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Research article

Rice Straw Availability and Postharvest Management Practices of Select Rice Farmers in Isabela, Philippines

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Abstract

The prevalent use of combine harvesters challenges rice farmers to efficiently manage rice straw. There is also an extremely low adoption of sustainable rice straw management by rice farmers. Hence, estimation of the total straw biomass and determination of rice straw management practices are necessary. The main objective of this study was to assess the availability of rice straw and postharvest management options of rice farmers. A case study was employed. Data gathered from household surveys and analyzed through descriptive statistics. Analysis revealed that the mean straw biomass ha^{-1} is 5,219.73 kg. Moreover, the type of soil and planting method influenced the generation of higher quantities of rice straw. In addition, sex, household size, rice production training, farm organization, land ownership, machine ownership, road structure, and type of soil showed a significant relationship to the postharvest management practices of rice farmers. Lastly, rice farmers predominantly practiced in-situ straw incorporation, but only a few practiced crop rotation, rice ratooning, straw mushroom production, and surface retention. It has been demonstrated that there is a massive contribution of rice straw biomass in Isabela. This provided data for authorities to implement plans and initiatives and for rice farmers to employ appropriate management to optimize the potentials of rice straw for a circular economy. The findings suggest that political will, partnership and collaboration, provision of physical infrastructures, and active participation of rice farmers are the key factors to the efficient rice straw management. Through this, rice farmers can strengthen their technical efficiency and can cultivate environmental efficiency.

Keywords:
Climate change mitigation, environmental efficiency, rice straw biomass, rice straw management, straw grain ratio.

Introduction

Mechanization has become a key feature in the major rice-farm activities. This involves the use of a combine harvester for harvesting and threshing. This shift is replacing the traditional methods that relied on portable axial threshers. The use of combine harvesters has provided convenience to the rice farmers. Consequently, the increasing adoption of combine harvesters in the Philippines has impacted the economic aspect of the rice farmers, such as labor efficiency and reducing postharvest losses by 2.2%, as reported by the International Rice Research Institute (IRRI, 2016). This technological advancement highlights the importance of mechanization in enhancing productivity and sustainability in rice farming.

The introduction of combine harvesters has led to a new challenge for rice farmers managing the loose and spread rice straw (RS) left in the rice field (Allen et al., 2020). To better understand the scope of this issue, various studies were conducted to determine the annual generation of rice straw globally. Table 1 shows the total annual RS generation, which varied significantly across countries, regions, and worldwide. It reflects that the total RS annual generation varies from one participating country to another, varies in reference to the total RS annual generation in the region, and varies in relation to the total RS annual generation in the world. Comparing the total RS annual generation of the Philippines against the annual total RS generation of the other countries, Thailand generated twice as much, and India generated almost five times as much, while Vietnam relatively shared almost the same amount. Thus, the Philippines shows the lowest generation of RS annually among these countries. Following these data, it is undeniable that the total RS annual generation in the regions and in the world is a considerably large amount. Thus, it is considered a big agricultural waste

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(Dominguez-Escriba and Porcar, 2010).

Table 1: Annual Generation of RS in the Various Parts of the World in Metric tons (Mt)

Location of the Study	Annual Generation of RS	Source
South Asia	5 - 6 t	Mandal et al. (2004)
World	About 800 Mt	Dominguez-Escriba and Porcar (2010)
Vietnam	24 Mt	Nguyen et al. (2016)
India	97.19 Mt	Bhattacharyya and Padhi (2019)
Thailand	21.86 Mt	Bhattacharyya and Padhi (2019)
Philippines	10.68 Mt	Bhattacharya and Padhi (2019)
Southeast Asia	100 - 400 Mt	Gummert et al. (2020)
Asia	330 - 470 Mt	Gummert et al. (2020)
World	370 - 520 Mt	Gummert et al. (2020)

Crop residues, including RS and stubbles, are considered agricultural waste if not properly managed. This underscores the need for efficient management of RS. Various scientific studies have determined the wide array of RS management options which are both economic and environmental friendly. Among these RS management strategies are mechanized collection of rice straw (Balingbing et al. 2020), straw incorporation (Mannepitak et al. 2019), surface retention (Bimbraw, 2019), composting (Romasanta et al. 2017), mushroom production (Nguyen et al. 2016), fodder (Sheikh et al. 2018), sources of energy (Swain et al. 2019; Bhattacharyya et al. 2020), production of paper (Kaur, Bhardwaj & Lohchab, 2017), and production of biochar (Bhattacharyya et al. 2020). These different methods of managing RS offer sustainable and promising options for reducing the environmental impact of rice production and potentially mitigating its carbon footprint.

