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Predictors determining the potential of inland valleys for rice production development in West Africa

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ABSTRACT

Water availability and high soil fertility make inland valley landscapes suitable for sustainable rice-based cropping. In this study, Random Forests statistical analysis was used on a database of 499 surveyed inland valleys in four study zones in three West African countries. The goal of the study was to assess parameters that indicate (are predictors for) high potential for development of rice-based systems in inland valleys. These parameters are related to the biophysical (hydrology, soil, climate, and topography) and socio-economic (demography, accessibility, and markets) environments. Farmer group surveys and secondary data from existing publicly available spatial data sets were used.

The analysis revealed that, across the four research areas, the following parameters were relevant predictors for rice development: (1) distance from the inland valley to the nearest market; (2) distance from the inland valley to the nearest rice mill; (3) population density in the immediate environment of the inland valley; (4) total nitrogen in the top 20 cm of the soil profile; (5) land elevation; and (6) soil texture on the upper slope of the inland valley. Several predictors were highly important for specific research areas, but not for all, thus showing the diversity in the studied agricultural landscapes. These predictors included soil fertility management, source of irrigation water, and the percentage of female farmers in the inland valley. The identified relevant predictors will be used to map the potential rice production development of the inland valleys. This will help development agencies to assess their zones based on quantitative analysis for inland valley potential development.

1. Introduction

Crop yields are generally poor in West Africa; crop production is insufficient and West Africa depends on food imports (Niang et al., 2017; Seck, Diagne, Mohanty, & Wopereis, 2012). Thus, food insecurity is a major problem. It was estimated that there were 239 million hungry people in sub-Saharan Africa (SSA) in 2010 (Meijer, Catacutan, Ajayi, Sileshi, & Nieuwenhuis, 2015; Xie, You, Wielgosz, & Ringler, 2014). West Africa has some of the most severe hunger in the world (Brown, Hintermann, & Higgins, 2009; Sasson, 2012). Consequently, West Africa remains a major food buyer, importing large quantities of rice (AfricaRice, 2014) and even local food staples such as millet and maize (Brown et al., 2009). To mitigate food insecurity in this region would require better use of resources, for example, by promoting agricultural use of inland valleys (IVs). These agro-ecosystems conserve moisture and have good soil fertility – good agricultural resources in the face of increasing drought induced by climate change (Van Oort & Zwart, 2018). Various studies (e.g. (Obalum, Nwite, Oppong, Igwe, & Wakatsuki, 2011; Rodenburg et al., 2014; Seck, Tollens, Wopereis, Diagne, & Bamba, 2010; Windmeijer and Andriesse, 1993)) have revealed that West African countries have large untapped IV resources that could be used for rice development. In the face of climatic variability and the effects of climate change, IVs are potential 'bread basket' areas in SSA. The IVs are the main rice cultivation agro-ecosystems in developing countries of SSA (Dossou-Yovo, Baggie, Djagba, & zwart, 2017; McCartney & Houghton-Carr, 2009; Rodenburg et al., 2014; Seck et al., 2012; Worou, Gaiser, Saito, Goldbach, & Ewert, 2012).

Lowland rice cultivation is mainly rainfed and requires stable water

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supply. Thus, large-scale irrigation developments have been promoted on a large scale in West Africa, because of the irrigation potential (Gruber, Kloss, & Shopp, 2009; Musa, 2009; Worou et al., 2012). Unfortunately, many of these implemented irrigation schemes in West Africa have failed or perform below their potentials. (Djagba, Rodenburg, Zwart, Houndagba, & Kiepe, 2014; Inocencio et al., 2007; Nwite, Obalum, Igwe, & Wakatsuki, 2016; Obalum et al., 2011). IVs are the principal rice cultivation agro-ecosystems and the identification of suitable IVs for future rice development is highly important. To know which areas are suitable for rice cultivation requires knowledge of the conditions that favor sustainable rice production development, while limiting environmental impacts (Danvi, Giertz, Zwart, & Diekkrüger, 2018; Djagba, Zwart, Houssou, Tenté, & Kiepe, 2018b). Study of these conditions enables to identify many environmental factors (hydrological, soil, topographical, climatic), socio-economic parameters (extension services, population density, accessibility to road, market, settlement), and farm management practices (e.g. chemical fertilizers, farm technologies) that are important (Abe, Buri, Issaka, Kiepe, & Wakatsuki, 2010; Danvi, Jütten, giertz, Zwart, & Diekkruger, 2016; Gumma, Thenkabail, Fujii, & Namara, 2009; Laborte, Maunahan, & Hijmans, 2012; Masoud, Agyare, Forkuor, Namara, & Ofori, 2013; Qin & Zhang, 2016; Rodenburg et al., 2014). Given the diversity of parameters and factors (variables) that may influence the potential for rice production development in IVs, the most appropriate method for selecting the most important variables must be used. Not all of these parameters and factors contribute to IV agricultural potential to the same degree – some parameters and factors could be more suitable than others. For example, descriptive methods for mapping IVs with agricultural production potential based on expert knowledge were developed and applied (Gumma et al., 2009), but are subjective and may include or exclude parameters or define underestimate or overestimate the importance of a parameter.

