# Sustainability of cereal production in Greece and factors affecting it

S. M. FAKHRUL ISLAM*, BASIL MANOS**

Jel classification: Q120, Q180

**Abstract**

This study estimates the biological, economic and ecological sustainability of the major cereal production in Greece by using total factor productivity (TFP) indices and specifies a methodological approach to quantify the determinants of a sustainable crop production. Biological sustainability of wheat and rice were found to rise during 1961-1997. Maize showed an increasing sustainability for the period 1961-1982; thereafter it had almost stable biological sustainability until 1997. All these crops were also found to be economically and ecologically sustainable. There were little differences between TFP and Total Social Factor Productivity (TSFP) of these crops, indicating that they had good ecological sustainability in the country. The study found that fertilizers, pesticides, labor, seed, irrigation, fixed capital, rainfall and temperature are important determinants affecting the long-term sustainability of cereal production in Greece.

**Résumé**

*Cette étude estime la durabilité biologique, économique et écologique des principales productions céréalières en Grèce en utilisant les indices de Productivité Totale des Facteurs (PTF) et elle précise une approche méthodologique pour quantifier les déterminants de la production culturale durable. La durabilité biologique du blé et du riz a augmenté dans la période 1961-1997. Le maïs a enregistré une durabilité croissante entre 1961 et 1982, et après cette date, il a enregistré une durabilité presque stable jusqu'en 1997. Toutes ces cultures se sont avérées durables du point de vue économique et écologique. Il y a eu de petites différences entre la PTF et la Productivité Totale des Facteurs Sociaux (PTFS) de ces cultures, ce qui indique qu'elles se caractérisaient par une bonne durabilité écologique dans le pays. L'étude a constaté que les engrais, les pesticides, la main d'œuvre, les semences, l'irrigation, le capital fixe, la pluie et la température sont des déterminants importants qui influent sur la durabilité à long terme de la production céréalière en Grèce.*

## 1. Introduction

Agricultural sustainability is an important global issue. Its importance increased from the rising awareness of conservation of resources and environment for future use to have smooth intergenerational consumption. Environmental consideration and sustainable agriculture have become a major concern of the Common Agricultural Policy (CAP) of the European Union (EU). The need to integrate environmental concerns was given effect in the Single European Act of 1986 (Commission of the European Communities, 1999). A sustainable production system is one that meets the needs of the present without compromising the ability of future generations to meet their needs (World Commission on Environment and Development, 1987). Population of Greece increased more than double from 3.7 million in 1950 to 10.5 million in 1997. Such increased population requires availability of more food. At least the growth rate in food production should be higher than growth in population.

There was a green revolution in food production. Crop productivity has increased sufficiently by adopting the modern technology. But the challenging issue is: could we have sustainable production over long time? In quest of sustainability of agricultural production system, there is a growing body of literature (Ruttan, 1991; Schroll, 1994; Cooke and Sundquist, 1989; Ali, 1996; Plucknett, 1990; Islam, 1998; Barnett et al., 1995; Cassman and Pingali, 1995; Zilberman et al., 1997; Callens and Tyteca, 1999; Hanley et al., 1999; Gerakis and Kalburtji, 1998; Kuyvenhoven et al., 1998; Hueting and Rejinders, 1999; Wackernagel, 1999; Islam at al., 2003). Physical evidence from around the world suggests that current farming practices in many areas cannot be sustained much longer. Agricultural resources are threatened or declining (Feth, 1993; Islam, 1998). The meaning of sustainability strongly depends on the context in which it is applied and on whether it is based on a social, economic or ecological perspective (Brown et al., 1987). This paper answers to the question of how to measure sustainability and quantify the determinants affecting sustainability of crop production. On the other hand it takes up a more practical issue concentrating on biological, economic, and ecological perspective of sustainability of major cereals production in Greece and the factors affecting their sustainability. Furthermore the paper proposes a methodological approach to quantify the factors affecting sustainability of crop production using a moment-based production function.

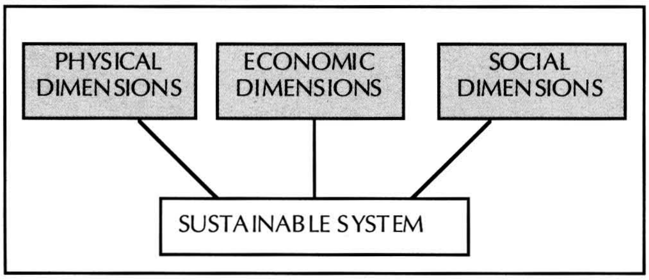
## 2. Methodology

### 2.1 Conceptual framework for sustainability measurement

Sustainability of major cereals production system in

* Department of Agricultural Economics, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh
** Department of Agricultural Economics, Aristotle University of Thessaloniki, Greece

Figure 1. *Dimensions of sustainable cereal productions system in Greece*




Greece has three dimensions - biological, economic and social. The biological and physical dimensions can be reflected in the quantity of output (e.g., food grain), which depend on the physical quantity of inputs and the biological growth process. Degradation of resources base can lead to falling quantity of output over time.

The economic dimension can be reflected in the value of outputs and costs of inputs, in turn, on prices of outputs and inputs. Even if the quantity of a system output is constant over time, the economic environment can lead to the system failure because of falling commodity prices, increased input prices and changing in their related economic phenomena.

The social dimension can be reflected in the capacity of the systems to adequately support farming communities and people of the country. Cereals production systems depend on the society and institutions. Poor agricultural policy, insecure land tenure system, and changing labor conditions are few factors that can affect sustainability of cereals production in the country. All these three dimensions of sustainability are interrelated as shown in Figure 1. While economic performance has important effects on farmer's decision-making regarding resource allocations and productions, biological performance, depending on the environment (physical dimensions), is the base, which is modified by costs and prices to give economic performance. Social performance is dependent on both physical and economic performance. Evidence shows that in most cases the important trends affecting the sustainability of a system usually become apparent in the first 20-40 years. In this study we deal with the sustainability of production of major cereals in Greece for 37 years, from 1961 to 1997.

