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Life cycle environmental impacts of rice production systems in Sindh province of Pakistan

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Abstract: Rice is an important cereal and staple crop in Pakistan after wheat crop and it is also a source of foreign exchange earnings. It is mainly cultivated in Punjab and Sindh provinces of Pakistan under irrigated conditions. It is responsible for the environmental degradation due to inefficient use of factors of production, low yield as well as being grown under ponded conditions. Therefore, this study was designed to assess the environmental impacts of rice production in the Sindh province of Pakistan using the life cycle methodological approach. Data was collected from two rice production regions of the province. The environmental impacts of each production region were assessed and compared. It was observed that different production practices and different levels of input consumption contributed to the different environmental impacts. Variations in the application of a different mix of chemical fertilizers, farmyard manure as well as tillage operations resulted in different levels of environmental impacts. Soil physical properties, availability of water, seed type, sowing methods as well as the socio-economic conditions were mainly responsible for these variations in the inputs consumption and associated environmental impacts.

Keywords: Life Cycle Assessment, Rice Production System, Irrigation, Sindh Pakistan.

1. Introduction

Rice is an important staple food crop for many countries. It is cultivated in different parts of the world under different climatic conditions. In Pakistan, it is one of the most important crops and is ranked as the second most consumed food after wheat and the second-largest source of foreign exchange earnings after cotton. During 2018-2019, the area under rice crop was reported as 2.81 million hectares and the total production was reported as 7.20 million tonnes, accounting 3% value addition to agriculture and 0.6% to the national gross domestic product [1]. Rice is mainly grown in the Punjab and Sindh provinces of Pakistan under irrigated conditions [2].

The agriculture sector contributes significantly to global greenhouse gas (GHG) emissions; using almost 35% of total land area, it is accountable for about 13.5% of the worldwide production of GHGs with a distribution of 25%, 50%, and 70 % of CO_2, CH_4, and N_2O, respectively [3]. Overall, the rice crop is responsible for the emission of 55% of the total GHGs from the agriculture sector [4]. Rice is also a high water-demanding crop as it is grown in flooded anaerobic conditions [5-6] and therefore, it is responsible for a significant amount of CH_4 emissions besides other field level GHG emissions from fertilizers, etc. [7].

Life cycle assessment (LCA) has been widely used in the agriculture sector. Several studies have been conducted to assess the environmental impact of rice production systems using the LCA methodological approach [8-11]. Depending on the variations in the farming practices and inputs consumption, various studies reported different levels of environmental impacts across different rice production systems. Life cycle environmental impact assessment of the rice can help to understand the comparative advantages amongst the systems as well as countries and it also helps to improve the systems in terms of environmental impacts through some technical or strategic measures.

Pakistan is one of the leading producers and exporters of rice in the world. But several factors such as stagnant yield, nitrogen use efficiency and nitrogen surplus significantly contribute to environmental degradation [12]. Besides, rice cultivation in Pakistan is contributing towards the water scarcity as well as towards the land degradation in terms of waterlogging and salinity which is a key issue of the Sindh province of Pakistan [13]. Therefore, this study aims to investigate the potential environmental impacts of rice production systems in Sindh province and figure out ways to potentially reduce its negative environmental impacts.

2. Methodology

Rice production in Pakistan is classified into four zones. Zone-I comprises the northern part of the country, which usually receives high annual rainfall ranging between 750-1000 mm per year, Zone-II comprises the area between Ravi and Chenab rivers in the Punjab province of Pakistan. There are two rice producing zones in the Sindh province of Pakistan consisting of Zone-III, situated in the right bank of the Indus river and Zone-IV comprising the deltaic areas of Sindh province.

2.1 Study area

In this study, four districts of Sindh province were selected, consisting of two from each rice-growing zones of the province i.e. Zone-III and Zone-IV. Districts Dadu and Larkana were selected from Zone-III and districts Badin and Thatta were selected from Zone-IV. Considering the prevailing dissimilar agroclimatic conditions, the comparisons of the environmental impacts from rice production systems of these districts of the Sindh province of Pakistan were performed.

