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Field Balance Estimation of Rice Straw Generation, Biomass Partitioning and Greenhouse Gas Emissions from In-field Burning of Rice Straw in Enugu State, Nigeria

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ABSTRACT

Data on empirical, field-based rice straw biomass generation, partitioning and global warming potentials under Nigerian smallholder rice farming conditions are extremely limited. This research estimated the quantity of harvestable and recoverable rice straw based on Enugu State farmer's harvesting practice and the potential greenhouse gas emissions from burning them in- field, using wind tunnel chamber. The state average straw yield was 7.53 t ha^{-1}, and rough and milled grain yield of 8.09 and 4.58 t ha^{-1}, respectively Total biomass varied significantly among the five prominent rice growing areas in the state. The fertilizing value (N, P_2O_5, K_2O) content of fresh straw was 0.96%, 0.26 and 2.09 gKg^{-1} respectively. That of the ash was 0%, 1.36 and 10.45 gKg^{-1}. They did not differ significantly among the locations. Farmers in the area burn their rice straw at a moisture content range of 16.5% at Adani to 29.8% at Amaechi Idodo, with state average of 22.5%. In Enugu state, the methane (CH_4, g/kg) and nitrous oxide (N_2O, g/kg) emission factors (EF) and global warming potential GWP_{100} (CO_2-eq/kg) from in- field burning of rice straw were 5.096, 0.142 and 0.2, respectively. By straw burning, for every one kilogram of milled rice produced in the state, there is a potential to warm the globe by 0.2 (CO_2-eq/kg). Therefore, the environmental footprint of burning rice straw in the state should be a source of concern as the farmers usually burn the straw immediately after harvest to plant their late season cucumber, okra and vegetables.

Keywords: *Rice straw, biomass partitioning, greenhouse gas emission, wind tunnel chamber, Enugu State*

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INTRODUCTION

Rice is grown in all agro-ecological zones of Nigeria, from the mangrove swamps of the Niger Delta to the dry zones of the Sahel in the North by 1.43 million farmers on a total land area of 3.2 million hectares (Mba *et al*. 2021). Its intensification has been associated with the use of high-yielding and short-duration varieties with shorter turnaround time between crops in multi-cropping systems. After rice harvest, a swath of loose straw is either scattered in the field or accumulated in piles and may impede succeeding land preparation, crop establishment, and early crop growth if left in the field, collecting and transporting them after harvest is difficult, laborious, and costly. Most farmers then, resort to burning, to quickly remove the biomass and prepare the field for the next crop. This practice results to loss of potential biomass energy (Tabil *et al.* 2011) and have negative long-term impacts on soil quality, SOC sequestration and contributes to the emission of greenhouse gas (GHG) which poses health and environmental hazards (Allen *et al.* 2020). It also depletes valuable soil nutrients such as nitrogen, phosphorus, and potassium (Oanh *et al.,* 2011).

Rice straw has vital economic and soil ameliorating potentials. Subhendu *et al*. (2020) noted that on average, rice straw contains 0.7% N, 0.23% P and 1.75% K. The total biomass is dependent on numerous factors such as varieties, _soil and_nutrient management practices, weather, etc. and as such are highly variable and site specific (Clay *et al,* 2019). However, the amount taken off the field depends mainly on the height of the stubble left in the field (Van Hung *et al.*, 2020) which are dependent on the prevailing practice among rural farmers who rarely mechanize their harvesting.

Matias *et al. (*2019) carried out a detailed assessment o**f** rice biomass yield, partitioning and straw collection in Spain and obtained **a**n average straw yield of 9.7 t·ha^{-1}. Straw yield, biomass partitioning indices and fiber composition varied significantly according to rice variety. Straw to grain ratio and harvest index were 1.00 and 0.50 on average for rough grain, and 1.25 and 0.41 for husked grain**.** Biomass partitioning indices significantly correlated with grain yield.

