DOI: 10.5433/1679-0359.2020v41n3p797

Energy efficiency and emissions of CO_2, CH_4, and N_2O in organic and conventional rice production

Eficiência energética e emissões de CO_2, CH_4 e N_2O em arroz sob cultivo orgânico e convencional

Roni Fernandes Guareschi[1*]; Marcio dos Reis Martins[1]; Segundo Urquiaga[2]; Bruno José Rodrigues Alves[2]; Robert Michael Boddey[2]; Leonardo Fernandes Sarkis[3]

Highlight:
Energy efficiency analysis identified some economic and environmental bottlenecks.
Seeds represent a high energy consumption factor in rice production.
Representative producing regions must evaluate energy efficiency.

Abstract

Rice is the second-most produced cereal worldwide and actively contributes to greenhouse gas (GHG) emissions, particularly methane, especially under deepwater production. Assessments of energy efficiency (EE) and GHG emissions can indicate the sustainability level of agrosystems and support decisions related to the reduction of production costs and environmental pollution. This study aimed to assess both EE and GHG emissions in organic and conventional rice production in the Southern region of Brazil. For this study, eight rice fields were evaluated. Energy inputs and outputs were calculated by multiplying the production input amounts by their respective calorific values or energy coefficients at each stage of production. EE was determined using the ratio between the total energy output and the total energy consumed during the production process. GHG emissions were estimated using the principles of the lifecycle assessment methodology in addition to the Intergovernmental Panel on Climate Change (IPCC) recommendations. Each 1.0 MJ consumed during the production of organic and conventional rice produced renewable energy averages of 10.5 MJ and 7.90 MJ, respectively, as grains. The primary energy expenses for organic rice were represented by seeds, fuel, tractors, and agricultural machinery and implements, and those for conventional rice were seeds, fuel, and fertilizers. Each kilogram of organic and conventional rice produced accounted for the emission of 0.21 and 0.32 kg of CO_2eq, respectively, during the production cycles and delivery to the warehouse, with seeds, fuel, and fertilizers being the main sources of CO_2eq emissions to the atmosphere.
Key words: Rice farming. Greenhouse gases. Organic farming. Sustainable production. Sustainability.

[1] Pós-Doutorandos, Programa de Pós-Graduação em Ciência do Solo, Universidade Federal Rural do Rio de Janeiro, UFRRJ, Seropédica, RJ, Brasil. E-mail: guareschiecotarelli@hotmail.com; marcio.dos.reis.martins@gmail.com
[2] Pesquisadores, Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA AGROBIOLOGIA, Seropédica, RJ, Brasil. E-mail: segundo.urquiaga@embrapa.br; bruno.alves@embrapa.br; robert.boddey@embrapa.br
[3] Discente, Curso de Doutorado do Programa de Pós-Graduação em Ciência do Solo, Universidade Federal de Lavras, UFLA, Lavras, MG, Brasil. E-mail: leonardo.sarkis@hotmail.com
[*] Author for correspondence

Received: Nov. 09, 2018 - Approved: Mar. 06, 2020

Resumo

O arroz é o segundo cereal mais cultivado no mundo e contribui ativamente nas emissões de GEE, principalmente em áreas produzidas sob inundação, com destaque para a produção de gás metano. A eficiência energética (EE) e as emissões de gases de efeito estufa (GEE) podem indicar o nível de sustentabilidade dos agrossistemas e a tomada de decisões relativas à redução dos custos de produção e poluição do ambiente. O objetivo deste trabalho foi avaliar a EE e emissões de GEE nas culturas do arroz sob cultivo orgânico e convencional na região sul do Brasil. Para isso, foram avaliadas oito áreas de arroz. As entradas e saídas de energia foram calculadas pela multiplicação da quantidade de produtos utilizados para a produção de arroz pelos seus respectivos poderes caloríficos ou coeficientes energéticos em cada etapa de produção. A EE foi obtida pela razão entre a quantidade de energia total de saída e o consumo total de energia durante o processo produtivo. Para estimar a emissão de GEE, foram aplicados princípios da metodologia de avaliação do ciclo de vida e recomendações do Painel Intergovernamental sobre Mudanças Climáticas (IPCC). Para cada 1,0 MJ de energia consumida na produção orgânica de arroz sob os sistemas orgânico e convencional, se produziram respectivamente em média, 10,5 MJ e 7,90 MJ de energia renovável, na forma de grãos. Os principais gastos energéticos no arroz orgânico foram com sementes, combustível, tratores, máquinas e implementos agrícolas e para o arroz convencional foram sementes, combustível e fertilizantes. Para cada 1 kg de grãos dos sistemas orgânicos e convencional são emitidos respectivamente 0,21 e 0,32 kg de CO_2eq durante seus ciclos de produção e entrega no armazém, sendo as sementes, combustíveis e fertilizantes as principais fontes de emissão de CO_2eq à atmosfera.

Palavras-chave: Arrozicultura. Gases de efeito estufa. Agricultura orgânica. Produção sustentável. Sustentabilidade.

