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Rice yield growth analysis for 24 African countries over 1960–2012

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ABSTRACT

In Africa, there have been scattered reports of yield stagnation. This study examined trends in rice yields in 24 African countries based on United States Department of Agriculture (USDA) data from 1960 to 2012 using segmented linear regression, and determined factors affecting variation in yield growth rates across countries. About 74% of rice harvested area in Africa recently witnessed positive rice yield growth rates of greater than 35 kg ha^{-1} year^{-1}. Lifting rice yields requires continued investment in rice research on technology development, development or rehabilitation of irrigation schemes, and upgrading of the existing rainfed lowlands to irrigated or partially irrigated systems. Priority should be given to countries with high rice consumption levels, where the investments will be more effective.

1. Introduction

Rice consumption is increasing faster than that of any other food staple in Africa, at about 5.5% per year (2000–2010 average). This increase is driven by urbanization and related changes in eating habits, and population growth (USDA, 2013; Seck et al., 2012). Rice consumption was approximately 24 million tonnes (Mt) per year in sub-Saharan Africa (SSA) in 2012, and only about 60% of rice consumption is satisfied by domestic production resulting in imports of 10–12 Mt year^{-1}, equivalent to one-third of what is traded on the world market. Demand for milled rice in SSA is expected to increase by 30 Mt by 2035, equivalent to an increase of 130% in rice consumption from 2010 (Seck et al., 2012).

Africa has great potential to close the gap between rice demand and supply through increasing domestic production. Large differences exist between potential yield and actual yields obtained by farmers ('yield gaps') across rice-growing environments (Saito et al., 2013). Saito et al. (2013) summarize field-level yield-gap assessments from previous studies in SSA, showing large yield gaps in the three major rice-growing environments: rainfed upland, rainfed lowland, and irrigated lowland. Rice is also grown in mangrove and deep-water environments, but they are only of local importance. Surface-water regimes and water sources (e.g., irrigation, rainfall, water table) distinguish the rice-growing environments. Irrigated lowland rice is generally grown in bunded fields with assured irrigation for one or two crops per year. Rainfed lowland rice is grown on level to slightly sloping, unbunded or bunded fields in lower parts of the toposequence and in inland valleys. Rainfed upland rice is generally grown on level or sloping, unbunded fields. Irrigated lowland rice, rainfed lowland rice, rainfed upland rice, and others account for 26%, 38%, 32%, and 4%, respectively, of the total rice area in SSA (Diagne et al., 2013a). Generally, irrigated lowland rice systems have higher yields than the other environments (Defoer et al., 2004; Diagne et al., 2013b). For example, yields of irrigated lowland rice, rainfed lowland rice, and rainfed upland rice are 4.0, 2.9, and 2.3 t ha^{-1}, respectively, in Mali (Diagne et al., 2013a).

It has frequently been reported that rice yields are stagnating in Africa and increasing rice production has been generally ascribed to expansion of rice-growing area (e.g., Lançon and Erenstein, 2002; Otsuka and Kalirajan, 2006; FARA, 2009). Causes of rice yield stagnation have been studied by various authors at field level (e.g., Saito et al., 2013; Otsuka and Kalirajan, 2006; Diagne et al., 2013b). The major constraints include yield-limiting factors (e.g., drought or excess water, nutrient deficiencies, extreme temperatures), yield-reducing factors (e.g., insects, diseases, weeds, birds), and socioeconomic issues (e.g., production orientation, household wealth, access to input and output markets, access to rice knowledge and technologies). However, no spatial assessment of rice yield trends at African continental scale has been attempted to date. Such assessments can guide decision-making in terms of investment in rice-sector development and targeting research efforts.

Fears about global food security led to a spike in food prices in 2007–2008 (Dawe and Slayton, 2010). In Africa, high rice prices in particular raised concerns about food security. As a result of this 'rice crisis', African governments and the international donor

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community embarked on ambitious rice-development programs. Using United States Department of Agriculture (USDA) data, Seck et al. (2013) show that the production growth rate in SSA increased from 3.2% per year before the rice crisis (2000–2007) to 8.4% per year after the rice crisis (2007–2012). Over the period 2007–2012, some 71% of the increase in paddy rice production can be explained by yield increase and 29% by area expansion, whereas before the rice crisis (2000–2007), only 24% of production increase could be attributed to increases in yield with 76% attributable to increases in harvested area. This is evidence of increased use of technological innovation, such as improved varieties, and improved crop management in general.

We analyzed changes in rice yields over time in 24 countries in Africa in more detail using the online database of USDA (2013). Our objective was to identify those countries for which rice has recently experienced yield growth stagnation, deceleration, or acceleration. We also examined causes for variation in such growth rates using data on distribution of rice area per growing environment per country, rice consumption per capita, number of varieties recently released, and producer price for paddy rice. As we could not include a wide range of factors, we provide a qualitative assessment of the other factors driving the yield increase at the end of Section 4.

