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Efficiency in Sustainable Farming Systems: The Case of Integrated Crop Management in Greece

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Abstract: The rising awareness concerning the effect conventional farming has on the environment coupled with growing consumer apprehension on food safety brought alternative farming systems such as the integrated crop management system in the fore front. It is a sustainable way of farming aiming at the production of safe agricultural goods to be achieved with the efficient use of resources and the effective employment of farm inputs. The objective of this paper is to investigate the efficiency of farms certified in integrated management. The research is based on primary data collected from a random sample of 100 farms in 2004. DEA is the methodology used to determine the relative efficiency of farms operating under similar conditions. Even though some reduction in the use of agrochemicals compared to conventional farming has already been achieved, it is demonstrated that there is a significant potential for further reductions (21% on average) through the improvement in the internal organizational effectiveness of the farms. The largest part of overall technical inefficiency is attributed to scale inefficiency while at the same time it is shown that most farms operate under increasing returns to scale, hence an increase in size is proposed. In addition, farm size plays an important role in determining the level of relative efficiency. Research results and the proposals that follow may assist policy makers and institutions concerned with sustainable farming systems and especially the integrated crop management system, to take the necessary measures to increase its efficiency with apparent benefits for environment and farmer income.

Key words: Environment · integrated crop management · efficiency · sustainable farming · DEA · inputs

INTRODUCTION

In recent years, attention in industrialized countries has focused on reducing fertiliser and pesticide pollution attributable to intensive agriculture. Mounting consumer concern on food safety and environmental pollution enhanced the value of Sustainable Farming Systems (SFS), such as Organic and Integrated Farming Systems (OFS and IFS). SFS is a system that can evolve indefinitely achieving greater human utility, greater efficiency of resource use and maintaining a balance with the environment which is favourable to most other species. OFS is a sustainable way of farming without chemical inputs during cultivation and IFS is a sustainable way of farming which falls somewhere between the conventional and organic farming system. Integrated Crop Management (ICM) or Integrated Agriculture, (IA) is an alternative farming system which compensates for some of the problems associated with intensive farming and is one of the two prevailing types of sustainable agriculture, organic farming being the other, both in Greece and worldwide. Sustainable agriculture is a system that is economically viable, ecologically sound, socially just and supportive of all forms of life.

According to IOBC (The initials stand for the International Organisation for Biological and Integrated Control of Noxious Animals and Plants.) the goals of integrated management are the reduction in inorganic input use (fertilizers and pesticides), the sustainable production of high quality foodstuffs, the stabilization of farmers' income, pollution abatement and the preservation of the multifunctional character of agriculture [1].

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Integrated Crop Management (ICM) is considered a way of farming that is friendly to the environment, with realistic economic potential, that uses up-to-date technology in order to produce high quality goods in the most efficient way [2]. This farming method offers producers the possibility to follow a mid-way between organic and conventional farming and serves well the twin objectives of environmental conservation and the protection of farmers' income [3, 4].

In the EU 3,700,000 hectares are under the integrated crop management system, corresponding to 2.71% of total available farmland. England with 1,600,000 hectares has the largest share whereas Denmark and Austria exhibit the fastest rate of adoption of integrated management [5].

The introduction of ICM in Greece began in 2000 and was mainly implemented by cooperatives and producer groups; ever since it has shown remarkable expansion. In 2003, 12,556 hectares were cultivated with ICM which is equivalent to about 0.36% of agricultural land in Greece. The prefecture of Imathia has the largest share in the country in terms of land devoted to integrated crop management with 46% of total farmland under Integrated Crop Management (ICM) concentrated in that area.

Integrated agriculture in Greece is mainly applied to the production of peaches, hence the focus of this paper, with 7,269 hectares of peach trees, a figure that corresponds to 58% of total farmland under ICM, being managed that way. As in the other European countries, fertilisation and pest management are the main fields of ICM implementation in Greece as well. It has been observed that in most cases in Europe integrated agriculture is associated with a reduction of production costs due to reduced expenditure for fertilisers and pesticides [6, 7]. The efficiency of the integrated crop management system inevitably depends on efficiency in the use of these inputs. So far no research has been done regarding the efficiency of farm units implementing ICM in Greece.