According to the United States Environmental Protection Agency (US EPA, 2020), the global greenhouse gas (GHG) emissions showed 54.59 billion tons (Bt) of CO_2 equivalent (e). In the Philippines, Climate Transparency (2021) reported that the GHG emissions are 269.93 million Mt CO_2e. The energy sector contributed the highest GHG contribution with 52%, followed by agriculture with 32%, while industrial processes contributed 8%, waste accounted for 7%, and land-use change and forestry contributed 1% (Global Climate Change, 2016). Following that, agriculture contributed the second largest emission in the major sectoral GHG contribution, rice cultivation, livestock manure, enteric fermentation, use of synthetic fertilizer, and crop residues are the main sources of GHG emissions in the Philippines Overall, the agriculture sector in the Philippines generated a total of 55 Mt CO_2e (Climate Transparency, 2021). In the recent study conducted by Ginez and Siladan (2025), they found out that the overall carbon footprint of rice farming in Isabela during the dry season was 5,017.80 kg CO_2e ha^{-1}, with soil emissions from methane (CH_4) and nitrous oxide (N_2O) contributing 3,953.79 kg CO_2e ha^{-1} . This significant generation of GHGs is attributed to the improper management of RS in rice paddies, specifically in-situ straw incorporation.

Absence or insufficient or inappropriate rice straw (RS) management can lead to an increase in the carbon footprint in the rice sector. This results in the intensification of the effects of climate change in the agriculture sector, greatly affecting the rice farmers and rice production in the country. Hence, this study aimed to estimate the localized generation of RS by rice farmers in Isabela. By determining the contribution of RS and postharvest management practices of the said province, it can contribute to the efficient management of RS. Specifically, the study's objectives (aims) were:

1. To estimate the total straw biomass of rough grain yield ha^{-1} generated by rice farmers during the year 2024 dry season;
2. To identify the different factors that contribute to the high generation of rice straw quantities; and
3. To determine the current postharvest management practices of rice farmers and factors influencing the implementation of postharvest management options.

Material and methods

To attain the objectives of the study, a case study research design was employed. Data were collected through household surveys conducted via interviews. In the selection of study sites, the researchers determined the top five municipalities in Isabela, Philippines with the largest production area and volume of

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production. These municipalities were Alicia, the City of Cauayan, Ramon, the City of Santiago, and San Mateo. They represented 34.23% of the total rice production area in the province, contributed 259% average yield ha^{-1}, and shared 34.99% in the overall yield. Figure 1 shows the study sites. The study focused on the current postharvest management practices of the rice farmers during the 2024 dry season.

