3. ENERGY EFFICIENCY IN AGRICULTURE. SHOWCASE AND ALTERNATIVES FOR WHEAT PRODUCTION IN PORTUGAL

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Key words: *wheat, energy efficiency, greenhouse gas emissions, production costs*

3.1. Introduction

It is expected that energy consumption will increase significantly in the coming years, causing a major impact on the economy in general and necessarily in the agricultural sector. One of the EU target indicators for Europe is a "20% increase in energy efficiency" by 2020. According to the Energy Services Directive 2006/32/EC, there is a need for improved energy end-use efficiency in all energy consuming systems. In this Directive, energy efficiency is defined as the ratio between an output of performance, service, goods or energy, and an input of energy. But energy efficiency in agriculture can also be assumed as the reduction of primary energy consumption (PEC) necessary to obtain one unity of product at the farm gate level (GJ/t). This was the definition used in this study.

Energy use reduction can be achieved by reducing energy input. Improved energy efficiency, however, is only achieved, if energy input per unit yield is reduced. Therefore, improved energy efficiency can be achieved with either increased or decreased energy inputs depending on the input-output relationship. The reduction in energy consumption is also associated with technological change, improvements in organization and management systems, or improvement of the economic conditions in the sector.

Agricultural production relies very much on the use of energy from fossil resources. However, the agricultural sector accounts for 3.7% of the total energy use in the EU-27 (EEA, 2012), which may seem insignificant, but it should be stated that in many countries national statistics record as energy use in agriculture only the direct energy (inputs used during the cultivation period). Energy use for the production of input materials (indirect energy), such as fertilizers, pesticides, machines and buildings is recorded under the industrial sector. According with Woods et al. (2010) and Pelletier et al. (2011), 50 % and more of the total energy used in agriculture is related to the production of nitrogen fertilizers and other indirect energy uses. If both direct and indirect energies are considered in an agricultural production system, then it becomes clear that a significant amount of total energy is required for the production of agricultural products and that energy saving should also be considered in this sector, as in most energy consuming sectors (Balafoutis et al., 2013).

This chapter presents some results obtained in the KBBE.2011.4-04 project "Energy Efficiency in Agriculture - AGREE" supported by the 7th Framework Program. It gives an overview into energy use and energy efficiency in wheat production in various agro-climatic zones of Europe. Among cereals, wheat is the crop with the largest cultivated area in Europe. In 2008, the percentage share of the area occupied by common and durum wheat in the countries analysed in the AGREE project ranged from 2.4% in Portugal to 18.9% in Germany (Gołaszewski et al., 2012). The different production systems in different climates vary substantially in their energy use and energy saving potential. A showcase of conventional wheat production in Portugal, where in 2012 it was cultivated in 54,761 ha (INE, 2013), is presented and some production alternatives are analysed. The main objective was to analyse the effect in the economic results, energy consumption and environmental impacts of three wheat production systems alternatives: 1. no tillage cropping systems, 2. reduction of phosphorous application and 3. the use of supplemental irrigation.

3.2. Methodology

In the first part of this chapter, it is presented the data regarding the energy use and energy efficiency in wheat production systems of 7 European countries. Both direct and indirect energy associated with all kinds of inputs used to produce wheat were considered. An LCA-like approach has been chosen, but the activities have been restricted to the farm gate. Energy use and productivity have been established for wheat production and the volume of inputs has been included considering Primary Energy Consumption (PEC). The energy equivalents used to convert the physical data of the input into the energy data have been preferably drawn on the BioGrace database (www.biograce.net). Some conversion factors, however, are specific for each country. For example, the PEC of electricity, which depends on the national energy mix used to produce electricity. The energy indicators used were Direct Energy Inputs, Indirect Energy Inputs, Total Energy Inputs and Specific Input of Primary Energy (GJ/ha and GJ/t).