## 2.2 Analytical model

### 2.2.1 The Growth model

To examine the growth rate of the area, yield and production of major cereals in Greece, trend models were estimated by fitting a log linear equation. Specification of the crop area/yield/production with a constant percentage growth over a discrete time interval of a year is made as

$$Y_t = A(1+g)^t U_t \qquad (2.1)$$

where $Y_t$ is the area/yield/production of a selected crop in time period t, g is the annual proportional rate of growth and $U_t$ is the error term. Linearisation of the above equation can be done as

$$LnY_t = a + b_t t + \mu_t \qquad (2.2)$$

where LnY is assumed to grow at a constant rate,

$a = LnA$, $b_t = Ln(1+g)$

is the rate of continuous growth, $\mu_t = LnU_t$, which is assumed to be normally and independently distributed.

### 2.2.2 Measurement of sustainability of cereal production

Sustainability concerns the preservation of crop productive capacity for the future. Productive capacity includes man-made capital, technical know-how and labor skill as well as land and other reproducible assets.

In this paper our concern is to develop an appropriate methodology to measure the sustainability of major cereal production systems in Greece. In a limited sense, the ability of agricultural cropping system of Greece to maintain a consistent flow of marketable output of food grains over time is an indicator of sustainability. However, these indicators ignore the mix and quantities of inputs used in conjunction with land (which includes characteristics of the lands in conjunction with its relationship to its environment- sunlight, air, and rain etc.) and basic natural capital. It also fails to account for (1) possible environmental degradation or negative externality and (2) non-market benefits associated with cropping pattern or possible externalities. For operational purposes, sustainability might be assessed in relation to an index of TFP with a due account of externalities such that "a sustainable food grain production system has a non-negative trend in total factor social productivity over time (Lynam and Herdt, 1989)". Over the long run, a sustainable system will exhibit resilience in the face of external events. Thus, it will be able to maintain constant productivity or a positive trend in productivity by using technology that resists both cumulative stresses such as environmental degradation and can withstand over time the impact of negative shocks such as drought. Shocks will lead to short-run variability in productivity, so it will be necessary to quantify the long run trend in TFP.

We use TFP, a ratio of index of aggregate output to aggregate inputs (Caplbo and Antle, 1988; Lingard and Rayner, 1975; Barnett et al., 1995). By constructing an index of TFP, it is possible to assess the foodgrains productivity performance of Greek agricultural system over time. Generally, the ratio of TFP between a couple of years, denoted by r and s is defined by:

$$\frac{TFP_s}{TFP_r} = \frac{Q_s/X_s}{Q_r/X_r} \qquad (2.3)$$

or $\ln(TFP_s/TFP_r) = \ln(Q_s/Q_r) - \ln(X_s/X_r)$ (2.4)

where $Q_t$ is an index of aggregate output in year t = r, s and $X_t$ is an index of aggregate input in year t = r, s. Output at time t can be written as:

$$Q_t = A(t)\ f(X_{1t}, X_{2t}) \text{ for } t = r, s \qquad (2.5)$$

where A(t) is a shift factor dependent only on the passage of time and reflecting technological change, and $f(X_{1t}, X_{2t})$ is linearly homogeneous production function in inputs $X_1$ and $X_2$. Expression (2.5) can be used to form a ratio of TFP between years s and r with the aggregator function $f(X_{1t}, X_{2t})$ being used to form the input index. This gives:

$$TFP_s/TFP_r = (A_s/A_r) = \frac{Q_s/(f(X_{1s}, X_{2s}))}{Q_r/(f(X_{1r}, X_{2r}))} \qquad (2.6)$$

Construction of the index of TFP requires knowledge of the form of production function, $f(X_1, X_2)$ in order to generate the aggregate index of the two inputs. Furthermore, assuming both a specific form of the production function and competitive equilibrium in production leads to a specific aggregator function in terms of input prices and input quantities. Since it would be unusual to have exact knowledge of the production function, economists have usually advocated measurement by an aggregator functional form that corresponds to a flexible functional form for the production function. In addition, the assumption of competitive behavior is required to derive results. In order to avoid these problems with production function appropriate TFP measurement, an alternative is to rely directly on index number approach.

Laspeyres, Paasche and Tornqvist-Theil (TT) indexes are the three commonly used arithmetic indexes for measuring TFP (Nadiri, 1970; Squires, 1988; Islam, 1998). The most widely used logarithmic index is TT index. The TT index number has appealing theoretical properties, including consistency with an assumed underlying homogeneous translog production technology (Christenson, 1975). Although Christensen warns that the TT and Laspeyres indexes may diverge when the period of analysis is very long, or when 'large' changes occur in either prices or quantities, several studies have found the difference to be small (Boyle, 1988; Ball, 1985; Sidhu and Byerlee, 1992). Most previous studies used aggregate data to analyze agricultural performance at the state, national or multinational level (Boyle, 1988; Ball, 1985; Jorgenson et al., 1987; Antle, 1987). A few studies (Sidhu and Byerlee, 1992; Cooke and Sundquist, 1989) have used survey data to analyze the performance of 'average' or representative producers by using TT index.

In this study, we used a TT index formula with 1961 as base year. The TT index was computed as (Ball, 1985):

$$\ln(TFP_r/TFP_s) = 1/2\,(R_{ir}+R_{is})\ln(Y_{ir}/Y_{is}) - 1/2\,(S_{jr}+S_{js})\ln(X_{jr}/X_{js}) \qquad (2.7)$$

where $Y_{ir}/Y_{is}$; $X_{jr}/X_{js}$ are output and input indexes, respectively; $R_i$ are output revenue shares and $S_j$ are input cost shares.

To partition the effect of biological, economic and ecological changes on sustainability of cereal production, three alternative measures of TFP were estimated. To evaluate biological sustainability over time, prices were held constant. This confines TFP changes to factors affecting yield. It allows a clearer identification of input use effects during the two time periods (Duff et al., 1995). To measure economic sustainability, both input and output prices were allowed to vary. Economic sustainability is a composite of biological changes, income and costs considerations (Duff et al., 1995). A sustainable crop production system is one that is both economically and ecologically viable.

The final step in using TFP to assess the sustainability of crop production system is adjustment for externalities. The conventional TFP attempts to account for all marketed outputs and inputs but omits non-marketed goods and services such as environmental quality. In our study, the main externalities to be considered are the effects of fertilizers and pesticides. It is natural to consider negative externalities of such input uses as costs. These externalities should be considered as additional costs associated with input factors. Considering these externalities we estimated the TSFP to evaluate whether cereals production is sustainable from the viewpoint of economic, ecological and social factors. Since no quantification or costing of externalities (or data upon which these could be based) was available, we assessed the behavior by the approximate method suggested by Steiner and Mclaughlim, 1992. This method uses proportional costing for fertilizers and pesticides related externalities. The additional externality cost of using a unit of such input with application cost c (per unit) is taken to be pc, where $0<p<1$. We have assumed a 50% increase in fertilizers and pesticides costs to estimate TSFP indexes.

