Chapter 5
Economic Analysis of Rice Straw Management Alternatives and Understanding Farmers' Choices

Cheryll C. Launio, Constancio A. Asis, Rowena G. Manalili, and Evelyn F. Javier

Abstract The negative effects of open-field rice straw burning on the environment and human health are well documented in local and international literature. This research project assesses the environmental consequences of rice straw burning and other straw management practices in terms of greenhouse gas (GHG) emissions, particularly that of methane (CH_4) and nitrous oxide (N_20). It also evaluates the cost-effectiveness of adopting selected rice straw management alternatives. On a per hectare basis, considering a time horizon of 5 years with associated assumptions on cost savings and secondary benefits, incorporating stubble more than 30 days before crop establishment and incorporating composted rice straw in the field yielded the lowest cumulative CH_4 and N_2O emissions. The study found that the most cost-effective option for farmers is to incorporate stubble and straw in the soil more than 30 days before crop establishment. This option is followed by rapid straw composting and incorporation of rice straw into the field. The study recommends looking for alternative uses of rice straw and finding ways to reduce the cost of collection and transportation of rice straw, coupled by the strict enforcement of laws banning rice straw burning.

Keywords Philippines • Rice straw • Cost-effectiveness analysis • Multinomial logit • GHG emission

C.C. Launio (✉) • R.G. Manalili
Socioeconomics Division, Philippine Rice Research Institute (PhilRice), Muñoz, Nueva Ecija, Philippines
e-mail: ccasiwan@yahoo.com; rg.manalili@philrice.gov.ph

C.A. Asis • E.F. Javier
Soils and Plant Physiology Division, Philippine Rice Research Institute (PhilRice), Muñoz, Nueva Ecija, Philippines
e-mail: ca.asis@philrice.gov.ph; ef.javier@philrice.gov.ph

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Introduction

Background

The practice of open-field burning of rice straw (including both 'stubbles' – the lower part of the rice plant left in the field after harvesting – and 'straw', the loose straw output after threshing) is a major source of air pollutants (Gupta et al. 2004; Wassman and Dobbermann 2006; Tipayarom and Oanh 2007) including greenhouse gases (GHG), particulate matter and other elements such as dioxins and furans that impact human health (Torigoe et al. 2000; Gadde et al. 2009). The Philippine Department of Science and Technology (DOST) study even reports that burning of rice straw and other agricultural waste contributes more dioxins and furans to air and land than vehicle emissions (DOST 2006). Other studies also show that rice straw burning causes loss of major nutrients in the soil: almost complete nitrogen (N) loss, phosphorous (P) losses of about 25 %, potassium (K) losses of 20 % and sulphur (S) losses of 5–60 % (Dobbermann and Fairhurst 2002).

Given these negative effects of open-field rice straw burning on the environment and human health as documented in local and international literature, farmers have been encouraged to refrain from burning rice straw and adopt more environment- and human-friendly rice straw management practices. In fact, both the existing solid waste management law in the Philippines (RA 9003) and the Philippine Clean Air Act of 1999 prohibit in principle open-field burning which includes burning of rice straw. Ordinances specifically against rice straw burning have also been passed in some provinces and towns.

Scientists and researchers, on the other hand, have studied the potential impacts of various rice straw management technologies as alternatives to rice straw open-field burning. Crop residues properly returned to the soil can maintain or enhance soil quality and productivity through favourable effects on soil properties and life-support processes (Lal 1995). Continuous rice stubble and straw incorporation into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long term (Dobbermann and Fairhurst 2002). Eagle et al. (2000) concluded that the retention of straw in rice fields can result in increased soil N supply, suggesting that nitrogen fertiliser application rates can be reduced. Javier (2009) also reported that several studies have proven that continuous rice straw incorporation can build up potassium reserves which are essential for plant vigour.

However, literature also recognises that the incorporation of straw and stubble into wet soil (during ploughing) also results in temporary immobilisation of N and a significant increase in methane (CH_4) emission from rice paddies, a practice that contributes again to GHG emissions (Dobbermann and Fairhurst 2002). The quantity of methane emission varies widely depending on the rice straw-based nutrient management practice used (Dobbermann and Fairhurst 2002; Wassman and Vlek 2004; Vibol and Towprayoon 2010). Hence, rice straw management can significantly impact GHG emissions from rice fields but also can provide a mitigation option. Using the proper rice straw-based nutrient management options may result in soil rejuvenation and environmental conservation (Javier 2009).

In practice, many farmers still burn their rice straw or, if not, incorporate it into submerged soil during ploughing. Local governments are also unable to implement the law especially with the large volume of rice straw produced each year in rice-producing regions. Rice straw burning thus continues to contribute to air pollution, compounding the already high methane emission levels inherent in irrigated rice-based farming systems. This raises the question of why farmers choose to burn their rice straw and which straw management alternatives are cost-effective to farmers and to society as a whole.