The Direct Energy Inputs include all the energy used directly in the production process, including electricity, diesel and natural gas. Indirect Energy Inputs includes energy used for the manufacturing of production inputs, including fertilizers, pesticides, farm machinery as well as seeding material. The indirect energy associated with the construction of farm machinery has been excluded from this study. The reason is that a large variety of farm machinery is used in the field operations, data on the energy associated with the construction of farm machinery is missing and finally, the indirect energy from machinery has only a limited potential to contribute to energy savings in agriculture. Used energy has been estimated by multiplying physical units of application (kg/ha or l/ha) with the parameters expressing the energy per physical unit (MJ/kg or MJ/L) to result in the energy used per hectare.

In the second part, it is presented a showcase focusing in the production of wheat in the Alentejo region, Southern Portugal. Alentejo is the largest agricultural region of Portugal, with a Mediterranean climate characterized by mild winters and dry and hot summers. Annual rainfall is between 400 to 600 mm, concentrated in autumn and winter. Daily average temperature is between 21 and 25 ºC, but maximum temperature can be higher than 40 ºC while minimum is frequently below zero during winter nights (Marques 1988). A typical farm of 250 hectares, with clay soils and a traditional crop farming system of dryland agriculture was chosen as the basic scenario.

The farm traditional production system is based in a four years crop rotation (sunflower – *durum* wheat 1 – green peas – *durum* wheat 2) established to achieve high production levels of cereals. Usually, cereal, namely *durum* wheat, because of specific subsidy policies, or other cash cereal crop, alternates with sunflower and peas.

Durum wheat I and 2 - Soil conventional preparation is based in a deep plowing followed by two chisel passages. Durum wheat 1 installation is then prepared with chisel and disc harrowing followed by sowing (200 kg seeds/ha) and fertilization (300 kg/ha of N20:P20:K0). Usually a crop weed control operation takes place (0.02 kg/ha of Tribenuron-Methyl and 0.5 l/ha of Clodinafop + Cloquintocete) followed by a fertilization with 150 kg/ha (N 27%). Harvest is in July, with an average yield of 3 ton/ha of grain and 1.5 ton/ha of straw.

Sunflower - Soil conventional preparation is similar to the one performed for wheat, consisting in a deep plowing, followed by two chisel passages during winter, and one before sunflower sowing, in March. Sowing density is 4 kg/ha of seeds (75 000 plants). Sunflower does not receive fertilization or herbicide treatments and it is harvested in August. Productivity is 850 kg/ha.

Peas - Green peas sowing occurs in January, with 150 kg/ha, after harrowing and two chisel passages for soil preparation. As for sunflower, green peas require neither herbicides nor fertilization treatments. Harvest is also in July, with productivities of 1100 kg/ha.

Farm machinery

To perform the above described field operations the farm machinery consists in one 105 HP tractor, one 9 tons trailer, one disc harrow, one chisel, one drill with 25 lines, a fertiliser distributor, a straw baler, a rake and a precision seeder. All the machines and agricultural equipment's are stored in a 75 m^2 building. The farmer also rents an 85 HP tractor with a plough implement, a 1000 L sprayer, and a combine harvester. In the economic evaluation, the rate value was calculated based in the replacement value and life span of each machine or agricultural equipment. The life span considers the durability of the item, the time between its first and last use. In the case of the tractors it was considered a life span of 12 years, for the seeders 13 years and for the disc harrow, the chisel and the trailer it was considered a life span of 20 years.

EU financial aids

All farms receive, each year, an EU subsidy, the RPU ("*Single Payment Scheme"*). The value received is different for each farm and it is calculated based on the farm history of producing the specific crop, and it also takes in account the existence or not of animals. The national average value attributed for the year of the study was 174 euros/ha.

Alternative option 1 – No tillage

No tillage or direct seeding has been studied in Alentejo in technological and economic terms by Azevedo and Cary (1972), Basch (1989, 1991), Marques and Basch (2002), Rosado (2009), Carvalho and Lourenço (2013). This cropping system has being applied in wheat for several years in Portugal, by a small number of farmers, but it's a practice that has been increasing over the years as a sustainable and environmental friendly agricultural practice for wheat production. Diesel used for the machinery is one of the most important production factors contributing to direct energy use and greenhouse gas (GHG) emissions. Reduced tillage or no tillage had been identified as efficient measures to reduce energy input use in agricultural systems. These systems need less fuel associated with lower mechanization use, which reduces production costs and greenhouse gas emissions.

