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Proceeding Paper

Life Cycle Assessment of an Alternative Water Management to Reduce the Environmental Impact of Italian Rice Cultivation †

Jacopo Bacenetti [1], Livia Paleari [2], Roberto Confalonieri [3] and Michele Zoli [4,*]

[1] Affiliation 1; jacopo.bacenetti@unimi.it
[2] Affiliation 2; livia.paleari@unimi.it
[3] Affiliation 3; roberto.confalonieri@unimi.it
[4] Affiliation 4
* michele.zoli@unimi.it

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Abstract: Italy is the most important European country in terms of rice production. However, Italian rice cultivation is one of the cultivation system with the highest environmental impact. Italian climatic condition led to a traditional rice cultivation characterized by continuous flooding, causing huge emissions of methane as a result of the degradation of organic matter in anaerobiosis. Previously studies reported that emissions of methane account for 45–55% of environmental impact in terms of global warming. The aim of this study is to evaluated an alternative water management, characterized by an additional aeration period, in order to reduce methane emissions and global warming of rice systems. To this purpose, field trials were carried out for two consecutive years in northern Italy, Life Cycle Assessment approach was applied with a from cradle-to-gate perspective and 1 ton of rice grain at commercial moisture was chosen as functional unit. The results confirm that methane emissions are responsible for 50% of the global warming. Furthermore, alternative water management reduced global warming by 12% and 11%, without affecting yield and other impact categories analyzed.

Keywords: rice cultivation; environmental impact; life cycle assessment; sustainability

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1. Introduction

Rice cultivation, with about 220,00 hectares on the national territory, represents one of the most important Italian agro-food sectors. Lomellina (45°19′00″ N, 8°52′00″ E) together with the Provinces of Novara and Vercelli is the most important rice production area in Europe. In this area rice represents the main annual crop and the main revenues source for farmers [1]. Nevertheless, Italian climatic condition led to a traditional cultivation characterized by continuous flooding, causing huge emissions of methane into the atmosphere. In this regard, the emissions are the net result of anaerobic decomposition of organic matter in the soil [2]. For this reason, Italian rice production is one of the crop with the highest environmental impact. The highest methane emissions occur with long and continuous submersions, with abundant application of organic fertilizer and with the burial of the straw [3]. In detail, a previously Italian study [4] reported that methane emissions account for 40–55% of environmental impact in terms of carbon footprint, for rice production. In others non-European countries methane emissions are responsible for an even greater share (up to 65%) of the impact [5–7]. However, alternative irrigation systems that limit the presence of a permanent water layer in the field can allow the diffusion of $O2$ into the soil, thus mitigating the production of CH_4 [8]. Despite an extreme specialization in rice farmers as regards crop management aimed at maximizing yields, there remains a limited knowledge of the beneficial effects which, in terms of reducing of GHG emissions, can be obtained through different water management. This study aims to evaluate an alternative water management, characterized by an addition aeration period, to reduce emissions of methane and the carbon footprint of rice cultivation in Lomellina (and also in all the rice-growing districts of northern Italy), without affecting the production (yield). To this purpose, Life Cycle Assessment (LCA) approach was applied to quantify the environmental benefits related to the adoption of the different flooding management.

2. Materials and Methods

2.1. Experimental Scheme

During 2020 and 2021 agricultural seasons, experimental trials were conducted in a rice farm in Lomellina. For each year, Caravaggio variety was grown in two adjacent fields characterized by chemical-physical characteristics as similar as possible, with the same cultivation practice, varying only for water management. More in detail: in one field, traditional water management, commonly performed by the farmer, was applied (baseline scenario, BS); in the other field, an alternative water management characterized by the addition of an aeration period of 7 days was applied (alternative scenario). This period must be placed during the phenological stage of stem elongation, but it must be interrupted before booting to avoid the spikelet sterility due to sudden drops in temperature.

2.2. Life Cycle Assessment

2.2.1. Goal and Scope Definition

LCA is an ISO standardized method [9] and it is the most widely used approach for assessing the environmental impact of a product or a process. This methodology allows to convert the amount of production factors consumed and the substances emitted into environment into some impact indicators (categories). The goal of this LCA study is to compare the two different water management systems described above from an environmental point of view. In particular, the application of LCA methodology allows to quantify the potential environmental benefits related to the adoption of the alternative water management. For the application of LCA, in this study, 1 ton of rice grains at the commercial moisture was selected as functional unite (FU).

