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Insights into Enteric Methane Emissions in Conventional and Organic Dairy Grazing Systems in Island Regions

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Abstract: Pasture-based dairy systems are a cornerstone of agricultural practices in the Azores, contributing significantly to both the local economy and environmental sustainability. However, the environmental impact of these systems, particularly in terms of methane (CH_4) emissions, remains a major challenge, especially given the need to balance productivity with ecological preservation. This study aimed to compare enteric methane emissions, floristic composition, productivity, and nutritional quality between conventional and organic pasture systems in the Azores. Data were collected from representative dairy farms over a 12-month period, with pasture samples analyzed monthly to assess floristic diversity, dry matter productivity, and nutritional quality (crude protein and digestibility). Methane emissions were estimated using the IPCC Tier 2 methodology, incorporating data on animal performance, diet composition, and energy intake to calculate CH_4 emissions per cow per year. The results showed that organic pastures had greater floristic diversity (5.10 ± 0.25 species/m^2) than conventional pastures (4.00 ± 0.23 species/m^2). However, conventional systems exhibited higher dry matter productivity (22.85 g/m^2 vs. 15.35 g/m^2) and incorporated corn silage, which enhanced digestible energy and reduced methane emissions (81.33 kg CH_4/cow/year) compared to organic systems (89.17 kg CH_4/cow/year). Although organic pastures had higher crude protein content (20.65%), their lower digestibility contributed to higher methane emissions. This study underscores the trade-offs between environmental sustainability, pasture productivity, and methane mitigation in pasture-based dairy systems, highlighting the need for integrated management approaches that balance ecological and production goals.

Keywords: enteric methane; dairy production; organic farming; conventional systems; Azores; pasture management

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1. Introduction

Dairy production is a cornerstone of agricultural activity in the Azores, particularly due to the region's favorable climate and soil conditions that support year-round pasture-based systems [1]. This agricultural sector plays a vital role in the local economy, with the

Azores contributing over 30% of Portugal's national milk production [2]. The reliance on pastures, which serve as the primary feed source for dairy cattle, highlights the region's dependence on efficient and sustainable pasture management. However, with the global emphasis on climate change mitigation, there is a growing need to address the environmental impacts associated with livestock farming in pasture, particularly greenhouse gas emissions. Methane (CH_4) is one of the most potent greenhouse gases, with a global warming potential significantly higher than that of carbon dioxide over a 100-year period [3]. Enteric methane, produced during the digestion of feed by ruminants, accounts for most methane emissions in dairy systems. Globally, livestock farming contributes approximately 11% of total anthropogenic greenhouse gas emissions, with ruminants being the primary source [4]. In the Azores, this issue is particularly pronounced as 99.5% of the region's methane emissions originate from cattle [5]. These emissions pose a significant challenge for balancing productivity with environmental sustainability in dairy systems.

Pasture-based systems, both conventional and organic, dominate dairy production in the Azores. Conventional systems typically prioritize productivity, often utilizing high-yield grasses, corn silage, and synthetic fertilizers. While effective in maximizing dry matter production and nutritional content, these systems may lead to increased environmental impacts, including soil degradation and biodiversity loss [6,7]. In contrast, organic systems emphasize ecological sustainability, promoting biodiversity and soil health by reducing the synthetic fertilizers and pesticides. The reliance on diverse plant species and organic fertilizers, however, may impact pasture productivity and nutritional quality, which in turn can influence methane emissions [8].

Although pasture-based systems are generally associated with lower daily methane emissions per animal, studies indicate that intensive systems using concentrate-rich diets may achieve lower methane emissions per unit of milk produced due to higher feed efficiency. However, they often lead to higher absolute daily emissions per cow, given increased intake and fermentation rates [9,10]. This highlights the complexity of comparing production systems and reinforces the need to assess their environmental impacts contextually.

In systems where diets are high in forage, such as in pasture-based dairy farming, enteric methane emissions tend to be higher due to longer fermentation periods in the rumen and lower energy density of the feed. Studies have shown that high-forage diets can produce between 100 and 120 kg CH_4/cow/year, depending on forage quality and intake levels [11]. This highlights the need to improve pasture quality to mitigate emissions without compromising animal health and productivity.

The floristic composition and nutritional characteristics of pastures play a crucial role in determining the efficiency of ruminant digestion and the subsequent production of methane. Pastures with high-quality forage, rich in crude protein and digestible fibers, can enhance feed efficiency and reduce methane emissions [12]. Conversely, low-quality pastures with high lignin content may increase fermentation time in the rumen, leading to higher methane outputs. While conventional systems often include energy-dense feed such as corn silage to optimize digestibility and reduce methane emissions, organic systems may face challenges in balancing productivity with emission reduction due to their reliance on natural inputs and diverse but less-productive pasture species.

Despite the importance of pasture quality and management in mitigating methane emissions, there is limited research on the comparative impacts of conventional and organic systems in the Azores. Understanding the trade-offs between productivity, sustainability, and methane mitigation is critical for developing strategies that align with both environmental and economic objectives.