It is imperative to address the issue of efficient use of resources in integrated agriculture especially after the last Common Agricultural Policy (CAP) reform, given that many productive sectors are expected to experience problems of reduced competitiveness, the number of farms may decline and the contribution of the agricultural sector in domestic GDP might fall [8]. Integrated agriculture as a sustainable way of farming offers an alternative, yet, it is the ability of farm units to efficiently manage inputs that will determine to a great extent its prospects.

The objective of the present paper is to examine the relative efficiency of this sustainable farming system and more specifically to study whether ICM farm units employ inputs in the most efficient way, to estimate their average efficiency and to determine whether efficiency is affected by farm size. The potential for further reductions in the cost of production and a more rational use of agrochemical inputs is also examined so as to achieve the goals of integrated agriculture, which are environmental conservation together with the protection of farmers' income.

RESEARCH METHODOLOGY

Data Envelopment Analysis (DEA) is the methodology employed in order to estimate the relative efficiency of farms that operate under similar conditions and use the same number of inputs to produce identical outputs [9]. Their difference lies solely on the quantities of inputs and outputs. It is a non-parametric approach and its mathematical formulation is as follows:
Objective function:

$$\text{Max}\,\theta_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \qquad (1)$$

Restrictions:

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \ (j = 1,2..., n) \qquad (2)$$

$$u_r \ge 0, \ (r = 1, 2..., s) \qquad (3)$$

$$v_i \ge 0 \ (i = 1, 2..., m) \qquad (4)$$

Where: n = number of farms, j = the farm whose relative efficiency is being measured, m = number of inputs, s = number of outputs, x_{ij} = quantity of input i in farm j, y_{rj} = quantity of output r from farm j, u_r = weight for output r, v_i = weight for input i, θ_j = relative efficieny of farm j.

With fractional programming, we proceed with the maximization of efficiency of farm j (1). Two restrictions are imposed in order to solve the problem: the weights can not be negative (3 and 4) and relative efficiency is less than or equal to one ($\theta j \leq 1$) [10].

In turn the fractional programming problem can be transformed into a linear programming problem [11]:
Objective function:

$$\max = \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \quad (5)$$

Restrictions:

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \ (j = 1, 2...., n) \quad (6)$$

$$\sum_{i=1}^{m} v_i x_{ij} = 1 \quad (7)$$

While (3) and (4) still hold.

The aim is to maximize function (5) or more to the point given restriction (7), to maximize the following:
Objective function

$$\max \theta_j = \sum_{r=1}^{s} u_r y_{rj} \quad (8)$$

Under restrictions (3, 4) and

$$\sum_{r=1}^{s} u_r y_{rj} \leq 1 \quad (9)$$

The relative efficiency of farm j is θj and $\theta j \leq 1$ is the imposed restriction. Farm j is efficient when:

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} = 0 \rightarrow \sum_{r=1}^{s} u_r y_{rj} = \sum_{i=1}^{m} v_i x_{ij} \rightarrow \sum_{r=1}^{s} u_r y_{rj} = 1 \rightarrow \theta_j = 1$$

On the contrary, when $\theta_j < 1$ farm j is inefficient.

The method relies in the use of linear programming to determine the production frontier for the sample of farms. All farms whose input-output ratio lies on the production frontier are technically efficient, while the degree of technical inefficiency of the others is measured by the Euclidean distance of the input-output ratio from the surface of the production frontier [12].

This methodology was originally proposed some decades ago [13], yet a lot later has been reformulated in a mathematical way. Recently, DEA has been implemented in the agricultural sector to measure, amongst other things, efficiency in horticulture [14], in the cotton sector [15], in the dairy sector [16-18], in the sheep sector [19] and in pig farms [20, 21].

The input oriented model is used in this paper and the measure of input efficiency indicates by how much inputs must be reduced by an inefficient farm, given the level of output, in order for it to become efficient. Overall Technical Efficiency (OTE) is measured by formula (8) and refers to Constant Returns to Scale (CRS) [22]. OTE can be distinguished into Pure Technical Efficiency (PTE) and Scale Efficiency (SE). PTE refers to Variable Returns to Scale (VRS) [23] and can be measured if the restriction:

$$\sum_{j=1}^{n} \lambda_j = 1 \quad (10)$$

$\{\lambda_j \geq 0 \ (j = 1, 2, \ldots, n)\}$, is added in the linear model where λ is the (n x 1) vector of parameters to be calculated. This restriction ensures that each inefficient farm is being compared with farms of similar size. Scale Efficiency for each farm is measured by the ratio OTE / PTE. A farm with SE=1 operates in optimal scale, whereas a farm with SE<1 has a sub-optimal size and it either overproduces or under produces compared to its size.

