# Exploring the role of fertilizer application on the sustainability of Greek potato farms: A DEA application

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**Abstract**

*Farm sustainability is becoming an increasingly important issue to European agriculture. However, fertilizer leaching to groundwater is still a major concern for Greek agriculture. The impact on the maximum potential short-run profit and yield, when fertiliser application dose is limited to certain point, was examined, using Data Envelopment Analysis (DEA). Spring potato farmers were found to apply rather high doses of chemical fertiliser, which poses high potential risk for nitrate and phosphorus leaching to groundwater. However, restricting nitrogen application to the doses recommended by agronomists would imply only little economic and yield sacrifices on potato farms, but resulting to significant reduction to potential environmental risk.*

**Keywords:** *farm management, data envelopment analysis, farm sustainability, short-run profit*

**JEL Classification:** M11, Q12, Q51, Q56

## Introduction

Increasing agricultural productivity has been a long time policy objective in almost all countries around the world. The Common Agricultural Policy (CAP) in fact motivated for several decades European farmers to intensify agricultural production in order to attain objectives such as (a) the stabilization of food and agricultural markets; (b) security of food supply and (c) the maintenance of an adequate income level for normally productive enterprises (Fearne, 1997). This was achieved by technological developments and by the substitution of fertilizer, concentrates and energy for labour and land.

Farming moved away from the traditional self-sustaining cycle towards an industrial model in which the quantity of chemical (fertiliser and pesticide) inputs is continuously raising in order to increase agricultural product. As a result, by early 80's, it started becoming apparent that a series of environmental problems have arisen in relation to European agriculture. Many of the applied chemicals find their way into water courses resulting to eutrophication and the elimination of sensitive aquatic species (IEEP, 2002; EC, 2005). Additionally, they reach into the groundwater contaminating also human water supply systems. Moreover, farm intensification in the Mediterranean countries is

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linked with the salinization (salt water incursion) along the coastline because of the over-use of aquifers (Lowe and Whitby, 1997).

The European Union introduced the agri-environmental measures in order to help agriculture to fulfil its multifunctional role in society, namely the production of safe and healthy food, the contribution to sustainable development of rural areas, and the protection and enhancement of the status of the farmed environment and its biodiversity (EC, 2003; 2005).

This study aims to explore the impact of reducing the amount of fertilizer applied by potato farms in the region of Elia in Greece on their profit and production (technical) efficiency. The next section deals with the role of fertilizers on crop growth, yield and crop quality, taking also into consideration their impact on environment. The DEA approach that was chosen to explore the consequences of reducing fertiliser applications on farm efficiency is analysed afterwards. Finally, the results and conclusions of the study are presented.

## Fertilizers role on farm productivity and their environmental impact

All plants require adequate amounts of water, light, carbon dioxide and nutrients to grow to their maximum potential. A shortage or excess of one or more of these raw materials may cause serious reductions in crop growth, yield and the quality of the crop produce. Most crops can significantly improve their yield and quality of the crop produce when fertilisers are used correctly in terms of quantity and time of application. Nitrogen, phosphate, potash, sulphur and magnesium are the most commonly used fertiliser nutrients (MAFF, 2000).

Nitrogen usually has a larger effect on crop growth, yield and crop quality than any other nutrient. The chart below shows a typical nitrogen response curve. It is clear that using nitrogen gives a large increase in yield but that using too much nitrogen can reduce yield. Additionally, using too much nitrogen will be financially wasteful and can aggravate problems such as lodging of cereals, foliar diseases and poor silage fermentation. Excessive use of nitrogen will also increase the risk of causing nitrate pollution of water. Nitrate is lost to surface waters by run-off or through land drains and to groundwater. The amount of nitrate lost depends on weather, soil and farming system (MAFF, 1998).

Nitrates in potable water are limited by the EU Drinking Water Directive to 50 mg/l because of potential risks to human health, although there is no strong evidence of this. However, it is estimated that around £199 M will be spent in the UK for a 20 years period to achieve this standard (Skinner et al., 1997). Water consumers pay on average £3.70 per ha of farmland for clean water because of the fertiliser use by the UK farms (Pretty 1998; Pretty et al, 2000). Kraemer & Kahlenborn (1998) concluded that it would be cheaper to spend DM 1 million in order encourage farmers in Munich to adopt organic farming than removing nitrates from drinking water.

In Scotland eutrophication and changes in the fauna and flora of Loch Leven have been associated with high levels of phosphate derived from farmland (Castle et al., 1999). For Loch Leven in 1992, summer algal blooms were estimated to have cost the area up to £783,000 in lost business, and increased production costs to the downstream industries by £160,000 (Castle et al., 1999).

Summing up, the increased use of fertilisers and pesticides helped the European agriculture to attain the objectives initially set by the CAP. However, the fertilisers applied by the European farms caused severe environmental problems, the most prominent of which derived from nitrate and phosphorous leaching into groundwater.