Aims of the Study

The study aimed to assess the environmental consequences of rice straw burning and evaluate the adoption and cost-effectiveness of selected rice straw management alternatives. Specifically, it:

- Estimated potential environmental impacts in CO_2-equivalent emissions of existing and potential rice straw management alternatives to open-field burning
- Compared selected rice straw management alternatives to open-field burning using cost-effectiveness analysis
- Determined factors and constraints driving adoption of rice straw management practices

Methodology

Data and Information Sources

Both secondary information and primary data were used in the study. Five-year (2006–2010) average data on area harvested, yield and production were obtained from the Bureau of Agricultural Statistics. Other assumptions used in the estimation were obtained from existing literature and previous studies in the Philippines and from results of key informant surveys and technical expert consultations. Household surveys were conducted in four major rice-producing provinces, namely: (1) Nueva Ecija, top producer; (2) Leyte, to represent the Visayas and a province with an existing provincial ordinance banning rice straw burning; (3) North Cotabato, largest rice producer in Mindanao; and (4) Ilocos Norte, to represent a province where there is an existing rice straw market. The questionnaire elicited information on rice stubble and straw management practices, perceptions of rice-based farming households on the environmental impacts of rice straw burning and other rice straw management practices. Two focus group discussions (FGDs) were also conducted in each of the four study provinces, covering farmers and farmer-leaders in irrigated and rainfed rice ecosystems. The purpose was to have thorough discussions on the perceived environmental impacts of rice straw burning and the existing and potential policy and institutional options to reduce the negative impacts and promote the positive impacts.

A multistage stratified area probability sample design was used in the household survey. The primary sampling unit (PSU) was the barangay (village) with the ecosystem (irrigated/rainfed) as a stratification variable. Ten barangays were randomly sampled from the entire population of rice-producing barangays in each province. The number of irrigated and rainfed barangays was prorated depending on secondary data of rice area harvested in the province. Ten farming households were randomly sampled in each sample barangay for a total of 100 household samples per province.

Data Analyses

GHG Emission Analysis

To estimate the GHG emissions from rice straw open burning and other straw management practices, methodologies and guidelines set by the Intergovernmental Panel on Climate Change (IPCC) Guidelines (2006) were used. Thus, while CO_2 emission is affected by straw management practice, CO_2 emissions from biomass burning were not included since the carbon released during the combustion process was assumed to be reabsorbed by the vegetation during the next growing season (IPCC 2006).

The following equation was used to determine the annual quantity of rice straw or rice stubble per hectare:

$$Q = \sum\sum P_{ij}\mathrm{SGR}_{ijj} \tag{5.1}$$

where Q is the annual quantity of rice straw or rice stubble (tons/ha/year), P_{ij} is the rough rice production (tons/ha) in season i and rice ecosystem j and SGR_{ij} is the straw to grain ratio or stubble to grain ratio in season i and rice ecosystem j.

Since in the Philippines the management of rice stubble usually differs from rice straw, the straw-grain ratio was differentiated from the stubble-grain ratio. Based on total biomass and grain yield data from an average of four WS and five DS experimental data in the Philippines by Corton et al. (2000) and stubble to straw ratio derived from special sampling at PhilRice by one of the co-authors, straw-grain ratios of 0.74 and 0.36 were derived and used and stubble-grain ratios of 1.21 and 0.59 for WS and DS, respectively. Equation 5.2 below was then used to calculate GHG emissions from rice straw burning:

$$E_a = (Q)(f_{Co})(EF_a) \tag{5.2}$$

where a = type of GHG, E_a = emission of a in kg/ha/year, f_{Co} = combustion factor and EF_a = emission factor of a in g/kg of dry straw.

Table 5.1 GHG emission factors for different rice straw management practices

Rice straw/stubble management practice	Name of pollutant	EF	Unit	Reference
Open burning	CH_4	1.2	$g/kg_{dryfuel}$	Based on EFs compiled by Gadde et al. (2009)
	N_20	0.07	$g/kg_{dryfuel}$	
	Combustion factor	0.8		IPCC Guidelines (2006)
Scattering and incorporation of rice stubble and straw in the soil (wet condition)	CH_4 (WS)	129.77	kg/ton yield	Corton et al. (2000) (Incremental CH_4 due to straw incorporation)
	CH_4 (DS)	36.99	kg/ton yield	
	Baseline EF for continuously flooded fields without organic amendments	1.3		IPCC Guidelines (2006)
	Conversion factor for rice straw amendment	1.0 for straw incorporated <30 days before cultivation; 0.29 for straw incorporated >30 days before cultivation		IPCC Guidelines (2006)
	Scaling factor to account for differences in water regime during cultivation period	0.78 for irrigated 0.27 for rainfed		IPCC Guidelines (2006)
	Scaling factor to account for differences in water regime in the preseason before cultivation period	1 for irrigated (<180 days); 1.22 for rainfed		IPCC Guidelines (2006)
Composting and incorporation	CH_4 (WS)	13.37	kg/ton yield	Corton et al. (2000) (Incremental CH_4 due to incorporated compost)
	CH_4 (DS)	2.1	kg/ton yield	
	Conversion factor for rice straw compost amendment	0.05		IPCC Guidelines (2006)
Rice straw used as animal feed	CH_4	10,000–20,000 gCH_4/ton dw		Singhal et al. (2005) as cited by Truc (2011)