Introduction

The energy efficiency (EE) of Brazilian agriculture has been assessed to determine the energy bottlenecks in the applied farming systems to identify energy-saving technologies, especially for fossil energy (fuel, fertilizers, agricultural pesticides, the energy spent in the manufacturing of machinery and implements, among others) (Campos & Campos, 2004; Cunha et al., 2015). Therefore, such studies are an excellent tool to indicate the sustainability of agrosystems.

There is a lack of studies assessing organic rice EE in Brazilian agriculture. Thus, EE studies in this field are needed to evaluate how the crop is currently farmed compared with the production system for conventional rice, in addition to determining the sustainability level of these systems.

In a study performed in Turkey, Gundogmus and Bayramoglu (2006) compared the energy demand of organic and conventional rice. The authors reported that the total energy required by the organic system was 22,204.94 MJ ha^{-1}, while the conventional system consumed 28,903.30 MJ ha^{-1}, resulting in a 23% higher efficiency for the organic system. The authors also highlighted that the organic systems required more labor per hectare than the conventional system and that the renewable energy input usage was 23.92% of the total input for organic production and 6.27% for conventional production.

Few studies have assessed rice crop's EE in Brazilian agriculture. Ferreira, Neumann and Hoffmann (2014) assessed irrigated rice crop development during the 2007 and 2008 harvests in the state of Rio Grande do Sul, Brazil, and calculated a 12.12 EE. This value mainly reflected the energy consumption through fertilizers (40.71%), especially nitrogen.

Lifecycle assessment (LCA) is a technique used to determine the environmental impact associated with the use of natural resources (energy and materials), pollutant emissions, and opportunities to improve the system with the aim of enhancing the product's environmental performance throughout its agricultural and/or industrial phases (Queiroz & Garcia, 2010). LCA is a useful tool to certify organic production areas (Pires, Rabelo, & Xavier, 2002). A certified organic product may quickly obtain an organic seal through the use of LCA, such as with industrial eco-sealed products (Pires et al., 2002). In Brazil, there have been few studies that utilized LCA. The subject is, however, emerging and becoming more popular because of the increasing public concern about socially fair and economically feasible sustainable production practices (Claudino & Talamini, 2013).

Rice is the second-most produced crop worldwide, and it actively contributes to GHG emissions, particularly methane (CH_4) and nitrous oxide (N_2O), especially in deepwater fields (Nunes, 2015). There have been few LCA studies on Brazilian farming conditions (Nunes, 2015). Nunes (2015) evaluated irrigated rice under minimum tillage and found emissions equaling 29 kg CO_2eq per kg of protein during farming stages, with agricultural operations and fertilizer expenditures as the main contributors to GHG emissions.

EE and LCA assessments can be performed to identify environmental degradation factors during the organic and conventional rice lifecycles. The results can then be used to propose practices to minimize or suppress these factors and build a more sustainable production chain for these crops. Therefore, this study aimed at assessing the EE and GHG emissions (LCA) in organic and conventional rice in different areas of southern Brazil.

Materials and Methods

This study was exploratory and followed the methodological guidelines from multiple case studies, using a literature review and interviews with farmers. The production units chosen for these studies were distinguished using an adopted production system, which produced non-generalized results that can be used as support and tools in other studies because they are not considered "sampling units" (Ferreira et al., 2014).

The management information collected for the EE and GHG calculations from the eight rice fields (four under organic and four under conventional farming) for the 2014/2015 harvest was obtained from interviews with farmers and through partnerships with research institutions such as the Company of Agricultural Research and Rural Extension of Santa Catarina, Brazil (EPAGRI-SC), the National Supply Company (CONAB), and the Rio Grande do Sul Rice Institute (IRGA).

The following main pieces of information were collected: a) Usage of labor, fuel, fertilizers, seeds, seedlings, agricultural pesticides, and other inputs from seeding to harvest; b) Types of operations performed for crop management, in addition to tractors, machinery, and implements (TMI) used; and c) Crop grain productivity; d) Technical indices, such as duration of each agricultural operation and fuel consumption (L h^{-1}).

Detailed information about the organic and conventional rice fields is provided below (Table 1).

Table 1
Location, size, and mean productivity of irrigated (deepwater) rice fields evaluated under organic and conventional farming in the southern region of Brazil

*ID	City/State	Area (ha)	Mean productivity (kg ha^{-1})
	------------------------------ Organic rice -----------------------------		
1	Meleiro-SC[1]	10	5,500
2	São João do Sul-SC[1]	60	4,500
3	Praia Grande-SC[1]	8	4,500
4	Araranguá-SC[2,3,4]	24	5,500
	------------------------------ Conventional rice -----------------------------		
5	EPAGRI-SC[2,3,4]	-	7,100
6	IRGA-RS[3,5,6]	-	7,536
7	Pelotas - RS[7]	350.00	7,270
8	Uruguaiana - RS[7]	350.00	8,000

*Field identification numbers used in the text. [1]Data provided by farmers associated with the EPAGRI-SC. [2]Data provided by the EPAGRI-SC. [3]Represents a standard or reference crop area for the real management conditions in the states of Santa Catarina and/or Rio Grande do Sul, Brazil. [4]Pre-germinated rice crop. [5]Data provided by the IRGA. [6]Farmed under the Clearfield System. [7]Data were provided by the CONAB, with a high level of technology.