Fan *et al.* (2017) noted that quantification of rice straw generation at regional scale represents an essential step towards designing effective policies and management practices that can contribute to mitigating GHGe. Biomass portioning approaches such as residue-to-product ratios (RPR}. Harvest index (HI) or straw/grain (S/G) ratio, are widely used to estimate the crop residue from data on harvested yield. At experimental level, all biomass residue is harvested and collected. However, at farm level practice, its use is constrained by some techno-economic and environmental factors as the amount generated in a place is often influenced by harvestable and recoverable quantity. Therefore, to obtain a valid and reliable estimate, a field scale–site specific evaluation that captures the farmer's prevalent practices is required. Data on field – level rice straw generation in smallholder farms in Nigeria are extremely sparse. Among smallholder farmers in Enugu State, mature rice plants are hand-reaped and put into a rice-threshing apparatus or piled up and beaten with long stick. Then, the straw is extracted and piled in a stack for burning. These practices give rise to varying straw burning conditions (quantities of straw in a stack and moisture content). Nowadays, one of the main world issues is how to reduce the greenhouse gases emissions (GHGe) in order to mitigate the climate change and ensure sustainable economic growth. It becomes necessary to estimate the contribution of rice straw burning to greenhouse gases emissions (GHGe) and global warming potential. Hayashi *et al.* (2014) noted that straw burning conditions need to be taken into account when considering regional GHG emissions. Hironori *et al* (2015) studied the effect of straw burning conditions (moisture of rice straw and size of rice straw stacks) on the amount of each gas emitted during straw burning. They reported that factors that increase moisture content of rice straw can cause smoldering combustion in small straw stacks or when straw is scattered on the ground, thereby inhibiting N_2O emissions but enhancing CO, CH_4 and non-methane volatile organic carbon emissions (NMVOC). This, they attributed to the slow and inefficient burning that was observed from the smaller straw stacks with higher moisture content. These results suggest that burning method and straw burning conditions influence the magnitudes of gas and particle emissions during open burning (Hays *et al*. 2005). These conditions are however influenced by the farmer's practice especially where little or no mechanized harvesting takes place. Therefore, quantifying GHG emissions from indigenous straw burning as practiced by farmers offer better and more reliable estimate.

In this study, only methane (CH_4) and nitrous oxide (N_2O) gases were estimated in accordance with Gadde *et al.,* (2009) assertion that the greenhouse gases of importance are N_2O and CH_4, which contribute to global warming and climate change as CO_2 emitted from biomass burning is considered to have a neutral effect due to its photosynthetic uptake during plant growth. Nigeria lacks empirical, field-based EF measurements. Several works relied on IPCC defaults (Ogbanje and Okpe, 2020)**.**

Thus, the aim of this work was to conduct a detailed farm level assessment of rice straw biomass yield, partitioning and quantification of greenhouse gas (methane and nitrous oxide) emissions from burning rice straw using wind tunnel chamber in smallholder farms at five prominent rice growing areas in Enugu State, Nigeria**.**

The specific objectives are:

(i) to estimate at field – level, the amount of rice straw generated and biomass partitions in Enugu State

(ii) To quantify greenhouse gas (methane and nitrous oxide) emissions from burning rice straw in smallholder

Table 1: Key characteristics of the major rice cultivation areas in Enugu state.

Location	Adani	Akpoga Nike	Amaechi Idodo	Ibite Olo	Oduma
Topography	Low land Plains	Low land	Low Land Plains	Low Land Plains	Low Land Plains
Latitude	6.739o N	6.833o N	6.153o N	6.453o N	6.153o N
Longitude	7.011o E	7.617o E	7.327o E	7.117o E	7.327o E
Main Soil Type	Sandy Clay	Limited soil data	Limited soil data	Limited soil data	Limited soil data
Mean Temperature	25 – 37o C	28.27^{o} C	18 – 32o C	Limited soil data	18 – 32^{o} C
Mean Precipitation	1700mm	1585mm	1650mm	2281mm	2185mm

farms at five prominent rice growing areas using a semi-controlled experimental approach (wind-tunnel system) that provide conditions that closely simulate natural field burning.

MATERIAL AND METHODS

Description of the Study Area

The research was carried out in Enugu State, located in the derived guinea savannah vegetation of southeastern Nigeria. A large percentage of the populace are mainly farmers that specializes in arable crops farming, however, large scale rice production is restricted to some areas notably Adani, Ugboka, Akpoga Nike, Ehamufu, Ibete Olo, Umulokpa, Oduma etc. Five of these prominent rice growing areas were purposively selected for this study based on information obtained from Enugu State Agricultural Development Program and the State Ministry of Agriculture. In each location, an inventory of rice farmers was conducted for purposes of identification and subsequent sampling. The key characteristics of the selected areas (Adani, Akpoga Nike. Amaechi Idodo. Ibite Olo, Oduma) are shown in (Table 1).