The 'Random Forests' model is an approach to map in an unbiased manner the parameters and their importance that contribute or explain a variable (Cutler et al., 2007; Díaz-Uriarte & Alvarez de Andrés, 2006; Hapfelmeier & Ulm, 2013). Random Forests was used by the International Rice Research Institute (IRRI) to map potential rice areas in Laos with a view to limiting environmental degradation due to rice production (Laborte et al., 2012). Elsewhere, Random Forests has been shown to give good accuracy without overfitting and it is relatively robust to outliers and noise (Breiman, 2001; Gislason, Benediktsson, & Sveinsson, 2006; Prasad, Iverson, & Liaw, 2006). Random Forests, considered for classification of multi-source geographic data, presents a comprehensive methodology to assess and analyze classification uncertainty based on the local probabilities of class membership (Gislason et al., 2006; Loosvelt et al., 2012).

The overall aim of this paper was therefore to explore the Random Forests approach to define the best predictors of rice production development in IVs in the diverse landscape of the West African context. An improved understanding of the relevant parameters supports national government agencies, donors and developers in the selection specific IVs or regions and thus increase the chance of success of agricultural development interventions. The specific objectives of this study were: (1) to identify the relevant factors or parameters that define an IV's potential for rice development; and (2) to select the most important parameters as predictive variables, which will then be used to map the potential of IVs for rice production.

The methodological approach, including the Random Forests method that was used in this study is presented in section 2, after the presentation of study area and explanation of heuristics for obtaining the candidate predictors. In section 3, the results on the effectiveness of variable importance measures and the selection of the most relevant predictors among the large number of candidate predictors for the four study areas are reported. In section 4, the methodological approach and the results are discussed, and finally conclusions are presented. The appendix provides the exhaustive list of candidate predictors.

2. Materials and methods

2.1. Study areas and sampling of inland valleys

This study was carried out in four regions located in Benin, Mali, and Sierra Leone (Fig. 1). A geo-located database was built covering a total of 499 IVs distributed in the four targeted study areas, with 100, 149, 100, and 150 IVs in Mono and Couffo departments (Benin), Ouémé River upper catchment (Benin), Sikasso and Kadiolo circles (Mali), and Bo and Kenema districts (Sierra Leone), respectively.

The selection of IVs was based on many criteria. The first was to locate areas where IV agro-ecosystems are most numerous in West Africa, as in the countries targeted for this study. The specific study regions were selected on the basis of available databases on IVs per country. For Benin, the databases of IMPETUS (a German research project, 2005–2010) and RAP-IV project (Realizing the agricultural potential of IV lowlands in sub-Saharan Africa while maintaining their environmental services, based in Africa Rice Center, 2009–2014) covered the upper of Ouémé River catchment and Mono and Couffo *départements*, respectively (Sintondji et al., 2016). These projects investigated the potential of IVs in target areas. In Mali and in Sierra Leone, the national agricultural research systems (NARS) – Institut d'économie rurale (IER) and Sierra Leone Agricultural Research Institute (SLARI) – have available information on the potential of IVs, their location, and general characteristics (Dossou-Yovo et al., 2017).

The identification of IVs systems was carried out by survey of leaders and key informants at village level. IV location was determined using GPS on the ground or Google Earth to map the boundary. Field surveys were also carried out at IV scale. Another criterion was the spatial distribution of IVs in the target areas. For the established sample of IVs, agricultural use, use for paddy, and crop diversification in IVs were also considered (Table 1).

2.2. Candidate predictors

The binomial variable 'presence or absence of rice cultivation in IVs' was used as the dependent variable in this study. Many factors and parameters, defined as variables (p), could explain the suitability of an IV for rice production. The project aim was to identify the relevant conditions that suggest rice production potential in IVs and to map the IVs most suitable for rice cultivation development. Using an empirical technique based on expert knowledge and literature review (e.g. (Gumma et al., 2009; Laborte et al., 2012; Masoud et al., 2013; Sakané et al., 2011), a total of 64 variables was proposed. These variables were highly diverse and from many sources (see Appendix). Environmental variables covered hydrological, topographical, climatic, and soil factors. Socio-economic variables related to accessibility and, demographic factors, and IV-use data. Many were also related to farm management practices.

In this study, candidate predictors were identified via three routes: (1) geographical location of IVs and rice sector development elements such as rice mills, markets, and agricultural input stores, and digitizing boundaries of IVs; (2) farmer surveys in IVs to collect environmental, socio-economic, and agricultural use data; and (3) spatial data related to topography, hydrology, climate, soil, accessibility, and population density. In this sub-section, the candidate predictors of rice cultivation potential in IVs are identified and the strategies which could enable their collection in the field or their derivation them from metadata are defined (Fig. 2).

2.2.1. Candidate predictors of location and accessibility

The first step was to identify prospective IVs in the study areas while geo-locating them using GPS. Markets, rice mills, and input stores were also located in the study areas and geographic coordinates were taken. Downloaded, extracted, and symbolized Open Street Map (OSM) data provided much of the location and accessibility data. From OSM nodes,