Agricultural Sciences, 2016, 7, 137-145
Published Online March 2016 in SciRes. http://www.scirp.org/journal/as
http://dx.doi.org/10.4236/as.2016.73013

Dairy Farming Systems' Adaptation to Climate Change

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Received 28 January 2016; accepted 20 March 2016; published 23 March 2016

Abstract

The measure of climate change in dairy farms can be achieved by using the emissions of methane by the ruminants converted in CO_2 equivalent ($CO_{2\text{-eq}}$). In order to know the impact of future quotes of methane in the Azorean dairy milk farms, a decision model is built to the Azorean intensive grazing system of dairy farms. Some scenarios of methane levels reductions from 10 to 75% are considered and their impact is evaluated upon dairy farms income, level of $CO_{2\text{-eq}}$ emissions and intensity level of grazing system. The results have shown that any reduction of the methane level always implies a consequent decrease in income. If the $CO_{2\text{-eq}}$ has to be limited than there is the need to find alternative income activities for farmers in order to preserve economic sustainability.

Keywords

Climate Change, Dairy, Economic Sustainability, Greenhouse Gas Emissions

1. Introduction

Agriculture is an important source of global emissions of Greenhouse Gas Emissions (GHG), mainly from ruminant production. The negative impact of animal production is due to two main factors: the atmospheric pollution (carbon dioxide—CO_2— and methane—CH_4— from enteric fermentation and manure management and nitrogen emission from soils and manure management) and water and soil pollution (nitrogen and phosphorus). The methane emissions are mainly due to ruminant farming as the ruminants emit methane as part of their diges-

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How to cite this paper: Silva, E., Mendes, A.B. and Rosa, H.J.D. (2016) Dairy Farming Systems' Adaptation to Climate Change. *Agricultural Sciences*, **7**, 137-145. http://dx.doi.org/10.4236/as.2016.73013

tive process (enteric fermentation), manure management and other processes.

The agriculture is estimated to be responsible for 540 million tons of $CO_{2\text{-eq}}$ in GHG emissions [1] and in the European Union (EU) it represents 9.2% to 11% of its total emission [1] [2] being France, Germany, Spain, United Kingdom and Italy the major contributors (60% of the total).

According to [1] in EU, the majority of $CO_{2\text{-eq}}$ in GHG emissions is from methane and nitrous oxide (5% and 4.3% of total, respectively). In the EU, the GHG agricultural emission fell 6% from 1990 to 1995 being the main sources the N_2O from agricultural soils (50%), CH_4 from enteric fermentation (35%) and CH_4 from manure management (15%) [3]. The contribution of Portugal for the total of EU 15, is 1.5% of enteric fermentation, 5.3% of manure management and 1.1% of agricultural soils [3].

The recent Common Agricultural Policy (CAP) reforms have decreased the GHG level because of the increased productivity, the reduction of cattle stocks, the improved management practices and the new agricultural and environmental policies [4].

According to the various scenarios of agricultural policy mitigation proposed by [5], in EU-27, between 1990 and 2008, the $CO_{2\text{-eq}}$ level would be reduced by 20.2%, the methane by 18.4% and the nitrous oxide by 21.5%. For instance, in the last scenario, which applied a livestock emission tax, would result in a substantial decrease of the methane, nitrous oxide and $CO_{2\text{-eq}}$ levels (28.8%, 25.6% and 27.1%, respectively) but would be the worst economic scenario to Portugal, with a negative impact on the farms income.

Therefore, the main objectives of this research are to estimate the amount of GHG emission (converted as CO_2 equivalent) in Azores dairy farms and, by integrating this data in an Azorean agricultural decision making linear programme developed previously by [6], to build scenarios for economic and environmental impacts on dairy farms. The results of this research can be applied to other similar productions systems.

2. Material and Methods

This study was carried out in the Azores, Portugal, where the agriculture is the main sector of its economy and represents 2.1% of the Portuguese global economy. The Azores is a Portuguese Archipelago (9 islands) located in the middle of North Atlantic-latitude (extreme points) 39˚43'23"N and 36˚55'43"N and longitude (extreme points) East 24˚46'15" WG and West 31˚16'24" [7]. Its surface area is 2322 km^2 equivalent to 2.6% of Portuguese territory [8].