Determination of rice straw yield (S) per hectare and biomass partitioning indices (BPI) by Field balances

In each location (town), two farmers' fields were randomly selected in November. At each field, one-hectare plot, grown to IR 1416 rice variety was chosen and divided into four, each measuring 2,500m^{2}. One portion was randomly chosen ensuring that the plots were representative of field variability. Aboveground biomass (B) of the rice in the chosen plots were harvested by hand in accordance with the farmers' practice (cutting height and stacking. On drying, the dry biomass weight was collected and the rough rice grains were separated mechanically from the rest of the biomass. Using a thresher and the weight recorded. The rough rice was later separated into husk and milled grain by milling. Each component was weighed, expressed on dry weight basis and recorded.
The following BPI were determined:

Rice straw yield (tha^{-1})

RSY = B – RG
Where,
RSY = Rice straw yield (tha^{-1}); B = Total aboveground biomass (tha^{-1}); RG = rough grain yield (tha^{-1})

Rice Straw – Rough Grain Ratio

RSRGR = RS /RG
Where,
RSGR = Rice Straw – Rough Grain Ratio
RS = Dry weight of rice straw yield (tha^{-1}); RG = Dry weight of rough rice grain yield (tha^{-1})

Harvest index for rice straw

HI = 1/ (1 + RSGR)

Where,
HI = Harvest index for straw; RSGR = Rice Straw – Grain Ratio

Rough Rice Grain – Milled Grain Ratio

RRGMGR = RRG /MGR

Where,
RRGMGR = Rice Rough Grain – Milled Grain Ratio, RRG = Rice Rough Grain; MGR = Milled Grain Ratio

Harvest index for Milled grain

HIMG= 1/ (1 + RRGMGR)

Where,
HIMG = Harvest index for Milled grain; RRGMGR = Rice Rough Grain – Milled Grain Ratio

Determination of NPK content (fertilizer value) of the rice straw

Collected straw samples were cut into small pieces, air dried to constant weight at 60 –70^{o} C, ground and sieved through 4 mm nylon sieve for chemical analysis. The nitrogen content was determined using a semi-micro Kjeldahl procedure (steam distilling unit UDK132); phosphorus was determined by applying the vanado molybdophosphoric acid method (H_2SO_4:HNO_3 with the ratio of 1:1) and a spectrophotometer (Spectro UV–Vis double beam UDV-3500); and potassium, using a photoelectric flame photometer (Corning 410-UK; H_2SO4:

HNO_3 with the ratio of 1:1). Based on the analysis, the mean N, P, K nutrients contained in the fresh and rice straw ashes were analyzed.

Estimation of emission potentials of rice straw burning in accordance with farmer's practice (stacking density and moisture content) using wind-tunnel chamber

Experimental setup

The experiment was setup in accordance with the method described by Kajima *et al.* (2001). After harvest**,** a flat cleared area in the open rice field was selected to minimize airflow disruption. The wind-tunnel chamber (4.5 m wide × 15 m long × 5 m high), constructed from heat-resistant galvanized iron sheets coated with zinc and oxide primer as reported by Miura and Kanno (1997). The chamber was equipped with an electric fan, attached at a height of 3.2m on the outlet to generate unidirectional airflow from the inlet (upwind) to the outlet (downwind). A gas sampling tube was attached to the wall opposite the fan blades so that air will be collected before been discharged through the fan. A 3D diagram of the chamber is shown in (Figure 1).

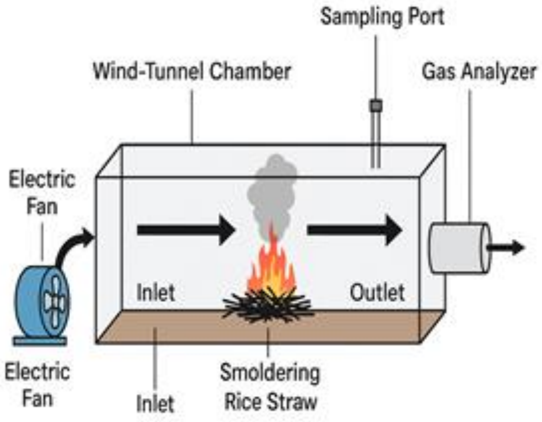

Figure 1. A wind - tunnel chamber for estimating the emissions in open burning of rice straw

Rice Straw Preparation and Burning

In each location, two heaps of stacked rice straw as left by the farmers in the sampled plots were chosen and weighed separately. Similarly, sub -samples of the straw were collected for determination of moisture content by oven drying at 70°C for 24 hours. The wind tunnel was set up by manually piling up the weighed heap of rice straw at the center of the burning tray. Then, the tunnel was sealed at ground contact using sandbags to minimize leakage. Air flow rate of $0.5 ms^{-1}$ in accordance with IPCC recommended protocols for combustion chambers replicating open burning condition were maintained. Environmental conditions, including ambient temperature, relative humidity, and wind speed, were recorded during the experiment. Burns were conducted during low wind conditions with ambient humidity below 70%. After burning, the rice straw-ash was collected, and its fertilizing value (NPK) determined.