This study hypothesized that conventional systems, due to their inclusion of energy-dense supplements and higher dry matter productivity, would result in lower enteric methane emissions compared to organic systems, which rely more on natural, diverse but lower-yield pastures. This hypothesis was confirmed by the results, which showed reduced methane emissions in conventional systems, albeit with trade-offs in floristic diversity and ecological sustainability.

This study aims to address these knowledge gaps by comparing enteric methane emissions, floristic diversity, pasture productivity, and nutritional quality in conventional and organic dairy systems in the Azores. Using Tier 2 methodology developed by the Intergovernmental Panel on Climate Change (IPCC) [13], this research provides a detailed analysis of the interactions between production systems and their environmental impacts. The findings are expected to offer valuable insights into optimizing pasture-based systems for improved sustainability, supporting both regional and global efforts to mitigate the impacts of climate change while maintaining dairy productivity.

2. Materials and Methods

2.1. Study Area Selection

This study was conducted on Terceira Island, the third-largest island in the Azores archipelago (400 km^2), which has a temperate climate with no dry season (Cfb, according to Köppen's Climate Classification) [14].

The research took place on two farms: one certified organic (38°45′57.15″ N; 27°09′56.39″ W) and the other conventionally managed (38°45′46.90″ N; 27°09′49.56″ W). Both farms are located in Agualva at an altitude of 130 m (Figure 1).

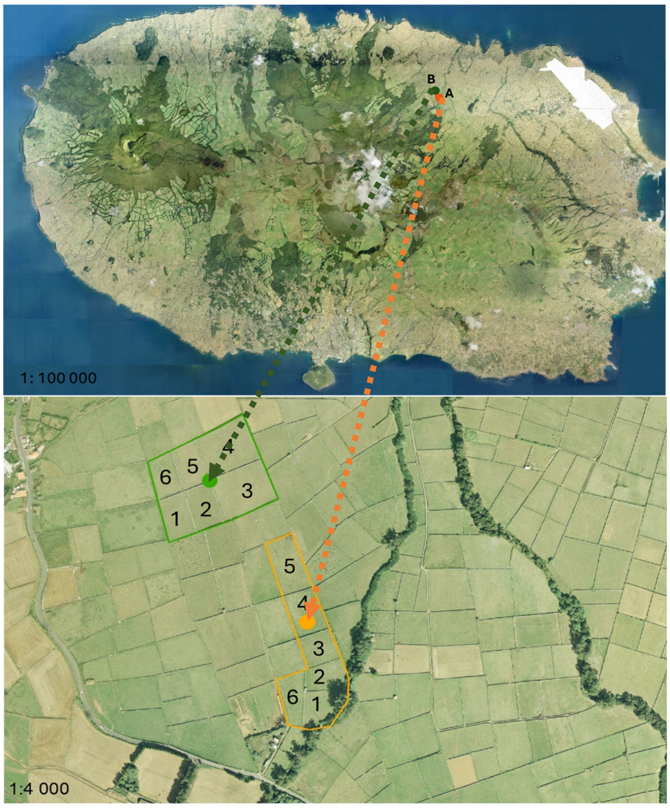

Figure 1. Location of sampling sites: (A) conventional farming system; (B) organic farming system. Numbers 1–6 refer to the plots from which samples were collected.

In the conventional system (2.5 ha), pastures primarily consist of *Lolium multiflorum* Lam. (Poaceae) and *Lolium perenne* L. (Poaceae), whereas organic pastures (3 ha) include *L. perenne* L. (Poaceae), *Poa trivialis* L. (Poaceae), and *Trifolium pratense* L. (Fabaceae). Six pastures were selected for sampling in each system, and these were used as experimental units for evaluating productivity, floristic diversity, and chemical composition.

2.2. Livestock Characterization

2.2.1. Organic System

The organic system (Farm B-Figure 1) primarily consists of Holstein-Friesian dairy cattle. In April, the herd included approximately forty-five pregnant dairy cows, five non-pregnant cows, ten heifers older than one year, and eight female calves younger than one year. Each pregnant dairy cow weighed an average of 500 ± 84 kg and produced about 25 ± 7 kg of milk per day, with an annual yield of 8000 ± 2678 kg over 305 days. The milk contained approximately 3.82 ± 0.22% fat and 3.2 ± 0.29% protein. The feed consisted mainly of pasture, supplemented with grass silage and concentrate (Table 1).

Table 1. Feed ingredients, chemical compositions, and digestibility under organic and conventional production systems.