For incorporation in the soil of rice straw and rice straw compost, the IPCC Guidelines were used for rice cultivation and emission from managed agricultural soils, adjusting the conversion factors for organic amendments. The estimates were compared with results using GHG emission changes from experiments conducted in the Philippines by Corton et al (2000) and considered the more conservative estimate. Table 5.1 shows the summary of emission factors and other parameters used and corresponding references.

In the analysis of GHG emissions, the study focused on estimating the incremental change in the GHG emissions from paddy areas as a result of rice straw management alternatives, not the GHG emissions from paddy rice systems per se.

Rice Management Options

Rice straw management options available to households engaged in rice production are shown in Table 5.2. The various alternatives were analysed on a per hectare basis considering the potential effects on GHG emission over a 5-year period. The base case scenario is the current major practice where rice stubble is incorporated into the soil during the first land preparation activity in a flooded condition, and rice straw is burned at the threshing site. Based on the household survey, the average duration from the start of land preparation to crop establishment is 21 days. The baseline case accordingly assumes that stubble is incorporated less than 30 days before cultivation.

While power generation and biofuel production are potential uses of rice straw removed from the field, a full-scale analysis was beyond the scope of the study. The analysis focuses only on the potential impact on GHG emissions in the paddy sector if stubble and straw are removed from the field.

Cost-Effectiveness Analysis (CEA)

CEA was employed to compare the selected rice straw management alternatives shown in Table 5.2. The analysis entailed the following steps:

1. Based on incremental GHG emission analysis, the net reduction in total CO_2-equivalent (CO_2-eq.) emission was determined if farmers switch from the baseline scenario to each management option, fulfilling the CO_2-eq. abatement capacity for each alternative. The total global warming potential (GWP) was estimated by multiplying the estimated emissions of each kind of GHG *(i)* from

Table 5.2 Rice straw management options evaluated for emission and economic analysis

	Rice straw management options	Stubble	Straw	Timing of incorporation
M1	Late stubble incorporation and straw burning (baseline)	Incorporated	Burned	<30 days before cultivation
M2	Late stubble and straw incorporation	Incorporated	Scattered and incorporated	<30 days before cultivation
M3	Late stubble incorporation and straw removal for animal feed	Incorporated	Removed from field for animal feed	<30 days before cultivation
M4	Early stubble and straw incorporation	Incorporated	Scattered and incorporated	>30 days before cultivation
M5	Late stubble incorporation and straw compost incorporation	Incorporated	Rapidly composted and incorporated as compost	<30 days before cultivation
M6	Early stubble incorporation and straw compost incorporation	Incorporated	Rapidly composted and incorporated as compost	>30 days before cultivation
M7	Stubble and straw composting and straw compost incorporation	Removed from field, composted with the straw and incorporated	Rapidly composted and incorporated as compost	>30 days before cultivation

paddy rice systems under each rice straw management practice (j) by its corresponding GWP, as in Equation (5.3) below:

$$\text{Total GWP}_j = \sum \left(\text{GHG}_{ij} \times \text{GWP}_{ij}\right) \tag{5.3}$$

where i is the type of GHG such as CH_4 or N_20 and GWP is an internationally accepted scale of equivalence for other GHGs in units of tons of CO_2-eq. (Lv et al. 2010). The GWP values used were $CO_2 = 1$, $CH_4 = 23$ and $N_20 = 296$ (IPCC 2006) measured in metric ton CO_2-eq. per year per hectare.