Gas Sampling and Analysis

Gas samples were collected simultaneously from the inlet and outlet ports of the tunnel during burning. At the inlet, ambient air samples were collected using 100ml plastic syringes. While, 500ml of air was collected at the outlet. Sampling was conducted at 5-minute intervals throughout the combustion period (15–30 minutes). Air samples were drawn into 5 L Tedlar bags. A gas chromatograph (SRI GC = 8610C) equipped with flame – ionization detector (FID) and electron – capture detector (ECD) was used for the analysis of CH_4 and N_2O, respectively. The temperatures of FID and ECD were 330 and 350^{o} C respectively while the column temperature was set at 70^{o} C. The carrier gas used was nitrogen.

Emission Calculations

The concentration difference between outlet and inlet air samples was used to determine emission rates:

$$\Delta C = Cout - Cin$$

Where:
ΔC = concentration difference**;** Cout = concentration at outlet (ppm or ppb)**;** C in = concentration at inlet (background)
The emission rate (E) was calculated as:

$$E = \Delta C \times Q$$

Where:
E = emission rate (mg/s); Q = airflow rate through the tunnel (m^3/s); ppm = part per million; ppb = part per billion
The emission factor (EF) was then derived by normalizing the total mass emitted to the dry weight of straw burned:
$EF_{CH_4 \text{ or } N_2O} =$ Total Emission/ Weight of Straw burnt (g CH_4 or mg N_2O/kg straw)

The emission data were averaged across replicates and locations. The results were compared with IPCC default emission factors and literature values.

Calculation of Global Warning Potentials (GWP) of the rice straw

To determine CH_4 and N_2O species contribution to global warming, the total emissions of CH_4 and N_2O from burning the rice straw were converted to CO_2 equivalent, on a mass

Table 2: Rice biomass portioning according to location

Location	Feature	Total Biomass (t ha-1)	Straw Yield (t-ha-1)	Rough grain (t ha-1)	Husk (t-ha-1)	Milled grain (t ha-1)	Straw/Rough grain ratio	Milled grain/ Husk ratio	Rough grain / harvest index
Adani	Mean	14.50	6. 28	7.76	1.57	6.19	0.85	3.89	0.53
	SD	0.990	0.488	2.185	0.156	2.029	0.303	0.907	0.114
Amaechi	Mean	19.25	9.73	9.61	1.58	8.03	1.01	5.65	0.50
Idodo	SD	1.909	1.103	0.679	0.707	0.28	0.403	2.548	0.014
Akpoga	Mean	15.15	7.51	7.58	1.41	6.17	0.99	4.46	0.50
Nike	SD	1.202	0.509	0.602	0.178	0.778	0.011	1.115	0.000
Ibite Olo	Mean	13.75	7.160	6.39	1.45	4.94	1.12	3.55	0.465
	SD	1.343	0.891	0.523	0.311	0.834	0.048	1.337	0.007
Oduma	Mean	19.30	6.98	9.00	1.45	7.56	0.75	5.34	0.47
	SD	2.262	3.725	1.160	0.374	0.785	0.316	0.841	0.005
Enugu	Mean	16.39	7.53	8.09	1.49	6.58	0.95	4.58	0.47
State	SD	2.798	1.829	1.491	0.306	1.421	0.199	1.388	0.047
Sign. Level	P<0.05	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

n.s = Non-significant at 0.05 level of probability, SD = Standard Deviation. Within a column, numbers followed by the same letters are not significantly different by Ducan New Multiple Range Test at 0.05 level.

basis,27.2 for CH_4 and 273 for N_2O (IPCC, 2023).

CO_2 equivalent = CH_4 emissions (kg) x 27.2 + N_2O emissions (kg) x 273

Data Analysis

Measured and calculated data were subjected to descriptive and inferential statistics of analysis of variance (ANOVA). In cases when F ratio was significant ($P < 0.05$), Duncan New Multiple Range Test was utilized for mean comparison. The SPSS Statistics 19 software (IBM) was used for this analysis.

RESULTS AND DISCUSSION

Rice biomass portioning according to location

The rice straw generation potential and biomass partitioning in the state were estimated based on harvestable and collectable quantities as detected by farmer's harvesting practices. The total biomass production was 16.39(±2.798) t-ha-^{1} (Table 2). It differed significantly ($p < 0.05$) across the five locations studied. The highest value of 19.30 t-ha-^{1} was obtained at Oduma, which did not differ significantly from that of Amaechi Idodo and Akpoga Nike. Least value (13.75 t-ha-^{1}) was obtained at Ibite Olo but was not different from that of Adani and Akpoga Nike. Total harvested and recovered straw in the state was 7.53 (±1.829) t ha-^{1,} although, it did not differ significantly across the five locations. Rice rough grain yield ranged from 6.39 to 9.61 t-ha-^{1} in Ibite Olo and Amechi Idodo, respectively with the state average as 8.09 t-ha-^{1}. The state average husk, milled grain, straw/rough grain ratio, milled grain/husk ratio and rough grain/ harvest index were, 1.49, 6.58, 0.95, 4.58 and 0.47, respectively. They however, did not differ significantly across the five locations studied. The straw generation values may be assumed as the quantity of rice straw subject to open field burning as the stubbles and uncollectable ones were not included in the estimate.