2.2 Data collection

The data was collected both from primary and secondary sources. Primary data was collected through a semi-structured questionnaire by using a quota sampling approach (it is a sampling technique in which samples are collected from specified groups based on quota). This sampling approach was used to assess the farm size effect on the inputs used and the outputs produced from small, medium and large farmers from each zone and district. The data including the use of energy, seed rate, chemical fertilizers, farmyard manure, pesticides, tillage operations and other cultural management practices to compute the total fossil fuel consumption and yield of each farm was collected through a structured questionnaire. The secondary data was collected from existing databases and the available literature.

2.3 Farm sizes classification

The farms were divided into three farm size categories including small-, medium- and large-sized farms with areas of 0-2 hectares, 2-10 hectares and above 10 hectares, respectively. The classification of farm size was made to assess the farm size effect on various inputs used in production and ultimately the yield of the farms and ultimately, environmental impacts.

2.4 Sampling design

Two districts, one each from Zone-III and Zone-IV, were selected based on major rice-producing areas. After selecting the districts from each zone, one sub-district from each district was selected randomly. Based on the quota sampling approach, 160 farms were selected consisting of 40 representative farms from each district of both zones.

2.5 Data analysis

Data collected from the field as well as from secondary sources was analyzed to assess the environmental impacts of different farm size categories of each zone. The potential environmental impacts of different rice production systems were computed using the LCA framework.

Since a major portion of Pakistani rice goes for export and it is difficult to get the routes, mode of transportation, and management practices during transportation, therefore, considering the complexities of the entire life cycle of rice, cradle to gate approach, including the production of inputs and its transportation as well as different field activities, was used to assess the environmental impacts of the selected rice production systems of Sindh province of Pakistan. The functional unit of 1,000 kg of unprocessed rice was used to assess the associated farm-level environmental impact associated with the inputs and management practices. The quantities of all the input parameters were translated into corresponding functional units to develop the life cycle inventory (LCI). In the life cycle impact assessment (LCIA) stage, the most common impact categories, viz., abiotic resource depletion, stratospheric ozone depletion, acidification, eutrophication, climate change, photo-oxidant formation, terrestrial ecotoxicity and human toxicity were considered in the analysis. The analysis was performed using the CML baseline method using SimaPro 8.3.

3. Results and Discussion

3.1 Environmental impacts of rice production

Life cycle inventory was developed using both the primary data including the inputs used in the entire crop cycle for the farm operations as well as the yield through the face to face interviews and from secondary sources. Rice crop in Pakistan is generally rotated with the wheat crop. After wheat harvest, the land is prepared for the upcoming rice crop. Nursery development and manual transplanting are commonly practiced in the country. However, in certain regions, farmers grow their crops through direct seeding. Land preparation starts in April and May after the harvest of wheat crop. However, in the deltaic region wheat is not grown due to the unavailability of water and other factors, and therefore, the land is kept fallow until the next rice crop.

Considering the variation in the field preparation, planting practices (direct seeding versus transplanting versus from nurseries), the soil physical properties, as well as the availability of irrigation water, the data of each district, was analyzed separately and compared. The environmental impacts of rice production systems of all four districts are shown in Table 1. The results show that rice production in the district Thatta is responsible for higher environmental impacts because of the use of a relatively higher amount of inputs as compared to the other districts. On the other hand, the yield of district Thatta is relatively lower due to poor soil quality as compared to the other districts. Planting low yield varieties are more common in Zone-IV and especially in Thatta district as compared to Zone-III. Besides, due to the differences in soil physical properties in Zone-IV, the farmers of the region need to put more effort in ploughing and land preparation activities and thus burn more fossil fuel. Lesser yield due to soil quality as well as due to agroclimatic conditions are contributing relatively higher environmental impacts in this region.