All the input and agricultural practice data were collected through structured interviews during visits to the production units used in this study and then converted to energy units by multiplying the physical product by the respective conversion index (energy coefficients), which were computed in MJ (megajoules) (Assenheimer, Campos, & Gonçalves, 2009; Capellesso & Cazella, 2013).

The conversion of inputs and agricultural practices to energy (megajoules) followed previously published methods, and the values were calculated and adapted to the research conditions of inputs (productive factors) and outputs (ethanol production, in sugarcane) (Capellesso & Cazella, 2013). Hence, the energy coefficients used to convert physical products/inputs to energy were labor = 7.84 MJ h^{-1} per person (Boddey, Soares, Alves, & Urquiaga, 2008); 63.79, 13.97, and 9.79 MJ kg^{-1} = synthetic nitrogen, phosphate, and potassium fertilizers, respectively; poultry litter = 0.126 MJ kg^{-1} (Souza, Casali, Santos, & Cecon, 2008); granular organic fertilizer = 0.35 MJ kg^{-1} (Fadare, Bamiro, & Oni, 2009); ground silicate rock = 1.31 MJ kg^{-1}, considering the same energy spent to manufacture and deliver the limestone to the farm (Macedo, Leal, & Silva, 2004); potassium sulphate = 1.67 MJ kg^{-1}; natural phosphate = 0.63 MJ kg^{-1} (Quadros & Kokuszka, 2007); "Super Magro" biofertilizer = 1.64 MJ L^{-1} (Quadros & Kokuszka, 2007); limestone = 0.167 MJ kg^{-1} (Macedo et al., 2004); gypsum = 0.167 MJ kg^{-1} (Macedo et al., 2004); micronutrients in general = 6.32 MJ kg^{-1} (Souza, et al., 2008); diesel = 43.93 MJ L-1 (Comitre, 1993); lubricants = 35.94 MJ L^{-1} (Comitre, 1993); grease = 49.22 MJ L^{-1} (Comitre, 1993); rice seeds = 34.78 MJ kg^{-1} (Miranda & Marchioro, 1985); tractors or self-propelled machinery = 69.83 MJ kg^{-1} (Macedônio & Picchioni, 1985); self-propelled harvesters = 69.87 MJ kg^{-1} (Macedônio & Picchioni, 1985); and pull-type implements = 57.2 MJ kg^{-1} (Macedônio & Picchioni, 1985). Lubricant consumption was considered to be 1.5% of the diesel consumption and grease to be 33% of the lubricant consumption. An energy coefficient was established for the maintenance of TMI, corresponding to 5% of the energy used to manufacture them.

Energy depreciation (ED) in MJ ha^{-1} year^{-1} and the secondary tractor, machinery, and agricultural implement energy were calculated following the equation used by Costabeber (1989):

$$ED = ((M - 10\% \cdot M) / L) \cdot ut \cdot EC$$

where M = mass of the tractor or agricultural implement in kg; L = lifespan of the tractor or agricultural implement in hours; ut = usage time in hours; and EC = energy coefficient of the analyzed tractor, machine, or agricultural implement (MJ ha^{-1} $year^{-1}$). The masses of TMI were obtained using the manufacturers' catalogs. Lifespan was obtained using CONAB's data (Companhia Nacional de Abastecimento [CONAB], 2010).

Organic rice fields did not undergo the application of herbicides and pesticides for pest and disease control; thus, the energy expenditure of these inputs was not considered. However, for the conventional rice fields, the energy coefficients of herbicides, insecticides, and fungicides were estimated using the literature (Pimentel, 1980). These energy expenditure inputs were calculated according to their formulas and expressed as MJ kg^{-1} or L^{-1} of the active ingredient, respectively, for herbicides and agricultural pesticides used for pest and disease control: dispersible concentrate (418.30, 363.87, and 271.76); soluble powder (262.80, 311.07, and 116.27); granulate (362.58, 311.07, and 216.04); and wettable powder (347.89, 257.36, and 216.04).

Energy consumption by agricultural operations (soil neutralization, planting, internal transport, application of herbicides and pesticides, and harvest) was calculated using the fuel consumption by the tractor+implement set (L h^{-1}) or the used machinery together with their operational performance (ha h^{-1}). The ratio of fuel consumption (L h^{-1}) to performance (ha h^{-1}) was used to obtain the fuel consumption per area (L ha^{-1}), which was then multiplied by the diesel's calorific value (43.93 MJ L^{-1}) to obtain the fuel energy expenditure in MJ ha^{-1}.

Several correction factors were used to calculate fuel consumption (diesel) for grain transportation and transshipment, water transportation, and tillage. The ratio of fuel consumption to useful load capacity (grains and water) per hectare was used for transportation operations. For example, if a tractor+water tank set consumes 10 L of diesel to transport 2,000 L of water and the pesticide spray volume to be used is 200 L ha^{-1}, then the 10 L of diesel spent to transport water was used for 10 hectares, and the diesel consumption in this operation is equal to 1 L ha^{-1}. The diesel and limestone consumption values for tillage and soil neutralization were divided by the residual effect time in years that the performed management operation may keep providing benefits to the soil.