The state average straw yield of 7.53 t·ha^{-1} was less than 11.8 and 9.7 tha^{-1} reported by Osorio *et al*. (2007) and Matías *et al*. (2019), respectively. The non-significant difference observed in most of the partitioning values among the locations may be attributed to common rice variety assessed, similar climatic and soil conditions as they are all in low land areas with similar rainfall regime, (Table1).

Singh *et al*., (2013) noted that among other factors affecting rice straw yields and biomass partitioning (e.g., harvest index = grain yield / total above-ground biomass), harvesting method plays a significant role. Manual Harvesting (with sickle) as is practiced by these farmers results in higher straw recovery (minimal shattering or loss). However, Veerangouda *et al. (*2023) demonstrated that using modern mechanical harvesters like mini-combines and reapers reduced grain losses (2.1–3.6%) compared to manual harvesting (6.4%) in rice. The implication is that mechanical harvesting may leave more intact straw but can affect partitioning ratios by slightly increasing residual straw. In contrary, Senanayake *et al.* (2024**)** in Sri Lanka compared manual, reaper, and combine systems, revealing that mechanical harvesting (combines or reapers) improves efficiency but often leaves chopped straw in the field, reducing recoverable straw and potentially biasing harvest index estimates. This underscores the need for location and practice – specific estimates. In Nigerian contexts, rice **s**traw yield under integrated nutrient management reached up to ~14 t/ha and Harvest Index of 0.5 and 0.3 for modern and traditional varieties, respectively (Danbaba *et al.* (2018), Iyanda *et al. (*2024).

Fertilizing value of fresh rice straw and ash

Table 3 shows the average N, P_2O_5, and K_2O contents of fresh rice straw across different locations and the state average. The state average was 0.9 %, 0.26 mgKg-1 and 2.09 mgkg^{-1} respectively. While, that of rice straw ash were 0 %,1.36 and 10.45 mgkg^{-1}, respectively. All of them did not differ significantly across the different locations in the

Table 3: Fertilizing value of fresh rice straw and ash.

Location	Feature	Fresh Straw N	Fresh Straw P2O5	Fresh Straw K2O	Straw Ash P2O5	Straw Ash K2O
Adani	Mean	0.97	0.24	2.11	1.45	11.03
	SD	0.190	0.109	0.233	0.327	1.168
Amaechi Idodo	Mean	1.04	0.24	2.39	1.40	9.43
	SD	0.132	0.079	0.520	0.192	1.717
Akpoga Nike	Mean	0.86	0.25	2.64	1.24	9.67
	SD	0.240	0.320	1.252	0.229	2.950
Ibite Olo	Mean	0.92	0.28	1.51	1.23	11.12
	SD	0.170	0.300	0.256	0.257	0.848
Oduma	Mean	1.03	0.28	1.81	1.48	11.00
	SD	0.216	0.557	0.330	0.301	0.999
Enugu State	Mean	0.96	0.26	2.09	1.36	10.45
	SD	0.178	0.049	0.686	0.250	1.641
Sign. Level	P<0.05	n.s	n.s	n.s	n.s	n.s

SD. = Standard Deviation, n.s = Non-significant at 0.05 level of probability

state. Okwulehie and Okoro (2014) reported that Oryza sativa straw contains, Ash: ~3.83%, Potassium (K): ~352.3 mg/100 phosphorus (P): ~158.1 mg/100 g and Calcium (Ca): ~203.1 mg/100 g. While, Kwaido, Saleh and Nasiru (2024) reported fresh straw composition prior to treatment to be Crude Protein: 23.6–32.6% (indicative of N), Phosphorus (P): 11.95–12.85% (noting high values likely from treatment) and Calcium (Ca): 1.23–2.36%. Liu et al. (2022**)** reports typical nutrients across rice straw globally: approximately 2.85% N**,** 0.46% P**,** and 6.67% K (on an air-dried basis). The nutrient composition of straw has implications for how it can be used (Dobberman and Fairhurst , 2000). They noted that straw contains a lot of K as observed in this study. Given the high level concentration of potassium in the ash, continual burning of straw as is common in the area will result in soil K deficiencies. The high phosphorus and potassium values indicate significant nutrient potential if used as soil amendments or animal feed.