The Azores has a temperate Atlantic climate with an annual mean temperature of 17.6˚C (max 26˚C; min 12.5˚C), an annual mean air humidity of 80% and an annual mean rainfall of 1300 mm, which is well distributed around the year [9].

In 2009, the utilized agricultural area was 112,054 hectares (3.23% of Portugal) and comprised 13,149 farms (4.8% of Portugal). In the Azores, the meadows and permanent grassland represent about 89% of the agricultural area and 65.5% of the holdings and the average agricultural area per farm, in 2009, was 8.52 hectares [10].

The Azores islands produce mainly cow's milk which contributes for about 30% of Portugal milk production and about 35% of Portuguese cheese being 12 Protected Designation of Origin cheeses, of which two are from the Azores: S. Jorge and Pico [11] [12]. The dairy milk quota in Portugal (2011) was 2.02 million tons and in the Azores was about 548 tons [13]. Portugal had, in 2009, 1391 thousand of cattle heads, including 278 thousands of dairy cows. The Azores archipelago contributed with 245 thousand cattle heads, of which 92 thousands were dairy cows [11].

Presently, no data are available neither on GHG emission from the Azorean dairy farms nor on the consequent effects of EU mitigation policies upon the farms economic income.

Seven production systems types of Azorean dairy farms were defined by [14], according with the indicators: 1) Specialisation (total dairy and beef cows minus dairy cows per dairy cows) and 2) intensity level (total cows per hectare). This study analysed only the intensive dairy milk typology, Type I–intermediate grazing systems (1.4 to 2.4 cows per hectare) and the mixed system (specialization 0.33 to 0.66) as this is the most representative system in the Azores and presents the biggest impact on GHG (methane emissions) of the regional animal grazing systems. According to [14] the main features of this group of dairy farms were on average as follows: agricultural area of about 15.5 hectares, number of dairy cows of about 36, number of cows per hectare of 2.4, net income per cow of 830.00€, dairy production per cow of 5990 litres, feeding cost per hectare of 236.93€ and fertilizer cost per hectare of 181.06€ [14].

The data used in this model came from the Farm Accountancy Data Network (FADN) for Portugal, a European database. A linear programming model (see **Appendix**) was built to the Azorean dairy farms in order to achieve the main impacts of decreasing of $CO_{2\text{-eq}}$.

The model was adjusted from [6] and [15] who develop the Azorean dairy farm programming model. In this model, the decision variables can assume any value of the feasible set, and this is defined by constrains of the systems (land, agronomic, feeding and labour requirements, grazing systems, risk profit), and the new constrain $CO_{2\text{-eq}}$ emissions-following the assumption, as has been explored earlier, that cattle represents an important source of methane [16]. The [6] programming model had 15 activities (crop and livestock) as belonging to the decision making processes of the Azorean dairy farms and involves: direct pasture cultivation high altitude (ha); direct pasture cultivation medium altitude (ha); direct pasture cultivation and silage medium altitude (ha); direct pasture cultivation and hay medium altitude (ha); direct pasture cultivation low altitude (ha); direct pasture cultivation low altitude silage (ha); direct pasture cultivation and hay low altitude (ha); maize cultivation medium altitude (ha); maize cultivation low altitude (ha); annual crop winter medium altitude (ha); annual crop winter low altitude (ha); annual crop winter medium altitude (ha); annual crop winter low altitude (ha); kilos of concentrated feed (Kg); and the number of dairy animals.

The objective of the model was the profit maximization (euro) as an indicator of economic performance. The model constrains were: total cultivation area per altitude (high, medium, low); rotational and agronomic considerations, (20% of the area was improved by maize over five years); different labour requirements concerning six periods and specific activities; risk profit (thousands of euro) over seven years; operational constrain; concerning six periods feeding and animal requirements of energy (UFL), protein digested in small intestine (PDI), calcium (CA) and phosphor (P), dry matter intake; intensity grazing system [6]. Finally, a new constrain was added, *i.e.*, the methane emissions, intended to convert it at $CO_{2\text{-eq}}$ level.