2. The cost of each rice straw management option expected to result in changes in GHG emission was estimated. It included the incremental operating and maintenance cost for the farmer implementing the management option as well as the secondary benefits due to changes in straw management practice. A 5-year period was considered in the cost analysis of the options. The shadow wage rate used was 60 % of the market wage rate as suggested by the Philippine NEDA (2004).
3. The cost-effectiveness or abatement cost per ton of CO_2-eq. was calculated and compared for each rice straw management alternative. The following generic

formula for abatement cost calculation similar to that cited in Davidson and van Essen (2009) was used:

$$\text{Cost-effectiveness} = \frac{I^{an} + \Delta_{O\&M} - \text{secondary benefits}}{\text{Annual reduction in } CO_{2}\text{-eq emissions}} \tag{5.4}$$

where I^{an} is the annuity of the investment cost (if applicable) and $\Delta_{O\&M}$ is the additional annual operating and maintenance cost. The formula also includes monetised secondary benefits (e.g. value of the composted rice straw) to be subtracted from the costs. The most cost-effective option is that with the lowest cost per reduction in tons CO_2-eq. (Php/ton CO_2-eq.). Costs in the study were calculated for a 5-year scenario to account for effects expected at around 5 years. A 7.5 % real discount rate was used, based on the discount rate suggested by the Philippine National Economic Development Authority (NEDA 2004) adjusted for inflation using the average from 2000 to 2010. The CEA was conducted from the farmers' perspective, without any assumed external social costs or benefits.

Results

GHG Emission Abatement Capacity of Options

Table 5.3 shows the estimated potential GHG emissions and global warming potential (tons CO_2-eq.) by rice straw management option for farmers, calculated per hectare for a 5-year period based on IPCC 2006 Guidelines, compiled factors from literature and various assumptions. For the baseline scenario, the total estimated emissions considering only CH_4 and N_2O emissions totalled around 51 tons CO_2-eq. per hectare over a 5-year period.

Results indicate that shifting from rice straw burning to rice straw incorporation will not necessarily reduce global warming potential if straw is incorporated less than 30 days before cultivation especially in a flooded condition after incorporation (M1 to M2). This is due to the higher CH_4 emission calculated. In the longer term, however, the increase in CH_4 emission due to straw incorporation can also be offset by the reduction in N_2O emission from potential reduction in the use of chemical fertilisers (Bird et al. 2002). At the same time, while there is less CH_4 emission in straw burning, the loss of nutrients from the straw might eventually lead to increased use of chemical fertilisers that can significantly increase N_2O emission. Although not considered in the GHG accounting here, Wang et al. (2011) also reported significant interactive effects of straw with nitrogen on N_2O emissions, i.e. straw amendment significantly reduced, on average, N_2O emissions from rice fields when they received nitrogen fertiliser.

Table 5.3 Estimated incremental GHG emissions (ton CO_2-eq. ha^{-1}) from rice fields for different rice straw management options

No.	Rice straw management option	Greenhouse gas emission (tons ha^{-1} $year^{-1}$) Years 1–4 CH4	Years 1–4 N_2O	Years 1–4 Total GWP	Year 5 CH4	Year 5 N_2O	Year 5 Total GWP	5-year total (tons CO_2-eq.)	% change from baseline
M1	Late stubble incorporation and straw burning (baseline)	7.60	0.16	7.77	7.60	12.32	19.92	50.99	
M2	Late stubble and straw incorporation	12.55	0.08	12.63	12.55	−12.07	0.48	51.01	−0.05
M3	Late stubble incorporation and straw removal for animal feed	9.02	0.07	9.10	9.02	12.23	21.25	57.63	−13.03
M4	Early stubble and straw incorporation	4.45	0.08	4.53	4.45	−12.07	−7.62	10.51	79.38
M5	Late stubble incorporation and straw compost incorporation	7.61	0.48	8.09	7.61	−11.67	−4.06	28.28	44.53
M6	Early stubble incorporation and straw compost incorporation	2.83	0.48	3.31	2.83	−11.67	−8.84	4.39	91.39
M7	Stubble and straw composting and compost incorporation	0.34	1.10	1.44	0.34	−11.01	−10.67	−4.91	109.64

Note: Details of calculation can be obtained from the authors

Merely shifting from burning rice straw (M1) or changing the timing of the stubble and straw incorporation from less to more than 30 days before cultivation (M2 to M4) can reduce the incremental GHG emissions due to straw management by around 80 % largely because of its effect on CH_4 emission, assuming other factors are constant. A significant reduction of more than 90 % in total incremental GHG emissions is also expected if the rice stubble is incorporated more than 30 days after cultivation and the rice straw is removed from the soil and returned as rice straw compost. This is even more significant when the rice stubble is completely removed and returned as rice straw compost. Corton et al. (2000) reported from their experiments in the Philippines that addition of rice straw compost increased CH_4 by only 23–30 % as compared with the 162–250 % increase in emissions with the use of fresh rice straw.