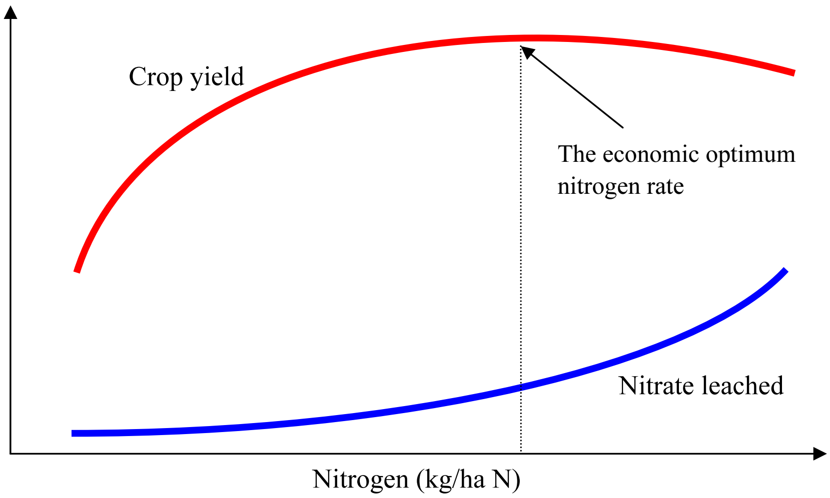


**Figure 1.** A Typical Nitrogen Response Curve and Corresponding Nitrate Leaching Losses. Adapted by MAFF (2000)

## Methodology

The non-parametric approach of Data Envelopment Analysis (DEA) has been used in a considerable number of studies regarding the estimation of the technical efficiency of the European farming systems (see for example Alvarez et al, 2004; Dimara et al, 2005; Galanopoulos et al, 2005; Tzouvelekas et al, 2002; Iraizoz et al, 2003; Wilson et al, 2001). Cherchye et al (2007) also studied the profit efficiency of German farm types under limited information, however the above mentioned studies did not deal with the environmental issues accruing from farm practices.

De Koeijer et al (2002) used a DEA approach to measure the sustainability of Dutch sugar beet farms in terms of technical efficiency and they concluded that there is a strong correlation between sustainability efficiency and technical efficiency. de Koeijer et al (2003) also used DEA to analyse the relation between nutrient (nitrogen) management and technical efficiency of Dutch arable farms finding that there was no correlation between the scores on technical efficiency of the individual crops, thus nitrogen efficiency should be analysed at both crop and farm level. Lansink and Reinhard (2004) employed a DEA approach to investigate both the technical and environmental efficiency and potential technological change in Dutch pig farming, concluding that introducing new technologies, which are available but not applied yet, would not change the overall technical efficiency but there would be a considerable improvement of environmental efficiency.

The basic standpoint of DEA, in calculating productive efficiency, is to identify the benchmark decision making units (DMUs) in order to construct what is called the best practice frontier. Simultaneously DEA calculates individually for each DMU the distance to that frontier. The relative performance based on the frontier performance provides a score for each DMU from 0 (worst performance) to 1 (best performance) (de Koejer, et al, 2003).

This study differs from the existing research on the sustainability of European farming on employing a DEA approach to investigate the impact of reducing the applied nitrogen on the profit and production attained by Greek potato farms. Interviews with local agronomists and spring potato farmers revealed that farmers follow a yield-maximising strategy. Since, it is difficult for them to forecast the potential yield of their farm and more importantly the price their produce may achieve, they usually aim to maximise the yield, which often implies high doses of fertiliser application. Greek farmers confess that very rarely do they analyse the nutrients content of potato leaves before deciding the dose of fertiliser application, thus it is questioned whether fertilisers are used correctly in terms of quantity and time of application.

The approach developed by Reig-Martinez et al (2004) and Picazo et al (2002) was adopted, after some appropriate amendments to fit to the objectives of our study, in order to estimate the impacts from fertiliser application reductions on profit and production achieved by Greek potato farms. Let us consider that potato farmers combine fixed and variable inputs (denoted by $x_f$ and $x_v$ respectively) to produce the output (potatoes, denoted by y) and the given prices for variable inputs and output are denoted by the vectors r, p respectively. The production plan that maximizes short-run profit (represented by Π), imposing variable returns to scale, arises from the solution of the following linear program (Reig-Martinez et al, 2004)

$$\text{Max}_{z,y,x_v} \Pi(p, r, x_f) = (py - rx_v)$$

$$\begin{aligned} \text{Subject to} \quad & X_f z \leq x_f && \text{(1a)} \\ & X_v z \leq x_v && \text{(1b)} \\ & y \leq Yz && \text{(1c)} \\ & \textstyle\sum z = 1 && \text{(1d)} \\ & z \geq 0 && \text{(1e)} \end{aligned} \qquad (1)$$

where, $py$ and $rx_v$ are the product of prices and quantities of outputs and variable inputs respectively. $Y$, $X_f$ and $X_v$ represent the matrices of total outputs, fixed and variable inputs, respectively.

Let us, now, consider that farmers or regulatory authorities wish to restrict the use of some of the variable inputs (denoted by $x_{v(r)}$) to a certain point ($\overline{x_{v(r)}}$), for instance the product of the amount of fertilizer nitrogen permitted to be applied per stremma (1

stremma = 0.1 hectare) and the number of stremmas of the particular farm.
The short run profit for each farm can be obtained by solving the following linear program (Picazo et al, 2002):

$$\mathrm{Max}_{z,y,x_v}\ \Pi(p, r, x_f, \overline{x_{v(r)}}) = (py - rx_v)$$

$$\begin{aligned} \text{Subject to}\quad & X_f z \le x_f && \text{(2a)} \\ & X_v z \le x_v && \text{(2b)} \\ & X_{v(r)} z \le \overline{x_{v(r)}} && \text{(2b}'\text{)} \\ & y \le Yz && \text{(2c)} \\ & \textstyle\sum z = 1 && \text{(2d)} \\ & z \ge 0 && \text{(2e)} \end{aligned} \qquad (2)$$

There is a prerequisite to obtain feasible solution from the above linear program (2) when restricting the use of fertilizer application; the dataset should include some farms that produce the maximum yield while applying nitrogen fertilizer bellow the examined certain point $\overline{x_{v(r)}}$, as described above, in order to satisfy the yield constraint (2c). Table 1 shows that there are 12 farms in the dataset applying less than 26 kg per stremma of nitrogen fertilizer, which produce at maximum 4 tons per stream fresh potatoes. However, 7 farms of the sample achieve yields more than 4 tons per stremma applying from 27.60 to 33.20 kg per stremma of nitrogen fertilizer. Academic and local agronomists claim that, given the soil and climatic conditions of the particular region, spring potato farmers should better apply nitrogen fertilizer between 15 and 25 kg per stremma. The farmers that participated in the survey revealed that relatively rarely do they analyse the nutrients content of the farm soil and they confessed to be completely unfamiliar to the analysis of the nutrients content of potato leaves, which may explain the high doses of nitrogen fertiliser applied by the sample ranging from 22.0 to 36.0 kg per stremma (Table 1).