The CO_2 equivalent was estimated by Tier II method [16], with higher level of complexity but including a more specific information to Azorean dairy farms (Holstein breed). In the Azorean dairy farms it reaches the value of 115.5 kg of methane per cow per year. To estimate the emissions of methane in the Azores the formula of [16] was used. The data was calculated based on the average dairy cow in the Azores (Holstein breed) considered having a live weight of 580 kg and producing18 kg milk/day (based on 5500 kg per year-305 days of lactation). To convert methane into $CO_{2\text{-eq}}$, the conversion index of 1 ton of CH_4 = 25 ton of $CO_{2\text{-eq}}$ [16] was used. It was necessary to estimate the emission factor (EF) and the Gross Energy intake (GE) (MJ/head/day). The energy requirements for maintenance and production were about 155 MJ Metabolize Energy/head/day and the need for dry matter intake was 14.5 kg/head/day (mix of: grass, grass and maize silage and concentrate). As a result:

GE = 14.5 (need of kg dry matter/head/day) × 18.7 (mean gross energy concentration of diet-MJ/kg Dry Matter) = 271 MJ/head/day, and

EF = [271 × (6.5/100 × 365)]/55.65 = 115.5 kg CH_4/head/year

3. Results and Discussion

The value found for total methane emissions per cow and year was 115.5 kg which is very close to the [16] estimation for dairy cows in the Occidental Europe by Tier method (level 1), which was 117 kg. The data of IPCC (1995) cited by [3] show that the emission factor (kg CH_4/head/yr.) was 100 for the dairy cow and 48 for other cattle.

The main results of the model showed that if no limitation is imposed on methane emission, than dairy farms can reach an income of 55721€ per year, producing 5611 kg of methane, and supporting about 3.2 animals per hectare as the level of intensification-corresponding to approximately 49 animals in the farm. If the methane emission level is restricted to 50% (being the emission of methane in the model of 2505 kg) than the profit will decrease to 27241€, the level of intensification will be approximately 1.5 animals per hectare (about 24 cows per farm) and the total agricultural area will be fully used. If that level is reduced by 75% (*i.e*. 1403 kg), than the income will drop drastically to 13366€ with only approximately 14 animals in the farm and the level of the grazing intensity system would go down to 0.84 animals per hectare (**Figure 1** and **Table 1**).

This data show the negative economic impact of decreasing levels of methane emission, mainly due to the effect that the reduction in cattle heads has on farmers' income.

The $CO_{2\text{-eq}}$ emission found was 2.9 ton/head for the Type I, intermediate grazing system, although other studies have been shown different figures because the emissions are affected by a multitude of factors including

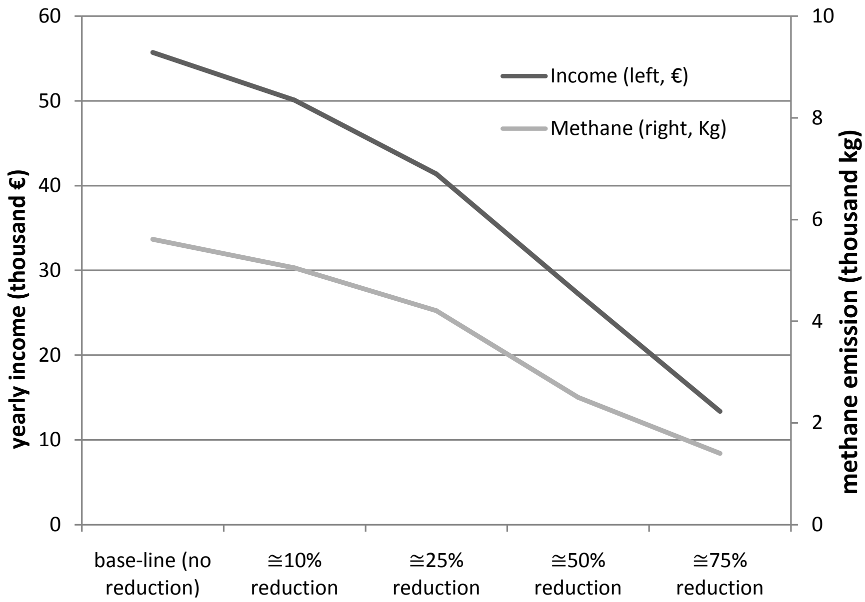

Figure 1. Impact of methane emission on yearly income of Azorean dairy farms.