Greenhouse Emissions and Global Warming Potentials

In this study, only methane (CH_4) and nitrous oxide (N_2O) emissions from rice straw burning were estimated. The emission properties (emission difference, emission rate and emission factors were estimated from the quantity of straw generated at their different field moisture content. For clarity, emission difference means variation in gas concentrations (e.g., ppm or mg/m³) between inlet and outlet air during combustion while, emission rate is mass of gas emitted per unit time (e.g., g/min or mg/s). On the other hand, **e**mission factor is mass of gas emitted per mass of straw burnt (e.g., g CH_4/kg straw). The quantity of straw burnt and stacking density did not differ significantly among the locations. (Table 4). This may be attributed to similar harvesting practices, and re- packing in the wind tunnel chamber. The moisture content (MC) of the rice straw at burning ranged from 16.5% at Adani to 29.8% at Amaechi Idodo, with the state mean value of 22.5%. The MC at Amaechi Idodo (29.8%) did not differ significantly from that of Akpoga Nike (24.9%) and Oduma (23.0%). The observed differences among the location may be attributed to differences in crop maturity, climatic and soil conditions at harvest. The straw generally was considered to be wet. The high moisture content of the straw caused smoldering during burning and may have increased the CH_4 emission (Andreae and Merlet, 2001; Gadde et al., 2009**;** Nishanth and Praseed, 2014).

At Adani, the emission difference of both CH_4 and N_2O were the least and differed significantly from that of other locations. The state average was 1.557 and 0.016 gkg^{-1}, respectively. The locations also differed significantly in their CH_4 and N_2O Emission Factors. CH_4 Emission Factor ranged from 1.555 at Adani to 6.235 g kg $straw^{-1}$ at Oduma, while that of N_2O ranged from 0.065 at Adani to 0.218 g kg $straw^{-1}$) at Amechi Idodo. Enugu state CH_4 EF (g/kg), N_2O EF (g/kg) and GWP_{100} (CO_2-eq/kg) were 5.096, 0.142 and 0.2, respectively. The CH_4 EF (g/kg value was far higher than that of the average reported in India, China and Thailand but the N_2O EF (g/kg value was lower (Gadde *et al.* 2009). The high CH_4 EF (g/kg) did not translate into high global warming potential as it has lower contribution than N_2O EF (g/kg) which was low in this study. Romasanta *et al.* (2017) using both combustion chamber and field-based measurements in Southeast Asia obtained CH_4 Emission Factor (EF)- 4.51 g/kg DM, N_2O Emission Factor (EF) -0.069 g/kg DM and GWP from Burning (CO_2-eq/ha) was 4,913 kg CO_2-eq/ha. However, most country averages did not specify emission measurement techniques (static chamber, wind tunnel, eddy covariance) used, and that may affect recorded emission rates and emission factors.

Table 4: Greenhouse emission and global warming potential

Location	Feature	WSB (Kg)	SD (kgm-3)	MC = (%)	ED CH4 (gkg-1)	ED N2O (mgkg-1)	ER CH4 (mgs-1)	ER N2O (mgs-1)	EF CH4 (g kg straw-1)	EF N2O (mg kg straw-1)	GWP (kgCO2eqKg1 of straw burned)
Adani	Mean	26.75	0.40	16.5b	0.475b	0.007b	1.580	0.218	1.555b	0.065b	0.060b
	SD	15.67	0.234	3.685	0.3403	0.0022	1.4452	0.3551	1.1149	0.0195	0.0355
Amaechi	Mean	31.50	0.47	29.8a	1.808a	0.024a	0.905	0.123	5.915a	0.218a	0.220a
Idodo	SD	7.506	0.112	8.394	0.5467	0.0120	0.2752	0.0602	1.7864	0.1073	0.0731
Akpoga	Mean	32.50	0.48	24.9ab	1.830a	0.020ab	0.963	0.103	5.990a	0.179ab	0.272a
Nike	SD	10.66	0.158	5.971	1.0873	0.0103	0.4714	0.0532	3.5600	0.0926	0.0237
Ibite Olo	Mean	30.25	0.45	17.2b	1.767a	0.009b	0.885	0.045	5.785a	0.077b	0.232a
	SD	19.34	0.153	3.335	1.1771	0.0037	0.5864	0.0192	3.8552	0.0333	0.0505
Oduma	Mean	30.25	0.45	24.3ab	1.905a	0.019ab	0.953	0.280	6.235a	0.171ab	0.216s
	SD	5.909	0.087	4.349	0.3078	0.0110	0.1539	0.4138	1.0047	0.0984	0.0396
Enugu	Mean	30.25	0.45	22.5	1.557	0.016	1.057	0.154	5.096	0.142	0.200
State	SD	9.591	0.143	7.078	0.8922	0.0104	0.7126	0.2356	2.9206	0.0936	0.0860
Sign. Level	P<0.05	n.s.	n.s.	*	*	*	n.s.	n.s.	*	*	*

SD. = Standard Deviation, WSB = Weight of Straw Burnt, SD = Stacking Density, MC = Moisture Content, ED = Emission Difference, ER = Emission Rate, EF = Emission Factor, GWP = Global Warming Potential, n.s = Non-significant at 0.05 level of probability, within a column, numbers followed by the same letters are not significantly different by Ducan New Multiple Range Test at 0.05 level.