As an alternative option for the traditional farming system it was considered a no tillage system for all the crops, maintaining the same rotation.

Durum wheat I - In the third week of October a weed control operation is performed using glyphosate (3 l/ha). Sowing is in November, using a direct drill seeder, with seed density of 200 kg/ha and fertilization level of 250 kg/ha (N 15: P 15: K 15). In late January there is a fertilization with 140 kg/ha (27% N). During February it takes place a crop weeding operation (0.02 kg/ha of Tribenuron-Methyl and 0.5 l/ha of Clodinafop + Cloquintocete). The harvest is in July, with the same average yield attained in the traditional farming system.

Sunflower - In late February an herbicide (glyphosate) is applied. The sunflower sowing is in March, also with a direct precision seeder and a plant density of about 75,000 plants/ha. Harvest is performed in August.

Durum wheat 2 - *Durum* wheat 2 ends crop farming rotation, and has exactly the same annual calendar and operations of *durum* wheat 1. The productivities are also similar to those of *durum* wheat 1.

Farm machinery

To perform the above described field operations the farm machinery consists in, (from the actual existent farm machinery): one 105 HP tractor, one 9 tons trailer, a fertiliser distributor, a straw baler. All machines and agricultural equipment are stored in a 75 m^2 building. The farmer would need to rent a direct drill seeder, and still rent a 1000 liters sprayer and a combine harvester.

Financial aids

In this option, besides the EU subsidies, there is a national aid from the PRODER national program. This aid is granted to farmers that do organic farming, integrated pest management, breed indigenous breeds, and no tillage systems. The program has specific rules and maximum amounts for the different crops and animal breeds.

Alternative option 2 – Reduced P_2O_5

Indirect energy use from fertilizers use contributes to 30 to 50 % of the total energy use in agriculture. Therefore, it is expected that all measures to improve fertilizers use efficiency contribute to great extent for energy use efficiency. Differential application according with soil fertility is an option that could contribute to this improvement.

Based on data obtained by experimental research (Marques da Silva 2012) a reduction of 30% on the application of phosphorous on wheat crops was analysed as an alternative option. Since in this rotation system the application of fertilisers is only in the wheat crops, I and II, this option only applies to the wheat and not to all crops of the rotation.

Alternative option 3 – Supplemental Irrigation

One of the limitations in wheat production, in the Portuguese conditions, is the lack of rainfall in the spring in most of the years. Therefore, the possibility of applying some irrigation water in the grain filling stage of the crop has proved to be very efficient in increasing wheat productivity. However, these require either the existence of an irrigation system used by the other crops of the rotation or an additional investment in acquiring an irrigation system. It is also necessary to consider the need for increasing fertilizer application and the additional costs of electricity and water required by the irrigation system.

3.3. Results and Discussion

3.3.1. Energy consumption of wheat production in Europe

One of the indicators of energy efficiency is the energy intensity of the economy expressed in units of energy used per unit of Gross Domestic Product (GDP). According to the EUROSTAT, from 2000 to 2009 energy intensity of the EU economy continued to decline slightly from 0.187 toe/€ in 2000 to 0.165 toe/€ in 2009. The EU agricultural sector accounts for 11.0 million jobs, which represent 5.1% of persons employed in the economy. At the same time the gross value added (GVA) of combined agriculture, hunting and fisheries accounted for only 1.7% in 2010. Nevertheless, there is a significant variance in GVA across Member States. In Greece and Poland the percentage share of persons employed in agriculture is relatively high, 13.0% and 12.5%, respectively, so the resulting percentage share of agriculture in GVA is also relatively high, 3.3% and 3.5%. On the other hand, Germany accounts only for 1.4% of the total employment and the 0.9% share of the sector in the GVA. Portugal is in between, accounting with 7.7% of the total employment and the 2.4% share of the sector in the GVA.

According to the European energy statistics, the total final energy consumption (FEC) of the EU-27 countries amounted to 49,205 PJ in 2008. The FEC of the sector "agriculture/forestry" was 1.071 PJ, corresponding to 2.2 % of the total FEC in the EU (Table 3.1). However, the Eurostat data presented in Table 3.1 is not sufficient to describe the energy consumption of European agriculture since not all the energy required for the production of agricultural products is allocated to the "agriculture/forestry" sector in the Eurostat statistics. For example, FEC of fertilizer production is allocated to the "industry" sector (Gołaszewski et al., 2012).