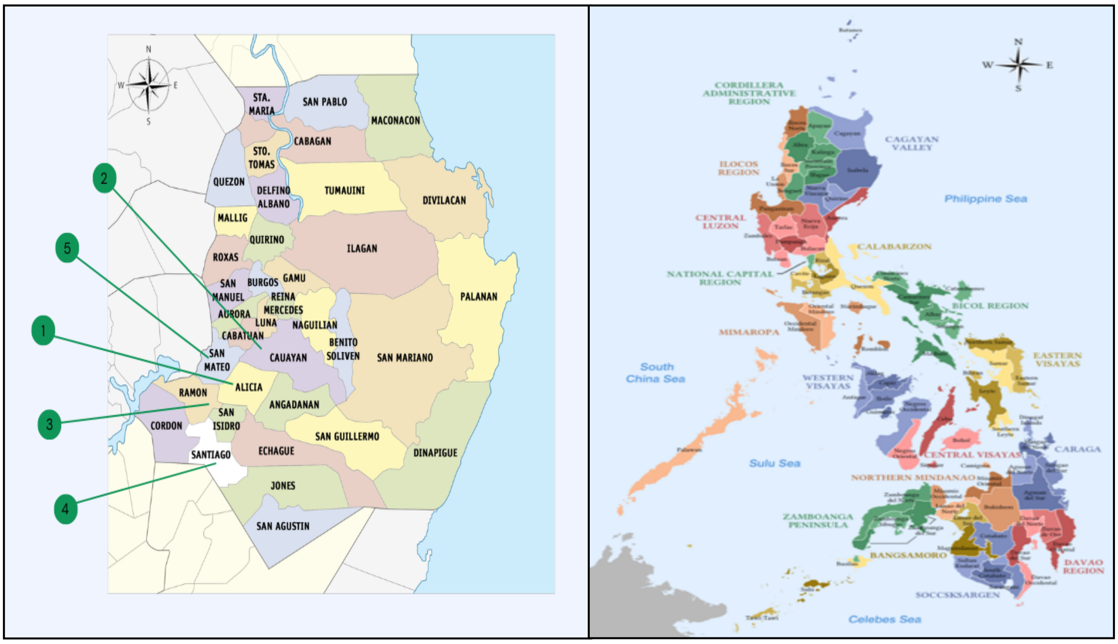

Fig. 1: The Five Study Sites in Isabela (Balingit, 2012) and the Political Map of the Philippines (Wikimedia Foundation, 2024)

Rice farmers were selected from among the five study sites as participants. The criteria in the selection of the participants were rice farmers who are owner, tenant or lessee and cultivates rice paddies with less than one hectare or more for at least five years. The participants were purposely selected from the list of farmers provided by the Municipal Agriculture Office, with the help of the Barangay Councilor in charge of agriculture.

The instrument used in this study was validated twice by two sets of validators to ensure its reliability and validity. In estimating the total straw biomass of rough grain yield, it used the straw grain ratio (SGR) model developed by Nguyen et al. (2020) as part of the International Rice Research Institute (IRRI) study. The SGR model was applied to determine the total biomass generated in rice cultivation. The total yield ha^{-1} was multiplied with the mean yield mass $sack^{-1}$ to estimate the total mass of grain yield ha^{-1}. Then, the value of SGR of 0.74 to 0.79 was multiplied by the rough grain yield ha^{-1}. It was then calculated through getting the mean of the maximum and minimum SGR. Data were analyzed and interpreted using descriptive statistics, including mean, Analysis of Variance (ANOVA), and Pearson correlation coefficient.

Results

Availability of Rice Straw Generated by Rice Farmers

The harvesting method employed by all the rice farmers involved the use of a combine harvester only. Harvesting typically took place in March or April during the dry season. To calculate the total biomass generated in rice cultivation, the estimated SGR was used.

The study discovered that the mean SGR of the total mass of rough grain yield ha^{-1} is 5,219.73 kg or 5.2t ha^{-1}. Nguyen et al. (2020) reported that the total biomass ratio of the Philippines ranged from 7.5 to 8t ha^{-1}. The present study's findings correspond to 65-69% of the aforementioned study. This means that the generation of total biomass straw of Isabela, Philippines represented a significant amount of rice straw in relation to the national generation of total straw biomass in 2020. The substantial contribution of Isabela to the country's rice production, being the second-largest producer, likely contributed to these results. Transplanting was the common method of planting employed by the rice farmers during the dry season, which also contributed to the high generation of rice straw. Hence, the massive contribution of total straw biomass of Isabela almost represented the national data on the generation of total straw biomass.

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Test of Difference on the Total Straw Biomass Generated Ha^{-1} in the Indicated Variables

The test of difference on the mean total straw biomass ha^{-1} according to the indicated variables is summarized in Table 2. The results show that the variables that had significant differences were type of soil and planting method. These two variables are significant elements in the rice farms that influenced the generation of higher quantities of rice straw. Rice farmers can take advantage of these two factors as they greatly influence the higher tendency of producing rice straw in higher quantities. These are key drivers for potential postharvest management activities that can be explored for a circular economy, providing employment opportunities for rice farmers.