To determine whether scale inefficiency can be attributed to increasing or decreasing returns to scale, the Non-Increasing Returns to Scale model (NIRS) can be applied if restriction (10) in the Variable Returns to Scale model is substituted with the following one:

$$\sum_{j=1}^{n} \lambda_j \leq 1 \quad (11)$$

If $\theta_{CRS} = \theta_{NIRS} < \theta_{VRS}$, there are increasing returns to scale and if $\theta_{CRS} < \theta_{NIRS} = \theta_{VRS}$, decreasing returns to scale. Relative efficiency measured on the basis of the Constant Returns to Scale model is θ_{CRS} (OTE), θ_{NIRS} is for the Non-Increasing Returns to Scale model and θ_{VRS} (PTE) for the Variable Returns to Scale model, respectively.

With DEA, efficiency is measured against feasible frontiers hence the improvement of each inefficient farm is also feasible through better management of inputs. It should be mentioned though that the evaluation is done taking as a benchmark existing technology which is accessible at present to farm units and any currently available but not yet applied technology is not taken into account [24].

Primary data for this research were collected by means of questionnaires and personal interviews from a representative stratified random sample of 100 certified peach farms in the prefecture of Imathia in 2004.

RESULTS AND DISCUSSION

Five inputs-one output model (An advantage of DEA method is that allows the use of inputs and outputs with different units of measurement (physical or monetary units). is used to measure efficiency in each peach farm under ICM in the sample. Gross income per hectare is the output variable, indicating the productive capacity and intensity of each farm. The inputs included in the model are the per hectare cost of fertilizers and pesticides, used farmland, labour expressed in terms of hours/ha and value of fixed capital (€/ha) including buildings, machinery, permanent crops and land reclamations.

The expenditure on agrochemicals for peach farms was on average 384 €/hectare for pesticides and 310 €/hectare for fertilizers. More specifically, 30% of farms had spent less than 550 €/hectare on agrochemicals, 42% from 550 to 800 €/hectare, while for the remaining 28% expenditure exceeded 800 €/hectare. The reduction in the cost of agrochemicals for the average farm rose to 210 €/hectare, which means 23% less expenses as a result of ICM. In further detail, 33% of the farms in the sample reduced that cost more than 250 €/hectare, while the majority of farms (64%) reduced expenditure on agrochemicals by more than 140 €/hectare.

The size of the average farm was 4.2 hectares but there was quite a variation in the sample, with 36% farming up to 2.5 hectares, 34% ranged from 2.5 to 4.5 hectares and the remaining 30% were larger farm units using more than 4.5 hectares. The average farm cultivated 2.1 hectares of peaches under the ICM system and as expected there was also some variation within the sample. 23% of farms applied integrated crop management to an area up to 1 hectare, 30% in the range from 1 to 2 hectares, 29% varied from 2 to 3 hectares, while only 18% of farms managed more than 3 hectares with this method.

Table 1-3 show the results for average efficiency (OTE, PTE και SE) with the respective standard deviations for every efficiency range and for the whole sample as well, along with frequencies in the different efficiency ranges (Relative efficiency ($\theta_j \leq 1$), is first computed and then turned to percentage form. Every efficiency range, except the first and the last one, is $\theta = 0.1 \rightarrow 10\%$.).

The Constant Returns to Scale model (CRS) gives an average Overall Technical Efficiency for the farms around 57% (sd= 24.5%) which means that they have to reduce inputs by 43% in order to become efficient (Table 1). The majority of farms (55%) operates at low levels of overall efficiency and can reduce input use by more than 40% and still produce the given level of output. Relatively high levels of efficiency (more than 80%) are found in 22 farms, out of which 13 show efficiency above 90%. Finally, only 6% of the farms are efficient ($\theta = 1 \rightarrow 100\%$), which means that they apply effectively current technology and produce the expected output.