Production System	Feed	% DM	Per 100 g of DM						% DMD	% ODM
			CP	NDF	ADF	ADL	EE	Ash		
Organic	Grass silage	34.39	17.88	72.77	43.33	3.73	2.23	10.34	44.45	37.28
	Concentrate	87.08	15.36	25.82	9.90	1.70	3.40	6.24	88.13	81.04
Conventional	Grass silage	39.64	12.65	62.12	37.31	6.98	1.65	11.59	68.92	58.07
	Corn silage	39.27	9.35	34.97	21.60	4.33	3.26	3.58	69.86	59.27
	Concentrate	85.96	25.02	23.38	10.27	3.81	3.58	8.87	87.35	76.51

2.2.2. Conventional System

The conventional system, referred to as Farm C (Figure 1), also consisted primarily of Holstein-Friesian cattle, with a small number of Holstein-Jersey crossbreeds. Only lactating, pregnant, Holstein-Friesian dairy cows were considered for methane emission estimations in both systems, in accordance with IPCC Tier 2 requirements. Other animal categories were recorded for herd characterization but not included in emission calculations. During sample collection, the herd included approximately 62 pregnant dairy cows, 23 non-pregnant cows, 10 pregnant heifers, and 30 non-pregnant heifers. Pregnant dairy cows weighed an average of 550 ± 52 kg and produced about 20 ± 10 kg of milk per day, with an annual yield of 7300 ± 3150 kg. The milk had a fat content of approximately 3.99 ± 0.28% and a protein content of 3.28 ± 0.29%. Feed for pregnant cows included pasture, grass silage, corn silage, and concentrate, as describe in Table 1.

2.3. Sample Collection

Plant samples were collected from six pastures within each production system to evaluate forage productivity and chemical composition. Three samples were obtained per pasture, resulting in a total of 18 samples per system and 36 samples overall. Forage productivity was estimated using a 1 m^2 wooden frame, which was randomly placed on the pasture. All plants within the frame, including leaves and pseudostems, were manually harvested using scissors at approximately 5 cm above the soil surface. Samples were placed in a labeled plastic bag and transported to the laboratory for weighing. To determine dry matter yield, samples were first weighed fresh, then dried in a forced-air oven at 105 °C until constant weight, and subsequently reweighed. Dry matter productivity was calculated based on the dry weight per square meter.

2.4. Floristic Composition

Floristic composition was evaluated by determining the percentage coverage of each plant species within the 1 m^2 wooden frame used for productivity assessment [15].

2.5. Chemical Parameters

Feed samples (pasture, grass silage, concentrate, and corn silage for the conventional system only) were collected from both systems. Samples were dried at 65 °C in a forced-air oven until reaching constant weight, cut into small pieces, and ground in a Retsch mill (GmbH, Hann, Germany). The ground material was sieved through a 1 mm mesh, stored in labeled bags, and analyzed using the Weende system. Dry Matter (DM) was determined using method 934.01, Crude Protein (CP) by method 2001.11 (Kjeldahl method), Ether Extract (EE) by method 920.39, and Total Ash by method 942.05, following the standard procedures established by A.O.A.C. [16]. Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Acid Detergent Lignin (ADL) were analyzed according to the procedures outlined by Goering and Van Soest [17].

2.6. Biological Parameters

In vitro digestibility of dry matter and organic matter was determined following the method of Tilley and Terry [18], with modifications by Alexander and McGowan [19]. Rumen fluid was collected from five healthy dairy cows at a local slaughterhouse, as described by Borba [20]. Before slaughter, the cows were fed pasture and grass/corn silage. The rumen fluid was obtained within 10 min of slaughter, filtered through two layers of cheesecloth, maintained at 38 °C under anaerobic conditions, and transported to the Animal Nutrition Laboratory at the University of the Azores within 30 min for incubation [21].

2.7. Estimation of GE, DE, and ME Values

The gross energy (GE), digestible energy (DE), and metabolizable energy (ME) values of the diet were estimated based on the chemical composition of the feed, following the equations recommended by the IPCC Guidelines [22]. Gross energy (GE) was calculated using CP, EE, and ash content, according to the following Equation (1):

$$\text{GE (MJ/kg DM)} = 0.023 \times \text{CP} + 0.039 \times \text{EE} + 0.017 \times (100 - \text{CP} - \text{EE} - \text{Ash}) \quad (1)$$

Digestible energy (DE) was estimated from the GE and the digestibility of gross energy, which was assumed to be equivalent to the *in vitro* organic matter digestibility (OMD) (2):

$$\text{DE (MJ/day)} = \text{GE} \times \text{Digestibility of gross energy (\%)} \quad (2)$$

Metabolizable energy (ME) was calculated from DE using the IPCC default conversion factor (3):

$$\text{ME} = \text{DE} \times 0.82 \quad (3)$$

These estimates were used to calculate daily energy intake as part of the Tier 2 model for enteric methane emission estimation.