**Table 1.** Farms' description regarding N fertiliser application and achieved yield

| | N kg/str | | Yield kg/str | |
|---|---|---|---|---|
| | Farms applying N ≤ 26 kg/str | All farms | Farms applying N ≤ 26 kg/str | All farms |
| No of farms | 12 | 42 | 12 | 42 |
| Mean | 23.05 | 27.71 | 3539.33 | 3826.81 |
| Std. Deviation | 1.343 | 3.739 | 249.356 | 392.357 |
| Minimum | 22.00 | 22.00 | 3200.00 | 3200.00 |
| Maximum | 25.90 | 36.00 | 4000.00 | 4500.00 |

Taking into consideration the above, it was decided to investigate the impact on the potential farm profit and production when the nitrogen fertiliser applied is restricted to 32, 31, 30, 29, 28, 27 and 26 kg per stremma. Model (2) could not give feasible solutions when fertiliser application is restricted to these certain points because of the yield constraint (2c). Thus, it was necessary to omit the yield constraint (2c) and the linear program employed to fulfil the objectives of this study is the following:

$$\text{Max}_{z,y,x_v}\ \Pi(p,\ r,\ x_f,\ \overline{x_{v(r)}}) = (py - rx_v)$$

$$\begin{aligned} \text{Subject to}\quad & X_f z \le x_f && \text{(3a)} \\ & X_v z \le x_v && \text{(3b)} \\ & X_{v(r)} z \le \overline{x_{v(r)}} && \text{(3b}'\text{)} \\ & \textstyle\sum z = 1 && \text{(3c)} \\ & z \ge 0 && \text{(3d)} \end{aligned} \qquad (3)$$

The equivalent linear program used in this study to investigate the impact on the potential farm production when the nitrogen fertiliser applied is restricted to certain point is the following:

$$\text{Max}_{z,y,x_v}\quad y$$

$$\begin{aligned} \text{Subject to}\quad & X_f z \le x_f && \text{(4a)} \\ & X_v z \le x_v && \text{(4b)} \\ & X_{v(r)} z \le \overline{x_{v(r)}} && \text{(4b}'\text{)} \\ & \textstyle\sum z = 1 && \text{(4c)} \\ & z \ge 0 && \text{(4d)} \end{aligned} \qquad (4)$$

**Data**

In this study we utilize the data selected from 42 farmers who produced spring potatoes in 2004 at the area of Elia which is situated in the Northwest part of Peloponnese, Greece. Local agronomists helped us to come in contact with potato farmers and convince them to participate in the survey, because Greek farmers are usually unwilling to provide data regarding their farm activities, especially to unknown persons. The sample consisted mainly by farmers that, considering the Greek farming reality, were relatively educated (75% completed secondary or high school studies) and young (mean value: 40.6 years), thus it could be judged that the sample is not representative of the Greek potato farmers. However, considering the forthcoming changes in the food supply chain, it could be argued that the sample profile is closer to those farmers who are expected to remain in Greek agricultural sector; those considered being able to adjust to the everyday changes of the food supply chain and consequently, satisfy the increasingly demanding food market. Given that it is rather rare for Greek farmers to keep records regarding the inputs and outputs of their activities, farmers made their best effort to recall all input and output aspects of potato production during the personal interviews that took place a couple of months after the end of the crop.

All farmers that participated in the survey produced on average 3 to 5 different crops in order to deal with the business uncertainty accruing from yield and product price yearly fluctuations. The data selected, however, focused on the spring potato crop consisting of a single output, the potato production in kilograms, and nine input variables (Table 2). The fixed input variable was the cultivated land measured by stremmas (1 stremma = 0.1 hectares) and the eight variable inputs included total (i) total labour (hours of use), (ii) total agricultural machinery, almost exclusively own (hours of use), (iii)expenditure in pesticides and other phytosanitary products (euros), (iv) seeds (kilograms), (v) nitrogen fertilizer applied (kilograms), (vi) phosphorus fertilizer applied (kilograms), (vii) potassium fertilizer applied (kilograms) and (viii) expenditure in other variable inputs such as electricity and marketing activities (euros).