The construction of an index of TFP or TSFP for a long period permits the evaluation of the ability of the cropping system to maintain productivity over time. We state that Greek cereal production system is sustainable if it can maintain productivity over time that would be reflected by non-negative trend in TFP or TFSP index. The index is set at 100 for a particular base production year and the output to input ratio is computed for all other years relative for the base.

Consider the ratio of TFP between any couple of years, denoted by r and s defined by the formula (2.3). If year r is taken as the base year and the numerical value of the ratio $TFP_s / TFP_r = b$, then $TFP_s = 100\,b$. If TFP for year s is less (or more) than 100, then productivity has fallen (or risen) between years r and s; that is less (or more) output is being produced from a given quantity of inputs in year s compared with base year.

### 2.2.3 Factors affecting sustainability

In this section we propose a new methodological approach to quantify the determinant affecting sustainability of crop production using the moments of the probability distribution of output. Many studies have used the moments of the probability distribution of output to represent the stochastic structure of an agricultural production process under uncertain environment (Antle, 1987; Antle, 1988; Rolla and Pingali, 1993; Islam, 1995). The moments of the output distribution can be expressed in general forms as functions:

$$\mu_1(x) = \int y\, f(y/x)dy$$
$$\mu_i(x) = \int (y - \mu_1)\, f(y/x)dy,\ i \geq 2 \qquad (2.8)$$

where x is the input, y is the output and $\mu_i$ is $i^{th}$ moment.

Thus, the moments are functions of input x expressing the functional relationship between the stochastic structures of the production function. These moment functions can be used to measure factors affecting sustainability of cereals production in Greece. The first moment function estimates the effect of use of inputs on mean output level. The second moment function measures the effect of inputs used on variance of output, i.e., it estimates for the influences of the factors on variability of output. While the third moment measures skewness of output distribution.

Specification of the stochastic production function used in this study was (Just and Pope 1979) proposed as a more general model with an additive heteroscedastic error of the form:

$$Y=f(x, \beta)+e^*=f(x, \beta)+h(x, \Omega)^{1/2}\, e;\ E(e)=0,\ V(e) = 1 \qquad (2.9)$$

This model allows inputs to have distinct effects on the mean, $E(Y) = f(x, \beta)$ and the variance, $V(Y) = h(x, \Omega)$ of output. Thus, the effects on mean and variance of output can be independent where $f(x, \beta)$ is the deterministic component of the production function and $h(x, \Omega)$ is the stochastic component of the production function, Y is the output (kg per hectare) and x is the vector of inputs $X_j$, j = 1,2, ..., 7 with $X_1$ the irrigated area (ha), $X_2$ the fertilizer used (kg per hectare), $X_3$ the pesticide used (kg per hectare), $X_4$ the seed used ( kg per hectare), $X_5$ the fixed capital ( Euro per ha), $X_6$ the monthly average rainfall (mm.), $X_7$ the monthly average temperature ($C^O$), e a random error term; $u \approx N(o,\sigma^2)$ and $\beta$ and $\Omega$ are the parameters to be estimated.

For estimation of production distribution function (2.9), both $f(x, \beta)$ and $h(x, \Omega)^{1/2}$ were specified as popular log-linear form, the Cobb-Douglas (Antle, 1987; Islam, 1995; Islam, 1997). The linear model presented here is based on the hypothesis that a linear in-parameters relationship exists between moments of the output distribution and input use decision variables.

The moment functions given in equations (2.8) are written in linear form as:

$$\mu_{1j}(X_j) = X_j\, \Phi_1 \text{ and } \mu_{ij}(X_j) = X_j\, \Phi_i,\ i \geq 2$$

where $\Phi_i$, i = 1, 2, ..., n are parameters which relate inputs to moments.

In this study, the moment function is specified as linear in-parameters functional form (Fuss et al., 1978). The output is random and $E(Y) = \mu_{ij}$, so the first moment function can be written as the regression equation:

$$Y_j = X_j\, \Phi_1 + u_j,\ \ E(u_j) = 0 \qquad (2.10)$$

Where $u_j$ is the error term, which is assumed to be independently distributed, similarly, noting that

$$E[(Y_j - \mu_{1j})^i] = E(u_j^i) = \mu_{ij},\ i \geq 2 \qquad (2.11)$$

The $i^{th}$ moment function is written as the regression equation

$$u_j^i = X_i\, \Phi_i + v_{ij},\ E(v_{ij}) = 0,\ i > 2 \qquad (2.12)$$

Here we have to estimate the $\Phi_i$ parameters. The least squares estimate $\Phi'_1$ of $\Phi_1$ is consistent. In addition, using the residuals $u'^i_j = Y_j - X_j\, \Phi'_i$, the least square regression of $u'^i_j$ on $X_j$ can be shown to produce a consistent estimate $\Phi'_i$ of $\Phi_i$, $i \geq 2$. However, the least squares formula for the standard errors of the $\Phi_i$ are not valid because (2.11) and (2.13) are heteroscedastic due to the fact that the variance of $Y_j$ is assumed to be $\mu_{2j} = X_j\, \Phi_2$, and the variance of $u_j^i$ is $E(v_{ij})^2 = \mu_{2i,j} - \mu_{ij}^2$, $i \geq 2$. Since $\Phi'_i$ is a consistent estimator of $\Phi_i$, it follows that the weight $W_{ij}^2 = x_j\, \Phi'_2$ is a consistent estimator of $\mu_{2j}$ and in general

$$W_{ij}^2 = x_j\, \Phi'_{2i} - (x_j\, \Phi'_i)^2,\ i \geq 2,$$

is a consistent estimator of $E(v_{ij}^2)$. Therefore, a feasible GLS estimator for $\Phi_i$ can be obtained by the weighted regression

$$Y_j/W_{1j} = X_j\, \Phi_i/W_{1j} + u_j/W_{1j}, \qquad (2.13)$$

and a feasible GLS estimator for any $\Phi_i$, $i \geq 2$, can be obtained by the weighted regression

$$u_j^i/W_{ij} = X_j\, \Phi_i/W_{ij} + v_{ij}/W_{ij} \qquad (2.14)$$

where $W_{ij}$ = weights. In the present study, the first, second and third moments of output were estimated using the weighted GLS regression procedure.