2.8. Tier 2 Enteric Methane Emission Factors

Enteric methane emissions were estimated following the Tier 2 methodology described in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [19]. This method requires the calculation of the gross energy intake of the animals, which is then multiplied by the methane conversion factor (Ym), representing the percentage of GE converted to methane. In our study, daily GE intake was calculated as the product of dry matter intake (DMI, kg/day) and the gross energy content of the diet

(GEfeed, MJ/kg), assumed to be 18.45 MJ/kg DM for forage-based diets. The DMI was estimated based on animal live weight and milk production, using the Equation (4) as recommended by the IPCC.

$$\text{DMI} = (0.025 \times \text{body weight}) + (0.1 \times \text{milk yield}) \quad (4)$$

The Ym value used was 6.5%, reflecting a pasture-based diet with moderate digestibility. Finally, the annual methane emissions (kg CH_4/cow/year) were estimated using the Equation (5):

$$CH_4\ (\text{kg/year}) = \text{GE} \times \text{Ym} \times 365/55.65 \quad (5)$$

where 55.65 is the energy content of methane (MJ/kg). This approach allowed us to integrate diet quality, animal performance, and feed intake to generate more accurate emissions estimates under local farm conditions.

2.9. Statistical Analysis

To evaluate the effect of pasture management (conventional vs. organic) on enteric methane emissions, biomass production, and forage quality, data were analyzed using independent samples *t*-tests. Assumptions of normality were assessed using Shapiro–Wilk tests and Q–Q plots. Homogeneity of variances was evaluated with Levene's test; when this assumption was violated, Welch's *t*-test was applied. Effect sizes were estimated using Cohen's d and interpreted following conventional thresholds (small: 0.2, medium: 0.5, large: 0.8). A significance level of $p < 0.05$ was adopted for all analyses. All analyses were performed using SPSS, version 27 [23]. Principal Correspondence Analysis (PCA) was used to assess the relationship between production systems based on floristic composition [24]. This analysis (CAP 4 software, v4.0) allowed evaluation of the contribution of each sampling site and plant species to the total variation, based on their percentage coverage.

3. Results

3.1. Floristic Composition

Floristic composition differed significantly between the two production systems ($t(34) = 3.25$; $p < 0.01$). The mean plant species richness per plot (1 m^2) was higher in organic pastures than in conventional ones ($\bar{x} = 5.10 \pm 0.25$ vs. $\bar{x} = 4.0 \pm 0.23$, respectively) (Figure 2). However, no significant differences were observed in floristic composition among the six pastures within the organic system or among those within the conventional system.

The relative percentage cover of each plant species in each production system was analyzed using PCA (Figure 3). The biplot of the first two PCA axes explained 61.57% of the total variation. The first axis, accounting for 43.24% of the variance in plant species composition, clearly separated the two production systems.

The contribution of the relative coverage percentage of each plant species in each production system was analyzed using PCA. Figure 3 presents the biplot for the first and second PCA axes, which together explained 61.57% of the total variation. The first axis, accounting for 43.24% of the variation in plant species composition, clearly distinguished the two types of production systems.

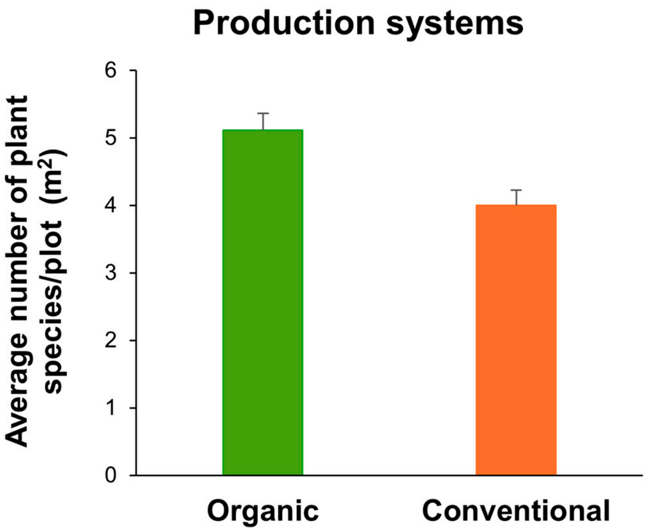

Figure 2. Average number of plant species per plot (m^2) in organic and conventional production systems.