Table 1. Methane and $CO_{2\text{-eq}}$ emissions and farms characteristics in the Azores.

	Original situation	Less 10% of the 5611	Less 25% of the 5611	Less 50% of the 5611	Less 75% of the 5611
Income (€)	55 721	50 090	41 390	27 241	13 366
Methane (kg)	5 611	5 050	4 208	2 505	1 403
Number of cows	48.5	43.7	36.4	24.2	13.5
$CO_{2\text{-eq}}$ (ton/head)	2.9	2.9	2.9	2.6	2.6
Area (hectares)	16	16	16	16	16
Intensification level	3.2	2.7	2.3	1.5	0.84

breed, nitrogen level in the soil, level of production and others.

[17] found that the Jersey cow (oriented for cheese production) presented a lower impact then the Holstein (oriented for milk production) while [18] argues that fertility improvement will decrease the methane emissions. [19] and [20] using the efficiency ratio (*i.e.* kg dairy milk per cow) in a research comparison, observed that the most efficient dairy cows reduces the maintenance requirements, as well as the kg of $CO_{2\text{-eq}}$ from 3.66 (1944) to 1.35 (2007).

The farm nitrogen appears as a good proxy for GHG emissions per unit of land area. According with the results of [21], the GHG emissions increase from 3.0 ton $CO_{2\text{-eq}}$/ha/year (with a level of 56 kg N/ha/year) to 15.9 ton $CO_{2\text{-eq}}$/ha/year (with a level of 319 kg N/ha/year).

[22] reported that a reduction of 1 g of nitrogen per kg of milk reduced the GHG emissions per kg of milk of approximately 29 g $CO_{2\text{-eq}}$. In 1985, the average dairy farms in the Netherland emitted 2.16 kg $CO_{2\text{-eq}}$ per kg milk, but in 2002 the emissions were reduced by 32% to 1.47 $CO_{2\text{-eq}}$ per kg milk.

[23] showed that the extensive system (sheep farming) causes higher emissions per kg of milk than the semi-intensive system: 5.45 and 2.99 kg of $CO_{2\text{-eq}}$, respectively.

GHG emissions were at the level of 14.3 - 18.3 ton $CO_{2\text{-eq}}$ per ton of live weight in French suckler farms and the livestock was the main driver of global warming potential [24]. In all the scenarios modelled, system adjustments designed to minimize the drop in income had a very limited impact on GHG emissions.

Figure 2 and **Table 1** show that when the level of intensification drops from 3.2 to 0.84 heads per hectare, the $CO_{2\text{-eq}}$ per cow slightly decreases from 2.9 to 2.6 tons but the income of farms falls deeply (from 55721 to 13366€). In opposition to data from [25], which suggest that the decrease of intensification increases the methane emission (while in North America a milk production of 9000 kg/cow/year originates 1.3 kg $CO_{2\text{-eq}}$/kg of