The following operations were performed in the rice fields: a) plowing, b) heavy harrowing, c) harrowing, d) rotary hoeing, e) leveling and its maintenance, f) liming, g) application of synthetic and organic fertilizers, h) mudding in, i) soil smoothing, j) seeding, k) top dressing, l) manual weeding or mowing, m) irrigation, n) application of herbicides and pesticides, o) harvest, p) transshipment, and q) transporting to the warehouse.

The number of labor hours, the total diesel consumed to perform all the operations, and the amount of fertilizer and seeds used are described below in Tables 2 and 3.

Table 2
Inputs used in the evaluated fields

City/ State	Seeds	Organic Fertilizer	Limestone	Fuel	Labor
	---------- kg ha^{-1} $year^{-1}$ ----------			L ha^{-1} $year^{-1}$	h ha^{-1} $year^{-1}$
------------------------------- Organic rice -----------------------------					
Meleiro-SC	150	400 ^{N}	375	66.2	34.5
São João do Sul-SC	175	500 ^{N}	600	59.6	20.0
Praia Grande-SC	150	2,500 ^{C} + 400 ^{N}	1,000	104.7	16.6
Araranguá-SC	170	4,000 ^{C}	-	120.7	20.1
------------------------------ Conventional rice ---------------------------					
EPAGRI-SC	109	-	0	129	22
IRGA-RS	105	-	0	127	9
Pelotas - RS	87	-	0	102	12
Uruguaiana - RS	87	-	0	115	11

^{C} - Poultry litter; ^{N} - Granular organo-mineral fertilizer GOMF.

Table 3
Amount of macronutrients applied in the evaluated conventional rice fields

City / State	N	*P_2O_5	*K_2O
	--- kg ha^{-1} $year^{-1}$ ---		
	--- Conventional rice ---		
EPAGRI-SC	90	50	50
IRGA-RS	105	60	90
Pelotas - RS	109	60	90
Uruguaiana - RS	96	60	90

* To convert the amount of P_2O5 and K_2O applied to P and K, please multiply by the 0.436 and 0.830 indices, respectively.

To standardize the energy output as grains calculation, a moisture content of 13% for rice grains was used, with an energy/grains conversion rate of 21.80 MJ kg^{-1} (Pimentel, 1980; Costabeber, 1989). The total energy production per hectare was obtained by multiplying this energy coefficient by the rice productivity as kg ha^{-1}. The crop residues left in the field after harvesting was not considered in the outputs because they are reincorporated in the system (Capellesso & Cazella, 2013).

EE was calculated using the ratio of the amount of energy produced (MJ ha^{-1}) to the amount of energy consumed (MJ ha^{-1}) in each rice production unit. The energy balance was calculated by subtracting the consumed energy (MJ ha^{-1}) from the produced energy (MJ ha^{-1}) (Santos, Fontaneli, Spera, & Dreon, 2013).

One way to estimate the contribution of grain production to GHG emissions is to convert the consumption of fossil energy to its CO_2 equivalent using standard GHG emission values in the literature (Macedo et al., 2004; Soares, Alves, Boddey, & Urquiaga, 2009).

Therefore, the total GHG emissions as kg of CO_2eq per hectare per year (kg CO_2eq ha^{-1} $year^{-1}$) were estimated using the calculated energy expenditure for organic rice fields. The following GHG emission factors were considered:

1) According to Soares et al. (2009), the energy used to produce herbicides, insecticides, and seeds comes from various sources. Therefore, the conversion from MJ to CO_2eq is used, assuming the petroleum emission factors provided by the Painel Intergovernamental sobre Mudanças Climáticas [IPCC], (2006). According to the IPCC (2006), the combusted petroleum required to produce 1 GJ of energy also produces 73.3 kg of CO_2, 0.003 kg of CH_4, and 0.00006 kg of N_2O.
2) The energy embedded in agricultural machinery is counted in the same manner as that used for steel production, i.e., provided by coal. According to the IPCC (2006), 1 GJ of energy produced by coal emits 94.6 kg of CO_2, 0.001 kg of CH_4, and 0.0015 kg of N_2O.
3) The energy produced by the diesel used as fuel by tractors and agricultural machinery is also converted to GHG, according to the IPCC (2006). Each 1 GJ provided by diesel emits 74.1 kg of CO_2, 0.003 kg of CH_4, and 0.00006 kg of N_2O.
4) The emission by liming with dolomitic limestone was considered to be 0.13 t of C-CO_2 per ton of limestone applied to the soil, according to the standard emission values indicated by the IPCC (2006).
5) The GHG emissions during fertilizer manufacturing, packing, and transportation were estimated using the amount of energy spent during the production and transportation stages (GJ kg^{-1}) and the amount of gases emitted by the main energy source (natural gas) used in the production (kg CO_2eq GJ^{-1}) (Nardi, Barbosa, Fioravante, Câmara, & Silveira, 2004; Soares et al., 2009). The following data from Gellings & Parmenter (2004) were considered for this purpose: the amount of energy required to produce, pack, and transport nitrogen, phosphate, and potassium fertilizers was 0.077, 0.016, and 0.013 GJ kg^{-1}, respectively. According to the IPCC (2006), every 1 GJ of energy from natural gas results in the emission of 56.1 kg of CO_2, 0.001 kg of CH_4, and 0.0001 kg of N_2O. It is possible to estimate, based on previously published data, that the production, packing, and transportation of nitrogen, phosphate, and potassium fertilizers in modern factories operating with natural gas emit, respectively, 4.32, 0.90, and 0.73 kg of CO_2eq per kg of fertilizer produced. Furthermore, it was important to consider the IPCC (2006) emission factor indicating that 0.3% of the N applied to the soil in conventional rice fields directly emits as N_2O.