Overall, farmers in Zone-III are getting a higher yield because of better natural resources endowment i.e. soil quality and availability of water as compared to Zone -IV. It is also interesting to note that the landholding in Zone-III is relatively higher as compared to Zone-IV. The farm size has also an impact on the quantity of input uses as well as the potential environmental impacts due to economies of scale. Smaller farmers tend to use higher inputs and thus produce higher environmental impact as compared to larger farmers.

The consumption of urea fertilizer, which is a predominant contributor to GHG emissions is higher in Zone-IV. It was observed that on average, in Thatta and Badin districts, 36.06 kg and 31.68 kg of nitrogen-based fertilizer are used to produce 1000 kg of rice. Whereas in Zone-III, the average nitrogen use is 21.15 kg and 21.99 kg in Dadu and Larkana respectively to produce

Table 1. District-wise results of environmental impacts.

Potential impacts category	Unit	Badin	Thatta	Dadu	Larkana
Abiotic depletion (fossil fuels)	MJ	2.60E+04	3.09E+04	2.44E+04	2.53E+04
Global warming potential	kg CO_2 eq	2.31E+03	2.68E+03	2.43E+03	2.59E+03
Ozone layer depletion (ODP)	kg CFC-11 eq	6.17E-05	6.69E-05	5.34E-05	5.72E-05
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	8.50E+00	1.01E+01	1.14E+01	1.15E+01
Terrestrial ecotoxicity	kg 1,4-DB eq	2.80E+00	3.50E+00	4.00E+00	3.90E+00
Photochemical oxidation	kg C_2H_4 eq	5.38E-01	6.50E-01	5.17E-01	5.34E-01
Eutrophication	kg PO_4^{3-} eq	2.04E+01	2.18E+01	2.21E+01	2.29E+01
Human toxicity	kg 1,4-DB eq	2.56E+02	3.08E+02	2.43E+02	2.51E+02
Acidification potential	kg SO_2 eq	6.48E+01	6.65E+01	4.27E+01	4.63E+01

