ASSESSING THE EFFICIENCY OF ARABLE CROPS PRODUCTION IN A CROSS-NATIONAL CONTEXT

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ABSTRACT

According to FAO, improving the efficiency of resources use for the production of agricultural products is a key prerequisite for achieving global agricultural sustainability. Thus, it is necessary to incorporate performance evaluations in order to assess sustainability from an academic standpoint in the context of supporting international agricultural policy such as the Common Agricultural Policy (CAP). While efficiency is a major issue, there is a marked lack of bibliographic references focusing on agricultural efficiency issues on a global scale. However, much of the relevant international agricultural literature focuses on issues that concern individual countries or groups of countries with common characteristics. In the light of the above, this research seeks to evaluate the efficiency of national agricultural sectors in the production of arable crops internationally, a fact that will be achieved through Data Envelopment Analysis (DEA).

Keywords*:* agricultural efficiency**,** arable crops, sustainability, Data Envelopment Analysis

1. INTRODUCTION

As United Nations estimate, current human population is 7,7 billion people and it will be increased to 9,7 billion until 2050 (United Nations, 2019), meaning that resource management is essential to ensure food security under sustainable development principles. It should be notified that population models predict an average of 12.9% of urban population rise, leading to the creation of territories with extremely high needs of energy and food in a very small scale. In this context, agricultural sector should deal with the new challenges, maximizing production output using the least needed resources as inputs. Considering also climate change consequences, efficiency of arable crops should be examined in a global scale perspective to achieve production of adequate amounts of food and feed, while on the same time environmental impacts should be minimized.

Cereals production is associated with almost 50% of total cultivated area globally (14 billion acres), covering human and animal nutritional needs, while being an essential ingredient for the production of a wide range of products (FAOSTAT, 2019). Food security, high energy value and adequate protein concentration are the primer reasons for which cereals hold leading positions in all national agricultural sector, both in developed and developing countries. Cereals can be found all around the globe apart from hot and very wet regions. Maize contributes 45% of global cereal production, playing a significant role both for human nutrition and animal industry as feed. Moreover, a series of products can be made out of maize and its by-products affecting multiple sectors. Maize, sorghum and rice grown in countries with warmer climate. Asia holds 92% of global rice production and maize feeds the largest amount of Americans. Wheat, barley, rye and oats can be concerned as colder climate cereals. Wheat is mainly produced in Asia and Europe while barley is mainly cultivated to Russia, Canada and Germany due to its ability of producing adequate amounts of yield in a wide range of soil and climatic conditions (Gustafson, Raskina, Ma, & Nevo, 2009). Rising interest for leguminous crops have been observed lately, due to their ability to produce high protein seeds, to increase soil fertility through nitrogen assimilation and being a great alternative as green manure instead of the conventional ones (Plaza-Bonilla, Nolot, Raffaillac, & Justes, 2017).

Land availability, labour cost and adaptation of new technologies can be critical factors for achieving high efficiency scores in national level. In order to face increasing needs for food due to rising human population and climate change consequences, a more efficient use of current resources is required. For example, Zhang *et al.* (2015) present a scenario of a greater distribution of nitrogen resources on a global scale depending on each country needs, for increased nitrogen efficiency use ratios and food security. Moutinho *et al.* (2018) have investigated European national agricultural sectors from 2005-2012 using DEA and SFA methodology in order highlight differences on resources use and environmental impact between different countries. Through this analysis Cyprus, Denmark and France achieved the highest efficiency scores thus Belgium and Bulgaria had the lowest scores. It should be notified that in this survey no climate data have been taken into consideration. Wang *et al.*, (2019) have also identify efficiency differences in China's provinces, concluding that the average grain production could be 25% more efficient for the reference period 2000-2010. A global scale analysis, examining economic and regional characteristics such as temperature, rainfall and slope, resulted in a high yield gap of 46%, 50%, and 46% for wheat, maize, and rice accordingly, revealing the need for an agricultural production management in a global context (Neumann *et al.,* 2010).