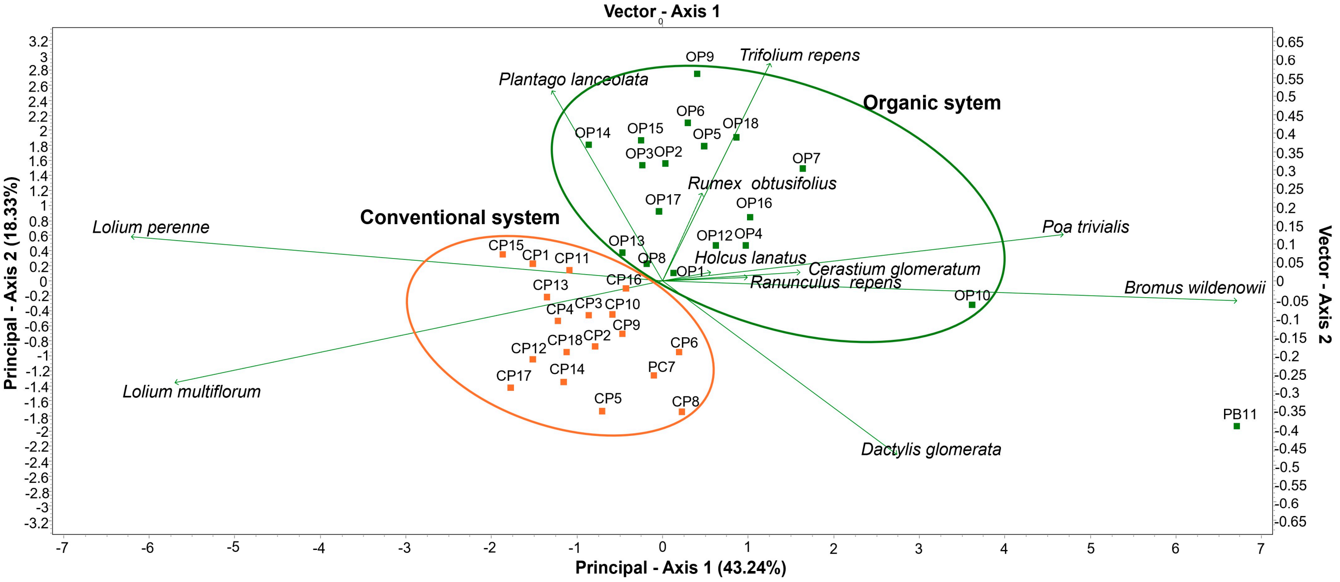

Figure 3. First and second axes of the PCA for the relative coverage percentage of samples collected in organic (n = 18) and conventional (n = 18) production systems. Plant species are represented as vectors.

In fact, *L. perenne* and *L. multiflorum* were the two plant species with the highest relative coverage percentages in both organic (36.17% and 23.89%, respectively) and conventional pastures (42.78% and 44.61%, respectively), followed by *Trifolium repens* and *Poa trivialis*. However, these latter species showed significantly higher coverage percentages in organic pastures (14.0% and 7.22%, respectively) compared to conventional pastures (5.94% and 1.72%, respectively).

On the other hand, some plant species were exclusively found in organic pastures, namely *Bromus wildenowii*, *Holcus lanatus*, *Ranunculus repens*, and *Rumex obtusiformis*, with mean relative coverage percentages of 10.28%, 3.01%, 0.33%, and 0.61%, respectively.

3.2. Forage Productivity

Productivity varied significantly between the two production systems ($t(34) = -4833$ $p < 0.001$), with higher values recorded in conventional pastures (Figure 4). The mean dry matter yield per square meter (m^2) was greater in the conventional system ($\bar{x}$ = 269.57 ± 22.16 g/m^2)

compared to the organic system ($\bar{x}$ = 173.00 ± 7.56 g/m^2) (Figure 4). However, within each production system, no significant differences were observed in productivity among the different pastures.

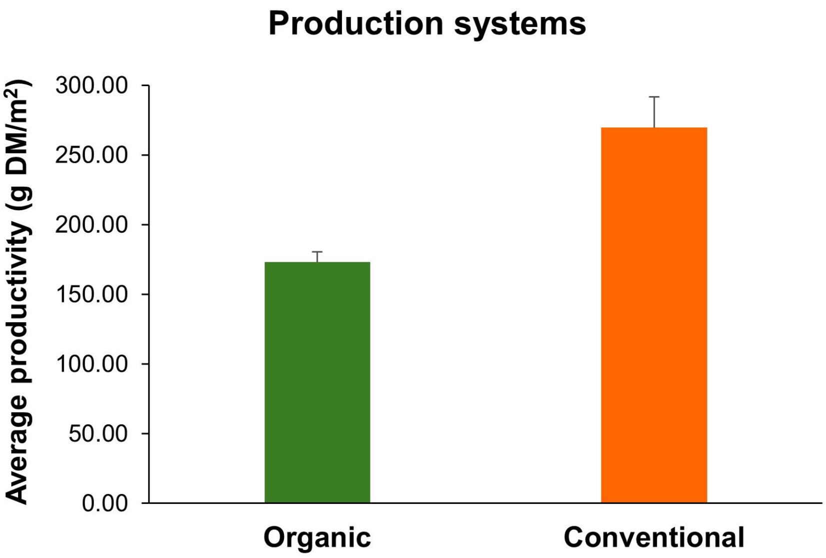

Figure 4. Average dry matter yield obtained (g/m^2) in organic and conventional production systems.

As a result, the mean dry matter yield per hectare (ha) was also higher in the conventional system compared to the organic system ($\bar{x}$ = 2758.55 ± 198.96 kg/ha vs. 1730.00 ± 75.55 kg/ha, respectively).

3.3. Pasture Nutritional Quality

Significant differences ($p < 0.05$) were found between the two production systems for all nutritional parameters analyzed, except for ADL and EE (Table 2). However, no significant differences in forage quality were detected among pastures within the organic system or among those in the conventional system.

Table 2. Nutritional composition of pastures from organic and conventional production systems.