2.2.2. System Boundaries

"System boundaries" indicates the boundaries of an LCA study to specify if a step of the life cycle is included in the study or not; in this study, for the definition of the system boundaries, the "from cradle to farm gate" approach was applied. Therefore, all the operations from the extraction of raw materials to the drying of the paddy rice were considered (Figure 1). More in detail, the following operations were included in the study: (I) extraction of raw materials (e.g., fossil fuel, metals and minerals); (II) manufacture, maintenance and disposal of capital good (e.g., tractors, agricultural machinery, she and dryer for cereals); (III) production of the different inputs (fertilizers, pesticides, electricity, diesel, etc.); (IV) emissions related to the use of input factors (e.g., emissions due to the application of fertilizers, diesel emissions due to the combustion in the tractor engine). The emission sources refer to the emissions of nitrogen and phosphate compounds mainly related to fertilization, to methane emissions due to the degradation of organic matter under anaerobic conditions and to pollutant emissions due to the combustion of fuels in agricultural machinery engines.

2.2.3. Inventory Analysis

Two different types of inventory data were used: primary data, directly collected in the farm during experimental tests and field surveys, and secondary data, obtained from databases for LCA studies (e.g., Ecoinvent®), scientific literature or estimated using specific models. Information regarding the cultivation technique (sequence of operations, timing, working time, characteristics of tractors and agricultural machinery, production factors used and their quantities) were collected with direct interviews with farmer (Table 1). The yield was also measured by means of the farm weighbridge (Table 1).

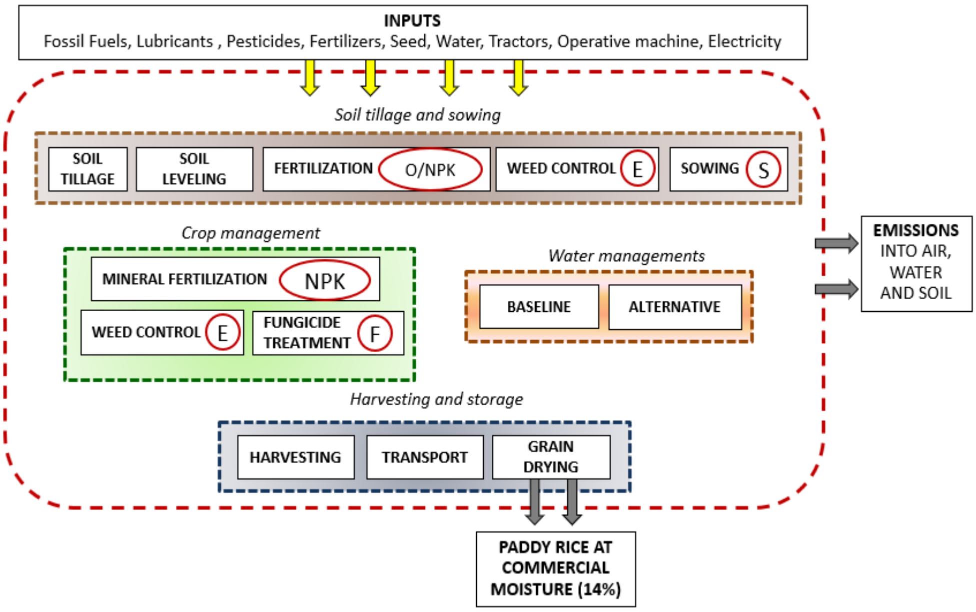

Figure 1. System boundaries. O: organic fertilizer; NPK: mineral fertilizer; H: herbicide; S: seed; F: fungicide.

Table 1. Grain yield at commercial moisture (14%).

	Scenario	Grain Yield ($t{\cdot}ha^{-1}$)	Δ%
2020	BS-20	6.38	
	AS-20	6.58	+3.1%
2021	BS-21	5.61	
	AS-21	5.78	+3%

Methane emissions were estimated using the emission factors and the methodology proposed by the IPCC [2]. The default methane emission factor (1.30 kg $CH_4{\cdot}ha^{-1}{\cdot}day^{-1}$) was used and scaled using a scaling factor for: (i) water regime before and during cultivation, (ii) the number of aeration periods, (iii) the application of organic matter into the soil (organic fertilizer and straw); (iv) the timing of straw incorporation; (v) the duration of flooding. The methane emissions of different scenarios are reported in Table 2.

