

NEXUS BETWEEN RICE PRODUCTIVITY AND GREENHOUSE GAS EMISSION IN NIGERIA

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ABSTRACT

Crop residue burning, which is a common land preparation practice for rice production, generates anthropogenic gases that compound climate change menace. Hence, this study estimated the nexus between rice productivity and greenhouse gas emission in Nigeria using time series that ranged from 1981 to 2020. Time series data on rice yield and residue burning-induced nitrous oxide, carbon dioxide and methane were obtained from the Food and Agriculture Organization. Augmented Dickey-Fuller and Phillips-Perron tests were used to ascertain the stationarity of the series. Johansen-Juselius cointegration and Engle-Granger causality models were used to test for long-run relationship and causality, respectively. The result shows that the series were I(1) and the trace and Max-Eigen tests produced divergent results on the existence of long-run relationship. Findings showed that there was a uni-directional causality from rice yield to nitrous oxide ($p < 0.05$), carbon dioxide ($p < 0.05$) and methane ($p < 0.05$) gases, respectively. The study concluded that rice intensification is a significant contributor to greenhouse gases (GHG) emissions in Nigeria. It was suggested that instead of burning crop leftovers, the Federal Ministries of Agriculture and Rural Development and Environment should educate farmers on proper crop residue management techniques.

Key words: rice, residue, yield, greenhouse gases (GHG), causality, Nigeria

INTRODUCTION

Rice (*Oryza sativa*) is the most important staple food crop in Nigeria (Gbenga *et al.*, 2020; Ademiluyi *et al.*, 2021). Nevertheless, its production has failed to keep pace with consumption. Mboyerwa *et al.* (2022) indicated that the largest challenge to global rice production is supplying an estimated 34% rise in worldwide population by 2050. In Nigeria, annual rice production of 3.3 million mt is less than the demand of 5.2 million mt (Ali *et al.*, 2020), and creates a gap of 1.9 million mt. At an average yield of 1.86 mt ha⁻¹, about 1,022 million hectares of rice should be cultivated, to satisfy local demand. Consequently, Nigeria resorted to massive import, which reduces foreign reserves (Abbas *et al.*, 2018). Data from FAOSTAT shows that between 2000 and 2021, Nigeria expended \$17.26 million dollars on rice importation. Ayuba *et al.* (2020) and Abiola *et al.* (2021) attributed the demand-supply gap to poor performance overtime and expanding population, respectively.

Ayinde *et al.* (2013) claimed that biotic and abiotic pressures adversely affect rice productivity, and that significant changes in the world's climate may exacerbate the consequences of these stresses. While some of the stresses are natural, others are human-induced. Jayeoba (2023) added that the anthropogenic factors can have both direct and indirect effect on the productivity of plants. The

adverse impacts of climate change undermine the ability of countries to achieve sustainable development. The United Nations Framework Convention on Climate Change (UNFCCC) emerged to control the menace of climate change.

As acknowledged in the sustainable development goals (SDG), the UNFCCC is the main international, intergovernmental platform for planning a global response to climate change (United Nations, 2016). As prescribed by the UNFCCC, Nigeria articulated National Communications (NC). The first NC requires each party to report the emissions of greenhouse gases (GHG), including CO₂, CH₄, and N₂O periodically (Federal Ministry of Environment, 2003). The second NC listed the sources of GHG emissions to include energy, industrial operations, agriculture, land use, among others (Federal Ministry of Environment, 2014). Nigeria is a signatory to the UNFCCC (Federal Ministry of Environment, 2014), which prohibits indiscriminate crop residue burning (CRB). The need to mitigate GHG emissions from agriculture and increase agricultural productivity precipitated the concept of climate-smart agriculture (CSA).

The CSA is a mitigation approach. Its major goal is to extenuate GHG emissions and associated effects. CSA is essential for controlling climate shocks to smallholder farmers in sub-Saharan Africa (Atta-aidoo *et al.*, 2022). Under the CSA,

members of UNFCCC have the responsibility of consciously reducing GHG emissions from various sources. According to Lipper *et al.* (2018), CSA is anchored on three pillars, which are productivity, resilience and mitigation. The World Bank (2021) added that the CSA methodically takes into account the trade-offs and synergies between productivity, adaptation, and mitigation and intends to seize new funding opportunities to eliminate the current investment shortfall. Relatedly, to boost the productivity and incomes of smallholder crop, livestock, fish, and forest production systems for food security, Benton *et al.* (2021) claimed that agricultural system resilience is essential. Accordingly, Osabohien *et al.* (2019) stated that lack of social protection to mitigate the impact of climate change makes agriculture unattractive.