# 3. Results

## 3.1 Overview of Greek cereal sector

At the beginning of the study period in 1961, the Greek cereal sector covered an area of 1,772 thousand hectares (63.4% of arable land) with a total production of 2,244 thousand metric tons, food grains having an average yield of 1.3 ton per ha. After 37 years, the total area has declined by 27.4%, but its total production becomes almost double (4,774 thousand metric ton) showing a clear increase in the productivity of the sector. In 1998, the average yield rose to 3.71 ton per ha, i.e., there is almost a triplicate increase in productivity. Among the cereals in Greece in 1961, wheat covered the largest area (1,173 thousand ha) followed by maize (191 thousand ha), barley (189 thousand ha) and rice (22 thousand ha). Rainfed wheat still dominates the cereal sector (it covers 65% of the total cereal-growing area). In 1998, the area covered by wheat was 835 thousand ha, that for maize was 228 thousand ha, for barley 139 thousand ha and for rice 220 thousand ha.

Table 1 shows the growth rate in the area, yield and production of wheat, maize, rice and total cereals in Greece for the study period, 1961 to 1998. A declining trend was observed in the total cereal-growing area in the past 4 decades as well a negative growth rate of 0.8% per annum for the whole period from 1961 to 1998 despite a positive 3% growth rate per annum. However, a positive growth rate in yield remained persistent in the past decades, except for 1991 to 1998. This happened partly as a result of declining trend in

Table 1. *Growth rate (percent) in area, yield and production of wheat, maize, rice and total cereals in Greece, 1961-98*

| Period | Wheat | | | Maize | | | Rice | | | Total cereals | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area | Yield | Production | Area | Yield | Production | Area | Yield | Production | Area | Yield | Production |
| 1961-70 | -1.8 | 3.2 | 1.4 | -2.0 | 10.4 | -8.5 | -1.7 | 3.7 | 2.0 | -0.8 | 4.6 | 3.8 |
| 1971-80 | 1.2 | 3.6 | 4.8 | -2.3 | 7.2 | 14.7 | 4.6 | -0.5 | 1.3 | -0.09 | 3.6 | 3.6 |
| 1981-90 | -1.1 | -0.7 | -1.9 | 2.8 | 1.3 | 4.1 | 28.7 | 1.6 | 3.7 | -1.3 | 1.2 | -0.1 |
| 1991-98 | -2.3 | -2.5 | -4.8 | -0.4 | -1.2 | -1.6 | 13.2 | 2.4 | 13.2 | -1.9 | -1.0 | -2.8 |
| 1961-98 | -0.7 | 1.6 | 0.9 | 1.3 | 6.0 | 7.2 | 2.1 | 1.8 | 2.1 | -0.8 | 3.0 | -2.2 |

wheat and maize area. During the period 1961-1998, wheat area declined by 0.7% per annum. In the past decades declining growth rate in wheat ranged from 1.1 to 2.3% per annum with an exception in 1971-80. During this decade, its area had a positive growth rate of 1.2% per annum. However, throughout the whole study period wheat had a positive growth rate of yield of 1.6% per annum. In 1961-80, it had a high growth rate in yield. Compared to other cereals, maize had a tremendous good performance. During 1961-1998, its area, yield and production increased by 1.3%, 6.0% and 7.2% per annum, respectively. This is due to the fact that new hybrid varieties started to get spread throughout the country. On the other hand, there was considerable high growth rate in rice area between 1971 and 1998 ranging from 4.6% to 28.7% per annum. This trend shows that the popularity of the crop increases over time because of better prices resulting from better yields. For the whole study periods of 1961-1998 the growth rate in area, yield and production of rice were 2.1%, 1.8% and 2.1% per annum, respectively.

## 3.2 Sustainability of cereal production

To measure the biological sustainability of major cereal productions in Greece, prices were held constant at 1990 level and TFP indices were estimated. The TFP indices for wheat, maize and rice are illustrated in Figures 2 (a), (b) and (c), respectively. These Figures illustrate changes in TFP due to factors affecting yield. It allows a clearer identification of input uses effect during the study periods.

Figure 2 (a) shows that there is an increasing trend in TFP of wheat over the 37 years' period from 1961 to 1997. This indicates that wheat production in Greece is biologically sustainable with the existing rainfed production technology. However, there are short-term fluctuations in TFP due to changes in environmental conditions and input combinations.

This is consistent with the long-term (1855-1991) experimental results of Rothamsted Experimental Station in UK, which showed a positive trend in TFP of wheat production (Barnett et al., 1995; Duff et al., 1995). Duff et al. (1995) also reported similar results showing that with the technological improvement, the biological sustainability of wheat rose in Pacific North-West America from 1967 to 1992.

Figure 2 (b) shows an increasing biological sustainability in maize production in Greece from 1961 to 1982 as indicated by an upward trend in TFP. However, from 1982 to 1997, the maize production system in Greece remained biologically sustainable with almost stable TFP. Brown et al. (1995) also showed similar results of maize production in the USA; an upward trend in TFP suggests that technology advances have been successful in increasing TFP. Maize production was also biologically sustainable in continuous culture in the USA.

A sharp upward trend in TFP of rice production for the period 1961 to 1997 reflects that rice production in Greece is biologically sustainable (Figure 2 (c)). Although there were short-term fluctuations, TFP was always higher than the base period, indicating a clearer increase in productivity gain over time.

Figure 2. *TFP of cereal production in Greece, 1961-1997, illustrating the biological sustainability of the crops*