When both stubble and straw are completely removed from the field and used for nonfarm uses such as power generation or bioethanol production, GHG emissions from paddy rice systems can also be potentially reduced. While the study could not afford to conduct a life cycle assessment of GHG emissions from using rice straw for power generation and bioethanol production, literature is available on this issue. Delivand et al. (2011) in the case of Thailand indicate that the life cycle GHG emission of the straw combustion process chain is 30 kg CO_2-eq. per ton of dry straw or 0.043 kg CO_2-eq./kWh, i.e. 0.613 kWh net electricity per kg straw. This considers both the logistics and grate boiler combustion. Using this as a factor and considering a scenario where the stubble is incorporated into the soil more than 30 days before cultivation, the approximate net GHG emission was estimated at 1,263 tons per year per hectare.

They also found that substituting the natural gas or coal fuels with rice straw fuels for power generation would result in a considerable fossil fuel savings and a lower GHG emission. For example, for the case of substituting natural gas with rice straw fuel, it is estimated that 0.368 ton CO_2-eq. will be avoided, while for imported coal, 0.683 ton CO_2-eq. can be avoided (Delivand et al. 2011). Using rice straw as raw material for power generation will thus avoid emissions of GHG and other air pollutant particulates when compared with open straw burning and methane emissions when compared with incorporation.

Regarding the use of rice straw for bioethanol production, a review by Cheng and Timilsina (2011) reported that all advanced biofuel technologies have the advantage of producing fuels with almost zero or very little net carbon dioxide emissions to the atmosphere. The same authors stated that the advantage of lignocellulosic materials such as agricultural residues is that these are abundant in most land areas and their generation does not have to compete for arable land against food and feed production. Using 0.28 L kg^{-1} as ethanol yield (Kim and Dale 2004), the approximate ethanol production per hectare is calculated at around 1,250 l per season. Assuming a 0.5 kg CO_2-eq. reduction per litre ethanol, the estimated net emission reduction is 625 kg per hectare.

Cost Estimates for Rice Stubble and Straw Management Options

Cost estimates were based on the incremental differences between the baseline practice of incorporating stubble during land preparation and burning straw and other stubble-straw management options. Some of the relevant cost savings and secondary benefits were expected to be incurred or realised after around 5 years of continuous practice. Based on existing literature, the total cost per hectare was calculated for a 5-year period as shown in Table 5.4. For most of the options, the rice stubble and straw will be incorporated into the soil but will vary in form and timing; the cost analysis largely revolves around changes in labour costs and some material costs in the case of composting. The expected changes in labour use associated with the management option and prevailing wage rate at Php200 per man-day were based on results of the FGDs and household survey conducted for the study. In the economic analysis, 60 % of the market wage rate was used as the shadow wage rate.

Removal of stubble and straw from the field requires significant labour cost so that at current prices and based on existing practices, composting of both the straw and stubble entails the highest cost followed by the options where the straw will be composted and incorporated into the soil as compost (see Table 5.4). Based on the household survey, manual cutting of rice stubble takes 20–21 man-days per hectare depending on the season. Collecting and gathering of the cut rice stubble was estimated to take another 7–10 man-days. For collecting and gathering piled rice

Table 5.4 Estimated costs for each rice straw management option (Php ha^{-1} $year^{-1}$)

	Rice straw management option	Years 1–4			Year 5		
		WS	DS	Total	WS	DS	Total
M1	Late stubble incorporation and straw burning (baseline)	156	156	312	1,615	1,615	3,230
M2	Late stubble and straw incorporation	552	552	1,104	552	552	1,104
M3	Late stubble incorporation and straw removal for use as animal feed	876	756	1,632	2,335	2,215	4,550
M4	Early stubble and straw incorporation	552	552	1,104	552	552	1,104
M5	Late stubble incorporation and straw compost incorporation	3,134	1,729	4,863	3,134	1,729	4,863
M6	Early stubble incorporation and straw compost incorporation	3,134	1,729	4,863	3,134	1,729	4,863
M7	Stubble and straw composting and straw compost incorporation	10,654	7,188	17,842	10,654	7,188	17,842

Note: Details of calculation can be obtained from the authors straw and hauling it onto the roadside ('roadsiding'), farmers estimated this to take about 12 man-days per hectare during DS and 14 man-days during WS. Rapid composting was considered, where rice straw is composted in a designated area on farmers' fields using inoculants such as manure, effective organism activated solution (EMAS) or *Trichoderma* spp. An alternative, common to developed countries and some Southeast Asian countries, is the use of combine harvester and baling machines, but these are capital intensive and their use is still relatively unpopular.

