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Abiotic stress and its impact on production efficiency: The case of rice farming in Bangladesh

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ABSTRACT

Enhancing technical efficiency of rice production in major rice producing countries of Asia and Africa can have positive impacts on farm household income, alleviation of poverty, and improvement of the livelihoods of millions. Using household income and expenditure survey (HIES) data from Bangladesh and a stochastic frontier production function estimation approach, we examine the technical efficiency of the rice farmers in Bangladesh. Particular attention is given to abiotic stress factors such as maximum temperature and rainfall. Results indicate that while maximum temperature (drought) alone leads to a significant loss in rice production, both maximum temperature and rainfall (floods) are major contributors to technical inefficiency in Bangladeshi rice farming. On the other hand, household assets and off-farm wages tend to increase technical efficiency.

1. Introduction

During the last decade or so, many agronomists and plant scientists have been discussing the issue of climate change and its impact on plants.[1] Plant breeding programs around the world have preemptively responded by breeding stress-tolerant crop varieties. Unfavorable environmental conditions – abiotic factors, causing abiotic stresses – play a major role in determining productivity of crop yields (Boyer, 1982). Biologically, this abiotic stress,[2] is considered a significant deviation from the ideal conditions in which plants are grown, preventing them from expressing their full genetic potential for growth, development, and reproduction (Rehman et al., 2005). All abiotic stresses profoundly influence ecological and agricultural systems. According to Larcher (2006), chronic stress (abiotic stress) leads to a reduction in plants' growth rate and the subsequent loss in productivity is significant. Miti et al. (2010) similarly conclude that abiotic stress can lead to reduction in yield compared to yield under the optimal conditions of cultivation. Farmers naturally want cultivars that produce a satisfactory yield when subjected to stressful conditions, but still have high productivity under ideal growing conditions.

In much of South Asia, abiotic stresses such as high or extreme temperature, flooding and salinity are common. In particular, abiotic

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[1] Crop farming is extremely vulnerable to climate change and it has been predicted that climate change will impact negatively on agricultural yield in the 21st century through higher temperatures, more variable rainfall and extreme climate events such as floods, cyclones, droughts and rising sea levels (Molua, 2002; Isik and Devadoss, 2006; WB, 2013). Climate change impacts are already being experienced through increasing temperatures, variable rainfall and climate related extreme events such as floods, droughts.

[2] Defined as nonliving, as in abiotic factor, which is a nonliving physical and chemical attribute of a system, for example light, temperature, wind patterns, rocks, soil, pH, pressure, etc. in an environment. Also, abiotic stress is defined as any environmental variable, which can induce a potentially injurious strain in plants.

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stresses such as droughts and floods significantly constrain rice production in Bangladesh and the frequency of these stresses is unfortunately likely to increase with climate change. Rainfall extremes through droughts and floods are very detrimental to rice productivity. Higher and/or heavy rainfall results in higher yield losses through flooding (Rosenzweig et al., 2002; Reid et al., 2007; Roudier et al., 2011). In contrast, insufficient rainfall leads to greater drought frequency and intensity, while increased evaporation leads to complete crop failure (Reid et al., 2007; Liu et al., 2010). Extreme drought and floods may lead to huge income and consumption losses for rice-growing farmers, which could increase incidences of poverty. Lal (2005) concludes that global food security threatened by floods, droughts, and winds is the most important challenge in the 21st century to supply sufficient food for the increasing population while sustaining an already stressed environment. Additionally, Abraha and Savage (2006) note that changes in crop production related to climatic variables—like temperature, flood etc.—may significantly influence regional as well as global food production.

Nowhere does this issue deserve more attention than in South Asia, particularly in the rice farming sector. Take the case of Bangladesh, where ever-increasing frequency of floods, droughts and cyclones cause extensive economic damage and impair livelihoods. Overall, agricultural GDP in Bangladesh is projected to decrease annually by 3.1% as a result of climate change (Titumir and Rahman, 2011). This not only affects those in the agriculture sector, but all the way up the food chain to household consumption.[3] The problem is exacerbated in rural Bangladesh where 66% of the labor force makes its living in farming, with more than 81% of that number operating fewer than one and a half acres (Ahmed et al., 2013).

Rice is the staple crop of Bangladesh and a primary source of income and employment for millions of households across Asia and Africa. Importantly, rice consumption in the world has been increasing over the years, both due to increasing income and population. Unfortunately, agricultural productivity is not increasing at the rate required to keep up with the food demand. Water shortages and depleted soil fertility play into this predicament, but the primary contributing factor is abiotic stress. Therefore, minimizing the losses caused by these stressors is a major area of concern for all nations, Bangladesh in particular, so they can rise to the increasing food demand. Extending the land frontier to produce more rice is not a viable solution to this issue, particularly in Asia, where 90% of the total rice is produced and consumed, because there is little or no land left to cultivate (Miah and Sarma, 2000).