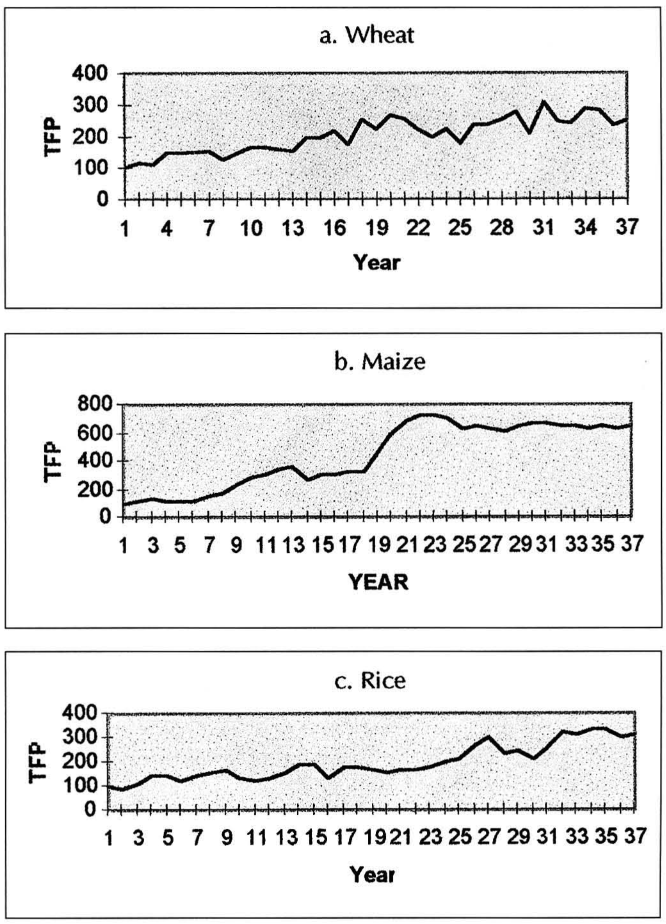
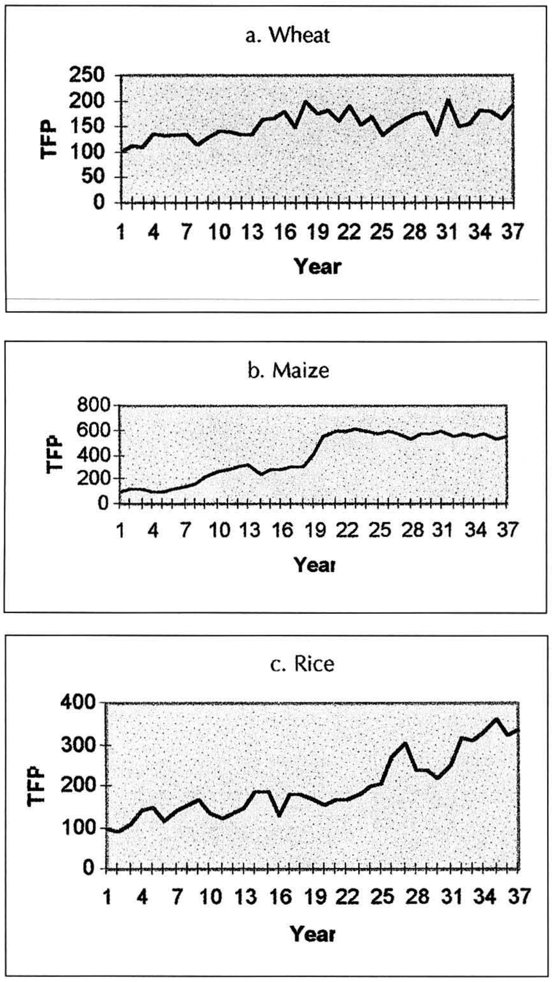


Figure 3. *TFP of cereal production in Greece, 1961-1997, illustrating economic sustainability of the crops*




From Asian studies it is also found that based on 1990 prices in the Philippines, trends in TFP of rice increased steadily from 1966 until 1989 followed by a slight decline through 1990. TFP trend in Bangladesh and India also follows a pattern similar to that in the Philippines (Cassman and Pignali, 1995; Islam, 1998). But Greek rice cropping system differs from the Asian systems in that it is irrigated and has single cropped pattern while the Asian ones are intensive with double or triple cropped systems.

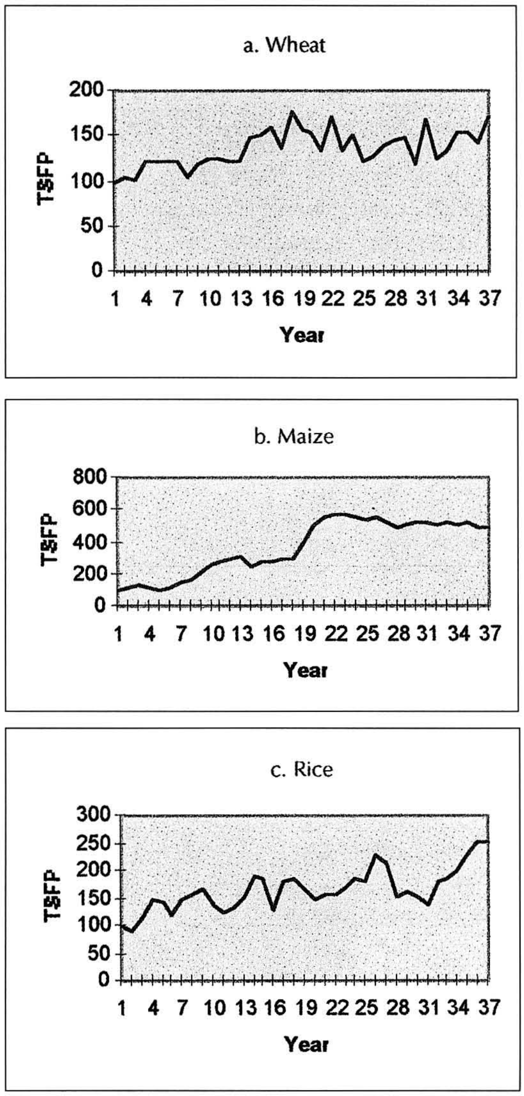
We used a second procedure to measure the economic sustainability of cereal production in Greece. In this case, both input and output prices were allowed to vary and TFP for each crop was estimated. Input and output prices were used for the production period of 1961 to 1997. Economic sustainability is a composite of biological changes, income and cost considerations. The economic sustainability of wheat, maize and rice are illustrated in Figure 3 (a), (b) and (c), respectively. These Figures illustrate changes in TFP due to factors affecting yield and changes in input and output prices over the production periods. It allows a clearer identification of the effect of input uses and price changes during the study periods.

Figure 3 (a) shows that there is an increasing trend in the TFP of wheat production over the period 1961 to 1997, indicating that rainfed wheat production in Greece is economically sustainable. It clearly identifies that wheat production is economically sustainable, since TFP is always higher than in the base period.

This is also consistent with the findings of long-term Rothamsted experiment of UK, where wheat production was found to be economically sustainable (Barnett et al., 1995). Wheat production was economically sustainable in Bangladesh from 1971 to 1990 (Islam, 1998).