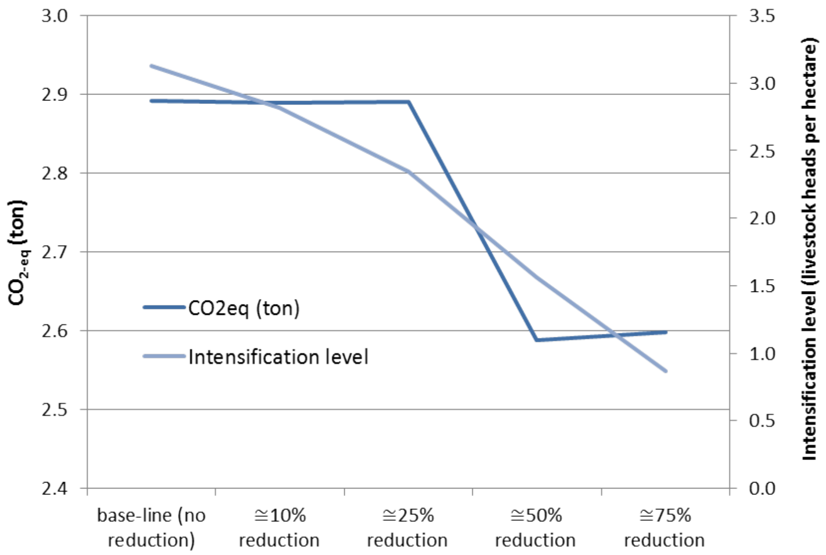

Figure 2. Intensification level (livestock heads per hectare) and $CO_{2\text{-eq}}$ (ton) in the Azorean dairy farms.

milk, in the South Asia a production of 1000 Kg/cow/year results in 5 kg $CO_{2\text{-eq}}$/kg of milk), the results of the present study showed a decrease (although small) in $CO_{2\text{-eq}}$ with a decrease (large) of intensification.

[19] and [22] found respectively, 1.35 and 1.46 kg of $CO_{2\text{-eq}}$ per kg of milk, a value clearly higher than the 0.53 Kg, found in this work (it was considered in Azorean case, the value of 2.9 tons $CO_{2\text{-eq}}$ and the milk produced per cow of 5500 kg, which means: 2.9/5500 × 1000 = 0.53 Kg of $CO_{2\text{-eq}}$ per kg of milk).

In the EU-27, [5] showed that to achieve the goal of 20% decrease of GHG emission, a livestock tax of 229€ per ton CO_2 should be applied. This value can be considered as a reference value. In this way, it is important to study the implications of methane level (converted to $CO_{2\text{-eq}}$) for the Azorean dairy farms. According to the present case study, the tax per cow would be 664.1€ (229€ × 2.9), below the mean for the EU (1000€ per cow), but still considerably detrimental for the Azorean dairy farms economic sustainability.

4. Concluding Remarks

The animal production in the Azores is mainly oriented to the dairy. Dairy cows appear as the main source of methane emission and consequently as the main source of GHG emissions. In this research, only the effect of enteric fermentation is considered. Further research is needed to clarify the effect of the grass impact in the model, as the animals feed mainly on pasture.

There is a conflict between the methane emissions (environmental performance) and income (economic performance). Greater income implies higher methane emissions and animal intensification. Therefore, if the European Union decides for a very rigorous legislation, this can strongly affect the cow's milk production in Portugal and mainly in the Azores. That decision will have a great impact on the economic activity of the Azorean farms and can negatively affect the economic sustainability of its animal farms as well as the jobs created by agricultural activities.

In the Azores, the impact of $CO_{2\text{-eq}}$ is 2.9 ton per cow and year when the intensification level is high (3.23 animals per hectare). For the intensification level of 0.84 animals per hectare, the $CO_{2\text{-eq}}$ is reduced to 2.6 ton per cow and year.

To reduce the emission of enteric methane, it is necessary to reduce livestock heads, to improve feed conversion efficiency, including efficiency of the rumen and increase animal productivity. To decrease the emission from manure management, it is necessary to reduce the animal number, to optimize the feed digestibility, to increase animal productivity and improve the efficiency of the manure management system, as suggested by [3].

The abatement costs are recognizably very important to determine the role that agriculture could play in the reduction of GHG emissions in the EU [26]. However, the present study showed that much care is needed in order to maintain the economic sustainability of the Azorean dairy farms.