A farm's overall technical inefficiency can be partly attributed to scale inefficiency and to some extent to the lack of organizational effectiveness in managing inputs when that farm is compared to farms of similar scale. The Variable Returns to Scale (VRS) model gives Pure

Table 1: Overall Technical Efficiency (OTE)

Efficiency range (%)	No. of farms	% Percentage	Cumulative	Average efficiency	Standard deviation
9.5 ≤ OTE < 10	1	1	1	9.52	-
10 ≤ OTE < 20	11	11	12	15.78	2.55
20 ≤ OTE < 30	12	12	24	25.53	2.57
30 ≤ OTE < 40	10	10	34	35.38	3.22
40 ≤ OTE < 50	10	10	44	45.67	3.18
50 ≤ OTE < 60	11	11	55	55.83	2.50
60 ≤ OTE < 70	12	12	67	65.21	3.01
70 ≤ OTE < 80	11	11	78	74.38	3.02
80 ≤ OTE < 90	9	9	87	86.88	2.83
90 ≤ OTE < 100	7	7	94	93.52	2.22
OTE = 100	6	6	100	100.00	0.00
Total	100	100	100	56.98	24.49

Source: Study's results

Table 2: Pure Technical Efficiency (PTE)

Efficiency range (%)	No. of farms	% Percentage	Cumulative	Average efficiency	Standard deviation
31.6 ≤ PTE < 40	4	4	4	36.77	3.33
40 ≤ PTE < 50	10	10	14	45.59	2.93
50 ≤ PTE < 60	14	14	28	55.82	2.88
60 ≤ PTE < 70	12	12	40	64.88	2.71
70 ≤ PTE < 80	17	17	57	76.31	2.44
80 ≤ PTE < 90	14	14	71	84.81	3.17
90 ≤ PTE < 100	12	12	83	94.33	2.21
PTE = 100	17	17	100	100.00	0.00
Total	100	100	100	78.95	17.58

Source: Study's results

Table 3: Scale Efficiency (SE)

Efficiency range (%)	No. of farms	% Percentage	Cumulative	Average efficiency	Standard deviation
15 ≤ SE < 20	2	2	2	17.81	2.89
20 ≤ SE < 30	7	7	9	24.82	2.93
30 ≤ SE < 40	9	9	18	34.20	3.23
40 ≤ SE < 50	10	10	28	45.52	2.38
50 ≤ SE < 60	11	11	39	53.00	2.18
60 ≤ SE < 70	11	11	50	65.33	2.23
70 ≤ SE < 80	12	12	62	75.99	2.62
80 ≤ SE < 90	15	15	77	85.59	2.99
90 ≤ SE < 100	17	17	94	94.98	3.11
SE = 100	6	6	100	100.00	0.00
Total	100	100	100	72.02	22.61

Source: Study's results

Technical Efficiency around 79% (sd=17.6%), hence ICM farms must cut input by 21% to become efficient (Table 2). Pure technical inefficiency more than 30% is detected in 40% of the farms while 28% of the farms are even more technically inefficient (more than 40%).

The majority of farms (57%) operates at low levels of pure technical efficiency (less than 80%) and can reduce input use by more than 20% provided they reorganize the use of the given input in a rational manner. Relatively high levels of pure technical efficiency (more than 90%) is found in 29% of the farms which cannot reduce inputs by more than 10% in order to produce the given level of output (Table 2). It is remarkable that 17% of the ICM farms are fully efficient with the currently available technology. Given their scale of operation, no change can be made in input use without affecting gross income.

The analysis so far has shown that the majority of farms operate under variable returns to scale and for this reason the VRS model reflects adequately the present conditions of operation. It is thought to be the appropriate model with which to investigate the possibilities for improved organizational effectiveness and rational use of inputs by the ICM farms.

The fact that there is a difference in the number of efficient farms in the two models suggests that a part of overall inefficiency can be ascribed to scale inefficiency as 11 farms have OTE<1 and PTE = 1 and consequently can be deemed efficient only when they are compared to farms of similar size. Table 3 shows that 94 farms have to a smaller or bigger extent a sub-optimal size. The average Scale Efficiency (SE) of the ICM farms is 72% (sd = 22.6%) and varies from 15 to 100%. Half of the farms have scale efficiency less than 70%. Low Scale Efficiency (SE<50%) is found in 28% of the farms and about one in five farms experiences intense problems (SE<40%) either by overproducing or by under producing relatively to its size.