Cost-Effectiveness Analysis of Rice Straw Management Options

Based on the estimates of GHG emission and potential abatement of GHG emission on farmers' fields from Table 5.3 and the estimated cost for each management option in Table 5.4, Table 5.5 presents abatement costs per ton CO_2-eq. From among the options that result in net reduction in incremental CO_2-eq., shifting from the current farmers' practice of late stubble incorporation or incorporating less than 30 days before cultivation and straw burning (M1) to early incorporation of both stubble and straw incorporation in soil more than 30 days before cultivation (M4) appears to be the most cost-effective with a negative abatement cost (net benefit) at Php21 or around US$0.50 per ton of CO_2-eq. reduction. Results also suggest that incorporating the stubble more than 1 month before cultivation and rapidly composting the straw and applying it back to the field (M6) is also a cost-effective option for farmers at around Php300/ton CO_2-eq. It significantly mitigates GHG emissions while improving the soil condition; thus, even with the additional labour cost of piling and composting, it is the next most cost-effective abatement option.

Incorporating both the stubble and straw less than 30 days before cultivation (M2), on the other hand, results in a slight net increase in emission. The increase in cost for the option is lower than the secondary benefit of savings from fertiliser given the time horizon. The amount of potential savings if a ton of CO_2-eq. is not emitted is very significant. Incorporating stubble and removing straw for use as animal feed (M3) will also result in a net increase in emissions, but the straw value as animal feed is very significant assuming rice straw can be sold at Php5/bundle of 5 kg. Stubble and straw removal and application as compost significantly reduce emissions, but the abatement cost is more than Php1000 per ton of CO_2-eq. which may not be affordable to farmers.

It was beyond the scope of the study to conduct a full-scale economic feasibility analysis of using rice straw for power generation and biofuel production which are potential uses of rice straw. However, based on reviewed literature, second-generation lignocellulosic technologies have considerably more potential for avoiding many of the GHG emission and other environmental shortfalls and

Table 5.5 Estimated abatement costs (Php/ton CO_2-eq.) by rice straw management option

No	Rice straw management option	Total emission (tons CO_{2e})	Abatement relative to baseline (tons CO_{2e}-eq/ha)	Incremental abatement cost (Php/ha)	Secondary benefit (Php/ha)	Abatement cost[a] (Php/ton CO_2-eq.)	Abatement cost[b] (US$/ton CO_{2e}-eq.)
M1	Late stubble incorporation and straw burning (baseline)	50.99					
M2	Late stubble and straw incorporation	51.01	−0.02	1,172	2,033		
M3	Late stubble incorporation and straw removal for use as animal feed	57.63	−6.64	5,341	18,122		
M4	Early stubble and straw incorporation	10.51	40.48	1,172	2,033	−21	−0.50
M5	Late stubble incorporation and straw compost incorporation	28.28	22.71	16,380	2,033	632	14.87
M6	Early stubble incorporation and straw compost incorporation	4.39	46.60	16,380	2,033	308	7.25
M7	Stubble and straw composting and straw compost incorporation	−4.91	55.90	68,892	2,033	1,196	28.14

Note: Details of calculation can be obtained from the authors
[a]Values for M2 and M3 were not included since there is no net abatement
[b]1US$ = 42.50Php – average for 2011 (Source: www.nscb.gov.ph)

perform better in terms of energy efficiency (CGIAR Science Council 2008). The same report, however, stated that cost-effective second-generation biofuels are at least 10 years down the road and bio-refineries and bio-based economies are even further afield. Gadde et al. (2009) studied the overall potential and limitations of energy contribution and greenhouse gas mitigation for rice straw as a renewable energy source in India, Thailand and the Philippines. They found that the energy potential from rice straw in theory was different from the realisable energy due to the fact that residue collection efficiency or capacity and its transportation were challenging. Delivand et al.'s (2011) study on the feasibility of using rice straw residues for power generation in Thailand concluded that straw-based combustion facilities are financially feasible and profitable if the capacity of the power plant is 8 MWe or greater. In order to ensure secure fuel supply, they report that smaller-scale power plants, i.e. 8 and 10 MWe, are more practicable.

On the part of Filipino rice farmers, if the demand for rice straw is created through its use as raw material for power or bioethanol production plants, they may be able to supply the straw with a direct cost of around Php 5,200/ha for two seasons or Php 1.20/kg of straw considering the labour cost of gathering and moving to a storage area. Removing even the stubble, on the other hand, will cost an additional Php 8,000/ha so that the rice straw cost will more than double at approximately Php 3/kg loose straw.

Factors Explaining Farmers' Choices of Rice Straw Management Options

The previous analysis attempted to explore the potential of selected rice stubble and straw management practices that can be implemented by rice farmers in order to reduce the incremental non-CO_2 GHG emissions and estimated the costs associated with them. This section uses farm survey data in four major rice-producing provinces to ascertain factors explaining actual farmers' choices of straw management options. Since there are some options with no adopters, the choices are generalised to straw burning, incorporation and removal options.

Table 5.6 shows the results obtained from the estimated multinomial logit model, reported as relative risk ratios. The model is statistically significant based on the likelihood ratio chi-square criteria and overall correctly predicts 76 % of respondents in terms of their choice of rice straw management practice.

