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Energy productivity and efficiency of wheat farming in Bangladesh

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A B S T R A C T

Wheat is the second most important cereal crop in Bangladesh and production is highly sensitive to variations in the environment. We estimate productivity and energy efficiency of wheat farming in Bangladesh by applying a stochastic production frontier approach while accounting for the environmental constraints affecting production. Wheat farming is energy efficient with a net energy balance of 20,596 MJ per ha and energy ratio of 2.34. Environmental constraints such as a combination of unsuitable land, weed and pest attack, bad weather, planting delay and infertile soils significantly reduce wheat production and its energy efficiency. Environmental constraints account for a mean energy efficiency of 3 percentage points. Mean technical efficiency is 88% thereby indicating that elimination of inefficiencies can increase wheat energy output by 12%. Farmers' education, access to agricultural information and training in wheat production significantly improves efficiency, whereas events such as a delay in planting and first fertilization significantly reduce it. Policy recommendations include development of varieties that are resistant to environmental constraints and suitable for marginal areas; improvement of wheat farming practices; and investments in education and training of farmers as well as dissemination of information.

1. Introduction

Energy is essential for development in Bangladesh as any other countries of the world. It is also one of the most critical as well as deficient resource in Bangladesh affecting all spheres of life including agricultural development. Effective use of available energy resources is crucial for an economy to develop and become competitive in the world market [1]. In agriculture, energy is used in various forms (e.g., directly as farm machinery powered by electricity and/or diesel fuel, human and draft animal power, and indirectly through inorganic fertilizers and pesticides), and therefore, its effective utilization is important.

Commercial energy use in Bangladesh agriculture has been modest but is increasing rapidly in recent years. For example, Bain [2] noted that energy intensity (i.e., commercial energy/GDP ratio) in Bangladesh agriculture has increased steadily from 0.36 in 1977 to 1.87 in 2000. More recently, Khosruzzaman et al. [3] noted that energy intensity in the agricultural sector has increased from only 1.78 in 2000 to a high level of 11.31 in 2008, implying that the sector is becoming energy intensive, thereby, adding further a crisis to the existing problem of acute energy deficiency in the economy. The main reason for rapid increase in energy use in agriculture can be attributed to widespread diffusion of the 'Green Revolution' technology which is composed of high yielding varieties of seeds, chemical fertilizers, pesticides and supplementary irrigation and drainage. Although the use of commercial energy in agriculture is not a bad sign but the phenomenon is creating additional strain on the already deficient resource. Wheat is one of the main cereal crops that meet major food demands of the world including Bangladesh. Wheat has contributed more calories and protein to the world's diet than any other food crops [4]. Although rice has been the dominant staple in Bangladeshi diet, import of wheat since the early 1970s to combat food deficit has resulted in a change of diet in recent years. Wheat area now ranks second after rice area in production. In fact, the total production of wheat has increased nearly six folds from only 110.0 thousand tons in 1972–735.5 thousand tons in 2006 [5].

According to the Bangladesh Soil Survey report, wheat can be planted in 3.1 million ha of land [5] which is equivalent to 42.3% of net cultivated area or 25.5% of gross cropped area of the country in 2005 [6]. Also, profit generated from wheat is much higher in regions with no irrigation and those unsuited to Boro rice (dry winter season) cultivation and represents the most efficient use of scarce resources when costed in terms of economic prices [7]. At face value, wheat can easily replace the dominant rice based staple in

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Bangladeshi diet as it uses significantly less amount of water in its production process, which in turn is also becoming a scarce resource. For example, rice consumes 1912 l/kg as compared to wheat at 900 l/kg [8]. However, given unprecedented rise of the demand for energy in Bangladesh agriculture, it is not known whether wheat production is a net energy user or producer. Bangladesh should aim to adopt production technologies that produce more energy as outputs than it uses as inputs at least and at the same time contributes to the nutritional requirement of its population. In fact, the major thrust of the National Food Policy of Bangladesh (2008–2015) is to link agricultural productivity and diversification with improvements of nutritional standards through a three-pronged approach: (a) raising productivity and efficiency of production for major cereals, (b) diversifying into non-cereal crops, including pulses, oilseeds and higher value horticultural crops (e.g., fruits, vegetables, spices); and (c) expanding fishery, livestock and poultry production [9]. This is because although rice has contributed to achieve self-sufficiency in foodgrain in Bangladesh, it was made possible through expansion of irrigation, use of inorganic fertilizers and modern varieties. However, there is a realization that rice cannot be expected to continue to perform as it did in the past [9]. The policy document also emphasized that food consumption trends in Bangladesh are not encouraging and diets remain poorly diversified, with as much as 80% of the dietary energy supply coming from rice alone [9].