High scale efficiency (SE>90%) is found in 23% of the farms whereas 6% is scale efficient and operates at optimal size managing their inputs in a rational way {OTE = PTE = SE= 100% (θ=1)}.

After the comparison of average scale efficiency (72%) and average technical efficiency (79%), it can be concluded that overall efficiency of the ICM farms is more affected by scale than by the internal management of inputs. More specifically, 57% of overall inefficiency can be explained by the sub-optimal scale of farm operation and the remaining 43% can be attributed to non rational use of inputs as deduced from the tables.

In the whole sample only six farms operate under constant returns to scale. The Non-Increasing Returns to Scale model (NIRS) was then applied in order to determine whether the other 94 work under increasing or decreasing returns to scale. The comparison of the relative efficiency (θ_{NIRS}), for each farm, with the relative efficiencies computed by the other two models (θ_{CRS}, θ_{VRS}) indicates increasing returns to scale. According to results, $\theta_{CRS} = \theta_{NIRS} < \theta_{VRS}$ for 85% of the farms and consequently for the 90.4% of farms operating under variable returns to scale. It can be concluded that in order for most ICM farms to be able to reduce their costs under current technology, they ought to increase their scale.

A statistically significant correlation is found between farm size and farm overall technical efficiency (χ^2=15.575, a=0.016, d.f.=6). Small size farms show lower overall technical efficiency compared to large farms. It is worth mentioning that 80.6% of farms cultivating land less than 2.5 hectares have OTE lower to 50% owing to the large scale inefficiency experienced by these small farms. This inference is confirmed by the statistically significant correlation that is established between farm size and scale efficiency (χ^2 = 38.552, a = 0.000, d.f. = 6). Indeed small farms show low scale efficiency in relation to the large farms. 83.3% of small farms appear to sustain scale efficiency less than 65% as opposed to the majority of the medium size farms which have higher SE, in the range of 65-85% and the majority of large farms which are the most efficient in terms of scale with an estimate greater than 85%. The above results are in accordance with the previous finding that small farms operate on the whole under increasing returns to scale. Nevertheless, small farms exhibit higher pure technical efficiency compared to relative large ones (χ^2 = 14.107, α = 0.030, df.= 3). The majority of farms cultivating less than two hectares under ICM system achieve PTE over 75% as opposed to farms with more than 2 hectares whose PTE is less than 75%.

CONCLUSIONS

The integrated crop management system shows low overall technical efficiency (57%), which can be attributed first of all to scale inefficiency and secondly to the lack of organizational effectiveness in managing inputs under currently available technology. The reduction of expenditure on agrochemicals (210 €/ha on average) during the first years of implementation is quite satisfactory, nonetheless, there is a potential for further reductions in input use taking into account that pure technical efficiency is around 79%. Consequently, it is feasible to reduce inputs by 21% with more rational management, without having to make any scale adjustments and with the level of gross income unaffected.

The majority of ICM farms achieve pure technical efficiency less than 80% and overall efficiency less than 60%. In view of the last CAP reform and the intensification of competition that is expected to follow, it is essential to focus on raising efficiency in this sustainable farming system and ensure that certified ICM farms can survive in the new environment.

The fact that the majority of farms operate under increasing returns to scale suggests that besides a more efficient use of inputs they have to increase their scale of operation as well. Farm size shows a positive correlation with overall technical efficiency and scale efficiency and a negative one with pure technical efficiency, all statistically significant. Thus small farms exhibit lower overall technical efficiency compared to larger farms owing to the much lower scale efficiency and despite the higher pure technical efficiency. For that reason, it is advisable for small farms to raise efficiency mainly by increasing their size. On the contrary, larger farms should aim at the improvement of their organizational effectiveness as a way to reduce inputs (more than 25% on average), given their level of output.

These results can prove useful to policy makers concerned with sustainable farming systems because the required reduction in the use of inputs, for a given level of output, that each farm is able and should accomplish in order to become more efficient, has been precisely determined. A series of necessary measures must be taken and appropriate incentives must be given, for instance to increase farm size, in order to raise the efficiency of sustainable farming systems. Moreover, it is important to increase efficiency within the integrated crop management system so as it can achieve the twin objectives of environmental protection, through the reduction in the use of agrochemicals and the protection of farmers' income via the cost reduction of production.

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