While season did not appear to be a significant factor affecting choice of straw management in the surveyed provinces, farm type was a significant factor with a 0.51 relative risk ratio. This means that if a rainfed farmer becomes an irrigated farmer, the ratio of the probability for him to choose to incorporate straw in soil relative to the probability to practise burning is expected to decrease by a factor of 0.51 given that the variables in the model are held constant. Irrigated farmers are also less likely to remove rice straw from the field as shown by the highly

Table 5.6 Results of multinomial logit model (baseline category: straw burning)

	Straw incorporation			Straw removal		
Variable	RRR	SE (RRR)	RRR	SE (RRR)		
Season dummy (1 – dry season)	1.35	0.33		1.02	0.32	
Farm type dummy (1– irrigated)	0.51	0.18	*	0.23	0.10	***
North Cotabato dummy	2.20	0.94	*	0.03	0.02	***
Leyte dummy	16.51	7.50	***	0.46	0.33	
Ilocos Norte dummy	5.11	2.29	***	5.44	2.84	***
Attendance in training (1 – attended training)	1.60	0.42	*	0.90	0.32	
Age	1.01	0.01		1.00	0.01	
Educational attainment	0.95	0.04		1.04	0.06	
No. of household members with age >13	1.25	0.10	***	1.38	0.14	***
Income in non-rice farming	1.00	0.00		1.00	0.00	***
Total area cultivated	0.97	0.07		0.67	0.10	***
Cow ownership (1 – owner)	2.50	0.91	***	4.41	1.78	***
Tenure status (1 – owner)	1.51	0.40		1.77	0.61	*
Distance from farm to house	0.87	0.07	*	0.79	0.11	*
Yield	1.00	0.07		1.07	0.09	
Perceptions						
Negative impacts of open-field burning	1.48	0.24	**	0.70	0.13	**
Positive effects of rice straw incorporation	1.78	0.41	***	1.08	0.31	
Negative effects of rice straw incorporation	0.72	0.11	**	0.86	0.17	
Awareness of environmental regulations	2.23	0.51	***	2.33	0.64	***
Attitudes towards incentives/market	0.36	0.05	***	0.37	0.07	***
Burning ordinance in province	1.17	0.32		0.47	0.18	**
Solid waste management programme in province	1.23	0.34		3.23	1.58	**

No. of observations = 687; *** $p < 0.01$; **$p < 0.05$; *$p < 0.10$
Log-likelihood: −390.81
Pseudo-R^2: 0.41

significant negative coefficient. A possible explanation is that intensive rice-rice cropping is largely practised in irrigated farms in the country so that the turnaround or interval period between rice crops is shorter and farmers have to dispose rice straw and stubbles more quickly. Flinn and Mariano (1984) in studying straw management practices in irrigated and rainfed environments concluded that stacking of rice straw for livestock consumption is higher in rainfed compared with irrigated areas. In relation to this, the model also shows that cow ownership is a significant variable related to choosing straw incorporation and straw removal over burning.

Relative to the largest rice-producing province of Nueva Ecija, farmers in North Cotabato, Leyte and Ilocos Norte are more likely to incorporate straw than burn when all other factors are held constant. For Leyte, for example, the risk for farmers incorporating relative to burning is higher by a factor of 17 given that other factors in the model are constant. For Ilocos Norte, the relative risk of farmers removing straw from the field relative to burning is higher by a factor of 5.

Considering economic factors, an increase in the number of adult household members who can be proxy for available family labour is positively related to choice of straw incorporation or straw removal relative to straw burning. This is consistent with the descriptive results that straw incorporation and removal are much more labour intensive than straw burning. Related to this, the total area cultivated is also significantly related with the choice of straw removal over straw burning possibly because the larger the total area cultivated, the more labour required in removing straw from the field. This result is consistent with the result of a binary analysis conducted using data from a separate national survey. Income from non-rice farming which can also be a proxy for household engagement in vegetable or other crop farming is a highly significant variable related to rice straw removal relative to burning. Rice straw has value as mulch to households engaged in non-rice farming especially onion and garlic production.

The increased distance from house to farm was found to be negatively related with the log odds of choosing straw incorporation and straw removal relative to burning. A possible explanation is the higher cost of collection and transportation when the farm is located farther from the house where they usually stack the rice straw for livestock feed or other purposes.

In terms of perception-related variables, the more farmers agreed with the statements on the negative effects of open-field burning on global warming and air pollution, the higher the relative risk ratio of choosing to incorporate straw relative to burning straw. An inconsistent result is that agreement with the statements on the adverse effects of open-field burning is negatively related to the choice of straw removal over burning. A possible explanation is that even while they agree with the negative impacts on air quality and climate, the additional cost of straw removal is much higher than their willingness to mitigate these perceived negative impacts. Also, a higher awareness of environmental regulations and policies is significantly and positively related to the choice of straw incorporation or straw removal relative to burning.