Table 2: Test of Difference on the Mean Rice Straw Biomass Ha-1 Generated when grouped According to the indicated variables

Variable	Source of Variation	F valu (F)	P-value (P)	Decision	Interpretation
	2 ha and below				
Category of Land Holdings	2.1 and above	0.52	0.599	Accept Ho	Not Significant
	Total				
	Inbreed				
Rice Cultivar	Hybrid	1.75	0.196	Accept Ho	Not Significant
	Total				
	Sandy-loamy				
Type of Soil	Sandy	6.48	0.005	Reject Ho	Significant
	Total				
	Transplanting				
Planting Method	Direct Seeding	5.01	0.033	Reject Ho	Significant
	Total				
	6-9 sacks				
Quantity of Fertilizer	10 and above	0.65	0.589	Accept Ho	Not Significant
	Total				
	2-3 times				
Frequency of Fertilizer Application	4 times and above	0.04	0.989	Accept Ho	Not Significant
	Total				
	NIA				
Source of Irrigation	Other sources	0.81	0.456	Accept Ho	Not Significant
	Total				
	4-7 times				
Frequency of Irrigation	8 times and above	2.44	0.086	Accept Ho	Not Significant
	Total				
	0 - 1 kg				
Quantity of Herbicide	1.01 kg and above	0.88	0.426	Accept Ho	Not Significant
	Total				
	0-1 times				
Frequency of Herbicide Application	2-3 times	0.14	0.714	Accept Ho	Not Significant
	Total				
	0 - 1 kg				
Quantity of Insecticide	Within Groups	2.85	0.075	Accept Ho	Not Significant
	Total				
	0-1 times				
Frequency of Insecticide Application	2-3 times	2.30	0.100	Accept Ho	Not Significant
	Total				
	0 kg				
Quantity of Fungicide	- 2 kg	0.97	0.424	Accept Ho	Not Significant
	Total				
	0 times				
Frequency of Fungicide Application	1-2 times	1.42	0.258	Accept Ho	Not Significant

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	Total			
Quantity of Molluscicide	0.50 kg 0.51 kg and above Total	1.47	0.247	Accept Ho Not Significant
Frequency of Molluscicide Application	1 time 2 times Total	1.24	0.276	Accept Ho Not Significant
Quantity of Rodenticide	0 kg 0.1 kg and above Total	1.02	0.321	Accept Ho Not Significant
Frequency of Rodenticide Application	0 times 1 time Total	1.02	0.321	Accept Ho Not Significant
Quantity of Other Pesticides	0 - 0.5 kg 0.51 kg and above Total	0.67	0.522	Accept Ho Not Significant
Frequency of Other Pesticides Application	0 time 1 time Total	0.63	0.538	Accept Ho Not Significant
Cropping System	Monocropping Crop Rotation Total	0.31	0.580	Accept Ho Not Significant

On the other hand, the various factors did not show a significant difference in the generation of total straw biomass. These factors included the category of land holdings, rice cultivar, fertilizer management, water management, pesticide application, and cropping system. These factors did not significantly have a substantial impact on the quantity of rice straw generated.

The results showed that the type of soil had a significant difference on the mean of straw biomass ha^{-1} generated. Sandy-loamy soil yielded the highest mean straw biomass ha^{-1} generated, while the sandy soil had the lowest generation of mean of straw biomass ha^{-1}. This implies that sandy-loamy soil is the most favorable condition of the soil in which rice straws are fostered for their growth and development until fully matured. The sandy-loamy soil is highly suitable for rice nutrient contents of the soil (PhilRice, 2015). The study of Li et al. (2012) revealed that soil is a significant factor that impacts the high production of agricultural residue. Additionally, Singh et al. (1995) stated that soil type and fertility result in variation in generation of straw biomass. Since the type of soil in the study sites is favorable for rice plants, it might contribute to the generation of a high mean of total straw biomass. Hence, there is a massive generation of mean total straw. This suggests that rice farmers seeking to produce higher quantities of rice straws for postharvest management activities should select the type of soil that is favorable for rice plants to grow and develop when purchasing rice paddies or managing their rice field to foster the favorable amount of crop residue yield. On the other hand, due to the characteristics of sandy soil, the generation of crop residues is lower and requires intensive proper care and maintenance.