Table 3.1. The total final energy consumption (FEC) and FEC of agriculture (*including forestry) for the years 1998 and 2008 according to the Eurostat data.

Country	Total FEC in PJ		FEC of agriculture* in PJ		FEC of agriculture* in % of total FEC	
	1998	2008	1998	2008	1998	2008
EU-27	46 658	49 205	1 257	1 071	2.7	2.2
Denmark	630	649	31	29	5.0	4.5
Finland	1 005	1 083	30	35	3.0	3.2
Germany	9 428	9 386	114	42	1.2	0.4
Greece	761	890	45	46	6.0	5.1
Netherlands	2 082	2 139	157	132	7.5	6.2
Poland	2 526	2 606	198	152	7.8	5.8
Portugal	672	773	25	15	1.0	0.6

The main indirect energy inputs concerning crop production are related with the accumulated energy in fertilizers and pesticides. Total consumption of nitrogen, phosphorus and potassium in the EU has been estimated at an average of 91 kg per hectare. The estimated average consumption of nitrogen in the EU has stood at 65.2 kg/ha, ranging from 21.8 kg/ha in Portugal to 136.6 kg/ha in the Netherlands. Phosphorus consumption has an average value of 8 kg/ha in the EU, ranging from 5.2 kg/ha in Denmark to 13 kg/ha in Poland, and potassium-based fertilizers averaged at 17.8 kg/ha across the EU, ranging from 7.6 kg/ha in Portugal and 9.5 kg/ha in Greece to 28.8 kg/ha in Poland, 25.0 kg/ha in Germany, and 23.1 kg/ha in Finland. Also, total use of active ingredients of pesticides per hectare of utilized agricultural area varies to a great extent across the studied European countries under consideration, ranging from 0.7 kg in Finland to 4.8 kg in Portugal, and 5.6 kg in the Netherlands.

Table 3.2 shows the results obtained for wheat production in the countries under study. The highest yield in tons per hectare has been recorded for the Netherlands and Germany and the lowest in the southern countries – Greece and Portugal. The average energy input per hectare of wheat production varied greatly among the countries involved. Specific energy inputs vary from 2.1 to 4.3 GJ/t among countries. This range results from a relatively moderate variation in energy use per ha (from 12.0 to 19.9 GJ/ ha) and a relatively high variation in the yield level ranging from 3 to 8.7 t/ha.

Table 3.2. The energy input (PEC) in wheat production in different countries (adapted from Gołaszewski et al., 2012)

Country	**Yield**	**Specific energy inputs**	
	t/ha	GJ/ha	GJ/t
Finland	4.50	12.0	2.7
Germany	7.66	18.6	2.4
Greece	5.00	19.9	4.0
Netherlands	8.73	18.1	2.1
Poland	5.80	15.1	2.6
Portugal	3.00	12.9	4.3

There is a tendency for higher energy uses to be associated with higher yield which becomes clear in Figure 3.1.

The main energy input in wheat production is associated with the use of fertilizers as can be seen in Figure 3.2. The energy inputs required for the use of fertilizers ranged from 6.3 GJ/ha in Portugal to 11.2 GJ/ha in Germany. The second main energy input is diesel use for field operations. The other direct and indirect energy inputs have been to a great extent specific for geographical location of countries. In the Central and Northern EU countries Germany, the Netherlands, Poland and Finland the additional energy on wheat production has been associated with drying. Indirect energy use is a considerable part of total energy use in wheat production. It varies between 50% and 72% depending on the country. This indirect energy use is mostly associated with synthetic fertilizer use. Diesel and fertilisers are very important production factors contributing to energy use and greenhouse gas emissions (GHG). Therefore, all measures to improve the efficiency of fertilizer and diesel use will contribute to energy use efficiency to a great extent and reduction of environmental impacts.

