




Proceeding Paper

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

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Abstract: Italy is the most important European country in terms of rice production. Nevertheless, rice farming in Italy is one of the crop systems with the highest impact on the environment. The main peculiarity of the rice cultivation practice is field water management: in fact, rice is cultivated keeping the soil submerged and in an anaerobic state. Under these conditions, organic matter degradation causes large methane emissions into the atmosphere. Previous studies show that methane emissions causes about 50% of climate change of rice production. This study reports the biennial results of the BESTsomRICE project in which the environmental performance of an alternative water management, characterized by an aeration period of the field during the cultivation, was evaluated. For this purpose, field trials were carried out for two consecutive years in northern Italy, a 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 the functional unit. The results confirm that methane emissions are responsible for 50% of global warming. Furthermore, alternative water management reduced global warming by 12% and 11% without affecting yield or the other impact categories analyzed.

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



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1. Introduction

Italy, with about 227,000 hectares on the national territory, is the largest rice producer in Europe and, in particular, Lomellina (45°19'00" N, 8°52'00" E) is the most important rice growing area. Nevertheless, the main peculiarity of the Italian rice cultivation practice is field water management: in fact, rice is cultivated keeping the soil submerged and in an anaerobic state. Under this condition, organic matter degradation causes large methane emissions into the atmosphere [1]. Long and continuous flooding, the application of organic fertilizers, and the burial of the straw lead to the highest methane emissions [2]. In detail, previous studies [3] reported that methane emissions are the main contributor to the carbon footprint of rice production and those represent about 50% of this environmental impact. Furthermore, in other countries, the share of impact related to methane emissions is even higher (up to 65%) [4,5]. However, several studies [6,7] report that practices that promote soil aeration can reduce methane emissions. Despite an extreme specialization in rice farmers as regards crop management aimed at maximizing yields, there remains limited knowledge of the beneficial effects which, in terms of reducing GHG emissions, can be obtained through different water management. This study aims to evaluate an

alternative method of water management characterized by an additional 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, a 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 the 2020 and 2021 agricultural seasons, experimental trials with Caravaggio variety were conducted on a rice farm in Lomellina. For each year, two adjacent fields were identified in which rice was grown with the same cultivation operations, the same input, but different water management. In particular, 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, during stem elongation stage, was applied (alternative scenario, AS).

2.2. Life Cycle Assessment

2.2.1. Goal and Scope Definition

LCA is an ISO standardized method [8], and it is the most widely used approach for assessing the environmental impact of a product or a process. This methodology allows the number of production factors consumed and the substances emitted into the environment to be converted 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 the LCA methodology allows the potential environmental benefits related to the adoption of the alternative method of water management to be quantified. For the application of LCA, in this study, 1 ton of rice grains at commercial moisture was selected as the functional unit (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 specifically, the following operations were included in the study: raw materials extraction (e.g., fossil fuel, metals and minerals); manufacture and input production (e.g., agricultural machines, fertilizers, pesticides, electricity, diesel); 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); use, maintenance and final disposal of machines;. The emission sources refer to the emissions of nitrogen and phosphate compounds mainly related to fertilization, methane emissions due to the degradation of organic matter under anaerobic conditions and 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 on 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 through direct interviews with the farmer (Table 1). The yield was also measured by means of the farm weighbridge (Table 1).

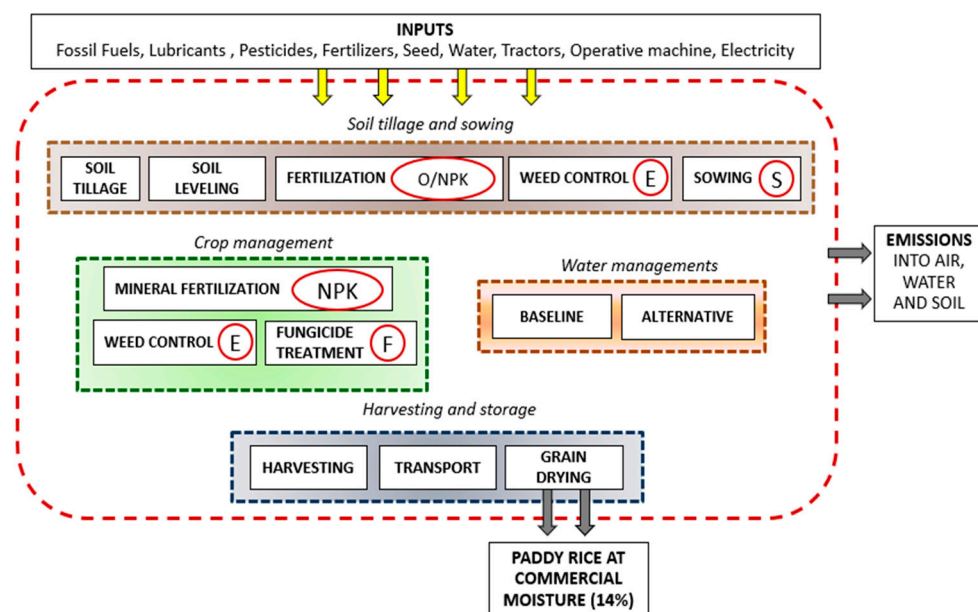


Figure 1. System boundaries graphical representation: the diagram shows all the operations included in the LCA study with the related inputs. O: organic fertilizer; NPK: mineral fertilizer; H: herbicide; S: seed; F: fungicide.