The findings also revealed that mean straw biomass ha^{-1} had a significant difference in the method of planting. This indicates that the planting method impacts the mean straw biomass generation in ha^{-1}. In application, if rice farmers prefer to produce higher rice straw for postharvest management activities, they should resort to employing a transplanting method. Transplanting has a greater mean of straw biomass ha^{-1} than direct seeding. The significant difference is primarily attributed to its high yield potential during the dry season, according to (IRRI, 2016). The yield is directly proportional to rice straw. This means, as the yield increases, the rice straw also increases. The SGR shows a more than three-fourths ratio of rice paddies and straw, which is almost a one-to-one ratio. Moreover, Reddy et al. (2003) revealed that planting methods influenced the quantity of crop residue production. Transplanting has a higher density of rice plants compared to direct seeding. Transplanting has a higher number of seedlings planted per hill which promotes higher generation of crop residues. On the other hand, direct seeding features broadcasting seeds randomly in the rice field. Consequently, this type of planting method has a lesser density of rice plants and has a lower generation of mean total straw biomass.

Rice Straw Management Activities of the Rice Farmers

Postharvest practices are common activities undertaken by rice farmers after a major cropping season. This activity deals with how rice farmers process their crop residue, especially the rice straw. Table 3 mentioned the postharvest

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management practices of rice farmers in Isabela.

According to the results, straw incorporation is the most widely practiced method, accounting for 54.84% of the respondents, followed by straw incorporation with crop rotation, consisting of 22.58%. Straw incorporation and rice ratooning are also practiced with 12.90%, while 3.23% use at least a combination of the three ways, such as straw incorporation, rice ratooning, straw mushroom production, or surface retention.

Table 3: The Postharvest Management Practices of Rice Farmers

Postharvest Activities	**Percentage (%)**
Straw Incorporation	54.84
Straw Incorporation + Crop Rotation	22.58
Straw Incorporation + Rice Ratooning	12.90
Straw Incorporation + Rice Ratooning + Straw Mushroom Production	3.23
Straw Incorporation + Surface Retention + Straw Mushroom Production	3.23
Straw Incorporation + Rice Ratooning + Surface Retention	3.23
Total	**100.00**

Discussion

The findings of the study are contrary to the results obtained by Singh et al. (2021), who reported that the most prevalent postharvest practice in the whole world is RSB, or open-field burning of straw; Mendoza (2015) reported that 76% of the Filipino rice farmers burn RS, and Gadde, Menke, and Wassman (2009) said that 95% of the RS are subjected to RSB. The prevalence of RSB in previous studies is attributed to the use of axial threshers, where rice crop residues are piled up during threshing. This allows rice farmers to easily burn RS.Nowadays, the axial threshers are progressively replaced by combine harvesters. The utilization of this newly introduced farm equipment became popular and brought convenience to rice farmers (IRRI, 2016). However, the collection of loose rice straw on the paddy fields has become a challenge. Gummert et al. (2020) suggested that mechanized collection of rice straw will solve the emerging concerns on loose rice straw.

However due to the expensive cost of mechanized collection of rice straw, all of the rice farmers practiced straw incorporation. The loose and spread rice straw is incorporated in the soil and is allowed for in-situ natural decomposition. However, improper in-situ straw incorporation results in a GHG emission spike from the soil. Ginez and Siladan (2025) revealed that soil emission from rice cultivation contributed 3,953.79 kg CO_2e ha^{-1}. The lack of knowledge and skills of rice farmers in in-situ straw incorporation contributed to the generation of high GHG emissions in rice cultivation. On the other hand, value-added products of rice straw have been introduced to farmers through technical briefings and orientations. As a result, 9.67% of the rice farmers, though in a very low adoption, practice surface retention and production of straw mushrooms as additional means of considering the value of RS. The gradual introduction of the value-added products of rice straw to the rice farmers would be necessary in order for them to promote a circular economy of rice straw. A cradle-to-cradle approach for rice straw could include fodder, a source of energy, the production of paper, and the production of biochar. This indicates that skills training is needed for rice farmers to deepen their appreciation and recognition of the value and importance of rice straw. This will certainly result in alternative means of livelihood, promotion of health and wellness, and climate change mitigation.