Mitigation, which should be compatible with national development priorities, can strengthen **climate change** adaptation and enhance food security (Ameyaw *et al.*, 2018), an important component of SDG, Goal 2 of which focuses on zero hunger. To achieve the Sustainable Development Goal 2, governments focused on agriculture as the best option for tackling such problems as food insecurity (Haruna and Murtala, 2019). The second goal of the 2030 SDGs targets food security, improved nutrition and sustainable agriculture (Osabohien *et al.*, 2020). Agricultural activities account for GHG emissions. Lynch *et al.* (2021) and Czyzewski and Michałowska (2022) stated that activities related to agriculture and food production cause the emissions of several climatic pollutants, including CO₂, CH₄, and N₂O. Tubiello *et al.* (2007) noted that agriculture causes land degradation and GHG emissions. In particular, rice production systems including the burning of the residue during land preparation are a major contributor to land degradation and GHG emissions (Sule *et al.*, 2022; Iboko *et al.*, 2023).

According to Mhlanga and Muoni (2002), crop residues are retained in the soil to achieve permanent soil cover, which also promotes productivity. Crop residues include husks, seeds, bagasse, molasses and roots (Singh *et al.*, 2019), straws, stovers and haulms (Adamu *et al.*, 2014), groundnut shells, rice husks, and oil cakes (Devi *et al.*, 2017; Gupta *et al.*, 2018). Elsewhere, more than 683 million tonnes (mt) of crop residues of different crops are produced, of which a major part is used as fodder, fuel, and in various industrial processes (Datta *et al.*, 2020). But in Nigeria, they are mainly burnt, thereby increasing GHG emissions, with attendant consequences. Kaur *et al.* (2022) noted that in India and emerging nations, burning is the most popular method of disposing of rice harvest waste. This is mainly due to its simplicity, low cost, increased mechanical harvesting, short window between rice harvest and wheat sowing, and lack of viable uses for residues. Kaur *et al.* (2022) warned that burning residue

contributes significantly to air pollution, releasing around 1.5 mt of particulate matter and volatile organic compounds (NO₂, SO₂, CO, CH₄, NH₃), which can cause a variety of respiratory infections in people, reduce soil nutrient and carbon inputs, and disrupt soil microbial activity. Rather than burning, the preservation of the residue is an important soil conservation practice. Soil is the most important resource on which sustainable agriculture and livelihood of the agricultural productivity of the farm household can be accommodated. Elenwa *et al.* (2019) stated that, due to changing human needs and competition for different uses of land, there is need for systematic land use and sustainable soil conservation practices.

While agricultural activities generate GHG emissions, the emissions can affect agricultural productivity. According to Onyeneke *et al.* (2021), climatic risks affect rice production in Nigeria. Kwakwa *et al.* (2022) stated that climate change caused by the emissions of GHGs affects crop and livestock production. Cline (2008) warned that emissions tend to reduce yields because crops develop too quickly and consequently produce less grain. Cline (2008) also emphasized that developing countries have relatively less capacity to curtail the impact of global warming. Lynch *et al.* (2021) stated that reducing agricultural emissions could enhance climate change mitigation.