**Table 2.** Basic statistics for the output and input variables of the 42 spring potato farms

| Variable | | Description | Quantities | | | Prices (€/unit) |
|---|---|---|---|---|---|---|
| | | | Units | Mean | Standard deviation | Mean |
| Output | y | | kg | 143170.74 | 84337.69 | 0.174 |
| Fixed Input | x1 | Cultivated land | str* | 37.37 | 20.62 | |
| Variable inputs | x2 | Labour | Hours | 1486.68 | 815.32 | 3.5 |
| | x3 | Machinery | Hours | 327.39 | 163.19 | 7.38 |
| | x4 | Pesticides | euros | 2185.75 | 1247.37 | 1 |
| | x5 | Seeds | kg | 7062.56 | 3891.54 | 1.03 |
| | x6 | Nitrogen (N) | kg | 1039.20 | 629.23 | 0.71 |
| | x7 | Phosphorus (P) | kg | 961.10 | 588.50 | 0.64 |
| | x8 | Potassium (K) | kg | 1029.36 | 630.46 | 0.68 |
| | x9 | Other Variable Costs | euros | 742.82 | 442.03 | 1 |

* Str = Stremmas (10 Stremmas = 1 Hectare)

The prices of output and variable inputs (except for family labour, pesticides and other variable costs) have been calculated by dividing monetary values by their respective physical quantities. The price of machinery labour included only the variable costs of it, namely oil and lubricants (the hours of tractor driving have been added to the total labour estimate). Family labour cost was considered to be equal to the average wage-earning labour. Pesticides and other variable costs are measured in euros and their price has conventionally been set to one.

**Table 3.** Comparison between the observed and the short run profit-maximising optimum

| | | Short Run Profit | Yield | Total Labour | Pesticides | Seeds | Other Var Costs | Tractor use | N | P | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | €/str | kg/str | Hours/str | €/str | kg/str | €/str | Hours/str | kg/str | kg/str | kg/str |
| (1.) Observed | Mean | 127.86 | 3822.57 | 39.90 | 58.48 | 189.63 | 19.88 | 9.01 | 27.78 | 25.68 | 27.33 |
| | Weighted Mean | 123.25 | 3835.35 | 39.79 | 58.40 | 189.26 | 19.85 | 8.75 | 27.74 | 25.66 | 27.50 |
| (2.) N Unrestricted | Mean | 160.40 | 3861.57 | 38.84 | 57.52 | 179.45 | 18.67 | 8.38 | 25.53 | 23.54 | 25.35 |
| | Change (1)–(2)% | 25.45% | 1.02% | -2.67% | -1.64% | -5.37% | -6.12% | -6.99% | -8.09% | -8.36% | -7.26% |
| | Weighted Mean | 151.09 | 3855.13 | 38.82 | 57.51 | 179.62 | 18.39 | 8.28 | 25.64 | 23.64 | 25.68 |
| | Change (1)–(2)% | 22.59% | 0.52% | -2.45% | -1.53% | -5.09% | -7.35% | -5.38% | -7.57% | -7.84% | -6.59% |
| (3.) N ≤32 kg/str | Mean | 160.35 | 3856.71 | 38.83 | 57.42 | 179.21 | 18.66 | 8.37 | 25.42 | 23.42 | 25.24 |
| | Change (2)–(3)% | -0.03% | -0.13% | -0.02% | -0.17% | -0.14% | -0.05% | -0.12% | -0.44% | -0.47% | -0.43% |
| | Weighted Mean | 150.97 | 3844.06 | 38.80 | 57.29 | 179.06 | 18.37 | 8.26 | 25.39 | 23.39 | 25.43 |
| | Change (2)–(3)% | -0.07% | -0.29% | -0.04% | -0.38% | -0.31% | -0.13% | -0.27% | -1.01% | -1.09% | -1.00% |
| (4.) N ≤ 31 kg/str | Mean | 160.29 | 3852.76 | 38.82 | 57.34 | 179.00 | 18.65 | 8.36 | 25.35 | 23.36 | 25.18 |
| | Change (2)–(4)% | -0.07% | -0.23% | -0.05% | -0.31% | -0.25% | -0.08% | -0.27% | -0.72% | -0.77% | -0.66% |
| | Weighted Mean | 150.86 | 3836.99 | 38.77 | 57.15 | 178.73 | 18.35 | 8.24 | 25.26 | 23.26 | 25.32 |
| | Change (2)–(4)% | -0.15% | -0.47% | -0.11% | -0.61% | -0.50% | -0.20% | -0.51% | -1.51% | -1.63% | -1.44% |
| (5.) N ≤ 30 kg/str | Mean | 160.23 | 3848.81 | 38.81 | 57.26 | 178.79 | 18.65 | 8.35 | 25.28 | 23.29 | 25.13 |
| | Change (2)–(5)% | -0.10% | -0.33% | -0.08% | -0.46% | -0.37% | -0.11% | -0.42% | -1.00% | -1.06% | -0.88% |
| | Weighted Mean | 150.75 | 3829.92 | 38.75 | 57.02 | 178.39 | 18.34 | 8.22 | 25.13 | 23.13 | 25.21 |
| | Change (2)–(5)% | -0.22% | -0.65% | -0.17% | -0.84% | -0.68% | -0.27% | -0.74% | -2.01% | -2.16% | -1.87% |
| (6.) N ≤ 29 kg/str | Mean | 160.11 | 3843.27 | 38.78 | 57.15 | 178.53 | 18.64 | 8.33 | 25.18 | 23.20 | 25.05 |
| | Change (2)–(6)% | -0.18% | -0.47% | -0.13% | -0.65% | -0.52% | -0.16% | -0.62% | -1.36% | -1.44% | -1.17% |
| | Weighted Mean | 150.59 | 3821.58 | 38.72 | 56.87 | 178.01 | 18.32 | 8.20 | 24.99 | 22.99 | 25.08 |
| | Change (2)–(6)% | -0.33% | -0.87% | -0.26% | -1.11% | -0.90% | -0.35% | -1.03% | -2.57% | -2.76% | -2.35% |
| (7.) N ≤ 28 kg/str | Mean | 159.82 | 3834.12 | 38.75 | 57.00 | 178.08 | 18.62 | 8.31 | 25.06 | 23.07 | 24.95 |
| | Change (2)–(7)% | -0.36% | -0.71% | -0.22% | -0.91% | -0.76% | -0.22% | -0.92% | -1.86% | -1.98% | -1.59% |
| | Weighted Mean | 150.17 | 3808.26 | 38.67 | 56.66 | 177.39 | 18.31 | 8.16 | 24.79 | 22.80 | 24.91 |
| | Change (2)–(7)% | -0.60% | -1.22% | -0.38% | -1.47% | -1.24% | -0.44% | -1.45% | -3.32% | -3.56% | -3.00% |
| (8.) N ≤ 27 kg/str | Mean | 159.11 | 3815.86 | 38.68 | 56.71 | 177.18 | 18.58 | 8.27 | 24.86 | 22.89 | 24.81 |
| | Change (2)–(8)% | -0.80% | -1.18% | -0.41% | -1.42% | -1.27% | -0.44% | -1.42% | -2.61% | -2.76% | -2.15% |
| | Weighted Mean | 149.53 | 3789.84 | 38.60 | 56.38 | 176.51 | 18.27 | 8.12 | 24.56 | 22.58 | 24.72 |
| | Change (2)–(8)% | -1.03% | -1.69% | -0.56% | -1.97% | -1.73% | -0.63% | -1.99% | -4.21% | -4.51% | -3.75% |
| (9.) N ≤ 26 kg/str | Mean | 157.90 | 3788.10 | 38.55 | 56.30 | 175.80 | 18.51 | 8.20 | 24.60 | 22.64 | 24.61 |
| | Change (2)–(9)% | -1.56% | -1.90% | -0.73% | -2.12% | -2.04% | -0.81% | -2.23% | -3.64% | -3.83% | -2.91% |
| | Weighted Mean | 148.60 | 3765.83 | 38.50 | 56.02 | 175.35 | 18.23 | 8.06 | 24.29 | 22.31 | 24.50 |
| | Change (2)–(9)% | -1.64% | -2.32% | -0.82% | -2.59% | -2.38% | -0.89% | -2.71% | -5.27% | -5.64% | -4.62% |