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Factors that Influenced the Postharvest Management Practices among Rice Farmers

The various factors that influenced the postharvest management practices among rice farmers include sex, household size, rice production training, farmers organization (FO), land ownership, machine ownership, road structure, and type of soil. Table 4, 5, and 6 summarize the test of the relationship between demographic profile, ownership, and farm characteristics, respectively.

Table 4: Test of Relationship Between Demographic Profile and Postharvest Management Practices

Variable	Chi-square	p	Decision	Interpretation
Age	4.37	0.112	Accept Ho	Not significant
Sex	9.14	0.010	Reject Ho	Significant
Household Size	6.55	0.038	Reject Ho	Significant
Number of Household Working in the Farm	2.59	0.298	Accept Ho	Not significant
Number of Farming Experience	0.88	0.643	Accept Ho	Not significant
Educational Attainment	1.91	0.385	Accept Ho	Not significant
Rice Production Training	5.93	0.028	Reject Ho	Significant
Farm Organization	6.81	0.012	Reject Ho	Significant
Source of Income	0.33	0.960	Accept Ho	Not significant
Household Monthly Income	3.32	0.190	Accept Ho	Not significant

Table 5: Test of Relationship Between Ownership and Postharvest Management Practices

Variable	Chi-square	df	p	Decision	Interpretation
Land Ownership	5.93	1	0.028	Reject Ho	Significant
Machine Ownership	5.99	1	0.032	Reject Ho	Significant
Animal Ownership	3.15	1	0.146	Accept Ho	Not significant

Table 6: Test of Relationship Between Farm Characteristics and Postharvest Management Practices

Variable	Chi-square	p	Decision	Interpretation
Category of Land Holdings	0.72	0.456	Accept Ho	Not significant
Road Structure	6.90	0.032	Reject Ho	Significant
Type of Soil	6.24	0.044	Reject Ho	Significant
Source of Irrigation	3.78	0.151	Accept Ho	Not significant
Water Availability	3.04	0.219	Accept Ho	Not significant
Rice Cultivar	0.02	0.889	Accept Ho	Not significant

For sex, female household heads tend to practice crop rotation after the major harvest more than their male counterparts. This implies that females adopt more economical and more sustainable practices than male heads. The visibility of women in rice farming is manifested in their higher adoption of newly introduced technologies and efficient management of resources, resulting in resource preservation (Tamang, Paudel & Shreshta, 2014; Takayama, Horibe, & Nakatani, 2018). The technology includes crop rotation which serves as an alternative source of income prior to the next cropping season. Through this, women maximize the optimum potential of the resources which in turn are more economical and more sustainable.

Household size is another variable that showed significant correlation to the postharvest management practices. The household size with four or fewer members tends to practice crop rotation after the main crop while households with five or more members do not. Meanwhile, rice straws are incorporated in their rice fields either for the next cropping or for planting cash crops. Hence, the ideal household size contributes to rice farmers' families practicing more economical and more sustainable rice cultivation practices than the households with more members through crop rotation.

The results of this study are contrary to the results of the study of Mukarumbwa et al. (2017). They reported that household size increases the number of postharvest practices. This is because more family members are needed in the performance of postharvest practices. Larger household sizes offer additional labor to rice farmers from tending the cash crops up to marketing them. The difference in the results is primarily

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associated with the farm size, type of crops, and purpose of planting. In the present study, rice farmers who practice crop rotation planted mung beans or corn using a small portion of their rice field. They intended to plant vegetables primarily for personal consumption. In case there was a surplus, they shared or sold it to their neighbors. Furthermore, for rice farmers who planted corn, they would not require additional labor because mechanization has replaced human labor from planting to harvesting. On the other hand, larger households prepared one family member for the next cropping season that requires intensive human labor.