Descriptive statistics of all the results were used for the eight evaluated rice fields to obtain the means and standard deviations.

Results and Discussion

Mean EE values of 10.5 and 7.97 were found for organic and conventional rice, respectively (Table 4). Because the average productivity used in the calculations of the energy produced in organic rice (Table 1) was within the regional average estimated by the EPAGRI and because the registered operations and inputs are commonly used in organic rice management, it is possible to conclude that the mean EE value (10.5) provides a good baseline for the crop's energy sustainability that can be compared with values from future studies. The mean EE found in irrigated rice fields in this study (7.90), however, was lower than the value of 12.12 reported by Ferreira et al. (2014) after evaluating two irrigated rice fields (mixed system) during the 2007 and 2008 harvests in the state of Rio Grande do Sul, Brazil. The main reason for this difference between the EE values found in this study and those found by Ferreira et al. (2014) was the productivity value used to calculate the produced energy, i.e., Ferreira's study used a higher rice productivity value (12,699.6 kg ha^{-1}), about 59.4% and 43.4% greater than the respective values used in this study and in CONAB's (Companhia Nacional de Abastecimento [CONAB], 2015) national average.

Table 4
Energy efficiency (EE) of the evaluated organic and conventional rice fields

Fields	------- EE -------
	-- Organic rice --
Meleiro-SC	13.3
São João do Sul-SC	10.4
Praia Grande-SC	8.5
Araranguá-SC	9.7
Mean	10.5
	- Conventional rice -
EPAGRI-SC	8.1
IRGA-RS	7.8
Pelotas - RS	7.6
Uruguaiana - RS	8.2
Mean	7.9

Based on these facts, it is possible to infer that the EE results found in this study better reflect the energy sustainability of Brazilian irrigated rice because we assessed a larger number of fields in two producing regions and because the recorded productivities were closer to the actual Brazilian values for the 2014/2015 harvest (CONAB, 2015).

Because of the lack of EE data for Brazilian organic rice to conduct a literature comparison, a comparison was performed using the EE results from this study and those from conventional rice fields, which were also assessed in this study. The mean EE value (10.5) for deepwater organic rice in this study was 24% greater than the mean EE found in conventional rice fields, and it was close to the value calculated by Gundogmus and Bayramoglu (2006), who found a 23% higher EE in the organic system. Pirdashti, Pirdashti, Mohammadi, Baigi and Movagharnejad (2015) assessed the EE of organic and conventional rice crops in Mazandaran, a province in the northern Iranian region along the Caspian Sea, and found EE values of 1.48 for the organic system and 1.19 for the conventional system.

A significant part of the organic rice energy economy comes from the practice of not using synthetic fertilizers and pesticides to control weeds, pests, and diseases, as a large amount of fossil energy is consumed during the production of these products (Pimentel, 1980). Regarding the energy savings in both systems (organic x conventional), the simple substitution of synthetic fertilizers with organic fertilizers and pesticides (herbicides, insecticides, and fungicides) used in the management practices for deepwater organic rice provides a 48% total energy savings during production. Based on this comparison, even though organic rice is less productive (5,000.0 kg ha^{-1}) than conventional deepwater rice (7,240.0 kg ha^{-1}), it has a higher EE because it requires less input energy early in its production cycle.

In this study, the highest energetic expenditure values for deepwater organic rice were for seeds (46.27%), fuel (36.48%), and TMI (5.82%) (Figure 1). For conventional rice, 81.79% of the expenditure was for synthetic fertilizers (40.74%), fuel (24.91%), and seeds (16.14%) (Figure 1). Similar results were reported by Ferreira et al.

(2014), who also found that the highest energy expenditures for irrigated rice were for fertilizers (40.71%), fuel (28.31%), and seed (19.30%). Based on these results, it is clear that unlike conventional rice fields where the greatest energy expenditure is accounted for by fertilizers (40.71%) (Ferreira et al., 2014), for organic rice, seed consumption is its greatest bottleneck. It is also evident that seeds are the third greatest energy expenditure among all the energy required for production, even in deepwater conventional rice (16.14%) (Ferreira et al., 2014).