Nutritional Parameters	*p*	Organic	Conventional
DM (%)	**	11.24 ± 0.29	9.75 ± 0.28
CP (% DM)	***	20.65 ± 0.44	16.80 ± 0.22
NDF (% DM)	**	66.00 ± 0.62	69.35 ± 0.76
ADF (% DM)	***	35.71 ± 0.52	40.41 ± 0.74
ADL (% DM)	n.s	5.81 ± 0.41	5.82 ± 0.30
EE (% DM)	n.s	2.60 ± 0.20	2.45 ± 0.11
Ash (% DM)	***	12.31 ± 0.22	11.22 ± 0.17
DMD (%)	**	66.26 ± 0.99	61.98 ± 0.79
OMD (%)	**	60.06 ± 1.04	55.53 ± 0.79

t and *p* values from the independent samples *t*-test for nutritional parameters (dry matter—DM, crude protein—CP, neutral detergent fiber—NDF, acid detergent fiber—ADF, acid detergent lignin—ADL, ether extract—EE, Ash, dry matter digestibility—DMD, and organic matter digestibility—OMD) for the significance between the two production systems (organic and conventional). ** $p < 0.01$; *** $p < 0.001$; n.s = not significant.

Higher DM values were recorded in the organic system, which followed the same trend as CP (Table 2). Regarding fiber fractions, NDF and ADF were higher in conventional pastures than in organic ones (Table 2). Conversely, both *in vitro* DMD and OMD were higher in the conventional system than in the organic system.

3.4. Enteric Methane Production

3.4.1. Diet Composition

Azorean dairy cows primarily feed on pasture in both systems, but they also receive supplementary silage and concentrate. A baseline diet was estimated for each production system based on data collected from farmers, reflecting the percentage composition of the diet (Figure 5A), including pasture, grass silage, corn silage, and concentrate.

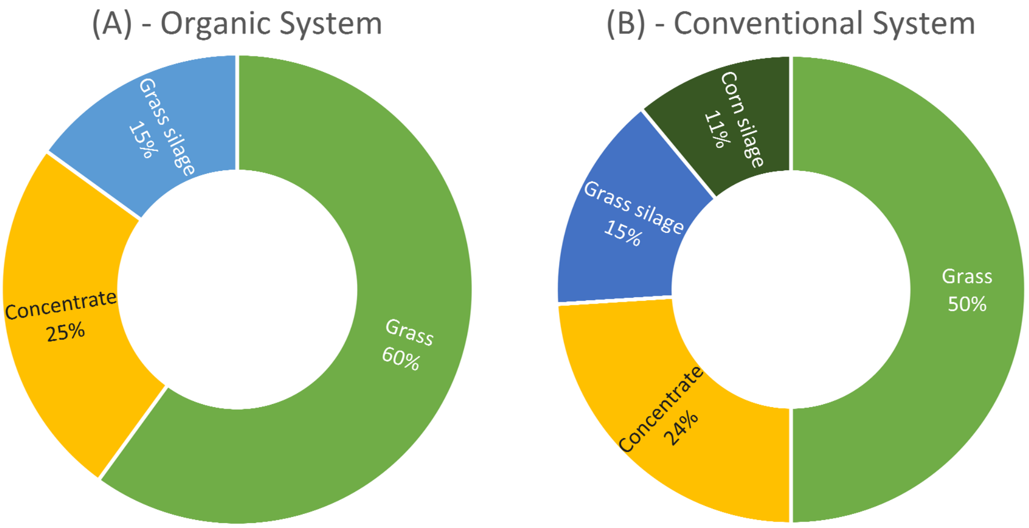

Figure 5. Composition of animal diet in the system: (**A**) organic and (**B**) conventional.

The main difference between the two diets lies in the proportion of pasture and the use of corn silage. The organic diet relies more heavily on pasture (60%) (Figure 5B) and completely excludes corn silage, whereas in the conventional system, pasture is reduced to 50%, and corn silage is included. Both diets use the same amount of grass silage (15%) and nearly the same amount of concentrate, with only a 1% difference.

The average nutritional values of comparative analyses of nutritional parameters between conventional and organic dairy cow production systems are shown in Table 3, considering the proportion of each diet component and variations in the chemical and biological composition of pasture. The dry matter content in the conventional system (35.75%) was higher than in the organic system (33.60%). Regarding crude protein content, the organic system had a significantly higher mean value (18.91%) compared to the conventional system (15.29%).

Table 3. Comparison of nutritional parameters of diets in organic and conventional production systems.

Nutritive Parameters	*p*	Organic	Conventional
DM (%)	***	33.60 ± 0.17	35.75 ± 0.14
CP (% DM)	***	18.91 ± 0.26	15.29± 0.11
NDF (% DM)	***	56.97 ± 0.37	52.36 ± 0.38
ADF (% DM)	n.s	30.40 ± 0.31	30.01 ± 0.37
ADL (% DM)	*	4.40 ± 0.24	5.23 ± 0.15
EE (% DM)	n.s	2.55 ± 0.51	2.75 ± 0.01
Ash (% DM)	***	10.50 ± 0.55	9.55 ± 0.36
DMD (% DM)	***	65.89 ± 0.48	68.80 ± 0.49
OMD (% DM)	**	59.70 ± 0.52	62.02 ± 0.47

Dry matter (DM: %), crude protein (CP: % DM), neutral detergent fiber (NDF: % DM), acid detergent fiber (ADF: % DM), acid detergent lignin (ADL: % DM), ether extract (EE: % DM), ash (% DM), dry matter digestibility (DMD; %), Organic matter digestibility (OMD; %). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s = not significant.