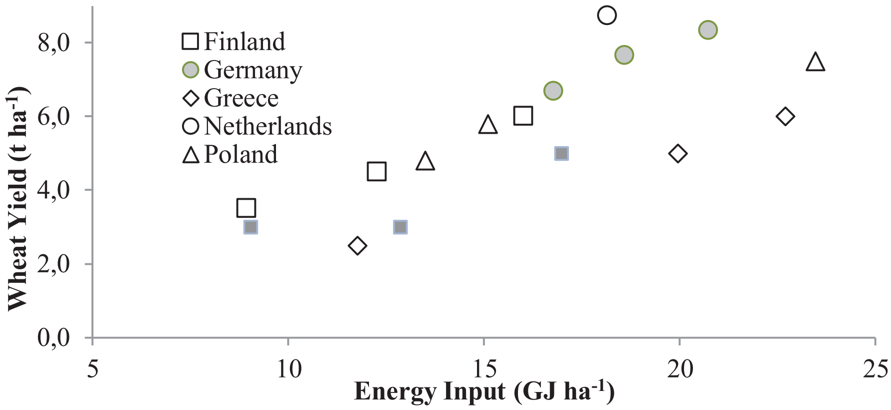

Figure 3.1. The relation of the total energy inputs in GJ/ha and yields in t/ha (Gołaszewski et al., 2012)

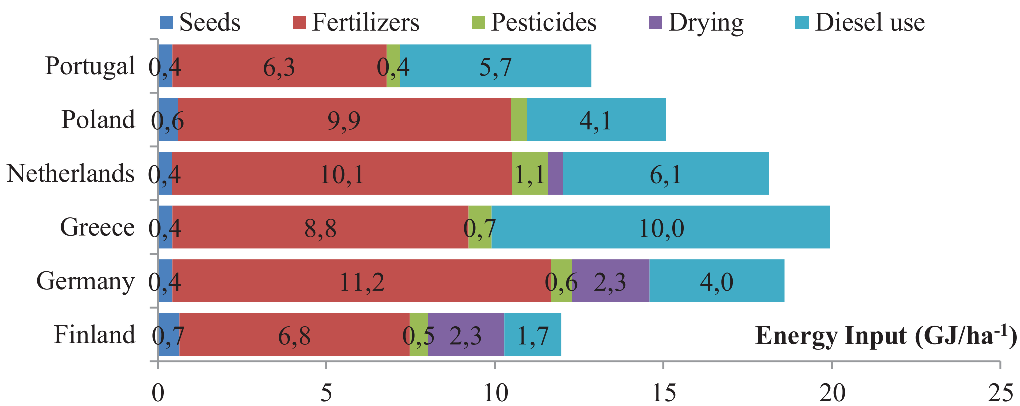

Figure 3.2. The structure of energy inputs in wheat production in GJ/ha (Gołaszewski et al., 2012)

3.3.2. Wheat production in Portugal. Showcase and alternatives

Concerning the showcase for the wheat production in Portugal, Figure 3.3 shows the relative contribution of the different inputs in the total costs, GHG emissions (CO_2eq) and energy consumption for all the crops considered in the conventional production system of this farm, assumed as the basic scenario. It is clear that different inputs contribute in different percentages to the total costs, primary energy consumption and GHG emissions. This implies that small changes may induce only little costs but high impacts on energy use and GHG emissions. Also, we can observe that fertilizers and diesel are the most important concerning

GHG emissions and energy consumption. The relative high contribution of seeds for the total costs is explained by the fact that two of the crops do not require fertilization and pesticides.