Table 1. Primary data regarding grain yield at commercial moisture (14%).

	Scenario	Grain Yield (t·ha ⁻¹)	Δ%
2020	BS-20	6.38	
	AS-20	6.58	+3.1%
2021	BS-21	5.61	
	AS-21	5.78	+3%

To estimate methane emissions the methodology proposed by the IPCC was applied. Methane emissions depend on the water regime before and during cultivation, on the quantity and type of organic substance introduced to the soil, on the number of aeration periods and on the timing of straw incorporation. The methane emissions of the different scenarios are shown 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 the atmosphere), phosphate emission and pesticide emissions were estimated using different specific models. Additionally, diesel fuel consumption was estimated considering the power requirements of 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 [9,10].

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, including 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 us 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 factor 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 the impact of different inputs, and the results shown in Figure 2 (BS-21) are representative of all scenarios considered. As expected, methane emissions are the main factor responsible for the global warming due to rice cultivation and represent half of the impact (50%); this is in line with other studies focusing on global warming due to paddy rice production [5,7]). The emissions associated with the application of the fertilizer (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%); and phosphate is important only for FE (37%). The paddy drying process has a relevant impact on Tex (44%), FRS (23%) and HT-c (19%) because it was considered a form of diesel drying, whereas the mechanization of field operations affects OF-hh (52%), HT-noc (49%) and MRS (46%). Fertilizer 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 pesticide production never exceeds 10% with the exception of MRS (20%), and pesticide emissions have an important impact only in Fex (51%).

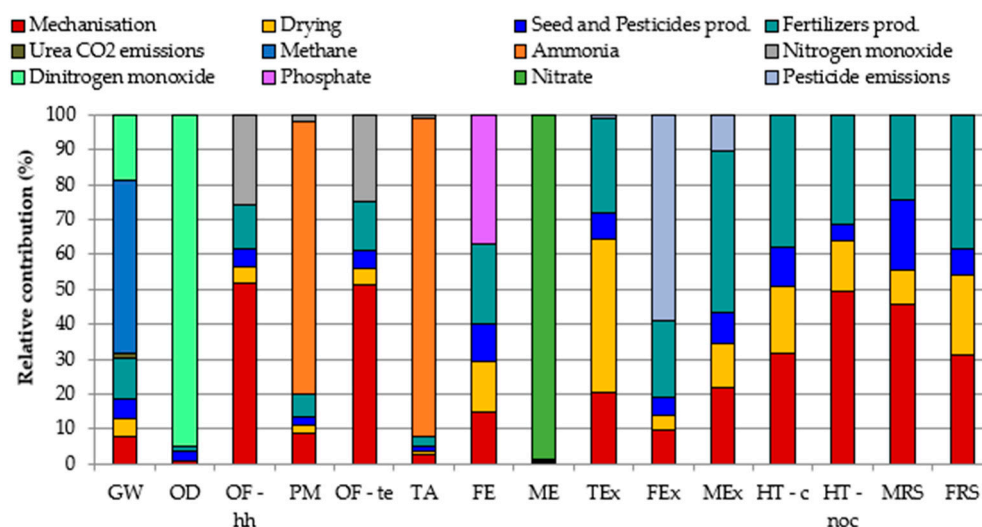


Figure 2. Relative contributions to the overall environmental impact of rice cultivation in the BS-21 scenario.

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 transitions 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 an alternative water management method has led to an improvement in environmental performance. 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 the 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 harvest. 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. Higher values are highlighted in red; for progressively lower impacts, it goes to orange-yellow and then green.

Impact Category	Unit	2020			2021		
		BS-20	AS-20	$\Delta\%$	BS-21	AS-21	$\Delta\%$
GW	kg CO ₂ 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 SO ₂ 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 global warming due to rice cultivation without compromising yield production. Despite the fact that 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 previous studies [3,11,12]. Considering the results of this study and the area dedicated to rice both in Lomellina and in Italy, it is important to highlight that a reduction in methane emissions, the main cause of global warming due to rice cultivation, can reduce the environmental impact of this important production system. Studies conducted in other countries [6,12] have reported how specific strategies for water management are able to reduce the carbon footprint of paddy rice production by 15–20%, without any reduction in yield, and this study confirms 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 growing consumer attention to environmentally sustainable production, and because the carbon footprint is increasingly an attribute that the consumer knows about and is willing to pay to reduce, reducing global warming due to rice cultivation could also increase the profitability of production by increasing the value of the rice produced.

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