There was an increasing economic sustainability in maize production in Greek agriculture from 1961 to 1982 as indicated by the positive slope in TFP curve (Figure 3 (b)). After that period until 1997, it had almost stable economic sustainability. Also the study of Barnett et al. (1995) report-

Figure 4. *TSFP of cereal production in Greece, 1961-1997, illustrating ecological sustainability of the crop*



ed an increasing economic sustainability of maize production in the USA.

Unlike wheat and maize, rice production in Greece in 1962 was economically unsustainable. But from 1963 to 1997, there was a dramatic improvement in economic sustainability of rice crop in Greece. During this period a sharp increasing trend in TFP of rice production was observed (Figure 3 (c)).

A sustainable cereal production system is one that is biologically, economically and ecologically viable in the long term. The final step in using TFP to assess the sustainability of the cereal production system in Greece concerns adjustment for negative externalities in the environment. For the assessment of negative externalities that might result from the use of fertilizers and pesticides, we estimated TSFP. Figure 4 (a), (b) and (c) show TSFP of wheat, maize and rice production in Greece, respectively.

Figure 4 (a) illustrates an upward trend in TSFP of wheat production, which clearly indicates ecological sustainability of this crop in the Greek agriculture. There is a little difference between TFP and TSFP of wheat production. This implies a good ecological viability of the crop.

The TSFP of maize shows an increasing trend for the first 22 years after which it becomes almost stable, implying the ecological sustainability of the crop.

But rice shows a sharp increasing ecological sustainability throughout the study period. Like wheat, the comparison of TFP and TSFP of maize and rice shows that there are little differences. This is also consistent with the findings of Rothamsted Experiment Station in UK (Barnett et al. 1995). All these crops have a good ecological viability.

## 3.3 Factors affecting the sustainability of cereal production

As regards wheat production, the estimated parameters of the production distribution moment functions are presented in Table 2. These estimates were obtained by using the three stages Generalized Method of Moment procedure, in order to account the factors affecting sustainability of production. The three functions are statistically significant as judged by the F-value and $R^2$.

The coefficients of fertilizers, pesticides, labor, rainfall, temperature and fixed capital are significant in the estimated first moment of production distribution. All the variable inputs have positive coefficients in the first moment. This implies that these factors are positively contributing to mean production. This is consistent with the findings of Islam (Islam, 1998) concerning agriculture in Bangladesh.

Labor contributes the highest in mean production followed by seed, while fertilizer is the fourth contributor. Also climatic variables like rainfall and temperature are playing a significant role in rainfed wheat production in Greece. But pesticides, labor and fixed capital are found to reduce variability in production. Hence, they are positively contributing to stable wheat production in Greek agriculture. On the other hand, fertilizer and temperature are adversely affecting stability of wheat production in Greece as evidenced by their positive signs in the second moment. The estimates of the third moment function show that fertilizer and seed increase skewness of yield distribution function while pesticides, labor, rainfall, temperature and fixed capital reduce skewness of the distribution.

As regards maize production, the estimated moment functions measuring the factors affecting its sustainability are presented in Table 3. The coefficients of fertilizers, pesticides, irrigation, temperature and seed are significant in the estimated first moments of production.

Table 2. *Estimated output distribution function of wheat production in Greece, 1961-1997*

| Parameters | First moment | Second moment | Third moment |
|---|---|---|---|
| Constant | 129.63*** (2.515) | 105.7516 (0.004) | 6.6629 (0.522) |
| Fertilizer | 0.31618* (1.569) | 0.0013154* (1.654) | 0.000097*** (2.355) |
| Pesticides | 0.18212* (1.522) | -0.00067989** (-2.441) | -0.000052864*** (-5.175) |
| Labor | 0.52758 *** (2.866) | -0.003226*** (-3.428) | -0.0003 2827*** (-5.009) |
| Rainfall | 0.24527** (2.110) | -0.0004555 (-0.645) | -0.000042154*** (-5.289) |
| Temperature | 0.20054*** (2.130) | 0.0052860* (1.637) | -0.000014548 (-.677) |
| Seed | 0.35019 (0.731) | 0.00075744 (0.595) | 0.00019529*** (4.623) |
| Fixed capital | 0.32767* (1.469) | -0.00033206*** (-0.351) | -0.000021575 |
| $R^2$ | 0.99 | 0.68 | 0.99 |
| F-value | 363655.9*** | 89.53431* | 708.4609*** |

Figures in parentheses are t- value
*, **, *** Significant at 11%, 5% and 1% respectively.

Table 3. *Estimated output distribution function of maize production in Greece, 1961-1997*

| Parameters | First moment | Second moment | Third moment |
|---|---|---|---|
| Constant | 0.5324 (0.240) | 0.14371 (0.396) | 10.240 (0.654) |
| Fertilizer | 0.60223*** (4.204) | -0.0011317*** (0.406) | 0.000376 (0.647) |
| Pesticides | 0.26125*** (6.264) | 0.0004285 (0.159) | 0.0011188*** (3.863) |
| Labor | 0.026680 (0.203) | 0.0016884 (0.282) | -0.00084288* (-1.107) |
| Irrigation | 0.54577*** (2.188) | 0.0022417*** (3.617) | 0.0039134*** (14.597) |
| Rainfall | 0.024534 (0.349) | 0.0022417*** (3.617) | -0.00050170*** (-5.623) |
| Temperature | -1.0491** (-2.284 | -0.032212*** (-3.102) | -0.00031567 (-0.229) |
| Seed | 0.25363** (1.578) | 0.021832*** (3.450) | -0.0024122*** (-4.782) |
| Fixed capital | 0.07730 (0.428) | -0.01022*** (2.144) | 0.00017464*** (6.2228) |
| $R^2$ | 0.99 | 0.97 | 0.99 |
| F-value | 76920*** | 168*** | 38640*** |

Figures in parentheses are t- value
*, **, *** Significant at 11%, 2% and 1% respectively.