Rice farmers who attended and received training in rice production implemented up to three postharvest methods while rice farmers with no training simply incorporated rice straw in their farm. According to the Philippine Statistics Authority (PSA, 2021), 19.6 - 28.1% of the rice farmers said that they received training. Seminars and training attended by the farmers include but are not limited to the application of pesticides, seeds, the application of fertilizers, pest control, and mushroom production. Thus, training provided rice farmers with necessary knowledge and skills in the value-added products offered by rice residues. Accordingly, rice farmers tend to integrate postharvest management practices in which they significantly benefit from it.

Membership in farmers' organizations (FO) also significantly influenced the adoption of postharvest management practices. Rice farmers who were members of FOs tended to practice a combination of two to three postharvest management methods, while non-members primarily practiced straw incorporation. Membership in FO has a positive influencing power to encourage rice farmers to implement a variety of postharvest management practices. FO also provides an avenue for farmers to establish links and networks with other rice farmers. IRRI (2016) highlighted the importance of FOs to rice farmers because they offer services for economic and technical efficiency among their members. Indeed, FOs play a critical role for rice farmers in the economic and technical as well as environmental efficiency.

For land ownership, rice farmers who are owner-cultivators tend to practice crop rotation while tenants do not. This signifies the land ownership is directly associated with the rice farmers' decision to explore alternative sources of income to increase their technical efficiency and productivity through crop rotation. Additionally, this practice implies environmental efficiency because of their intention to maximize the optimum benefits given by the rice straws in their rice field. Rice straws serve as mulch to retain moisture of the growing crops and eventually serve as compost and organic fertilizer over time. This certainly reduces the inputs of commercial and inorganic fertilizer. Bokusheva et al. (2012) studied the factors on the adoption of postharvest storage and found out that owner-cultivators adopted postharvest storage facilities. This indicates that owner-cultivators seek technical productivity by storing their crop residues and finding value-added products for them such as mulch, organic fertilizer, fodder, straw mushroom production, thatching, and stover.

Additionally, machine ownership directly influenced the practice of postharvest management. Rice farmers who own agricultural machinery have a higher tendency to practice crop rotation, while rice farmers who do not own agricultural machinery do not practice crop rotation. Though this agricultural machinery is not directly involved in the postharvest management practices, it influenced them to practice crop rotation. Agricultural machinery involved in crop rotation for vegetable crops is intended for land preparation only. Other rice farmers who practice crop rotation usually rent machinery, especially for land preparation and harvesting. This implies that it is high time to realize the advantages of postharvest technologies both for rice production and production technology for crop rotation. Castro (2004) underscored the significant contribution of postharvest technologies to the economy of the 90% of smallholder farmers in the country. Given the present circumstances of rice farmers, postharvest technologies will greatly influence them to maximize the potential of crop residues. If rice farmers are subsidized with farm machinery, especially for postharvest technologies, they have a higher probability of efficiently managing their crop residues. Thereby, their technical productivity and efficiency can be enhanced as well as their environmental sustainability. Likewise, governments should adopt projects and services for infrastructures and invest in agricultural machinery intended for rice farmers.

Meanwhile, farm characteristics such as road structures and type of soils had significant relationships to the postharvest management practices. This signifies that these two factors are significant considerations for rice farmers to employ favorable postharvest management practices in their own fields. For rice farmers who have earthen road access from their residence to their rice fields, they commonly employ straw incorporation. Pure earthen roads may contribute to the difficulty of delivering services such as proper care and maintenance of crops and products such as yield for rice farmers. Consequently, rice farmers resorted to simply incorporating crop residues on their own rice farms.

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On the other hand, rice farmers who have fully concrete, and a combination of concrete and earthen road structures leading to their farm lands tend to practice a combination of two or more postharvest methods. Rice farmers under these road structures have explored straw incorporation, rice ratooning, crop rotation, surface retention, and mushroom production. Employing combinations of these postharvest methods is likely attributed to the accessibility of roads which provides rice farmers the ability to easily deliver the services and products to and from their rice fields (IRRI, 2016).