Table 2. Methane emissions during rice cultivation.

	Scenario	CH_4 Emissions	Δ%
2020	BS-20	101.2	
	AS-20	85.98	−15%
2021	BS-21	109.97	
	AS-21	96.33	−12%

Nitrogen emissions (nitrate leaching, ammonia volatilization, and nitrous oxide emissions in atmosphere), phosphate emission and pesticide emissions were estimate using different specific models. Also diesel fuel consumption was estimated considering the power requirements by the operative machines, their effective field capacity, and the soil characteristics. Background data regarding the production of the different inputs used were retrieved from the Ecoinvent database v3.6 [10,11].

2.2.4. Impact Assessment

The conversion of inventory data into potential environmental impacts was calculated with the ReCiPe 2016 method and by means of the Simapro v 9.1.1 software. Different impact categories (environmental effects) were analysed: global warming (GW), stratospheric ozone depletion (OD), ozone formation-human health (OF-hh), fine particulate matter formation (PM), ozone formation-terrestrial ecosystems (OF-te), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial ecotoxicity (TEx), freshwater ecotoxicity (FEx), marine ecotoxicity (Mex), human carcinogenic toxicity (HT-c), human non-carcinogenic toxicity (HT-noc), mineral resource scarcity (MRS), fossil resource scarcity (FRS).

3. Results and Discussion

3.1. Contribution Analysis

Contribution analysis allows to identify the relative contribution to the total impact of the different sub-processes, production factors or emissions that characterize the analyzed process. In this way, for each impact category, it is possible to identify the main responsible for the impact (hotspot). The results of this analysis are similar for all the cases. In fact, there are no relevant differences between baseline and alternative scenarios; this means that water management does not influence the relative share of impact of different inputs and the results shown in Figure 2 (BS-21) are representative for all scenarios considered. As expected, methane emissions are the main responsible of the global warming of rice cultivation and represent half of the impact (50%); this is in line with other studies focusing on global warming of paddy rice production [5,7]). The emissions associated with the fertilizers application (nitrate leaching, nitrous oxide production, ammonia volatilization and phosphorus run-off) affect several categories: dinitrogen monoxide affects GW (18%) and OD (95% of the total impact); ammonia emissions contribute to 78% of fine particulate matter formation and to 91% of terrestrial acidification, while nitrate is the main cause of ME (98%); phosphate is important only for FE (37%). Paddy drying process has a relevant impact on TEx (44%), FRS (23% and HT-c (19%) because it was consider a diesel drying, whereas mechanization of field operation affects OF-hh (52%), HT-noc (49%) and MRS (46%). Fertilizers production, which is a very energy-intensive process, has a deep impact on MEx (46%), FRS (38%), HT-c (38%) and HT-noc (31%). Finally, the impact share of seed and pesticides production never exceeds 10% with the exception of MRS (20%) and pesticide emissions have an important impact only in FEx (51%).

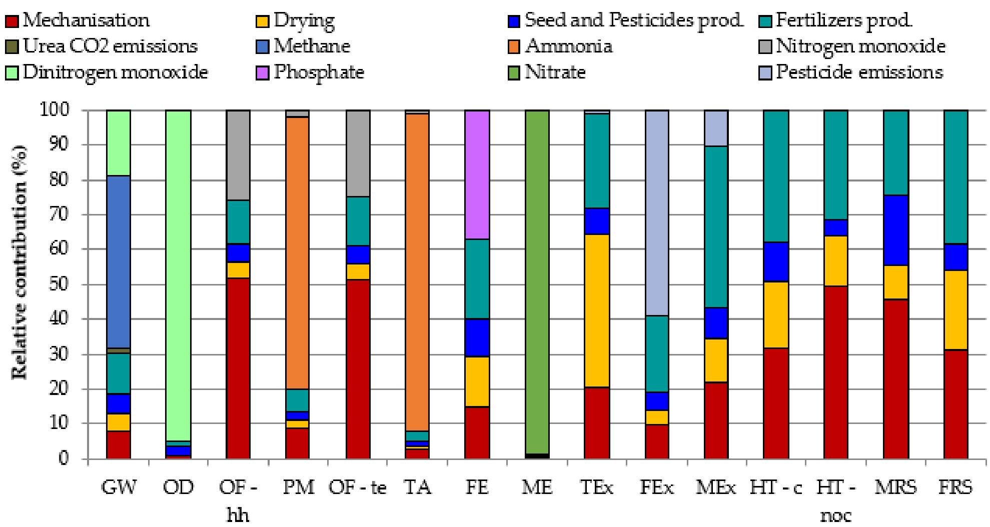

Figure 2. Relative contributions to the overall environmental impact for rice cultivation in the BS-21 scenario.