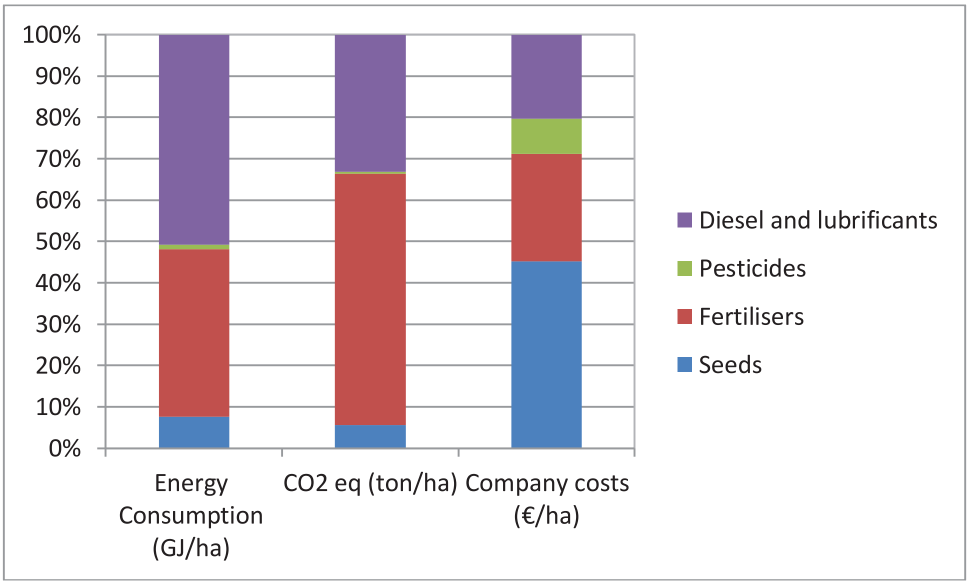

Figure 3.3. Relative contribution of different processing units and inputs in the crop rotation to economics, energy use and greenhouse gas emissions (GHG) for the basic scenario

Table 3.3 and Figure 3.3 present the costs, energy consumption and GHG emissions per hectare and considering all the crops of the rotation. In an overall analysis it can be stated that options 1 (no tillage) and 2 (fertilizer reduction) decrease costs, energy consumption and GHG emissions and the opposite occurs with option 3 (irrigation). In fact, production costs decrease about 10% with no tillage, 1% with less use of P_2O_5 and increased around 50% with the introduction of irrigation. The same is observed in energy consumption and GHG emissions.
No tillage allows reducing energy consumption for about 40%, fertiliser reduction reduces it around 2% and irrigation increases energy consumption for almost the double compared to the conventional system. For the CO_2eq emissions a decrease of 20% is obtained with no tillage, 2% with reduce fertiliser application and an increase of around 70% with irrigation. The decrease in the two first options is explained by less use of machinery/diesel and fertilisers and the increase in the

last one is due to the increase inputs of fertilisers and electricity for the irrigation system.

Table 3.3. Annual costs, PEC and GHG emissions with energy efficiency measures in the farm rotation

Specification	**Annual Costs**		**PEC**		**GHG**	
	€/ha	%	MJ/ha	%	CO_2eq/ha	%
Conventional	528.43	100.0	7171.26	100.0	535.97	100.0
No Tillage	482.90	91.4	4109.36	57.3	431.70	80.5
Reduction P_2O_5	522.63	98.9	7045.01	98.2	527.06	98.3
Irrigation	770.25	145.8	13979.11	194.9	900.23	168.0

In Figure 3.3 it is also showed the impact of the different options on the farm profit. It is possible to see that all three options allow an increase of farm profit (43% with no tillage, 2% with less P_2O_5 and more than the double with the irrigation option). In the first two the increase is due to a decrease of the production costs and in the last one due to the increase of yield. Figures 3.4 and 3.5 allow a more detailed analysis for the wheat crop (produced in 125 ha of the showcase crop rotation), taking in account the wheat productivity in the different options. These figures show the costs, profits, energy consumption and CO_2eq emissions per hectare and per ton of wheat produced in the farm.

In Figure 3.4 it is shown the same tendency mentioned before considered all the rotation crops. Options 1 and 2 decrease costs, energy consumption and GHG emissions and the opposite occur with option 3. In fact, production costs decrease about 8% with no tillage, 2% with less use of P_2O_5 and increase around 66% with the introduction of irrigation. The same is observed in energy consumption and GHG emissions. No tillage allows reducing energy consumption for about 45%, fertiliser reduces around 3% the energy consumption and irrigation increases energy consumption for almost the double compared to the conventional system. For the CO_2eq emissions a decrease of 30% is obtained with no tillage, 2% with reduce fertiliser application and an increase of around 70% with irrigation. Finally, the profit per hectare, increases with no tillage (24 %) and with irrigation (approximately the double).