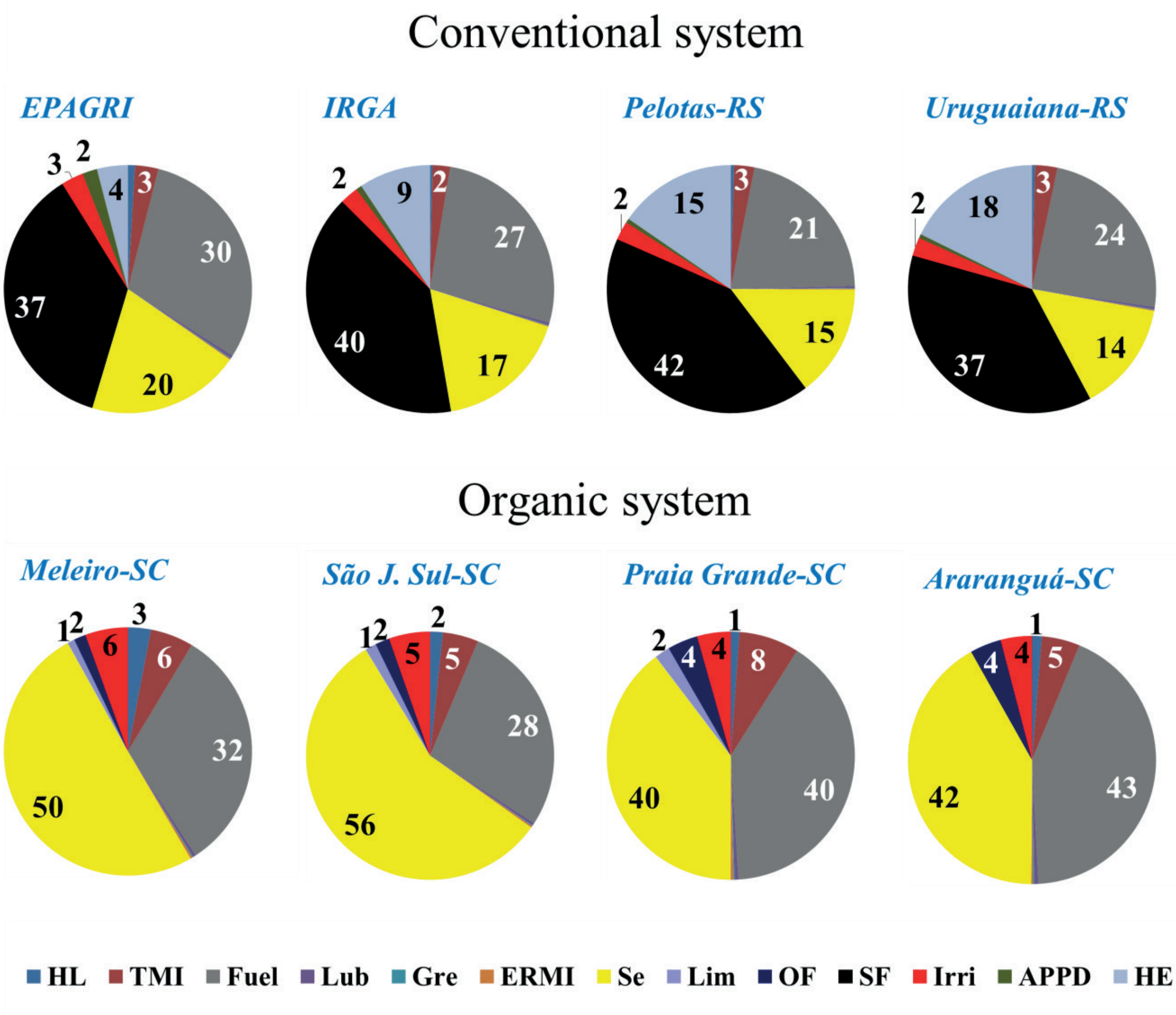

Figure 1. Percentage of the main energy expenditures evaluated as human labor (HL); tractors, machinery, and agricultural implements (TMI); fuel (Fuel); lubricants (Lub); grease (Gre); energy spent in the maintenance of tractors, machinery, and agricultural implements (ERMI); seeds (Se); limestone (Lim); organic fertilizers (OF); synthetic fertilizers (SF); irrigation (Irri); and agricultural pesticides to control pests and diseases (APPD). Energy consumption values less than 1% were not included in the figure for visualization purposes. Total respective produced and consumed energy values for each field (MJ ha-1) = EPAGRI (154,780.00 and 18,983.18); IRGA (164,295.70 and 20,947.77); Pelotas-RS (158,486.00 and 20,766.64); Uruguaiana-RS (174,400.00 and 21,105.59); Meleiro-SC (119,900.00 and 9,041.00); São João do Sul-SC (98,100.00 and 9,401.20); Praia Grande-SC (98,100.00 and 11,488.00); and Araranguá-SC (119,900.00 and 12,360.10).

There was a high proportion of energy consumed by seeds associated with the large amount of energy per kg of seeds (34.78 MJ kg^{-1}) because seed production requires higher inputs than grain production. A significantly higher quality is required for seed production, which involves the thorough control of pests and diseases, red rice elimination (rouging), processing, classification, and packing (Mourad & Walter, 2011; Riquetti, 2014). Therefore, technologies that can significantly improve operational efficiency during seed production will help to increase the EE of deepwater organic rice.

