Agricultural response functions for limited resource farmers in Sub-Saharan Africa

Pierre-Justin Kouka, Curtis M Jolly & Julio Henao

Department of Agriculture, University of Arkansas, Pine Bluff, Arkansas, 71601, USA; Department of Agricultural Economics and Rural Sociology, Alabama Experiment Station, Auburn University, Auburn, Alabama 36849-5406, USA; International Fertilizer Development Center, Muscle Shoals, Alabama, USA

Received 20 April 1994; accepted in revised form 2 December 1994

Abstract

The von Liebig, Cobb-Douglas, and Quadratic functions were evaluated using Generalized Least Squares on fertilizer response data for crops grown in Ghana and Mali. This was done to determine which model is most likely to overestimate fertilizer use. Model fit varied for crops and soil types. The von Liebig was slightly superior, based on prediction criteria and number of significant variables. The von Liebig functional form also produced the most conservative optimum yield estimates and input levels, while the Cobb-Douglas was most likely to overestimate yield and hence input use, but produced the highest net returns for cotton.

Introduction

Countries in Sub-Saharan Africa have experienced a decline in agricultural output per capita since 1970 (Cherfas, 1990; Tshibaka, 1988; Tshibaka and Baanante, 1988). The decrease in per capita agricultural production over the past two decades has been associated with unpredictable weather conditions, accompanied by long droughts, soil degradation, the partial absence of a complete technology package appropriate to the various ecological zones and low fertilizer use (Greenland, 1975; Lal, 1987; Lawson and Sirakumar, 1991). In spite of the area cultivated in crops and the number of countries of Sub-Saharan Africa, absolute as well as per-hectare fertilizer use levels are low. In 1992, Sub-Saharan African countries consumed about 1.6 million tons of nutrients and accounted for less than 1.0 percent of global fertilizer use. The quantities of fertilizer used per hectare amount to only 12 kg per hectare of arable land (Bumb, 1989, 1994). Fertilizer is applied mainly on cash crops, and especially, those crops produced under contractual agreements, but very little on local grain crops, such as millet and sorghum. Under irrigated conditions fertilizer use on rice and maize are higher than on other food crops. Farmers have, however, developed a cropping pattern of rotating food crops and cash crops so that the food crops benefit from the residual fertilizer used on the cash crops (Adesina et al., 1988; Baanante and Thompson, 1988). The low level of fertilizer use is attributable to limited capital, high farmgate costs, inadequate and untimely supply of fertilizers, low fertilizer efficiency, and farmers’ perception of the stochastic nature of net benefits of fertilizer use, particularly in situations of non-controllable climatic conditions (de Janvry, 1972; Lal, 1987). Information on optimal fertilizer dosage could help provide some guidance to policymakers and agricultural extension agents as they attempt to encourage farmers to increase fertilizer use. In this paper, functional forms used for determining the optimum fertilizer application rates for both cash and food crops are evaluated.

Fertilizer recommendations for profit maximization by farmers in Sub-Saharan Africa have been rarely determined for each crop, crop variety and ecological zone (Kagbo, 1986). Crop response functions commonly used by economists for determining optimum fertilizer levels have mostly been derived from Cobb-Douglas and polynomial models. Researchers (Ackello-Ogutu et al., 1985) indicated that the use of these models consistently overestimated the maximum yields and the optimal fertilizer recommendations. They feared that overestimation of maximum yield and optimum fertilizer recommendations might
result in waste of scarce resources and eventual environmental pollution (Frank et al., 1990). In the case of Sub-Saharan African farmers, limited fertilizer application is more prevalent than an overdose. It is, therefore, important to investigate whether the response functions used in determining optimum fertilizer rates are the best to describe plant soil and fertilizer relationships under farmers' conditions.

Previous studies

The functional forms most commonly developed by researchers in developing economies are the linear, the Cobb-Douglas, and the Quadratic. Researchers in Africa have used the Cobb-Douglas functional form in a study of tractor use in rice production in Nigeria (Okereke, 1991; Yeager and Matlon, 1990). Agronomists, who studied crop response functions in developing economies, are prone to use simple linear regression and the quadratic functional forms because of their mathematical simplicity, computational ease, and good fit (Ackello-Ogutu et al., 1985). The question posed is: "are these forms appropriate for analyzing crop response functions in areas of low rainfall and on marginal soils, and can a functional form be universal?"

The disadvantages in using polynomials in the study of behavior of biological organisms have been well documented (Nelder, 1966). It was thought that the effect of increasing a factor indefinitely is to produce a negative effect after the saturation point has been attained. The negative effect eventually reduces yield to zero and this phenomenon is not always captured by polynomials. It has been shown that since plant-level agricultural functions do operate on a limiting concept, then estimation of these plant level production functions with continuous concave functional forms will not provide meaningful results (Berck and Helfand, 1990).

The utility of polynomial functional forms in explaining crop yields due to fertilizer has been questioned (Ackello-Ogutu et al., 1985; Adams et al., 1983; Lanzer and Paris, 1981; Menz and Pardey, 1983; Perrin, 1976). The advantages and disadvantages of each of the various functional forms have been listed (Tronstad and Taylor, 1989). It was concluded that it was not possible to ultimately establish the dominance of one functional form over another since the forms may vary according to the crop. The particular form chosen, however, should explain crop soil relationship in the particular environment (Swanson, 1962).

In the past, several researchers (de Janvry, 1972; French, 1956; Johnson, 1953; Russell, 1972; Waggoner and Norvell, 1979) have used functional forms such as Spillman, the Mitscherlich-Baule, the Transcendental, and the von Liebig which they thought could more aptly explain crop responses. The linear response and plateau (LRP) forms were the most popular. Economists have been slow in accepting these forms because they do not account for substitution among nutrients. The smooth functional forms can be derived by aggregating the effects of heterogeneous inputs on LRP functions (Berck and Helfand, 1990). The debate goes on as to which forms are best suited to explain yield response.

The question remains whether one should search for a universal functional form, or whether the form is unique to the crop, crop variety, and/or environment. This has serious implications as to whether the econometric model should be specified a priori or posteriori. Uniqueness of functional form to crop, or crop variety should not affect a priori model specification if one takes into consideration the crop agronomy and environmental influences on yield when developing the models. Given the low level of fertilizer presently used in Sub-Saharan countries, and the extent to which climatic and soil conditions influence projected crop yields, response functions appropriate to economic fertilizer decisions should be explored. In this study, an LRP functional form, and two polynomials are fitted on two crops to show that there may be no one general functional form, but the form may vary from one crop to the next and for different varieties of the same crop. The von Liebig functional form is compared to the general Cobb-Douglas and quadratic forms to determine which ones are most likely to overestimate the maximum and the likely cost accrued due to mispecification.

Crop response functions

The yield response function forecasts levels of agricultural quantities or yields as levels of one input are varied while others are held constant. Though one can control some factors, other factors, such as cultural practices, soils and environmental conditions are variable. A model to explain the variations in yield can be