Evaluation of energy productivity and efficiency of various field crops including wheat using various approaches are quite common in the literature [10–22]. However, a large number of these studies concentrated on evaluating energy productivity and energy ratio (which is also termed as energy use efficiency) by applying an accounting approach [10–12,14,15,17,22]. However, a limitation of the accounting approach is that it provides information on the observed use of inputs and outputs produced but cannot determine whether such outcome is technically efficient or not. In other words, this approach does not provide information on whether the farmers are using the minimum possible input levels to produce a given amount of output or producing a maximum possible level of output by using a given amount of inputs known as technically efficient production process.

Some of the recent studies have utilized a non-parametric programming approach, specifically DEA (Data Envelopment Analysis), to examine energy productivity and efficiency of crops [16,21] which suffers from a disadvantage of attributing all errors and statistical noises to inefficiency and hence understates the level of true production performance of the individual producers. A few studies have also used parametric and/or econometric approach to examine energy productivity and efficiency of crops, but their procedures were largely confined to deterministic models which assume perfect technical efficiency in the production process [18,19] which is not true as there is ample evidence of widespread inefficiency in the production process. Only recently, Rahman and Barmon [20] have used the stochastic input distance function model to estimate energy productivity and efficiency of 'gher' (prawn-rice-fish) farming system in Bangladesh that allows for inefficiency in the production process at the level of individual producers. Also Rahman and Rahman [13] applied stochastic production frontier model to estimate energy productivity and efficiency of maize cultivation in Bangladesh while accounting for the socio-economic and environmental factors affecting choice of the growing season (summer versus winter) as well as production performance of the farmers.

Wheat is a crop that is particularly sensitive to variations in the production environment as well as management practices. For example, a delay in sowing beyond the optimum period (i.e., Nov. 30th in Bangladesh) can result in a loss of yield @ 1.13% per day [5]. But most of the studies in the literature examining energy productivity and efficiency in crop farming did not take into account any environmental constraints within which production occurs, thereby leading to biased results. This is because omission of the environmental constraints within which farmers operate result in omitted variable bias in the estimation procedure, thereby leading to biases in the parameter estimates of the production frontier, technical efficiency scores as well as the determinants of inefficiency [23,24]. The problem of such omission is even higher for wheat farming because of its high level of sensitivity to variations in the production environment as explained above.

Given this backdrop, we evaluate productivity and efficiency of energy use in wheat production, while accounting for the environmental constraints within which farmers operate. Specifically, we set out to measure: (a) energy productivity of wheat output while allowing for inefficiency at the level of individual farmers; (b) technical (energy) efficiency of wheat production; and (c) identify the socio-economic determinants of technical (energy) inefficiency. The specific contribution of this study to the existing energy literature is three fold: (a) first, we address these aforementioned objectives while explicitly accounting for the environmental constraints to affect productivity and provide a measure of their influence on the productivity level using a parametric approach (i.e., the stochastic production frontier approach) which in turn allows for inefficiency in the production process at the level of individual producers; (b) second, we demonstrate the magnitude of the bias in technical (energy) efficiency scores that results due to omission of the environmental constraints; and (c) third, the study also provides confirmation that wheat farming is highly efficient in energy use along with its financial merit or profitability [25]. This confirmation is important because not all crops that are deemed to be profitable are also efficient in terms of energy use. For example, Rahman and Barmon [20] noted that the prawn-fish enterprise of the gher farming system, which is the most financially rewarding enterprise, is actually highly inefficient in terms of energy use. The gher farming system as a whole passes the test of sustainability in terms of energy use because of the high level of energy ratio (or energy use efficiency) of the associated rice enterprise of the system. Therefore, it is important to judge the merit of a crop production system in terms of its energy use which serves as an indicator of its sustainability, particularly in an economy where energy deficiency is acute, such as Bangladesh.

2. Research methods

2.1. The study area

Although wheat is cultivated throughout Bangladesh, the production intensity differs substantially across regions. As such, we have constructed a WI (wheat intensity index) for each greater district.[1] The WI for the jth district is given by:

$$WI_j = (WA_j/GCA_j)*100, \tag{1}$$

where WI is the index, WA is the area cultivated with wheat and GCA is the gross cropped area. The computed value of the index, which can also be regarded as the area share of wheat in GCA, is used to classify the regions into three levels of intensity: high intensity ($WI > 8.0$), medium intensity ($4.01 < WI < 8.0$), and low intensity areas ($WI < 4.0$).

[1] This is because official data are available for 21 regions (former districts). Currently, there are 64 new districts in Bangladesh.