Table 4. *Estimated output distribution function of rice production in Greece, 1961-1997*

| Parameters | First moment | Second moment | Third moment |
|---|---|---|---|
| Constant | 0.329 (0.94) | 0.000019 (0.014) | 18.625 (2.337) |
| Fertilizer | 0.45946*** (2.342) | 0.005948 (0.059) | 0.00027774 (0.660) |
| Pesticides | 0.091025*** (3.438) | 0.0023468 (0.183) | 0.00055356*** (2.672) |
| Labor | 0.10640 (1.308) | -0.048581*** (-2.440) | 0.00027925(0.569) |
| Irrigation | 1.1437*** (6.745) | -0.069482*** (-2.2289) | 0.0052937*** (5.920) |
| Rainfall | 0.21137** (2.110) | 0.012724** (2.020) | -0.0015625*** (-4.944) |
| Temperature | 0.0975** (2.422) | 0.20919 (1.088) | 0.0010881 (0.780) |
| Seed | 0.17492*** (2.533) | -0.0064251*** (-2.41) | 0.0014514*** (5.313) |
| Fixed capital | 0.21742*** (2.533) | 0.052106 (0.789) | -0.0037170*** (-6.736) |
| $R^2$ | 0.99 | 0.60 | 0.99 |
| F-value | 551583.1*** | 28.77654** | 107089.1*** |

Figures in parentheses are t- value
** *** Significant at 5% and 1% respectively.

All the variable factors, except temperature, have positive signs in the first moment. This implies that fertilizers, pesticides, labor, irrigation, rainfall, seed and fixed capital are positively contributing to mean production.

Fertilizer contributes the highest in mean production followed by irrigation, while pesticides is the third contributor. On the other hand, pesticides, labor, rainfall and seed increase variability of output as evidenced by the positive sign in the second moment. But fertilizer, irrigation, temperature and fixed capital are found to be positively contributing to the stability of maize production in Greece by reducing the variability of production distribution.

The estimates of third moment function show that fertilizer, pesticides, irrigation and fixed capital increase skewness of the yield distribution of maize while labor, rainfall, temperature and seed reduce skewness of the distribution.

Table 4 shows the factors affecting sustainability of rice production in Greek agriculture. The coefficients of fertilizers, pesticides, irrigation, rainfall, temperature, seed and fixed capital are significant in the estimated first moment of production. All the variables are positively contributing to the mean of rice production.

Irrigation contributes the highest in mean production followed by fertilizers, while rainfall and fixed capital are the third contributors. But labor, irrigation and seed are significantly contributing to stable rice production in Greece as evidenced by their negative sign in the second moment function. They are found to be yield-stabilizing factors, thus positively contributing to sustainable rice production in Greece. On the other hand, fertilizer, pesticides, rainfall and fixed capital have positive sign in the second moment but found to be insignificant.

The third moment indicates that rainfall and fixed capital have negative skewness, while the other variables have positive skewness. But only pesticides, rainfall and fixed capital are significant.

## 4. Conclusions

This study investigates and analyzes long-term sustainability of wheat, maize and rice crops production in Greece. The theoretical framework to measure sustainability in terms of biological, economic and ecological context was developed by using the concept of TFP. The TFP shows crop production efficiency compared to the base period. If TFP is higher (lower) in a particular period than in the base period, then there is increased (decreased) productivity or efficiency.

With improved rainfed production technology, biological sustainability of wheat production in Greece rose in the period 1961 to 1997. Maize had increasing biological sustainability during 1961-1982 after which it had maintained a stable biological sustainability. Also rice had increasing biological sustainability in the same period. All these crops were also found to be economically sustainable in Greece. The TSFP indices showed that all these crops are also ecologically sustainable in the country at issue. There were little differences between TFP and TSFP indices of these crops for the long term (1961-1997), implying that wheat, maize and rice had good ecological sustainability in Greece.

We proposed a methodology to quantify the determinants affecting sustainability of crop production. For this purpose a moment-based production function was estimated through weighted GLS regression procedure. This model has some advantages since it uses the production function in popular Cobb-Douglas form. The moment function can be used to quantify the effects of decision variables in the first moment (mean) and second moment (variance) as well as in higher moments of output. Moreover, the heteroscedasticity problem is solved automatically by weighted GLS estimation technique.

The first three moments of production function were used to analyze the factors affecting the sustainability of wheat, rice and maize production. It was found that fertilizers, pesticides, labor, rainfall, temperature and fixed capital are significantly affecting long-term mean wheat yields.

As for maize, fertilizers, pesticides, irrigation, temperature and seed rate are significantly affecting long-term mean yield. But temperature is found to have negative influence on the long-term mean yield of maize.

Similarly, fertilizers, pesticides, irrigation, rainfall, temperature, seed rates and fixed capital are significantly positively influencing long-term mean yield of rice.

The magnitude of the effects of these factors on the mean yield differs according to the crop. These factors are also found to affect the variability of production. Pesticides, labor and fixed capital were found to reduce long-term variability in wheat production whereas fertilizers and temperature were found to increase its variance.

As for maize, pesticides, labor, rainfall and seed are increasing long-term variability of maize output. But fertilizer, irrigation, temperature and fixed capital had a negative influence on maize variability. Thus they are influencing the stability of long-term production. On the other hand, labor, irrigation and seed rates were found to be long-term yield stabilizing factors for rice whereas fertilizers, pesticides, rainfall and fixed capital were found to increase its variability in yield.

## References


Ali, M., 1996. Quantifying the socio-economic determinants of sustainable crop production: an application to wheat cultivation in the Tarai of Nepa, Agriculture Economics, 14, 45-60.

Antle, J.M., 1987. Econometric estimation of producer's risk attitudes, American Journal of Agriculture Economics, 69, 509-522.

Antle, J.M., 1988. Pesticide Policy, Production Risk and Producer Welfare: An Econometric Approach to the Welfare Economics, Resources for the Future, Washington, D. C.

Ball, V.E., 1985. Output, input and productivity measurement in U.S. agriculture 1948-1979, American Journal of Agriculture Economics, 67, 478-486.

Barnett, V., Johnston, A. E., Landau, S., Payne, R.W., Welham, S. J. and Rayner A. L., 1995. Sustainability- the Rothamsted Experience, in: Barnett, V., Pyne, R. and Steiner, R. (Ed.), Agricultural Sustainability: Economic, Environmental and Statistical Considerations, New York John Wiley and Sons.

Boyle, G. E., 1988. The Economic Theory of Index Numbers: Empirical Tests for Volume Indices of Agricultural output, Irish J. Agric. Econ. and Rural Soc. 13, 1-20.

Brown, B. J., Hanson, M. E., Liverman, D. M. and Meridets, R.W., 1987. Global sustainability: Toward Definition, Environ. Manage. 11, 713-719.