Besides increasing the amount of rice-growing acreage, another solution to increase rice production is enhancing the existing farm level rice production efficiency. Rice production efficiency can be achieved by increasing rice production level per unit under a given set of inputs and technology, or by minimizing production costs under a given production target. Further, production efficiency can be increased by closing the yield gap, developing and disseminating abiotic stress tolerant rice varieties, and releasing varieties with higher yield potential. To close the yield gap, the impact of abiotic stresses (drought/maximum temperature and flood) on production efficiency of rice farmers must first be clearly defined.

Herein lie the objectives of this study: to analyze the role of abiotic stress factors such as maximum temperature (indicator of drought) and rainfall (indicator of submergence) in explaining production efficiency of rice farmers in Bangladesh; and to identify the factors that determine the technical efficiency of rice farmers in Bangladesh.

We use Bangladesh as a case study for two distinct reasons. Firstly, more than 75% of the cropland in Bangladesh is dedicated solely to rice cultivation (Ganesh-Kumar et al., 2012), which means that the majority of the agricultural households produce rice. Similar to many other rice-dominated agrarian economies, more than 30% of the nearly 150 million people in Bangladesh are extremely poor (GOB, 2012). Additionally, Bangladesh, which has developed from a country with chronic food shortages to one of food self-sufficiency, still faces food security challenges (Ahmed et al., 2013). Secondly, while it is well known that drought and submergence stresses are two of the major limiting factors that substantially reduce rice yield and production in the rainfed ecosystem (Bernier et al., 2008; Widawsky and O'Toole, 1996; Khush and Toenniessen, 1991; Stephen, 2007; Dey and Upadhyaya, 1996; Pandey et al., 2007; Gauchan and Pandey, 2012; Evenson et al., 1996; Grover and Minhas, 2000), very few studies have investigated the impact of these stresses on production efficiency of rice farmers. In Bangladesh, 45% of the total rice farmland is rainfed in nature. Similar to other Asian and African countries, the frequent occurrences of submergence and drought are the major causes of crop failure, income volatility, and the persistent poverty among the small and marginal rice farmers in the rainfed ecosystem of the country.

A number of studies have examined rice farmers' technical efficiency (e.g., Wadud and White, 2000; Sharif and Dar 1996; Coelli et al., 2002; Rahman et al., 1999), but to our knowledge none have examined the impact of maximum temperature (i.e., drought) and rainfall (i.e., submergence) on the production efficiency of rice farmers. Findings from this study will help policymakers design appropriate policies to ensure increased production, profitability and food security of rice farmers in the rainfed rice ecosystem. To explain the farm level variation of production efficiency, this article includes farm and household characteristics as well as the extent of drought and submergence.

It is generally known that farm level efficiency can be achieved in two ways: by maximizing the level of production under a given set of inputs, or by minimizing cost under a prescribed level of production. The popular approach to measure the level of efficiency at the farm level is to use the frontier production function to determine technical efficiency (Tzouvelekas et al., 2001; Wadud and White, 2000; Sharma et al., 1999; Battesse and Coelli, 1995). In this study, we follow Ali and Flinn (1989), Kumbakhar and Bhattacharyya (1992) and Ali et al. (1994) and apply a stochastic production function model to rice farmers in Bangladesh. Technical efficiency is assumed as the ability of a farm to achieve the highest possible production given the level of inputs, existing level of technology, climate variables and abiotic stresses.

Also, a number of studies deal with efficiency measurement and regress the predicted efficiency score against a number of household level demographic variables, with an aim to identify the sources of technical efficiency at the farm level using a two-stage procedure (e.g., Sharif and Dar, 1996; Wang et al., 1996). In this paper, we also attempt to identify the sources of efficiency, particularly to quantify the impacts of drought, submergence and other climate variables (e.g., rainfall) on rice farmers' technical efficiency. Note that characteristically, farm households in Bangladesh are predominantly small, subsistence farms which average 0.53 ha in size (Hossain et al., 2007). Understanding the impact of abiotic stresses on technical efficiency of these small rice farmers has the potential to help shape policies which would ensure viable income for them. Interestingly, similar to Bangladesh, 85% of the total population in Laos is engaged mostly in rice cultivation (Ly et al., 2012), and in Nepal and India respectively, 50% and 33% of all cropland is used to cultivate rice; drought and submergence are also major limiting factors in rice production in these localities (Gumma et al., 2011; Pandey et al., 2007). The striking similarities in the importance of rice on

[3] Although household income in Bangladesh has increased by 59% between 2005 and 2010 (from about Taka 11,479 per month to about Taka 7203 per month), there is a significant gap in both income and consumptions expenditures of rural and urban Bangladeshis.