The second highest energy expenditure found in organic and conventional rice fields in this study was for fuel. One method to reduce this energy expenditure is to increase the efficiency of diesel engines used in tractors, harvesters, and trucks to consume less fuel per labor hour and hectare. Another method to reduce energy expenditure is to reduce the number of agricultural operations by integrating activities.

The third highest energy expenditure found in this study was for TMI because of the high degree of mechanization involved in deepwater organic rice field production, mainly during tillage before seeding. Furthermore, the practice of mechanized crop management (mowing) to reduce or eliminate the use of herbicides and pesticides to control pests and diseases makes a significant contribution to the total energy expenditure. Hence, the small increase in energy consumption with mechanization results in a large savings regarding agricultural pesticides.

The mean emission factors for GHG emissions by the assessed organic and conventional rice fields were 0.22 and 0.32 kg de CO_2eq kg^{-1}, respectively (Table 5). Similar to the EE variable, there is also a lack of mean emission factor results for Brazilian deepwater organic rice fields in the literature. Therefore, the same comparison was performed with the conventional rice fields assessed in this study. This comparison revealed that the emission factor of the organic rice fields assessed in this study (0.25) was 34% below that found in conventional rice fields (0.32). The lower emissions observed in the organic system are attributed to the practice of not using synthetic fertilizers, herbicides, insecticides, and fungicides, which are large emission sources in deepwater conventional rice production. Notably, although the conventional system produces more with these inputs, there was not sufficient productivity to result in higher EE and lower GHG emission values than those obtained in deepwater organic rice production (Tables 4 and 5).

Table 5
Ratio between kg of CO_2eq emitted per hectare and grain productivity (kg ha^{-1} $year^{-1}$) (FE) in the studied fields

Areas	------- FE ------- (Kg CO_2eq/kg of grains)
	-- Organic rice --
Meleiro-SC	0.14
São João do Sul-SC	0.19
Praia Grande-SC	0.29
Araranguá-SC	0.24
Mean	0.22
	- Conventional rice -
EPAGRI-SC	0.31
IRGA-RS	0.32
Pelotas - RS	0.33
Uruguaiana - RS	0.30
Mean	0.32

In this study, the main CO_2eq emitters in deepwater organic rice fields were seeds (34.19%), fuel (27.25%), organic fertilizers (21.07%), and TMI (10.14%) (Figure 2). In deepwater conventional rice fields, the main CO_2eq emitters were nitrogen fertilizers (46.53%), fuel (15.85%), phosphate fertilizers (11.27%), and seeds (10.15%) (Figure 2). Nunes (2015) reported similar results and noted that the highest CO2eq emitters in deepwater rice fields were nitrogen fertilizers, phosphate fertilizers, fuel, and seeds. Notably, seeds and fuel were the highest CO_2eq emitters for organic rice (Figure 2).