According to previous remarks, different regions have been specialized in different types of crops, producing bigger amounts of products and gaining a competitive advantage among others in global markets. Aim of this paper is to assess efficiency levels of different agricultural sectors around the globe, while the efficiency differences between various types of crops. In order to achieve the above-mentioned goal, the basic research question of the present is the following:

1. Is there any efficiency deficit on arable crops farming among the different areas of the world?

2. METHODOLOGY

In order to run a DEA model we suppose that we have *n* national agriculture sectors expressed as NAS_j $(j = 1,2,\ldots,n)$, and $x_{ij} > 0$ is the amount of input i used in NAS_j and $y_{rj} > 0$ is the amount of output r of NAS_j. Then, the efficiency score for the NAS_i is extracted by solving the following model (Zhu, 2014)

$$\begin{aligned} &\varphi^* = max\,\varphi \\ &\text{s.t.} \sum_{j=1}^{n} x_{ij}\,\lambda_j \le x_{io} \quad i = 1,2,\ldots,m \\ &\sum_{j=1}^{n} y_{rj}\,\lambda_j \ge \varphi y_{ro} \quad r = 1,2,\ldots,s \\ &\lambda_j \ge 0 \qquad \mathrm{j} = 1,2,\ldots,n \end{aligned} \tag{1}$$

Where φ^* is the decision variable which represents the relative technical efficiency of NAS_0 and λ_j the weights that NASj places on NAS_0 to construct its efficiency reference set. For a fully efficient NAS the φ^* score is 1, whilst inefficient NASs acquire a score above 1. Analysis incorporates various models which correspond to different types of arable crops which are presented in Table 1. Model 1 considers the total aggregated production of arable crops whilst the Models 2-4 focus on specific types of crops. For all the models the output is the total produced output volume expressed in thousand tonnes whilst the input is the total cultivated area expressed in hectares.

Table 1. The Data Envelopment Analysis models for the different types of arable crops

DEA Model	Model 1	Model 2	Model 3	Model 4
Arable Crops Considered	Total Arable Crops (Cereals, Coarse Grains, Fiber and Roots, Pulses, Vegetables	Cereals	Coarse Grains	Pulses
Output	Production in thousand Tonnes			
Input	Area in Hectares			

Efficiency assessment is conducted in a two-step approach. In the first step, the globe is divided in 17 sub-regions and respective efficiency evaluations are conducted among the countries of each region by applying all the four models (the first stage DEA analysis is omitted for North America and Oceania due to the small sample of countries). For each region the two most efficient countries under the four models are selected and then included in the final global sample of countries. Then, in the second step all four models are applied on the global sample in order to extract efficiency evaluations and respective rankings of the considered countries. Figure 1 presents the methodological context of this paper explaining the two stages of the analysis. First stage contains the assessment of efficiency of national agricultural sectors (NAS) both in regional and global scale, giving them a representative ranking. For this purpose, Data Envelopment Analysis has been used in order to classify different national agricultural sectors using an output maximization approach (output-oriented).

3. RESULTS

3.1 Results of regional and global efficiency assessment

In Table 2 the basic descriptive statistics of the variables of the global model are presented. The area is expressed in thousand hectares (kha) and the production in thousand tonnes (kt). The mean cultivated area for arable cops is estimated at 68,293kha and the output at 467,632kt. The coefficient of variation (CV) values of the two variables signify that the output present larger variations than the cultivated land among the countries. The larger variability of output is also testified by the larger max-min difference. The lowest variability of the variables is found for the pulses as the CV coefficients are smaller than these of the other crops.

Table 2. The descriptive statistics of the variables of the DEA global models. Source FAOSTAT (2019)

	Variables							
Statistics	**Total Arable Crops**		**Cereals**		**Coarse**		**Pulses**	
	Area	Production	Area	Production	Area	Production	Area	Production
Mean	68,293	467,632	32,210	142,475	25,327	139,194	3,992	5,590
St.dev	206,728	1,813,154	87,578	479,845	78,205	578,600	8,696	13,592
CV%	303%	388%	272%	337%	309%	416%	218%	243%
Min	58	363	6	14	6	23	3	4
Max	1,444,043	13,198,639	597,164	3,558,932	435,997	386,2154	44,713	65,079

In addition, Table 3 illustrates the results of the four models. In more detail, the first column shows the average yield values for the 17 regions, followed by descriptive statistics of the efficiency scores, as well as the three best performing countries and the worst performing countries for different types of arable crops. Individual results of all countries can be shared by the creators upon request, as they are not presented here due to the difficulty caused by the limited size of the paper. Concerning the different types of arable crops, the results show that there are considerable variations in the efficiency of the regions. The average yield score for the total production of arable crops (6.495) is higher than the average scores of all the four models, indicating that it has the highest levels of inefficiency. On the contrary, cereal production has the lowest inefficiency with a yield score ranging to 2,932. Finally, the Coefficient of Variation proves that coarse grain production has the largest variability of efficiency, while the lowest variability belongs to pulses΄ production.