* Weighted Mean by the cultivated land

**Table 4.** Comparison between the observed and the yield-maximising optimum

| | | Yield | Total Labour | Pesticides | Seeds | Other Var Costs | Tractor use | N | P | K |
|---|---|---|---|---|---|---|---|---|---|---|
| | | kg/str | Hours/str | euros/str | kg/str | euros/str | Hours/str | kg/str | kg/str | kg/str |
| (1.) Observed | Mean | 3822.57 | 39.90 | 58.48 | 189.63 | 19.88 | 9.01 | 27.78 | 25.68 | 27.33 |
| | Weighted Mean | 3835.35 | 39.79 | 58.40 | 189.26 | 19.85 | 8.75 | 27.74 | 25.66 | 27.50 |
| (2.) N Unrestricted | Mean | 3912.49 | 39.53 | 58.07 | 186.27 | 19.36 | 8.62 | 26.93 | 24.88 | 26.58 |
| | Change (1)–(2)% | 2.35% | -0.94% | -0.71% | -1.77% | -2.63% | -4.32% | -3.07% | -3.14% | -2.77% |
| | Weighted Mean | 3908.09 | 39.56 | 58.12 | 186.70 | 19.32 | 8.49 | 27.13 | 25.07 | 26.96 |
| | Change (1)–(2)% | 1.90% | -0.59% | -0.49% | -1.35% | -2.64% | -3.00% | -2.20% | -2.28% | -1.96% |
| (3.) N ≤32 kg/str | Mean | 3906.77 | 39.51 | 57.97 | 185.98 | 19.31 | 8.61 | 26.78 | 24.73 | 26.43 |
| | Change (2)–(3)% | -0.15% | -0.03% | -0.17% | -0.16% | -0.27% | -0.14% | -0.56% | -0.60% | -0.57% |
| | Weighted Mean | 3896.47 | 39.54 | 57.90 | 186.12 | 19.27 | 8.47 | 26.85 | 24.79 | 26.67 |
| | Change (2)–(3)% | -0.30% | -0.05% | -0.38% | -0.31% | -0.27% | -0.27% | -1.05% | -1.13% | -1.06% |
| (4.) N ≤ 31 kg/str | Mean | 3901.38 | 39.44 | 57.84 | 185.63 | 19.01 | 8.83 | 26.58 | 24.54 | 26.24 |
| | Change (2)–(4)% | -0.28% | -0.21% | -0.39% | -0.35% | -1.83% | 2.38% | -1.27% | -1.35% | -1.28% |
| | Weighted Mean | 3887.99 | 39.46 | 57.73 | 185.61 | 18.97 | 8.67 | 26.61 | 24.55 | 26.44 |
| | Change (2)–(4)% | -0.51% | -0.25% | -0.68% | -0.59% | -1.84% | 2.08% | -1.94% | -2.08% | -1.92% |
| (5.) N ≤ 30 kg/str | Mean | 3895.63 | 39.39 | 57.74 | 185.25 | 19.18 | 8.57 | 26.41 | 24.37 | 26.08 |
| | Change (2)–(5)% | -0.43% | -0.36% | -0.56% | -0.55% | -0.92% | -0.68% | -1.93% | -2.03% | -1.89% |
| | Weighted Mean | 3879.17 | 39.39 | 57.58 | 185.05 | 19.11 | 8.42 | 26.38 | 24.32 | 26.23 |
| | Change (2)–(5)% | -0.74% | -0.42% | -0.93% | -0.88% | -1.11% | -0.88% | -2.79% | -2.98% | -2.71% |
| (6.) N ≤ 29 kg/str | Mean | 3887.50 | 39.30 | 57.56 | 184.78 | 19.07 | 8.54 | 26.18 | 24.15 | 25.89 |
| | Change (2)–(6)% | -0.64% | -0.58% | -0.87% | -0.80% | -1.49% | -0.97% | -2.78% | -2.91% | -2.60% |
| | Weighted Mean | 3867.86 | 39.29 | 57.35 | 184.38 | 18.97 | 8.39 | 26.09 | 24.05 | 25.99 |
| | Change (2)–(6)% | -1.03% | -0.67% | -1.32% | -1.24% | -1.83% | -1.22% | -3.84% | -4.08% | -3.58% |
| (7.) N ≤ 28 kg/str | Mean | 3874.80 | 39.19 | 57.33 | 184.02 | 18.95 | 8.50 | 25.88 | 23.86 | 25.63 |
| | Change (2)–(7)% | -0.96% | -0.85% | -1.27% | -1.21% | -2.13% | -1.40% | -3.89% | -4.07% | -3.56% |
| | Weighted Mean | 3850.23 | 39.16 | 57.05 | 183.30 | 18.80 | 8.34 | 25.71 | 23.68 | 25.68 |
| | Change (2)–(7)% | -1.48% | -0.99% | -1.84% | -1.82% | -2.72% | -1.75% | -5.24% | -5.54% | -4.77% |
| (8.) N ≤ 27 kg/str | Mean | 3851.10 | 39.03 | 56.96 | 182.34 | 18.82 | 8.43 | 25.48 | 23.48 | 25.31 |
| | Change (2)–(8)% | -1.57% | -1.26% | -1.91% | -2.11% | -2.79% | -2.32% | -5.37% | -5.62% | -4.77% |
| | Weighted Mean | 3826.13 | 39.00 | 56.67 | 181.66 | 18.64 | 8.27 | 25.27 | 23.25 | 25.31 |
| | Change (2)–(8)% | -2.10% | -1.40% | -2.49% | -2.70% | -3.54% | -2.60% | -6.87% | -7.24% | -6.11% |
| (9.) N ≤ 26 kg/str | Mean | 3818.38 | 38.85 | 56.45 | 180.34 | 18.64 | 8.32 | 25.00 | 23.02 | 24.98 |
| | Change (2)–(9)% | -2.41% | -1.72% | -2.78% | -3.18% | -3.71% | -3.57% | -7.14% | -7.46% | -5.99% |
| | Weighted Mean | 3796.27 | 38.83 | 56.20 | 179.81 | 18.44 | 8.18 | 24.77 | 22.78 | 24.96 |
| | Change (2)–(9)% | -2.86% | -1.85% | -3.31% | -3.69% | -4.58% | -3.67% | -8.70% | -9.15% | -7.43% |

