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On-farm rice yield and its association with biophysical factors in sub-Saharan Africa

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ABSTRACT

Although increase in rice (*Oryza* spp.) production is a common objective for rice-producing countries in sub-Saharan Africa (SSA), basic information on yield and its variation at farm level is lacking. Field surveys were conducted in irrigated lowland (IL), rainfed lowland (RL), and rainfed upland (RU) rice production systems in 19 SSA countries in the 2012–2014 wet seasons. Mean yield varied widely across

Abbreviations: AEZ, agro-ecological zone; IL, irrigated lowland; RL, rainfed lowland; RU, rainfed upland; SSA, sub-Saharan Africa.

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sites: 2.2–5.8 t/ha, 1.1–5.2 t/ha, and 1.0–2.5 t/ha in IL, RL, and RU, respectively. Rice yield levels differed between the agro-ecological zones (AEZs) with the highest yield in the semi-arid zone in IL, and in the highlands zone for RL and RU. Cluster analysis identified four groups using mean yields, coefficient of variation, and skewness of yield distribution of 42 site–production system combinations. Grouping was related to production system, AEZ, and field water condition. A high-yielding group with 5.3 t/ha mean yield and negative skewness had only four site–production system combinations. Other groups had mean yields from 1.6 to 3.5 t/ha with positive skewness. In these groups, research and development priority for lifting rice yield could be given to low-yielding IL and RL sites with large yield gaps. Raising rice yield in the humid zone irrespective of the production systems and RU across AEZs remain major challenges. Further assessment of the impact of farmers' agricultural practices on yield variation is warranted to identify potential interventions to realize further yield enhancement.

1. Introduction

In sub-Saharan Africa (SSA), agricultural imports of basic food products are dominated by wheat (*Triticum* spp.) and rice (*Oryza* spp.) (FAO, 2015). Unlike wheat production which is restricted to mostly highlands in East Africa (Livingston et al., 2011), rice can be produced in diverse agro-ecological (AEZs) zones in SSA and its production can be substantially increased (Andriesse et al., 1994; Balasubramanian et al., 2007). Increase in local rice production could contribute to improving food security, generating income, alleviating poverty, and socio-economic growth in SSA (Seck et al., 2013). There are two ways to augment rice production: expansion of cultivation area and increase land productivity (i.e. yield). In SSA, rice production was increased mainly by area expansion in the past (Otsuka and Kalirajan, 2006). However, recent statistical data show that, after the 2007–2008 food crisis, paddy yield growth in SSA increased by 108 kg/ha per year from 2007 to 2012 (Seck et al., 2013). This high yield growth rate was at a level equivalent to that observed in Asia during the Green Revolution period (Saito et al., 2015). However, despite progress in increasing production in SSA, domestic rice production satisfied only 60% of consumption in 2012, due to the fact that the rice consumption rate has been continuing to increase, driven by urbanization, changes in eating habits, and population growth. Between 2010 and 2035, demand for rice is expected to increase by 130% in SSA (Seck et al., 2012). Rice importation is likely to drain foreign currency reserves and aggravate poverty and food insecurity. Further increase in domestic rice production remains a considerable challenge for SSA.

Understanding the current state of farmers' yields is fundamental to identify low-yielding areas or areas where yield improvement is possible. However, production data are only available at sub-national and national levels for SSA countries (Haefele et al., 2013; Sadras et al., 2015; You et al., 2009). Such data are not disaggregated by rice production systems, despite the large differences in yield level between those systems. Rice production systems are determined by surface water regime and water source (Saito et al., 2013). In SSA, production systems comprise irrigated lowlands (IL), rainfed lowlands (RL), and rainfed uplands (RU), with deep-water and mangrove-swamp rice being of minor overall importance. Rice yield is generally higher in IL than in RL and RU in SSA (van Oort et al., 2015). Although it is well known that water availability affects rice yield greatly and varies from field to field in SSA (Tanaka et al., 2013; Worou et al., 2013), production data at sub-national and national levels cannot capture such variation in field water availability and its linkage with rice yield variation. In these circumstances, on-farm survey is a practical and useful approach to assess farmers' actual yields and identify biophysical factors that affect rice yield (Affholder et al., 2013; van Ittersum et al., 2013; Zandstra et al., 1981). Saito et al. (2013) summarize previous on-farm surveys of rice in SSA, and indicate that most of the studies at field level were conducted in the 1990s in a few West African countries (Burkina Faso, Côte d'Ivoire, Mali, and Senegal).

Soil quality is considered a major factor in agricultural productivity, as soil quality defines the crop growing condition and determines indigenous nutrient supply to the crop. The latter is especially relevant for SSA, where chemical fertilizer application is not a common practice among farmers (Balasubramanian et al., 2007). However, except for iron toxicity (Becker and Asch, 2005), few studies show evidence that rice yield is strongly affected by soil quality in SSA.

In this study, five AEZs delineated by HarvestChoice (2009) were adopted (Fig. 1), and considered as one biophysical factor. Area with greater than 1200 m elevation was classified as tropic-highlands. The rest of the area, tropic-warm, was further categorized into four moisture zones by length of the growing period (LGP): arid zone (<70 days LGP), semi-arid zone (70–180 days), sub-humid zone (180–270 days), and humid zone (>270 days) (HarvestChoice, 2009). The humid zone is characterized by lower solar radiation, higher relative humidity, and smaller temperature fluctuations compared with other zones. Along the agro-ecological gradient from humid to arid, solar radiation increases, relative humidity becomes lower, and temperature fluctuates more.

In West Africa, Becker et al. (2003) found that on-farm yields in IL were variable across AEZs. However, they assessed the variation in only one site per AEZ in West Africa for just one production system. Large variation might exist in farmers' yields within the same AEZ; moreover, with the age of the data (mentioned above), the information could be out of date. For rainfed systems, previous studies were limited to Côte d'Ivoire. There are also few reports of on-farm rice yields from East Africa (Nhamo et al., 2014).

It has been frequently indicated that differences in methods used in on-farm surveys and yield analyses inhibit making comparison of yields and yield gaps across different studies (Fischer, 2015; Lobell et al., 2009; Stuart et al., 2016). To overcome such obstacles, the Africa Rice Center (AfricaRice) and African national agricultural research institutes (NARIs) launched an agronomy research network, the Africa-wide Rice Agronomy Task Force, in 2011. The Task Force undertook a collective effort to assess current yield variation and on-farm yield gaps in different rice production systems. Having used consistent methods for crop cutting, soil sampling, other field observations, and interviews with farmers to collect farmers' agricultural practices, the dataset was available for comparative analysis across SSA.

As the first to use this collectively assembled dataset, this study aimed to (i) assess degrees of on-farm yield variation, (ii) identify its relationship with biophysical factors, and (iii) identify areas where research and development should be focused. We did not consider any farmers' agricultural practices in this study – analyses of those practices will follow in a subsequent paper.