Apart from the growing food supply-demand imbalance, there are mixed results on the interaction between GHG emissions and agricultural productivity. Some researchers noted that climate change boosts productivity (Tubiello *et al.*, 2007; Cline, 2008), others (Gowda *et al.*, 2018; Ovuoba *et al.*, 2022) noted the reverse. This leads to the concept of causality. Granger causality measures the directional relationship that may exist between two variables, Y_t and X_t (Shirazi *et al.*, 2005; Ogbanje and Igboke, 2019). A relationship can be unidirectional or bidirectional. It is unidirectional if causality runs from Y_t to X_t without feedback (Verter, 2014; Ogbanje *et al.*, 2016). A bidirectional causality runs from Y_t to X_t with feedback (Meyer and Sanusi, 2019). Causality can be absent between Y_t and X_t , where the lagged values of Y_t does not explain X_t (Odetola and Etumnu, 2013; Hussain, 2014). Also, studies on the nexus between GHG emissions from CRB and rice productivity are rare and poorly understood (Boateng *et al.*, 2017; Onyeneke *et al.*, 2021). Hence, this study seeks to fill these gaps. The objective of the study was to determine the direction of causality between anthropogenic GHG emissions from CRB and rice productivity. It was hypothesized that there is no long-run relationship between GHG emission and rice productivity in Nigeria. The relevance of this study is situated within the directive of the United Nations (2016) to protect future agricultural systems from deterioration and guarantee sustainable production and consumption.

MATERIALS AND METHODS

The study covers Nigeria. Nigeria has the largest population and economy in Africa (Ismail and Kabuga, 2016). With agriculture as the major occupation, Nigeria is located between latitudes 4° 16 and 13° 53 N and longitudes 2° 40 and 14° 4' E. The climate varies with Equatorial Guinea in the South through the Guinea savannah in the central region and dry Sahel savannah in the North (Hamzat *et al.*, 2006; Ogbanje and Salami, 2022). Climate change is evident in Nigeria by way of rising temperature, varying rainfall, rising sea level and seasonal flooding, drought and desertification (Haider, 2019). Its agricultural activities exacerbate climate change through anthropogenic GHG emissions (Federal Ministry of Environment, 2014; Zegeye, 2017; Win and Win, 2020), including rice production. Rice is produced in Nigeria mostly by smallholder farmers, predominantly under rainfed system (Bitrus *et al.*, 2021). Most ecologies and states of the federation produce rice.

Time series data on rice productivity (mt ha⁻¹) and GHG emissions from CRB (kt) were obtained from the Food and Agriculture Organization, between 1981 and 2020. Since these time series variables are vulnerable to fluctuations (Gujarati and Porter, 2009; Musa, 2015), stationarity test was necessitated to ensure that estimation results are reliable (Djokoto *et al.*, 2014; Ogbanje and Ihemezie, 2021). The study used Augmented Dickey-Fuller test (ADF) and Philips-Perron (PP) to test for stationarity. While the ADF test uses a parametric autoregression to approximate the structure of the errors, the PP test ignores any serial correlation (Wiah and Twumasi-Ankrah, 2017; Ogbanje and Ihemezie, 2021). The model for ADF is as follows:

$$\Delta Y_t = \beta_1 + \beta_{1t} + \delta Y_{t-1} + \sum_{i=1}^m \alpha_i \Delta Y_{t-1} + \epsilon_t \dots \dots \dots (1)$$

Ho: $\delta = 0$ (*There is unit root*)
 Ha: $\delta < 0$ (*There is no unit root*);

where Y_t is time series variable, Y_{t-1} is lagged value of Y_t , β, δ is first parameter to be estimated, Δ is first – difference operator, ϵ_t is pure white noise or error term which is assumed to be serially uncorrelated Johansen-Juselius’ (JJ) cointegration test ascertains long-run relationship among series (Gujarati, 2003) Adongo *et al.* (2020) and Ogbanje and Ihemezie (2021) have adopted this model in their works. Its main and confirmatory statistics, the trace and maximum Eigenvalue (Siaw *et al.*, 2017), normally concur on the number of cointegrating equations. The presence or absence of cointegration leads to the adoption of vector error-correction model (VECM) or vector autoregression model (VAR), respectively (Ogbanje and Ihemezie, 2021; Ogbanje and Salami, 2022). Sukati (2013)

and Anetor *et al.* (2016) affirmed cointegration test the null hypothesis of no cointegration.