* Weighted Mean by the cultivated land

**Table 5.** Characteristics of the farms in the short-run profit frontier

| Farms in the frontier | Short Run Profit | Yield | Cultivated land | Total Labour | Pesticides | Seeds | Other Var Costs | Tractor use | N | P | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | €/str | kg/str | str | Hours/str | €/str | kg/str | €/str | Hours/str | kg/str | kg/str | kg/str |
| 1 | 96,36 | 4.500 | 80 | 42 | 65,47 | 200,00 | 19,57 | 9,7 | 32,5 | 30,5 | 31 |
| 2 | 146,10 | 3.600 | 30 | 38 | 54,89 | 180,00 | 19,40 | 7,4 | 22 | 20 | 22,5 |
| 3 | 114,43 | 4.333 | 60 | 41 | 61,65 | 200,00 | 17,10 | 9,8 | 29 | 27 | 29,5 |
| 4 | 114,05 | 3.600 | 25 | 39 | 52,17 | 200,00 | 17,45 | 7,5 | 22,44 | 20,68 | 24,2 |
| 5 | 220,31 | 3.314 | 35 | 37 | 50,95 | 165,00 | 17,05 | 7,4 | 22,88 | 20,8 | 24,96 |
| 6 | 116,90 | 3.200 | 50 | 41 | 56,00 | 175,00 | 15,60 | 7,6 | 22,88 | 20,8 | 24,96 |
| 7 | 44,70 | 3.333 | 60 | 39 | 53,26 | 175,00 | 16,80 | 7,4 | 22,44 | 20,68 | 24,2 |
| 8 | 185,01 | 3.629 | 70 | 40 | 58,22 | 160,00 | 17,45 | 7,2 | 22 | 20 | 20,5 |
| 9 | 192,17 | 3.696 | 92 | 37 | 53,26 | 170,00 | 17,85 | 7,3 | 22 | 20 | 22,5 |
| 10 | 150,03 | 3.400 | 50 | 37 | 48,00 | 170,00 | 16,50 | 8,8 | 22 | 20 | 26,5 |
| 11 | 93,27 | 4.300 | 90 | 38 | 65,00 | 200,00 | 19,16 | 8,5 | 36 | 34 | 36,5 |
| 12 | 192,70 | 4.200 | 30 | 38 | 69,32 | 200,00 | 18,12 | 9,6 | 32,2 | 29,4 | 28,5 |
| 13 | 86,65 | 4.500 | 20 | 42 | 68,45 | 200,00 | 21,12 | 9,5 | 27,8 | 25,4 | 25,2 |
| 14 | 134,34 | 4.100 | 25 | 39 | 65,00 | 190,00 | 19,27 | 7,8 | 28,4 | 26,2 | 26,35 |
| 15 | 207,98 | 3.750 | 20 | 38 | 52,47 | 170,00 | 19,85 | 8,9 | 25,9 | 24,3 | 25,15 |
| 16 | 121,01 | 3.750 | 20 | 38 | 58,45 | 165,00 | 18,42 | 7,8 | 24,8 | 22,8 | 24,1 |
| | | | | | | | | | | | |
| mean | 138,50 | 3.825,32 | 47,31 | 39,00 | 58,29 | 182,50 | 18,17 | 8,26 | 25,95 | 23,91 | 26,04 |
| std dev | 49,644 | 436,131 | 25,460 | 1,713 | 6,715 | 15,492 | 1,462 | 0,974 | 4,538 | 4,436 | 3,851 |
| min | 44,70 | 3.200,00 | 20,00 | 37,00 | 48,00 | 160,00 | 15,60 | 7,20 | 22,00 | 20,00 | 20,50 |
| median | 127,67 | 3.722,83 | 42,50 | 38,50 | 57,11 | 177,50 | 17,98 | 7,80 | 23,84 | 21,80 | 25,06 |
| max | 220,31 | 4.500,00 | 92,00 | 42,00 | 69,32 | 200,00 | 21,12 | 9,80 | 36,00 | 34,00 | 36,50 |
| | | | | | | | | | | | |
| Average of 42 farms | 127.86 | 3822.57 | 37.31 | 39.90 | 58.48 | 189.63 | 19.88 | 9.01 | 27.78 | 25.68 | 27.33 |