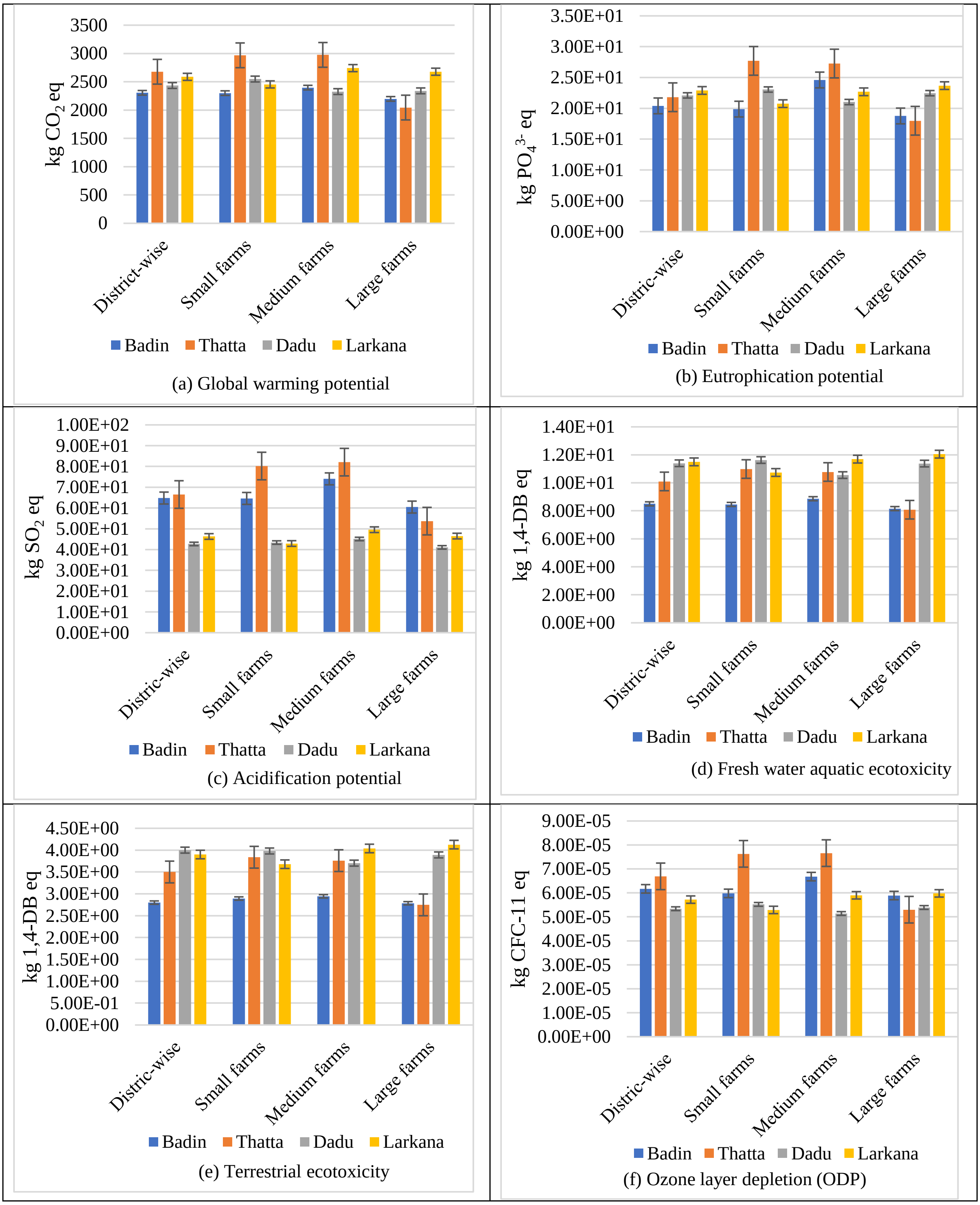

Figure 1. District-wise comparison of the environmental impacts as per farm size categories.

1000 kg of rice. But on the other hand, farmers in Zone-IV are using even less than one kg of phosphate fertilizers while in Zone-III, the amount of phosphate fertilizer is about 7 kg per 1000 kg rice produced. The huge difference in terms of phosphorus use may be associated with the socio-economic condition of the farmers and the knowledge of the impact of phosphorous on the yield. Since phosphorus-based fertilizers are quite expensive as compared to urea, smallholders and financially weak farmers, therefore tend to apply higher amount urea as they are not aware that both types of fertilizers are not complementing one other. These differences in input consumptions are contributing to the differences in the environmental impacts among rice-producing zones in the Sindh province of Pakistan.

Planting methods also vary between Zone-III and Zone-IV. In Zone-III, the majority of the farmers transplant the rice seedlings from nurseries. However, in the Zone-IV majority of the farmers use a direct seeding approach. Both of these planting approaches can significantly influence the number of inputs used and environmental impacts as well. To develop the nurseries, the farmers generally use a certain amount of farmyard manure. First, the manure is burnt and then used to develop rice nurseries. Since the farmers of Zone-III are using a significantly lower amount of N-based fertilizers as well as burning lesser fossil fuel during ploughing and seedbed preparation as compared to farmers of Zone-IV, therefore Zone-III have lesser environmental burdens. However, in Zone-III, open burning of farmyard manure contributes to the CO_2 emissions, though biogenic CO_2, and therefore not much difference in global warming potential was observed among regions. It is obvious from these facts that if lesser manure use and burning are practiced in Zone-III, lesser could be the global warming potential of Zone-III. However, a reduced amount of farmyard manure in Zone-III may affect the yield and the farmers may need to alter the input mix as well. The variation in eutrophication potential concerning zones is influenced by the amount of nutrient applications, whereas the variation in acidification potential is mainly associated with the background emissions of fertilizer production.