The Engle-Granger causality estimates causal relationship between any two series at a given time, t . It is a technique for determining whether one time series is useful in forecasting another (Wiah and Twumasi-Ankrah, 2017). Following the works of Fan *et al.* (2019) and Ogbanje and Igboke (2019), the causality model for a four-variable VAR is specified as follows:

$$\Delta LRYD_t = \theta_1 + \sum_{i=1}^k \beta_{1i} \Delta LRYD_{t-1} + \sum_{i=1}^k \delta_{1i} \Delta LMNT_{t-1} + \sum_{i=1}^k \gamma_{1i} \Delta LCD_{t-1} + \sum_{i=1}^k \alpha_{1i} \Delta LNO_{t-1} + \mu_{1t} \dots \dots \dots (2)$$

$$\Delta LMNT_t = \theta_2 + \sum_{i=1}^k \beta_{2i} \Delta LRYD_{t-1} + \sum_{i=1}^k \delta_{2i} \Delta LMNT_{t-1} + \sum_{i=1}^k \gamma_{2i} \Delta LCD_{t-1} + \sum_{i=1}^k \alpha_{2i} \Delta LNO_{t-1} + \mu_{2t} \dots \dots \dots (3)$$

$$\Delta LCD_t = \theta_3 + \sum_{i=1}^k \beta_{3i} \Delta LRYD_{t-1} + \sum_{i=1}^k \delta_{3i} \Delta LMNT_{t-1} + \sum_{i=1}^k \gamma_{3i} \Delta LCD_{t-1} + \sum_{i=1}^k \alpha_{3i} \Delta LNO_{t-1} + \mu_{3t} \dots \dots \dots (4)$$

$$\Delta LNO_t = \theta_4 + \sum_{i=1}^k \beta_{4i} \Delta LRYD_{t-1} + \sum_{i=1}^k \delta_{4i} \Delta LMNT_{t-1} + \sum_{i=1}^k \gamma_{4i} \Delta LCD_{t-1} + \sum_{i=1}^k \alpha_{4i} \Delta LNO_{t-1} + \mu_{4t} \dots \dots \dots (5)$$

where L is logarithm; RYD is rice yield, a measure for rice productivity (mt ha⁻¹); MTN is methane emissions from CRB (kt); CD is carbon dioxide equivalent emissions from CRB (kt); NO is nitrous oxide emissions from CRB (kt). Following Wiah and Twumasi-Ankrah (2017), the F -statistic which tests the null hypothesis that X does not Granger-cause Y is specified as follows:

$$F = \frac{(RSS_R - RSS_{UR})/m}{RSS_{UR}/(n-k)} \dots \dots \dots (6)$$

RESULTS

Descriptive Statistics

The descriptive statistics of the variables are presented in Table 1. The results show that rice yield (mt ha⁻¹) ranged from 1.30 to 2.67, averaging 1.86. The mean yield implies that about 1,860 kg or 18.60 100kg⁻¹ bag equivalence were obtained from a hectare of rice. The trend of rice yield in Figure 1 depicts an unstable pattern. The mean, minimum and maximum N₂O emissions were 0.39, 0.06 and 0.76 kt, respectively. On average, residue burning emitted 0.39 kt, thereby increasing total GHG emissions. The trend of N₂O emissions from CRB between 1981 and 2020 in Figure 2 displays an upward trend, with minimal decline around 1995 to 1999. The rise from around 2009 to 2020 was quite sharp. Findings also showed that the mean, minimum and maximum amounts of CO₂ emissions (kt) from CRB were 524.81, 74.09 and 1,018.82, respectively. This result places CO₂ emissions above that of N₂O. The trend in Figure 3 shows that CO₂ rose from 1981 until it began to

decline in 1995. The decline ended in 1999 when it

Table 1: Descriptive statistics of GHG emissions

Variables	Rice yield	Nitrous oxide	Carbon dioxide	Methane
Mean (kt)	1.86	0.39	524.81	15.05
Median (kt)	1.95	0.37	499.98	14.34
Maximum (kt)	2.67	0.76	1,018.82	29.22
Minimum (kt)	1.30	0.06	74.09	2.13

FAOSTAT (2023). GHG - greenhouse gases

The result further shows that the mean, minimum and maximum methane emissions from CRB were 15.05, 2.13 and 29.22, respectively. In comparative terms, methane emissions were less than CO₂ but greater than N₂O emissions. Lynch *et al.* (2021) in their study reported that, methane emissions are less than N₂O. The trend in Figure 4 shows a rise from 1981 to around 1995 when it declined and picked up again around 2000. It remained on the rise since then.