## Results

Models (3) and (4) were used to estimate the maximum potential short-run profit and production of the 42 potato farms, respectively. Cultivated land was considered as the only fixed input. Family labour was considered to be a variable input and only estimates of the total labour use were made because of the difficulty to estimating farmers' contribution to total labour use. However, taking into consideration that all farmers claimed that none of their family members were involved in any of the farm activities and the high seasonality of labour demand which peaks during crop collection, it could be argued that in all cases most of the labour comes from seasonal labour. Moreover, the variable cost of machinery use was only calculated, since it is rather common for Greek farmers to aim to maximise the short run profit and thus not considering capital depreciation.

Table 3 summarizes the mean and the weighted (by cultivated land) mean values per stremma of the observed and maximum potential short-run profit, yield and the variable inputs used by the 42 farms when N fertiliser application is unrestricted or restricted to certain level. Table 4 also presents the same type results as above (except short run profit), which derived from running model (4) for the estimation of maximum potential yield under no restriction or restriction of N application.

Rather interestingly Table 3 shows that the weighted mean maximum potential short run profit for the whole sample could increase by more than 22% in relation to the respective observed, while achieving almost the same level of yield (+ 0.5%) as potato farms already do. Even more interestingly, this potential increase in the short run profit would not imply any increase on the level any of the variable inputs are now used, but in contrary all of them would be reduced, including fertilizer application doses which would be reduced by around 7 to 8 % on (weighted) average.

Table 4 shows that there is little potential for the sample farms to increase significantly their yield. However, the 2% potential increase in their yield could also be achieved by reducing the level that any of the variable inputs are now used, but to less extent that would be feasible when farmers aim to maximize their farm short run profit. Thus, in terms of technical efficiency it could be argued that farmers are rather efficient, however they do not seem to utilise their recourses in such manner to maximize their farm short-run profit efficiency. This confirms the findings derived from the personal interviews with local agronomists that farmers' main aim to maximize their produce, since it is difficult for them to forecast the final yield and market prices, often results to over-consumption of variable inputs such as of seeds, tractor use and especially fertilisers. This means that farmers should make more prudent use of variable inputs in order to achieve higher short run profit. Higher yields often require higher level of use of variable inputs, however, this increase in yield usually implies higher costs than revenues to farmers.

On average, the farms that belong to the short run profit frontier achieve significantly higher short-run profit than the whole sample of farms, with almost the same yield, but use less of the variable inputs (Tables 3 and 5). The variable returns constraint (3c) forces the model's solutions to include small, medium and large farm enterprises, in terms of the cultivated land, in the short-run profit frontier. Ten out of the twelve farms that apply less than 26 kilograms of N fertiliser per stremma are included in the short run profit frontier (consisting of 16 out of the 42 farms of the whole sample) also indicating that it would be more wise to farmers to make prudent use of fertiliser applications if they wish to maximise their short run profit. The presence of four farms applying more than 29 kg/str of nitrogen in the short run profit frontier imply that high doses of fertiliser application may also help farmers attain high levels of short run profit, which may explain why farmers tend to use high doses of fertilisers. However, it could be recommended to farmers to make more prudent use of fertiliser application since this could contribute to reducing their potato business uncertainty (Table 6).