On the other hand, for the attitudinal statements on possible behaviour given incentives or increased demand of rice straw, farmers who require incentives are less inclined to practise straw incorporation or straw removal relative to burning unless such incentives are given. Finally, the presence or absence of a provincial ordinance against rice straw burning appears to be insignificantly related to the choice of farmers to practise straw incorporation; respondents in provinces with an ordinance banning rice straw burning are less likely to remove their rice straw. This result is probably because in Leyte province where there is a specific ordinance against rice straw burning, the more common practice is straw incorporation. The implementation of a provincial solid waste management programme is significantly and positively related to the practice of straw removal relative to straw burning.

Conclusions and Recommendations

This research project was generally aimed at assessing the environmental consequences of rice straw burning and other straw management practices and evaluating the cost-effectiveness and adoption of selected rice straw management alternatives. Based on the emission inventory considering the incremental GHG emissions from rice straw management practices, the estimated contribution of rice residues is around 16 M tons of CO_2-eq. considering only CH_4 and N_2O emissions. This is approximately 8 % of the total projected CO2-eq. emissions for 2008 based on the Philippines' first initial national communication on climate change. The current practice of incorporating rice straw/stubble into soil during land preparation in wet or flooded conditions less than a month before transplanting is the largest contributory rice residue management practice on a per year basis not considering potential long-term impacts.

On a per hectare basis calculated for a 5-year period based on IPCC 2006 Guidelines, compiled factors from literature and various assumptions, the total estimated emission level, considering only CH_4 and N_2O gases, is around 51 tons CO_2-eq. for the baseline scenario. This is not very different if the practice changes from straw burning to straw incorporation less than 30 days before crop establishment. Aside from GHG, rice straw burning, however, emits particulates that are known to be harmful to human health. Changing the timing of straw incorporation from less than 30 days to more than 30 days before crop establishment will significantly reduce the incremental GHG emissions in paddy fields due to straw management by around 80 %.

Economic analysis from the point of view of rice farmers indicated that merely shifting from incorporating stubble before transplanting and straw burning to incorporating both stubble and straw in the soil over 30 days before crop establishment appears to be the most cost-effective option with a negative abatement cost (i.e. benefit) of Php 21 (US$ 0.50) per ton CO_2-eq. reduction. Incorporating both rice stubble and straw less than a month before cultivation, on the other hand, appears to result in a slight net increase in emissions. Rapid composting and incorporating the rice straw compost in the field entail significantly higher additional costs, but significantly mitigate GHG emissions; hence, it is the next most cost-effective option. While a full-scale cost-effectiveness analysis of using rice straw for power generation and bioethanol production was not included in this study due to data limitations, creating higher rice straw demand given the same supply will result in higher economic value for rice straw which is favourable for rice-based farmers. Further study on the technical and economic feasibility of using rice straw for power generation and bioethanol production and the consequent GHG emissions from these options in the case of the Philippines is recommended.

Also, there is evident uncertainty about the rate of growth of emissions, their general effects and their local effects (GEF 1992). The results of this study, particularly on GHG emissions, are only indicative, and the cost-effectiveness analysis must be interpreted in relative terms. For rice-based farmers, there are other mitigation options such as water management and tillage options. Since affordability of technologies is a prime issue in the mitigation of GHG emissions, further study of the economics of these other mitigation options relative and complementary to rice straw management practices would provide broader information useful for farmers, policymakers and other rice stakeholders.

On the determinants of rice straw management practice or why farmers choose to burn, incorporate or remove rice straw, a mix of socio-economic, farm and awareness and attitude variables are prominent. Continually providing training on rice production to farmers is a particular policy direction that significantly relates to choice of straw incorporation over straw burning, as shown by the significantly positive coefficient of the training variable and perceptions of the benefits of straw incorporation. Increasing the demand for rice straw for other uses such as mulch is also another significant factor, as shown by the significance of non-rice farm income used as proxy for households engaged in vegetable and other non-rice farming.

While awareness of the environmental impacts of rice straw burning appears to be a significant positive factor for choosing straw incorporation over straw burning, farmers' choice of straw removal relative to burning may not be affected in the same manner owing to the significantly larger cost of straw removal. Options for reducing the cost of collection and transportation of rice straw such as mechanisation of harvesting and baling activities may reduce costs in the long run and increase the probability of the adoption of straw removal options including composting. Awareness of environmental laws and regulations appears to be a consistent positive factor that can increase the relative risk of choosing straw incorporation and removal over burning, so that increasing information campaigns and drives regarding these laws and strict implementation of sanctions are also recommended.

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