Table 3. The Data Envelopment Analysis results per region and the three best and worst performing country per each model

Average Efficiency per Region	Total Arable Crops	Rank	Cereals	Rank	Coarse Grain	Rank	Pulses	Rank
Central Europe	1.985	1	1.032	1	1.158	1	1.283	1
West Asia	2.378	2	4.147	15	3.757	11	2.692	4
East Asia	2.861	3	1.448	2	2.943	9	3.540	7
South Europe	3.755	4	2.366	6	1.910	2	2.786	5
South America	3.926	5	1.622	4	2.436	5	4.115	9
North Europe	4.883	6	1.555	3	2.084	4	2.028	2
North Africa	5.418	7	3.689	13	4.434	13	3.981	8
Central Asia	5.464	8	3.069	12	2.772	7	2.383	3
Southeast Asia	6.117	9	2.025	5	2.574	6	5.353	11
North America	6.560	10	2.467	8	1.958	3	4.274	10
Central Africa	6.817	11	7.005	16	7.321	14	6.115	14
South Asia	7.341	12	2.451	7	2.903	8	5.365	12
Oceania	7.983	13	3.025	11	2.982	10	3.240	6
Central America	10.379	14	3.965	14	3.793	12	5.432	13
South Africa	10.469	15	2.819	9	9.350	16	7.482	16
West Africa	13.090	16	3.024	10	8.280	15	7.173	15
Statistics								
Grand Total	6.495		2.932		4.106		4.392	
Max	32.263		14.904		26.459		12.729	
Coefiicient of Variation	0.784		0.778		1.025		0.564	
Most Efficient	Netherlands Jordan Belgium		Ireland Belgium Netherlands		Belgium Mexico Israel		Ireland Belgium Netherlands	
Lest Efficient	Mali Namibia Mauritania		Jordan Trinidad and Tobago Congo		Congo Mauritania Namibia		Ghana Zambia Mauritania	

Central Europe, represented by the countries of Belgium, the Netherlands and Ireland, is the region with the highest efficiency in the four models. In more detail, Ireland is the best player in the cereal and legume models, Belgium in the coarse grains model and the Netherlands in total arable crops.

With exception of Models 1 and 3, the countries in the region are represented in the best performing team in all models. In more detail, Jordan appears to be the second most effective country in the sample in the first model, while the latter model, Belgium, Mexico and Israel appear to be the leading countries. Central Europe is followed by countries in Western and Eastern Asia, South Europe and South America. As far as West Asia is concerned, the efficient production of legumes and other vegetables is the reason for its high yields, while cereals and coarse cereals are less efficient. East Asia's high position is due to efficient cereal production, while South Europe's competitive advantage in the production of coarse grains is responsible for the region's high ranking.

In contrast, South and West Africa, but also Central America, are the least effective regions of the genus that are proven to have low yields in terms of the overall arable crop model, with rather low yields for individual crops as well. In addition, countries in both West and South Africa, with the aim of focusing on cereal production, have the potential to improve their overall competitiveness. Mauritania and Namibia are considered the weakest countries as they are most often included in the worst performing categories.

The revealed variability of the scores and rankings of the various regions signify their strengths and weaknesses regarding their ability to remain competitive in the production of the various types of arable crops. Therefore, regions which are rather inefficient in a type of crop could be strongly competitive in the production of other crops. Illustrating, Central Asia is very weak in cereal production as it ranks 12th whilst possessing a strong advantage in pulses productions signified by the fact that it is found to be the third most efficient region of the world. The same stands true for the countries of Oceania which also present a competitive advantage in pulses production. In addition, North America seem to present modest performance in all types of crops with excepting the coarse grain for which is found to be the third most efficient region. Finally, for the least developed countries of South and West Africa it is apparent that their competitive advantage could be based on the cereals production for which its relevant position is far better than the respective position under the other types of crops.

5. Conclusions

In this paper, total agricultural production along with cereals, coarse grains and pulses production of agricultural sectors around the globe have been examined with the use of four different models in order to highlight efficiency differences in both national and continent level. Countries of Central Europe have achieved the highest efficiency scores regarding arable crops production. Average scores of different NAS have resulted in no significant differences of efficiency in continent level, highlighting the fact that developing countries should focus on arable crop production in order to gain an advantage in the global market. Moreover, developing countries should intensify their efforts on arable crops production in order to use land more efficiently for cultivation of suitable cultivars depending on their climatic conditions. Increased food security in national and worldwide level, higher revenues for local food networks and greater resistance of food supply chain to climate change can be achieved from the intensification of arable crops production, under the circular economy context.

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