Ogbanje and Okpe (2020) modeled CH_4 and N_2O emissions from crop residue burning in Nigeria using IPCC default emission factors and obtained CH_4: 2.7 g/kg dry matter, and N_2O: 0.07 g/kg dry matter, with estimated straw biomass of 5.5 t DM/ha. Comparatively, the result of the EF of CH_4 and N_2O obtained in this study were far higher than Nigerian reported values. The lower emission factors and GWP recorded at Adani may be attributed to their long standing relationship with improved practices of the famous government ADARICE Project.

Conclusion

In this study, field – level assessment of rice straw generation, BPI and the GHG emissions from different rice growing areas in Enugu State was made. An average straw yield of 7.53 $t \cdot ha^{-1}$, and rough and milled grain yield of 8.09 and 4.58 tha^{-1}, respectively were obtained. Our findings on nutrient composition of rice straw indicate its great potential for use as fertilizer and animal feed. Moisture content of rice straw at burning significantly, influenced the GHG emissions. The implication of these findings were discussed.

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REFERENCES

Allen, J., Pascual, K.S., Romasanta, R.R., Trinh, M.V., Thach, T.V., Hung, N.V., Sander, B.O. and Chivenge, P. (2020). Rice Straw Management Effects on Greenhouse Gas Emissions and Mitigation Options. Chapter 9 In: M. Gummert et al. (eds.), Sustainable Rice Straw Management.

Andreae, M.O. and Merlet, P. (2001). Emission of trace gases and aerosols from biomass burning. Global Biogeochem. Cycles, 15, 955–966. doi:10.1029/2000GB001382.

Clay, D. E., Alverson, R., Johnson, J.M.F., Karlen, D.L., Clay, S., Wang, M.Q., Bruggeman, S. and Westhoff, S. (2019). Crop Residue Management Challenges: A Special Issue Overview. Agron. J. 111:1–3.

Danbaba, N., Idakwo, P. Y., Kassum, A. L., Bristone, C., Bakare, S. O., Aliyu, U., Kolo, I. N., Abo, M. E., Mohammed, A., Abdulkadir, A. N., Nkama, I., Badau, M. H., Kabaraini, M. A., Shehu, H., Abosede, A. O., and Danbaba, M. K. (2019**).** Rice postharvest technology in Nigeria: An overview of current status, constraints and potentials for sustainable development. *Open Access Library Journal, 6*, e5509. https://doi.org/10.4236/oalib.1105509 academicjournals.org+8

Dobermann, A. and T.H. Fairhurst. 2000. Rice: Nutrient Disorders and Management. International Rice Research Institute

Fan, J., Mconkey, B., Janzen, Townley-Smith, H. L., Wang, H. (2017). Harvest index–yield relationship for estimating crop residue in cold continental climates. In Field Crops Research, vol. 204, pp. 153–157**.**

Gadde, B., Bonnet, S., Menke, C. and Garivait, S. (2009). Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. Environmental Pollution 157: 1554-1558.

Hayashi K, Ono K, Kajiura M, Sudo S, Yonemura S, Fushimi A, Saitoh K, Fujitani Y, and Tanabe K (2014). Trace gas and particle emissions from open burning of three cereal crop residues: increase in residue moistness enhances emissions of carbon monoxide, methane, and particulate organic carbon. Atmos. Environ., 95, 36 –44. doi:10.1016/j. atmosenv.2014.06.023

Hays, M. D., Fine, P.M., Geron, C.D., Kleeman M.J., and Gullett B.K. (2005): Open burning of agricultural biomass: physical and chemical properties of particle-phase emissions. Atmos. Environ., 39, 6747–6764. doi:10.1016/j.atmosenv.2005. 07.072

Hironori A., Yasukazu H., Van Nguyen P. H., Nga Truong T., Chiem N.H. and Kazuyuki (2015). Greenhouse gas emissions from rice straw burning and straw-mushroom cultivation in a triple rice cropping system in the Mekong Delta, Soil Science and Plant Nutrition, 61:4, 719-735, DOI: 10.1080/00380768.2015.1041862,

IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team: H. Lee and J. Romero (Eds.)]. IPCC, Geneva, Switzerland. https://doi.org/10.59327/IPCC/AR6-9789291691647

Iyanda, O. J., Adeyemo, A., Oyekanmi, A. A., Atayese, M. O., and Adejuyigbe, C. (2024). Influence of integrated nutrient sources of nitrogen on productivity of lowland rice varieties in a derived savannah ecology of Nigeria. Vegetos, 37(2), 500–505. https://doi.org/10.1007/s42535-024-00819-1

Kajima,J.; Haruta, S.; Ishikura, K. and Kimura, M. (2001). Deevelopment of a wind- tunnel system to evaluate greenhouse gas emission during biomass burning. Japanese jour. Of crop science, 70 (4):512 – 518.