3.2. Environmental Impacts

Table 3 reports the results of the environmental impacts in absolute terms per ton of paddy rice at commercial moisture of the two scenarios analysed in 2020 and 2021. For each category, considering both years, higher values are highlighted in red; for progressively lower impacts, it goes to orange-yellow and then green. In this way it is easy to note that AS-20 is the best environmental scenario in all impact categories. From the relative comparison between the baseline and alternative scenarios of the two years, it emerges that the application of alternative water management has led to an improvement in environmental performances. Indeed, the reduction in methane emissions reduced global warming by 12% in 2020 and by 11% in 2021. It is important to note that the other impact categories also decreased in the two ASs. These variations are mainly due to yield. In both years, the alternative scenario shows a slightly higher yield (+3.1% and +3%) and this determines an improvement in environmental performance since BS and AS had the same cultivation practice; therefore, the production factors consumed are amortized over a greater quantity of product thanks to a greater efficiency of the entire process. Moreover, the impact of terrestrial ecotoxicity (TEx) decreased more than the other impact categories. TEx is influenced by the drying of paddy rice. This process requires a large amount of diesel and it is affected by moisture at paddy harvester. Since in the BSs the paddy rice had a higher humidity (20.5% in BS-20 and 21% in BS-21) than the ASs (17.5% in AS-20 and 19.5% in AS-21), in the latter the drying process has a lower impact.

Table 3. Potential environmental impact for all scenarios evaluated.

		2020			2021		
Impact category	**Unit**	**BS-20**	**AS-20**	**Δ%**	**BS-21**	**AS-21**	**Δ%**
GW	kg CO2 eq	1053	924	−12%	1342	1192	−11%
OD	kg CFC11 eq	0.007	0.007	−5%	0.010	0.009	−3%
OF-hh	kg NOx eq	1.56	1.50	−4%	1.95	1.85	−5%
PM	kg PM2.5 eq	2.14	2.04	−5%	2.83	2.74	−3%
OF-te	kg NOx eq	1.61	1.54	−4%	2.00	1.90	−5%
TA	kg SO2 eq	14.92	14.25	−5%	19.82	19.25	−3%
FE	kg P eq	0.15	0.14	−7%	0.18	0.16	−10%
ME	kg N eq	2.53	2.42	−4%	3.33	3.25	−2%
TEx	kg 1,4-DCB	1271	1093	−14%	1468	1132	−23%
FEx	kg 1,4-DCB	7.84	7.40	−6%	21.50	20.44	−5%
Mex	kg 1,4-DCB	9.26	8.61	−7%	13.64	12.46	−9%
HT-c	kg 1,4-DCB	12.05	11.05	−8%	15.47	13.67	−12%
HT-noc	kg 1,4-DCB	276.97	257.70	−7%	349.82	316.71	−9%
MRS	kg Cu eq	1.40	1.32	−6%	1.73	1.60	−8%
FRS	kg oil eq	85.27	77.36	−9%	108.69	94.33	−13%

4. Conclusions

Although only one experimental site is analysed in this study, the results show that the addition of an aeration period is an effective strategy to mitigate the global warming of rice cultivation, without compromising yield production. Despite it is not always possible to compare different LCA studies due to different cultivation techniques, system boundaries, functional units, etc., the carbon footprint of the rice production analyzed in this work is in line with previously studies [4,12,13]. Considering the results of this study and the area dedicated to rice both in Lomellina and in Italy, it's important to highlight that a reduction in methane emissions, the main cause of the global warming of rice cultivation, can reduce the environmental impact of this important production system. Studies conducted in other countries [7,13] reported how specific strategies for water management are able to reduce the carbon footprint of paddy rice production by 15–20%, without any reduction of yield and this study confirm the trend. The environmental sustainability of agri-food sectors is a topic that affects both the agricultural production system and related supply chains. Since there is a growing consumer attention for environmental sustainable production and the carbon footprint is increasingly an attribute that the consumer knows and is willing to pay, reducing global warming of rice cultivation could also increase the profitability of production by increasing the value of the rice produced.

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement:

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