The amount of NDF in the conventional diet was lower than in the organic diet, with a highly significant difference ($p < 0.001$), whereas no significant differences were observed for ADF ($p > 0.05$) between the organic (30.40%) and conventional (30.01%) systems. Similarly, no significant differences were found between the two systems for EE. For biological parameters, *in vitro* DMD and OMD were lower in the organic system (DMD—65.89%; OMD—59.70%) than in the conventional system (DMD—68.80%; OMD—62.02%). These differences were statistically significant ($p < 0.001$ and $p < 0.01$, respectively).

3.4.2. Gross, Digestible, and Metabolizable Energy of the Diet

Gross energy, digestible energy, and metabolizable energy differed significantly between the two production systems (Table 4). However, the highest energy values (GE, DE, and ME) were recorded in the conventional production system. The largest difference between the two systems in terms of energy content was observed for digestible energy, followed by ME and GE (Table 4).

Table 4. The energy value of the diet.

Parameters	*p*	Organic	Conventional
GE (MJ/kg of DM)	*	13.43 ± 0.03	13.84 ± 0.03
DE (MJ/kg of DM)	**	8.85 ± 0.07	9.52 ± 0.05
ME (MJ/kg of DM)	*	7.26 ± 0.06	7.81 ± 0.05

GE—gross energy; DE—digestible energy; ME—metabolizable energy; for the significance between the two production systems (organic and conventional). * $p < 0.05$; ** $p < 0.01$.

3.4.3. Methane Production

The three coefficients used to assess different production systems, both organic and conventional, are presented in Table 5. These coefficients, recommended by IPCC 2019 [19], consider the characteristics of each farm. The values remained the same for both systems across all coefficients.

Table 5. Coefficients used to estimate the enteric methane emission factor for dairy cows in conventional and organic systems.

Production System	Maintenance Coefficient (Cfi)	Activity Coefficient (Ca)	Pregnancy Coefficient (Cp)
Organic	0.386	0.17	0.10
Conventional	0.386	0.17	0.10

Values for NEm (MJ/day), NEa (MJ/day), NEp, (MJ/day), NEl (MJ/day), NEg (MJ/day), ED (as % of GE), REM (%), REC (%), GEI (MJ/kg), and Ym (%) were calculated for each dairy cow production system, considering pasture nutritional value for each plot as well as the nutritional value of all other diet components. The average values for each diet are presented in Table 6.

The results indicate that the organic system has slightly higher emissions per dairy cow per year compared to the conventional system. The absolute difference between the two systems is 7.83 kg CH_4/head/year (Table 7), indicating a high measurement precision for both systems, as demonstrated by the low standard error values.

Table 6. Estimated requirements of different parameters needed to estimate enteric methane emissions by dairy production system category.

Parameters	Organic	Conventional
NEm (MJ/day)	40.81	43.84
NEa (MJ/day	6.94	7.45
NEl (MJ/day)	74.75	61.32
NEp (MJ/day)	7.475	6.132
ED (as %GE)	65.21	65.51
REC (%)	0.30	0.31
REM (%)	0.62	0.62
GEI (MJ/day)	1.14	1.21
Ym (%)	6.50	6.50

Table 7. Estimation of enteric methane production (Kg CH_4) emitted per dairy cow per year, considering organic and conventional system feeding.

	p	Organic	Conventional
Methane Emission (kg CH_4/head/year)	*	89.167 ± 0.49	81.3324 ± 0.52

* $p < 0.05$.

4. Discussion

4.1. Floristic Composition

The analysis of floristic composition revealed significant differences ($p < 0.01$) between organic and conventional production systems. Organic pastures presented higher plant species richness, (5.10 ± 0.25 species/m^2) compared to conventional pastures (4.0 ± 0.23 species/m^2) ($p < 0.01$). This increased diversity is likely a result of reduced herbicide and synthetic fertilizer use, which favors the establishment of a wider range of species, including nitrogen-fixing legumes like *Trifolium repens* and species adapted to less disturbed environments such as *Bromus wildenowii* and *Holcus lanatus*. The PCA further supported this distinction, with the first axis (explaining 43.24% of the variation) clearly separating the systems based on species composition.