Kwaido, M. A., Saleh, B., and Nasiru, A. (2024). Composition of rice straw ensiled with urea and molasses at varying levels. *Nigerian Journal of Animal Production*, **51**(1), 91–100. https://doi.org/10.51791/njap.vi.7207

Matias, J. Cruz. 'Garcia, A. and Gonzalez D. (2019). Evaluation of rice straw yield, fibre composition and collection under Mediterranean conditions. Acta Technologica Agriculturae 2 Nitra, Slovaca Universitas Agriculturae Nitriae, 2019, pp. 43–47

Mba, C.L.; Madu A.I., Ajaero, C.K. and Obetta , A.E (2021). Patterns of Rice Production and Yields in South Eastern Nigeria. Afr. J. Food Agric. Nutr. Dev. 2021; 21(7): 18330-18348 **https://doi.org/10.18697/ajfand.102.20105.**

Miura, K., and Kanno, H. (1997**).** Emission of methane, carbon monoxide, carbon dioxide and nitrous oxide from rice straw burning in a combustion chamber (wind tunnel type). *Soil Science and Plant Nutrition, 43*(3), 527–533. https://doi.org/10.1080/00380768.1997.10414651

Nishanth, T. and Praseed, K.M. (**2014)**. "Emission characteristics of rice straw burning." *Atmospheric Environment*, 88: 36–41.

Oanh N.T.K., Ly B., Tipayarom D., Manandhar B. R, Prapat, P, Simpson C. D .and Liu, L-J (2011). Characterization of particulate matter emission from open burning of rice straw. Atmos. Environ., 45, 493–502. doi:10.1016/j. atmosenv.2010.09.023

Ogbanje E.C. and Okpe C.P. (2023). Nexus between rice productivity and greenhouse gas emission in Nigeria. Agro-Science, 22 (2), 64-72. DOI: https://dx.doi.org/10.4314/as.v22i2.9

Okwulehie, I. C., and Okoro, K. O. (2014). Assessment of the phytochemical, proximate, mineral and heavy metal constituents of some grass straws used in cultivating *Pleurotus ostreatus* var. *florida* Egger. *IOSR Journal of Pharmacy and Biological Sciences*, **9**(6), 58–63. https://doi.org/10.9790/3008-09615863

Osorio, J. F. (2007). Evolution of growth, grain yield and partition of photosynthates in 14 varieties of rice representing various breeding cycles in Colombia. Universidad de Colombia, Palmira. 135 pp.

Romasanta, R.R.; Sander, B.O; Gaihre, Y.K.; Alberto, M.; Camelita,R.; Gummert M.; Quilty, J.R.; Nguyen, V. H.; Castalone A.G.; Barlingbing C.; Sandro ,J. M.; Correa ,T.Q and Wassman ,R. (2017**).** How does burning of rice straw affect CH_4 and N_2O emissions? A comparative experiment of different on – field straw management practices. Agric. Ecosyst. Environ. 239:143 **-**153.

Singh, Y., Singh, B., and Thind, H. S. (2013). Crop residue management with conservation agriculture: Potential, constraints and policy needs. *Indian Journal of Agronomy*, 58(3), 321–333.

Subhendu , B.G., Ramyajit, M and Sanjib, K.M. (2020). Crop residue management options in rice -rice system: a review. Archives of Agronomy and Soil Science, vol.66 (9).

Tabil L, Adapa P, and Kashaninejad M. (2011). Biomass feedstock preprocessing–Part **2:** Densification. In Bernardes MADS (ed) Biofuel's Engineering Process Technology, p. 439–464

Van Hung, N., Maguyon-Detras, M.C., Migo, M.V., Quilloy, R., Balingbing, C., Chivenge, P. and Gummert, M. (2020). Rice Straw Overview: Availability, Properties, and Management Practices. Gummert et al. (eds.), Sustainable Rice Straw Management**, https://doi.org/10.1007/978-3-030-32373-8_1**

Veerangouda, M., Prakash, K. V., Kawale, N., Ramappa, K. T., Anantachar, M., and Jholgikar, P. (2023). Effect of design parameters on mechanical harvesting of ginger. The Pharma Journal*,* 12*(5).*