2. Material and methods

We used the USDA data on national-level rice yield and harvested area from for the period 1960–2012 (USDA, 2013), in line with Seck et al. (2013). We considered data from '1960/61' in the database as equivalent to 1960 in this study. The 24 countries covered are Angola, Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Egypt, The Gambia, Ghana, Guinea, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo, and Zambia. The first year with data varied among countries: Cameroon (1961), Madagascar (1962), Malawi (1975), Mauritania (1971), Rwanda (2000), Zambia (1972), and others (1960). Data on both 'rice supply quantity' (equivalent to rice consumption per capita) and producer price were taken from FAOSTAT (2013), as they were not available in the USDA database. Data on 'rice supply quantity' were averaged over 2007–2009. Only 11 countries have reported rice prices until at least 2008. It should be noted that the quality of data may be poor for some countries and complete information may be lacking because of political strife, weak institutions, incentives to misreport data, or simple lack of access to existing data. However, as we had no alternative methods to detect uncorrected data, we used all the data available in these databases for this analysis.

As scatter plots for the relationship between year and rice yield in most countries showed that different types of relationships occur in different periods (Fig. 1), segmented linear regression technique, a form of regression that allows multiple linear regressions to fit the data for different ranges of years, was used (Grassini et al., 2013; Vito and Muggeo, 2003). This technique can be useful to quantify one or more abrupt changes of the response of a varying influential factor (Anderson and Nelson, 1975, 1987; Mayaka, 1994; Berman et al., 1996; Cox, 1996; Willcutts et al., 1998). The breakpoints are the values of years where the slope of the linear function changes and can be interpreted as critical or threshold values beyond or below which (un)desired effects occur (Vito and Muggeo, 2003). The following are three equations with two breakpoints.

$$\begin{aligned} y &= a_1 + b_1 x \quad \text{if } x < x_1 \\ y &= a_2 + b_2 x \quad \text{if } x_1 \le x \le x_2 \\ y &= a_3 + b_3 x \quad \text{if } x > x_2 \end{aligned} \qquad (1)$$

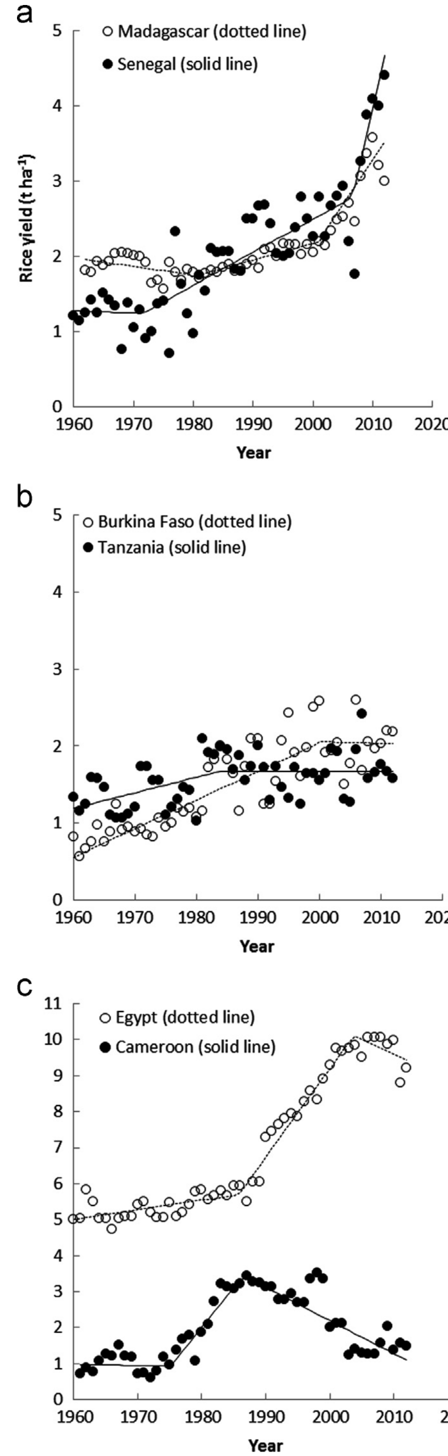

Fig. 1. Rice yield trends in (a) 'yields increased', (b) 'yield stagnated', and (c) 'yield collapsed' countries of recent rice yield growth rate (refer to Table 1). Breakpoint indicated by arrow.

where y is rice yield (kg ha^{-1}), x is year, and x_1, x_2 are the breakpoint years. The slope of the linear regression line from the most recent breakpoint to 2012 (parameter b_3) was defined as the 'recent yield growth rate' (kg ha^{-1} year^{-1}). Models with different breakpoints were fitted for each country and the model with the smallest residual mean square error was selected. Segmented linear regression was not used for Rwanda, because data were only available from 2000 onwards; rather we analyzed rice yield growth rate using simple linear regression instead. Because