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Appendix

The decision variables selected as belonging to the decision making processes of dairy farms was: X_1—direct pasture cultivation high area (ha); X_2—direct pasture cultivation medium area (ha); X_3—direct pasture cultivation medium area and silage (ha); X_4—direct pasture cultivation medium area and hay (ha); X_5—direct pasture cultivation low area (ha); X_6—direct pasture cultivation low area silage (ha); X_7—direct pasture cultivation low area hay (ha); X_8—maize cultivation medium area (ha); X_9—maize cultivation low area (ha); X_{10}—Annual crop winter medium area (ha); X_{11}—Annual crop winter low area (ha); X_{12}—Annual crop winter medium area (ha); X_{13}—Annual crop winter low area (ha); X_{14}—kilos of concentrated feed (Kg); X_{15}—number of dairy animals.
Objective: Profit maximization, MB (€)
Model constrains: 1-4: Total cultivation area per altitude (high, medium, low); 5-7: Rotational and agronomic considerations, (20% of the area was improved by maize over five years); 8: different labor requirements concerning 6 periods and specific activities, and the possibility of finding work in the exterior of farm; 9-10: Risk profit (euro) over 7 years; 11-17: Feed and animal requirements of energy (UFL), protein (PDIE and PDIN), calcium (CA) and phosphor (P), and dry matter intake; 18 to 19: Intensity grazing system; 20: methane emission; 21: Negativity constrains.
MB = Gross margin,
MO = Familiar labor;
SA = High altitude area
SM = Medium altitude area
SB = Low altitude area
ST = Total area
UFL = Animal requirements of energy,
PDIE and PDIN = Protein,
CA = Calcium,
P = Phosphor,
MS = Dry matter.

$$(1): \text{MAX}MB = \text{MAX}\sum_{i=1}^{15} X_i MB_i$$

s.a.

$$(1): X_1 \le S_A$$

$$(2): X_2 + X_3 + X_4 + \frac{1}{2}X_8 + \frac{1}{4}\left(X_{10} + X_{12}\right) \le S_M$$

$$(3): X_5 + X_6 + X_7 + \frac{1}{2}X_9 + \frac{1}{4}\left(X_{11} + X_{13}\right) \le S_B$$

$$(4): S_A + S_M + S_B \le S_T$$

$$(5): X_8 + X_9 \le 0.2\left(S_M + S_B\right)$$

$$(6): X_{10} + X_{11} \le X_8$$

$$(7): X_{11} + X_{13} \le X_9$$

$$(8): \sum_{i=1}^{15}\left(MO_j X_i\right) + n_j - p_j = \overline{MO_{dj}},\ \ j = 1,\cdots,6$$

$$(9): \sum_{i=1}^{15}\left(MB_{ik} X_i - \overline{MB_{ik}}\right) + N_k - P_k = 0,\ \ k = 1,\cdots,7$$

$$(10): \sum_{i=1}^{15} MB_i X_i \ge 15497.65$$

$$(11): \sum_{j=1}^{6}\sum_{i=1}^{14} UFL_{ij} MS_{ij} X_i \ge \sum_{j=1}^{6} UFL_{15j} X_{15}$$

$$(12): \sum_{j=1}^{6}\sum_{i=1}^{14} PDIE_{ij} MS_{ij} X_i \ge \sum_{j=1}^{6} PDIE_{15j} X_{15}$$

$$(13): \sum_{j=1}^{6}\sum_{i=1}^{14} PDIN_{ij} MS_{ij} X_i \geq \sum_{j=1}^{6} PDIN_{15j} X_{15}$$

$$(14): \sum_{j=1}^{6}\sum_{i=1}^{14} CA_{ij} MS_{ij} X_i \geq \sum_{j=1}^{6} CA_{15j} X_{15}$$

$$(15): \sum_{j=1}^{6}\sum_{i=1}^{14} P_{ij} MS_{ij} X_i \geq \sum_{j=1}^{6} P_{15j} X_{15}$$

$$(16): \sum_{i=1}^{14} MS_i X_i \geq MS_{15} X_{15}$$

$$(17): X_{14} - 547.7 X_{15} = 0$$

$$(18): X_{15} - 1.4 \sum_{i=1}^{13} X_i \geq 0$$

$$(19): X_{15} - 2.4 \sum_{i=1}^{13} X_i \leq 0$$

$$(20): 115.5 X_{15} \geq 0$$

$$(21): X_i \geq 0, \quad i = 1, 2, \cdots, 15$$