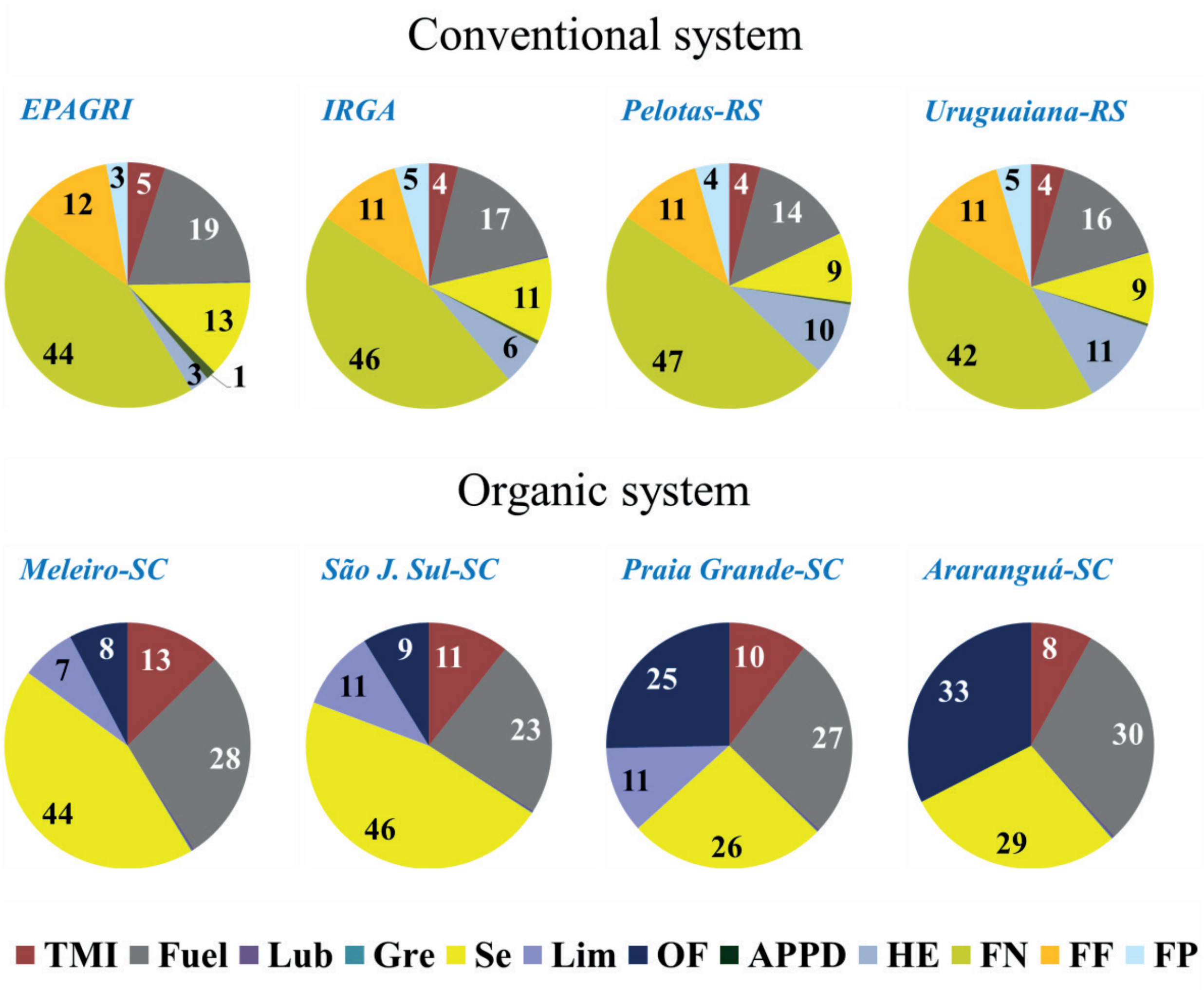

Figure 2. Percentage of the CO2eq in the evaluated areas emitted from human labor (HL); tractors, machinery, and agricultural implements (TMI); fuel (Fuel); lubricants (Lub); grease (Gre); energy spent in the maintenance of tractors, machinery, and agricultural implements (ERMI); seeds (Se); limestone (Lim); organic fertilizers (OF); irrigation (Irri); and agricultural pesticides to control pests and diseases (APPD). Emission values less than 1% were not included in the figure for visualization purposes. Respective grain productivity (kg ha^{-1} $year^{-1}$) and CO2eq emission values for each field: EPAGRI (7,100 and 2,176.47); IRGA (7,536 and 2,422.96); Pelotas-RS (7,270 and 2,434.55); Uruguaiana-RS (8,000 and 2,382.40); Meleiro-SC (5,500 and 763.51); São João do Sul-SC (4,500 and 838.20); Praia Grande-SC (4,500 and 1,286.62); and Araranguá-SC (5,500 and 1,311.44).

The significant emission contributions by seeds, fuel, and TMI are the result of the high energy expenditures (Figure 1) of these sources during the production stages of organic and conventional rice, and there is the possibility of reducing these expenditures using the previously discussed methods for reducing EE.

For organic rice, the source of emission from organic fertilizers was considered in their manufacturing, storage, transportation, and post-application. One method to mitigate such emissions is to apply a dosage to fulfill the nutritional needs of organic rice through fertilization using organic residues from the property or nearby regions, without any excess. With these measures, the fact that organic fertilization replaces synthetic fertilizers reduces GHG emissions compared with those from deepwater conventional rice production. Based on the results of this study and compared with the deepwater conventional rice fields, replacing synthetic fertilizers with organic fertilizers results in an 85% reduction in GHG emissions.

In addition to the amount applied, the higher emissions by synthetic fertilizers in rice fields may be attributed to the process used in their production, packing, and transportation, which emits 4.32 and 0.90 kg of CO_2eq per kg of nitrogen and phosphate fertilizer, respectively, before reaching the agricultural property. Therefore, the development and/or consolidation of technologies to replace these synthetic fertilizers with other sources of phosphorus, potassium, and nitrogen may be the best methods to mitigate GHG emissions into the atmosphere under upland or irrigated crop management. Brodt et al. (2014) also highlighted this point in their study, where fertilizer manufacturing and logistics accounted for 19.31% of deepwater rice emissions.

Conclusions

Each 1.0 MJ consumed in organic and conventional deepwater rice production resulted in respective renewable energy averages of 10.5 and 7.9 MJ as grains. The principal energy expenditures for organic crops were for seeds, fuel, and TMI, while fertilizers, fuel, and seeds were the major expenditures for the conventional system.

Each kg of rice grain produced under the organic and conventional systems accounted for the emission of 0.22 and 0.32 kg of CO_2eq, respectively, through their production cycle and delivery to the warehouse. The main CO_2eq emission sources were seeds, fuel, and organic fertilizers in the organic system and nitrogen fertilizers, phosphate fertilizers, fuel, and seeds in the conventional system.

Organic deepwater rice crop is more efficient than the conventional system and produces approximately 24% (2.6 MJ) more renewable energy as grains for each energy unit consumed during production than that obtained with the conventional system.

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