Stationarity Test

Equation 1 was used to generate the results in Table 2. All the variables were not stationary at levels since the ADF and PP values were less than the critical values at 5% in absolute terms, as supported by Ee (2016), Joshi *et al.* (2019) and Ribaj and Mexhuani (2021). However, at first difference, the series became *I* (1), in line with Akinwale *et al.* (2018), Zehra *et al.* (2019), and Ogbanje and Ihemezie (2021).

Long-Run Test Using Johansen-Juselius Cointegration Test

The result of the long-run test in Table 3 shows that the ‘none’ and ‘at most 2’ null hypotheses could not be rejected. However, the study failed to reject the ‘at most 3’ null hypothesis because the trace statistic (2.92) was less than the critical value (3.84), indicating three cointegrating equations. This

picked up and moved steadily until 2020.

observation was in line with Ajayi *et al.* (2017) and Oparinde *et al.* (2017). Rather than corroborating the result of the trace test, the Max-Eigen test indicated no cointegration. With these divergent results from the trace and Max-Eigen tests, neither the long-run nor the short-run estimation was feasible. Consequently, the study resorted to Engle-Granger causality which was based on the fact that the variables were *I* (1).

Lag Order Selection

As presented in Table 4, four optimal lag order selection criteria were used. These were: final prediction error (FPE), Akaike information criterion (AIC), Hannan-Quinn information criterion (HQIC), and Schwarz information criterion (SC). Based on the positions of the asterisk from the software and the concept of least value, the recommendation of three lags by AIC criterion was accepted. Hence, the estimation of Granger Causality was done as suggested and implemented by Adongo *et al.* (2020).

Four-Way Granger Causality

The result of the four-way Granger causality between gas emissions from CRB and rice yield is presented in Table 5. Emphasis was placed on the models that involved rice yield. The result of the model for the causality between nitrous oxide emissions from CRB and rice yield shows that the *F*-statistic (3.8878) for causality running from LRYD to LNO was statistically significant (*p* < 0.05). The *F*-statistic (3.91539) for the causality running from LRYD to LCD was statistically significant (*p* < 0.05). Hence, the study rejected the null hypothesis. The *F*-statistic (3.91742) for the causality running from LRYD to LMTN was statistically significant (*p* < 0.05). Hence, the study rejected the null hypothesis.

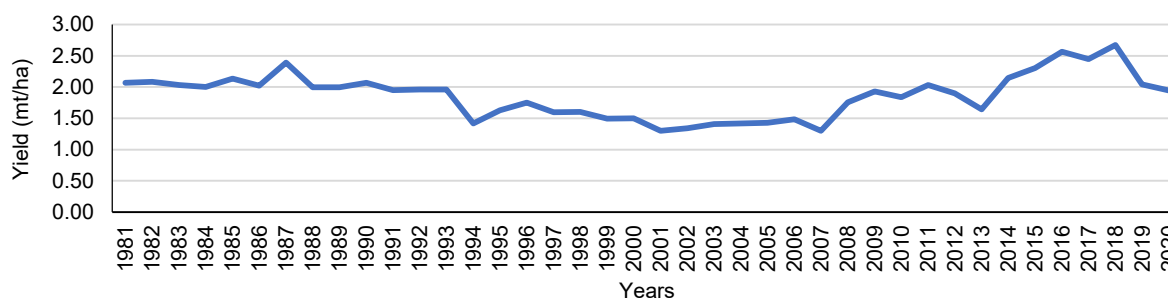


Figure 1: Trend of rice yield in Nigeria (1981-2020) (FAOSTAT, 2023)