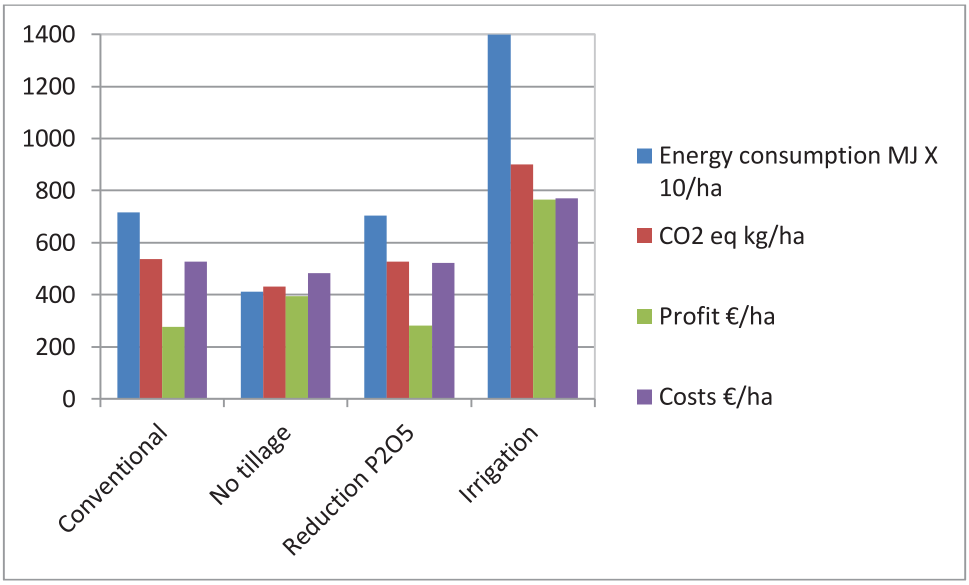

Figure 3.4. Impact of different energy saving measures on costs, profit, energy use and greenhouse gas emissions (GHG) per ha

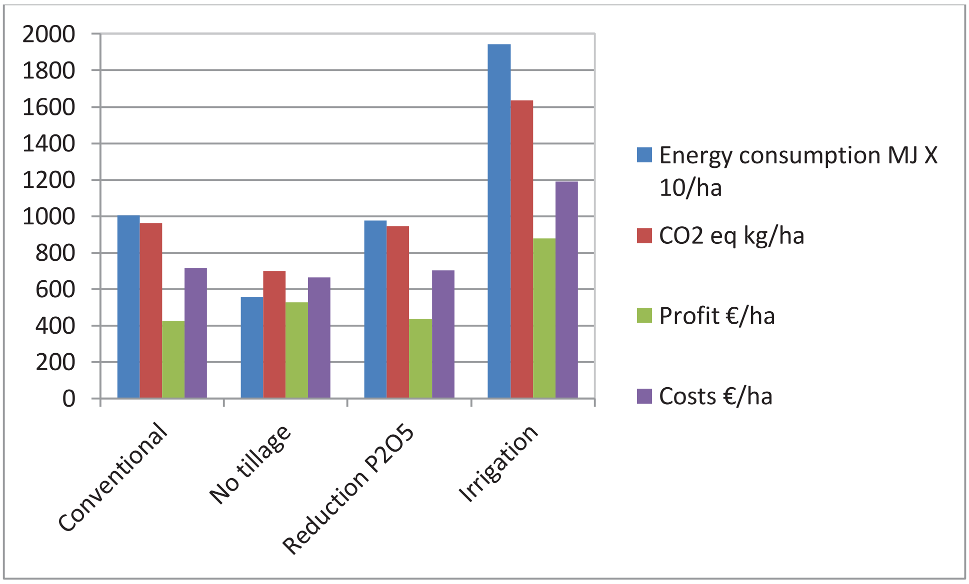

Figure 3.5. Impact of different energy saving measures on costs, profit, energy use and greenhouse gas emissions (GHG) per ha of wheat

Figure 3.6 presents a slightly different picture compared with the analysis performed by hectare. In fact, when considering the impact of the alternatives on costs, energy consumption and GHG emissions it is possible to say that the three options can contribute to an increase of the resources use efficiency (in different scales). Less energy is consumed, less GHG are emitted, and higher farm profit is obtained due to reduction of the production costs or either due to the increase of the productivity.