Previous studies [25–27] have emphasized the role of pasture biodiversity in promoting ecosystem sustainability, improving soil health, and reducing reliance on external inputs. The greater species richness observed in organic systems is often attributed to the limited use of herbicides and synthetic fertilizers, which enables the proliferation of beneficial species such as *Trifolium repens*, known for its nitrogen-fixing capacity [27]. In contrast, the lower diversity found in conventional pastures can increase susceptibility to pests, diseases, and climate-related stress and may also contribute to higher enteric methane emissions [26]. These findings align with broader evidence linking plant diversity to improved soil fertility, forage quality, and ruminal fermentation dynamics—all of which influence methane production.

4.2. Productivity

Conventional pastures showed higher dry matter yield per square meter and, consequently, per hectare (269.57 ± 22.16 g/m^2 and 2758.55 ± 198.96 kg/ha, respectively) than organic pastures (173.00 ± 7.56 g/m^2 and 1730.00 ± 75.55 kg/ha). As a result, productivity per hectare was also higher in the conventional system due to the application of synthetic fertilizers and pesticides [28], which rapidly increase nutrient availability, such as nitrogen, promoting plant growth [29]. However, this higher productivity may lead to soil nutrient depletion in the medium and long term [30].

Despite the lower productivity, organic pastures may offer a more balanced nutritional composition for animals [31]. Some studies suggest that, when well-managed, organic pastures can be as productive as conventional ones [32,33].

4.3. Pasture Nutritional Quality

Nutritional quality differed significantly ($p < 0.05$) between the two production systems in nearly all analyzed parameters, except for ADL and EE, which showed no statistical differences. Organic pastures presented higher concentrations of dry matter, crude protein, and ash, indicating a more nutrient-dense forage beneficial for animal feeding [34]. In contrast, conventional pastures exhibited higher levels of structural fibers, namely NDF and ADF, which are generally associated with reduced digestibility [31].

Despite the increased fiber content in conventional pastures, *in vitro* digestibility parameters favored the organic system. Dry matter digestibility and organic matter digestibility were significantly higher in organic pastures, suggesting improved forage quality. This could be attributed to the higher presence of legumes, such as *Trifolium repens*, which enhance nitrogen content and overall digestibility [34–36].

These differences in nutritional composition are crucial for understanding ruminal fermentation dynamics and their downstream impact on enteric methane production. While pasture quality is important, it is the nutritional balance of the total diet that ultimately determines methane emissions.

4.4. Enteric Methane Production

The composition and nutritional quality of the total diet differed markedly between the two production systems and played a key role in explaining the variation in enteric methane emissions. In the organic system, the diet was more pasture-based (60%) and excluded corn silage altogether, whereas the conventional system included 10% corn silage and a slightly lower proportion of pasture (50%). This difference in diet formulation influenced several nutritional parameters: the conventional diet exhibited higher dry matter content (35.75%) as well as superior digestibility indices (DMD: 68.80%; OMD: 62.02%), while the organic diet presented higher crude protein (18.91%) but reduced digestibility (DMD: 65.89%; OMD: 59.70%).

These nutritional characteristics have direct implications for methane emissions. Diets with higher fiber content and lower digestibility tend to increase methane production due to a shift in rumen fermentation pathways favoring acetate production and methanogenesis [37,38]. In this study, methane emissions estimated using the IPCC Tier 2 methodology [22]—enhanced with system-specific coefficients—revealed significantly greater emissions in the organic system (89.17 ± 0.49 kg CH_4/cow/year) compared to the conventional one (81.33 ± 0.52 kg CH_4/cow/year) ($p < 0.001$).

The primary contributors to this outcome were the higher fiber content and poorer quality of grass silage in the organic system, which increased the proportion of structural carbohydrates such as ADF and NDF. Although the organic diet avoided fermentable feeds like corn silage—which can pose a risk of ruminal acidosis [39]—this also limited energy availability and reduced overall feed conversion efficiency.

To mitigate methane emissions in organic systems, improving the nutritional profile of forage—through the inclusion of legumes or enhancing silage conservation techniques—is recommended [40,41]. Such strategies can increase digestibility and reduce methanogenic potential without compromising the principles of organic production. Ultimately, optimizing diet composition is essential not only for improving animal performance but also for reducing the environmental footprint of dairy systems.

5. Conclusions

This study demonstrated that organic dairy systems support greater floristic diversity in pastures, which can enhance ecological resilience, improve soil health, and reduce reliance on external inputs. However, forage productivity per hectare was significantly higher in conventional systems, primarily due to the use of synthetic fertilizers and energy-rich dietary supplements.

Nutritionally, organic pastures showed higher crude protein content and good dry matter digestibility. Nevertheless, when considering the complete diet consumed by animals, the conventional system proved more energy-dense and digestible, owing to the inclusion of corn silage and high-quality concentrates.

These dietary differences had a direct impact on enteric methane emissions, which were significantly lower in the conventional system. This finding highlights an inherent trade-off between biodiversity and environmental efficiency, particularly in relation to greenhouse gas emissions.

To bridge these goals, organic systems should prioritize improving forage digestibility—especially of silage—by integrating leguminous species and optimizing forage conservation practices. Such improvements can enhance animal performance while contributing to climate change mitigation, supporting the development of more sustainable and balanced dairy production systems.

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