Lastly, the type of soil directly influenced rice farmers to employ postharvest activities. Rice farmers with sandy-loamy soil tend to practice two or three combinations of postharvest methods while those with sandy and loamy soil practice straw incorporation only. The favorable type of soil influences rice farmers to maximize the various benefits of sandy loam for crop rotation and rice ratooning. PhilRice (2015) examined the soil series in Isabela, in which they emphasized the suitable types of soil for lowland rice crops. It was revealed that sandy-loamy and clay-loamy soils are the highly favorable soils for rice production. Given these data, rice farmers may take advantage of the economic benefits they derive from practicing the aforementioned postharvest method based on the type of soil found in their respective rice fields. The more knowledgeable rice farmers are in their rice fields, the more they employ sustainable agricultural practices. For the government, infrastructure for soil analysis should be established; mandatory soil testing should be done; and training rice farmers to conduct soil analysis will be practiced. Through these ways, rice farmers are equipped with necessary knowledge and skills for the said purpose and for environmental efficiency.

Conclusion and recommendations

The mean straw biomass ha^{-1} generated by the rice farmers is 5,219.73 kg or 5.2 t. This comprises 65-69% of the total straw biomass in comparison to the national straw generation. Thus, there is a massive significant contribution of Isabela, Philippines vis-à-vis the national generation of total straw biomass in 2020. Relative to the massive contribution of rice straw in Isabela, Philippines, factors such as type of soil and planting method are proven considerations for the high generation of total straw biomass. Moreover, sex, household size, rice production training, farm organization, land ownership, machine ownership, road structure, and type of soil are key determinants in the determination, selection, and implementation of postharvest management practices of the rice farmers.

This substantial massive generation of total straw biomass in Isabela, Philippines, could provide a wide array of benefits, most especially to the rice farmers. The involved persons could take advantage of the massive generation of rice straw especially the rice farmers. Political will, partnership and collaboration, provision of physical infrastructures, and active participation among rice farmers are main ingredients to the effective management of rice straws. The political leaders can fully exercise their political will in support of the sustainable management of rice straw; the Department of Agriculture (DA) and Local Government Units (LGU) can strengthen and further their partnership and collaboration with the various national government agencies, private companies and institutions; the DA and LGUs should invest more in postharvest activities such as facilities and trainings; and rice farmers are well stimulated with various benefits for them to guarantee their full cooperation and active engagement.

When all stakeholders participate in the sustainable management of rice straw, RS will no longer be considered as agricultural waste (cradle-to-waste) but rather an additional agricultural wealth (cradle-to-cradle). Consequently, RS can be subjected to its various potentials leading to a circular economy which in turn contributes to the productivity, technical efficiency, and environmental efficiency of the community, especially to the rice farmers.

Based on the foregoing conclusions, the following recommendations are proposed. For the DA and LGU, it is recommended that:

- They should strengthen and sustain long-term partnerships and collaboration with other national government agencies, private and public institutions, private industries, and non-government organizations to promote fresh perspectives and ideas in rice farming and to maximize shared facilities to cater to the needs, demands, and requirements of the rice farmers.
- Allocate more funds and invest in the physical infrastructures for postharvest facilities in managing the rice crop residues. It can help rice farmers in diverting their RS into a circular economy as an alternative source

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of livelihood.

- Provide more extensive skills training on postharvest management activities to all rice farmers in order for them to be more adept and more skillful in managing their crop residues.
- Devise a scheme for a localized incentivization program to encourage rice farmers to integrate and implement sustainable rice-farming practices. Incentives may come in modest forms such as food assistance or financial support for barangay-level farm input projects such as RS vermi-composting, RS mushroom production, handicrafts made of RS, etc.
- For farmers, they should actively participate and be involved in any capacity-building activities conducted by DA and LGU in order to learn, unlearn, and relearn valuable knowledge, skills, and attitudes in sustainable rice farming needed in enhancing productivity, increasing technical efficiency, and fostering environmental efficiency.

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