Analysing the variation of the costs per ton of wheat produced a reduction of around 8%, 2% and 17% was attained for option 1, 2 and 3 respectively. Concerning the energy consumption a reduction of 45%, 3% and 3% was found for option 1, 2 and 3 respectively. For the CO_2eq a reduction of 30%, 2% and 15% was attained. Profit increases for all the options, around 24% for no tillage, 3% reduced P_2O_5 and 4% for the irrigation. It is possible to see that the introduction of irrigation can contribute to the highest savings in the production costs. No tillage allows the higher savings in energy consumption and GHG emissions and the highest increase in farm profit. However, and in spite of the work done the wheat area in Portugal with no tillage is only approximately 4%, which indicates further research needs on costs not considered so far and adoption constraints.

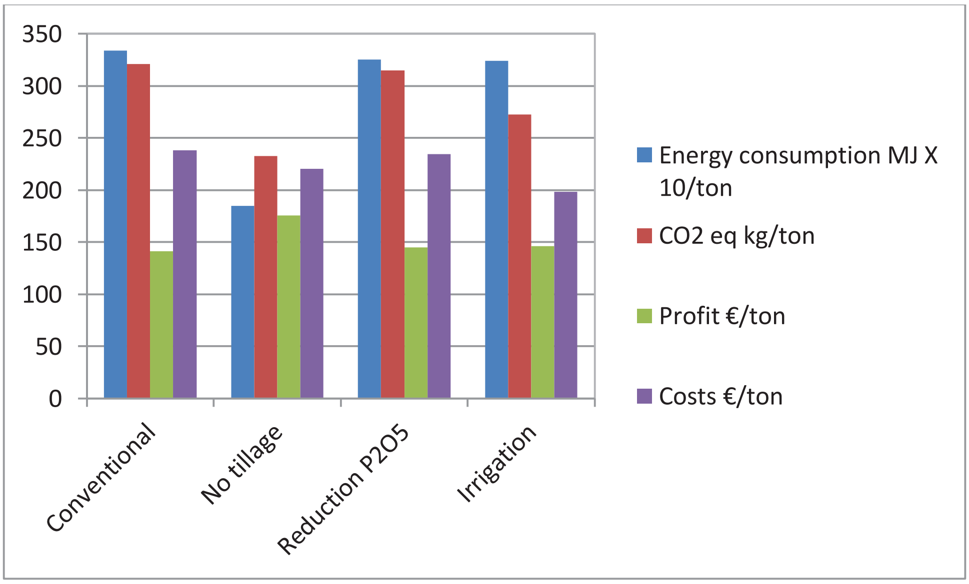

Figure 3.6. Impact of different energy saving measures on costs, profit, energy use and greenhouse gas emissions (GHG) per ton wheat

If we look to the specific energy inputs presented in Table 3.2, the wheat production in Portugal was the most energy consuming in comparison with the other countries. But that can be changed, if the production technology is adapted to our soil and climate conditions. In fact, as shown before energy consumption can be reduced to 5.6 GJ/ha and 1.85 GJ/t in different production systems, which could contribute to the sustainability of wheat production in Portugal. However, the knowledge must be transferred and farmers convinced of the advantages of these technologies. Also, more studies are in order to answer some remaining questions: Can this technology be used in all type of soils and climates?

3.4. Conclusions

The actual energy consumption of the European agriculture reported in the Eurostat statistics is underestimated. The efficiency of energy use in agricultural production is specific to the EU country and geographical location. The total and specific energy consumption varies substantially for all crops considered across Europe.

In the Portuguese case, the three analysed options showed a good potential to reduce inputs use in this farm, increasing the efficiency use of resources, thus contributing to the increase of the farm profit. The no tillage option seems to be the better one, with energy consumption and GHG reductions, and higher profit per ton of produced wheat. However, several factors interact in the production system and more research is needed in order to obtain more experimental data, in similar and different wheat production systems to allow a more conclusive analysis.

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