.

This study was undertaken in Benin with the goal of assessing the suitability of inland valleys, as a function of the biophysical environment, for three rice cultivation systems: rainfed bunded (RB), cultivation under natural flood (NF) and irrigated cultivation (RI). To evaluate suitability spatially, we used the proposed method of Sys et al. (1991, 1993) and the FAO Guidelines for Land Evaluation (FAO, 1976). The parameters analysed were soil, climate, hydrology and topography. Maps of these parameters were required for the generation of the final suitability maps. Rating maps were overlaid for each cultivation system using Liebig's law of the minimum, which states that plant growth is controlled by the scarcest (limiting) resource and that an increase in this resource increases yields the most (Casanova et al., 2002; Gorban et al., 2010; Spektrum, 1999). For the validation of the suitability maps, in association with the identification of limiting factors for rice production, we proceeded to the identification and classification of the predominant types of agricultural land use, to the assessment of the spatial distribution of rice yields, and to stakeholder interviews in the inland valley. This approach was chosen because of data availability and in accordance with the requirements for the different rice cultivation systems. It was essentially led by the following research questions: (i) How can areas suitable for rice production be identified to aid farmers in selecting favourable fields for a potential rice growth achievement? (ii) How can a resulting suitability map be validated? (iii) What are the physical factors limiting the inland valley suitability for rice production? This study contributes to improving development strategies and land use planning to promote a sustainable management of rice-growing wetland ecosystems in Benin.