**Table 6.** Comparison between farms applying N ≤26 kg/str and >26 kg/str

| | N groups | N | Mean | Std. Deviation |
|---|---|---|---|---|
| Yield tons/str | N ≤ 26 kg/str | 12 | 3,539 | 0,249 |
| | N > 26 kg/str | 30 | 3,942 | 0,382 |
| Land (str) | N ≤ 26 kg/str | 12 | 50,75 | 10,15 |
| | N > 26 kg/str | 30 | 57,40 | 12,67 |
| Labour (hours/str) | N ≤26 kg/str | 12 | 38,50 | 1,31 |
| | N > 26 kg/str | 30 | 40,47 | 1,91 |
| Pesticides (E/str) | N ≤ 26 kg/str | 12 | 54,75 | 4,36 |
| | N > 26 kg/str | 30 | 59,83 | 5,99 |
| Seeds (Kg/str) | N ≤ 26 kg/str | 12 | 175,00 | 12,79 |
| | N > 26 kg/str | 30 | 195,83 | 7,89 |
| Other Variable Costs (E/str) | N ≤ 26 kg/str | 12 | 17,70 | 1,20 |
| | N > 26 kg/str | 30 | 20,71 | 3,45 |
| Tractor use (hours/str) | N ≤ 26 kg/str | 12 | 8,01 | 0,95 |
| | N > 26 kg/str | 30 | 9,40 | 1,09 |
| N (kg/str) | N ≤ 26 kg/str | 12 | 23,05 | 1,34 |
| | N > 26 kg/str | 30 | 29,57 | 2,55 |
| P (kg/str) | N ≤ 26 kg/str | 12 | 21,13 | 1,40 |
| | N > 26 kg/str | 30 | 27,41 | 2,46 |
| K (kg/str) | N ≤ 26 kg/str | 12 | 24,09 | 1,59 |
| | N > 26 kg/str | 30 | 28,56 | 2,84 |
| Short Run Profit (E/str) | N ≤ 26 kg/str | 12 | 131,40 | 64,70 |
| | N > 26 kg/str | 30 | 126,44 | 59,41 |
| Short Run Profit (E/kg) | N ≤ 26 kg/str | 12 | 0,037 | 0,018 |
| | N > 26 kg/str | 30 | 0,032 | 0,016 |
| Total Variable Costs (E/kg) | N ≤ 26 kg/str | 12 | 0,139 | 0,010 |
| | N > 26 kg/str | 30 | 0,141 | 0,011 |

The potato farms would on (weighted) average sacrifice only less than 2% of their potential maximum short-run profit if they were forced to restrict the N fertiliser application to less than 26 kg/str (Table 3). By doing so, the weighted average reduction of fertilisers' application would range between 4.6 to 5.6 %. Restricting N application to less than 26 kg/str would also imply 3% reduction to the maximum potential yield, but fertilisers' doses would reduce by around 8 to 9%. Thus, restricting the fertiliser application to the doses studied would have marginal (negative) impact on the maximum potential short-run profit and yield, but in return there would be potentially significant improvement to environmental protection.

**Discussion**

Farm sustainability is an issue of increasing importance for the European agriculture. Farm yields' impressive increase during the last decades resulted to high level of security of food supply along the European Union. However, this achievement is often associated with important environmental problems, such as the contamination of human water supply systems because of the excessive and uncontrolled use of chemical inputs.

This study revealed that on average Greek potato farmers may also contribute to environment deterioration since they claim to apply rather high doses of chemical fertiliser. The high usage of fertilisers may result to high yields, however this does not often help farmers to enjoy high short-run profit. Restricting nitrogen application to less than 26 kg/str would possibly imply only little sacrifices to the average maximum potential short-run profit and yield of potato farms, but resulting to significant reduction to potential environmental risk. Moreover, it was found that the prudent use of chemical inputs may contribute to reduce the potato business uncertainty. The key message to potato farmers is that they should better cease to aim maximising the potential yield by applying high dosage of fertilisers, because this often does not result to maximum potential short-run profit.

The focus of the paper was on fertilizer reduction. However, as the levels of nitrogen are restricted, a very large proportion of pesticides are largely reduced as well. It seems that there is a high correlation between the use of nitrogen and pesticides (Table 5). This may be attributed to the fact that farmers applying chemical fertilizers in a prudent way they also tend to do the same with pesticide applications. Thus, this study revealed that Greek potato farmers could as well restrict their pesticide applications, magnifying the improvement to environmental protection, without any essential implications to their yields.

**Farm managerial implications**

The results indicate that on average the potato farms apply rather high doses of chemical fertiliser, which poses high potential risk to environmental pollution because of nitrate and phosphorus leaching to groundwater. The local agronomists who contributed to data selection mentioned that it is rather rare to almost all potato farmers to hire any agronomist to monitor their crop. Instead they take all production related decisions alone and in several occasions they take more into consideration other farmers' opinions than scientists' advice. This may explain to great extent the unwise use of chemical (fertiliser and pesticide) inputs.

Joining to any official Farm Assurance Scheme is, thus, strongly recommended to Greek potato farmers. Farmers would be obliged to follow the guidelines recommended by agronomists, which would result to less potential environmental risk. Additionally, the production cost would be lower and potatoes' quality would be certified ensuring higher market price. Consequently, potato farmers could improve both the economic and environmental performance of their enterprise.

## Study limitations

The main restriction of this study is related with the reliability of the data selected, since Greek farmers very rarely do they keep records of their farming activities. The authors and the local agronomists that kindly helped to come in contact with the potato farmers refined the data selected and it was decided to exclude the data of nine potato farmers from further analysis, as they were considered not to be sufficiently reliable.

This research has demonstrated the usefulness of DEA to explore the sustainability of farms and more specifically to investigate the potential impact on farms' short-run profit and yield when some inputs' use is limited to certain point in order to reduce environmental risk such as nitrogen fertiliser application. However, additional research using data selected in experimental fields would provide useful insights regarding the optimum use of fertiliser or other chemical applications in order farms to simultaneously attain the economic and environmental objectives, namely the sustainability.

## Conclusions

This paper examined the impact on the maximum potential short-run profit and yield of farms when fertiliser application dose is limited to certain point. Data Envelopment Analysis was employed to analyse the data selected by 42 Greek spring potato farms. The survey revealed that it is possible to reduce the potential environmental risk due to fertiliser leaching to groundwater with only little economic and yield sacrifices on potato farms. Further research based on data selected in experimental fields would very probably provide useful insights regarding the optimum use of fertiliser or other chemical applications.

## Acknowledgments

The author wish to thank the potato farmers and local agronomists for their invaluable contribution to the survey

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