Due to the differences in the practices, the potential environmental impacts amongst the farm size categories also varies. Considering the variations in practices concerning farm sizes, the environmental impacts were further analyzed based on farm size categories which are shown in Figure 1. Overall, the global warming potential of small and medium farmers in Thatta district is highest amongst the four studied districts due to higher uses of N-based fertilizers and fossil fuel burning during ploughing practices. Whereas, the higher global warming potential of Larkana was observed due to the higher amount of manure burning. The least amount of greenhouse gas emissions from rice production in the district of Badin is because the farmers apply a lesser amount of urea as well as burn lesser fossil fuel during tillage then Thatta. Besides, the farmers in Badin use less amount of manure as compared to Larkana and Dadu.

In terms of other environmental impacts, similar trends were observed. The variations in the environmental impacts reflect the variations of the input consumption and field practices amongst all districts and among the different farm sizes of the same districts. It is interesting to note that there is a reasonable variation in the environmental impacts of all farm size categories. However, in district Dadu and district Larkana, only trivial variations were observed in the environmental impacts among all farm size categories. It was observed that the small and medium-size farm categories in Thatta district are responsible for higher global warming potential, eutrophication potential, acidification potential and ozone layer depletion potential. However, freshwater aquatic ecotoxicity and terrestrial ecotoxicity of Thatta are lower compared to Larkana and Dadu but higher than Badin. It indicates that a reasonable variation of the environmental impacts exists among different farm size categories of each district which ultimately affects the overall status of the potential environmental impacts of rice production of each district.

The variation in the environmental impacts is associated with the method of cultivation of rice the amount and types of inputs applied. In district Thatta, the direct seeding method of cultivation is practiced by the majority of the farmers whereas transplanting is more common in district Badin of Zone-IV. In Zone-III, rice cultivation is only performed through nurseries development and transplanting. Another potential reason is that majority of the small and medium-sized farmers in Thatta use local seeds and large farmers in Thatta used hybrid seeds and because of that their yields vary and variation in the environmental impacts can be observed. In Thatta district, the cultivation of non-hybrid coarse varieties is common especially among small and medium farmers. Whereas in other districts, farmers mostly grow hybrid seed varieties. The socio-economic conditions, soil properties as well as agroclimatic conditions and water availability are the main factors that influence the decision of the farmers regarding the selection of the available seed varieties.

4. Conclusion

In this study, the assessment of the environmental impacts of rice production in the Sindh province of Pakistan was performed using the life cycle assessment approach. Four districts were considered including Dadu and Larkana districts from Zone-III, and Badin and Thatta districts from Zone-IV. It was observed that environmental impacts vary between Zone-III and Zone-IV and among all four districts. Variation of the environmental impacts was observed as per farm size categories. A few factors were identified which have a significant influence on environmental impacts. Land quality is probably the most important influencing factor that farmers perceive needing to be addressed through more ploughing and nutrients inputs. In terms of environmental impacts, Zone-III has a comparative advantage over Zone-IV due to better soil quality as well as the availability of irrigation water that helps to increase the yield. It was observed that farmers are not using a proper mix of nutrients required to grow rice crops. In Zone-IV nitrogen use is quite higher and phosphate fertilizer use is very limited and it is presumably causing the yield difference and higher environmental impacts especially GHG emissions. A higher amount of phosphorus-based fertilizer may help the farmers of Zone-IV to increase their yield and a reduced amount of N-based fertilizer may help to reduce the environmental impacts without compromising the yield. It is possible only when the relevant governmental organizations and policymakers work closely with the farmers and introduce some awareness programs. The farmers should have access to those programs to improve their net benefit through increasing the yield and using the recommended level of inputs and thus reducing the input cost without compromising yield. It will eventually help to reduce environmental impacts. Efficiency analysis of the rice production system including the environmental efficiency may be used to understand and benchmark the level of input as well as the output.

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