Cassman, K.G. and Pingali, P. L., 1995. Extrapolating trends from long-term experiments to farmer's fields: The case of irrigated rice systems in Asia, in: Barnett, V., Pyne, R. and Steiner, R. (Ed.). Agricultural Sustainability: Economic, Environmental and S-tatistical Considerations, New York John Wiley and Sons.

Callens, I. and Tyteca, D., 1999. Towards Indicators of Sustainable Development for Firms: A Productive Efficiency Perspective, Ecological Economics. 28, 41-53.

Capalbo, S.M. and Antle, J.M., 1988. Agricultural Productivity: Measurement and Explanations. Resources for the Future, Washington, DC. 25.

Christenson, L.R., 1975. Concepts of Measurement of Agricultural Productivity, Am. J. Agric. Econ. 75, 910-915.

Commission of the European Communities, 1999. Direction Towards Sustainable A-griculture, Communication from the Commission, COM (1999) 22 Final, Brussels.

Cooke, S.C. and Sundquist. W.B., 1989. Cost efficiency in U.S. corn production, Am. J. Agric. Econ. 71,1003-1010.

Cooke, S.C. and Sundquist. W.B., 1989. Measuring and Explaining the Decline in U.S. Cotton Productivity Growth, Southern J. Agric. Econ. 23, 105-120.

Duff, B., Rasmussen, P.F. and Smiley, R.W., 1995. Wheat/Fallow systems in semi-arid regions of the Pacific NW America, in: Barnett, V., Pyne, R. and Steiner, R. (Ed.). A-gricultural Sustainability: Economic, Environmental and Statistical Considerations, New York, John Wiley and Sons.

Faeth, P., 1993. Agricultural Policy and Sustainability: Case Studies from India, Chile and the U.S. World Resources Institute. Washington DC. 4.

Fuss, M., D. McFadden and Mundlak, Y., 1978. Survey of functional forms in economic analysis of Production, in Fuss, M. and MacFadden, D. (Ed.) Production Economics: A Dual Approach to Theory and Applications, Amsterdam. North-Holland Publishing Co.

Gerakis, A. and Kalburtji, K., 1998. Agricultural Activities Affecting the Functions and Values of Ramsar Wetland Sites of Greece, Agric. Ecosyst. and Environ. 70, 119-128.

Hueting, R. and Rejinders, L., 1999. Uncertainty and Sustainability, Ecol. E-con.29,9-11.

Hanley, N., Moffatt, I., Faichney, R. and Wilson, M., 1999. Measuring Sustainability: A Time Series of Alternative Indicators for Scotland, Ecol. Econ. 28, 55-73.

Islam, M. S., 1998. An Analysis of Agricultural Productivity in Bangladesh, Q. Jr. Intern. Agric. 37, 298-309.

Islam, S. M.F., 1995. Decision Making on Technology Selection and Resource Allocation of Rice Farmers in Risky and Uncertain Agricultural Environment of Bangladesh, Ph. D. dissertation, Department of Agricultural Economics, University of Philippines at Los Banos, Laguna.

Islam, S. M.F., 1998. Modern Technology Adoption and Sustainability of Major Foodgrains Production in Bangladesh, Research Report, Department of Agricultural Economics, BMSR Agricultural University, Salna, Gazipur, Bangladesh.

Islam, S.M.F. and Karim, M.R., 1997. Farmers' Technology, Economic Performance and Relative Economic Efficiency of Country Bean Growers, B. Jr. Agric. Econ. 20, 85-96

Islam, S.M.F., Papadopoulou, H., Manos, B., 2003. Ecological sustainability in Greek agriculture: An application of energy flow approach, Journal of Environmental Planning and Management, volume 46, No 6.

Jorgenson, D.W., Gollop, F.M. and Fraumeni, B.M., 1987. Productivity and U. S. Economic Growth, Harvard University Press.

Just, R.E. and Pope, R.D., 1979. Production Function Estimation and Related Risk Considerations, Am. Jr. Agric. Econ. 75, 776-784.

Kuyvenhoven, A., Ruben, R. and Kruseman, G., 1998. Technology, Market Policies and Instrumental Reform for Sustainable Land Use in Southern Mali, Agric. Econ. 19, 63-71.

Lingard, J. and Rayner, A.J., 1975. Productivity Growth in Agriculture: A Measurement Framework, J. Agric. Econ. 26, 87-104.

Lu. Y., Cline, P. and Quance, L., 1979. Prospects for Productivity Growth in U.S. Agriculture, Agricultural, Economics Report No. 435, Economics, Statistics and Cooperative Service, USDA, Washington, DC.

Lynam, J. K. and Herdt, R. W., 1989. Sense and Sustainability: Sustainability as an Objective in International Agricultural Research, J. Agric. Econ. 3, 381-398.

Nadiri, M.I., 1970. Some Approaches to the Theory and Measurement of Total Factor Productivity: a Survey, Jr. Econ. Litr. 8, 1137-1177

Plucknett, D .I., 1990. International Goals and Role of the International Agricultural Research Centers, in Sustainable Agricultural System, Conservation Society, Soil and Water.

Rolla, A. C. and Pingali, P. L., 1993. Pesticides Rice Productivity and Farmer's Health: An Economic Assessment. International Rice Research Institute, Philippines, and World Resources Institute, Washington, D. C.

Ruttan, V.N., 1991. Sustainable Growth in Agricultural Production: Poetry, Policy and Science, CREDIT Research Paper No. 91/13. University of Nottingham. P-23.

Schroll, H., 1994. Energy-flow and Ecological Sustainability in Danish Agriculture, A-gric. Ecosyst. and Environ. 51, 301-310.

Squires, D., 1988. Index Number and Productivity Measurement of Total Factor Productivity Measurement in Multispecies Fisheries: an Application to the Specific Coast Trawl Fleet, NOAA Technical Report Atmospheric administration, U.S. Department of Commerce.

Steiner, R., and Mclaughlin, L., 1992. Measuring Externalities of U.S. Agriculture for use in the Economic Analysis of Long Term Agronomic Experiments, International Report, Rockefeller Foundation. New York.

Wackernagel, M., 1999. Ecological Economics Forum: why Sustainability Analysis must Include Biophysical Assessment, Ecol. Econ. 29, 13-15.

World Commission on Environment and Development, 1987. Our Common Future, Oxford University Press, Oxford, UK, pp. 393.

Zilberman, D., Khanna, M., and Lipper, L., 1997. Economics of New Technologies for Sustainable Agriculture, Austr. Jr. Agric. and Res. Econ. 41, 63-80.