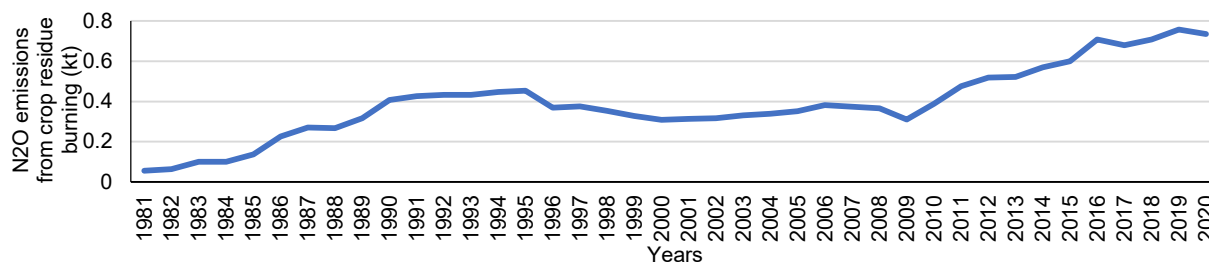


Figure 2: Trend of nitrous oxide emissions from crop residue burning in Nigeria (1981-2020) (FAOSTAT, 2023)

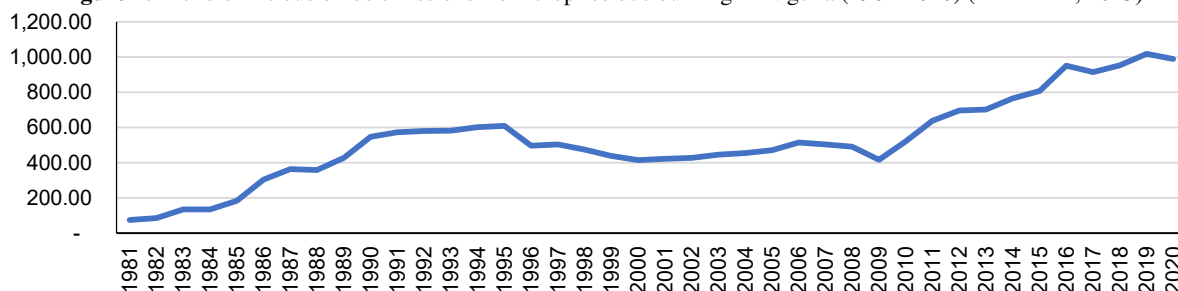


Figure 3: Trend of carbon dioxide emissions from crop residue burning in Nigeria (1981-2020) (FAOSTAT, 2023)

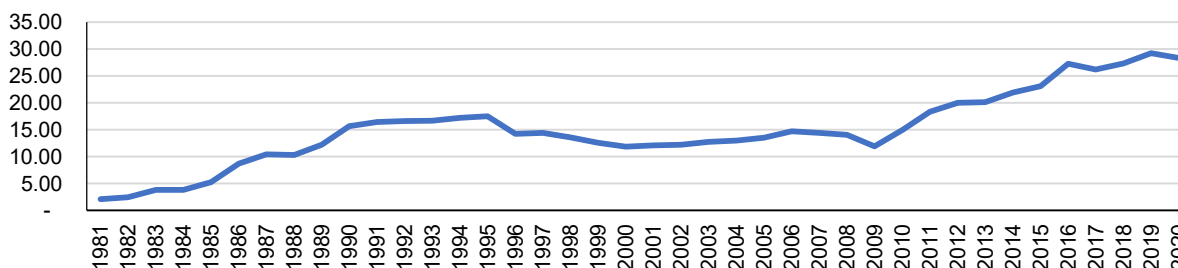


Figure 4: Trend of methane emissions from crop residue burning in Nigeria (1981-2020) (FAOSTAT, 2023)

Table 2: Summary result of unit root test

Variables	Level		Stationarity status	First difference		Stationarity status
	ADF	PP		ADF	PP	
LRYD	-2.04 (-3.53)	-1.95 (-3.53)	Not stationary	-7.75*** (-2.94)	-7.75*** (-2.94)	I(1)
LNO	-3.19 (-3.53)	-3.05 (-3.53)	Not stationary	-4.36*** (-2.94)	-4.37*** (-2.94)	I(1)
LCD	-3.19 (-3.53)	-3.05 (-3.53)	Not stationary	-4.32*** (-2.94)	-4.32*** (-2.94)	I(1)
LMTN	-3.19 (-3.53)	-3.05 (-3.53)	Not stationary	-4.32*** (-2.94)	-4.32*** (-2.94)	I(1)

Figures in parentheses represent critical values at 5%, (1) - integrated of order one, *** - statistical significance at 1% level, ADF - augmented-Dickey Fuller, PP - Phillips-Perron; LRYD - log of rice yield, LNO - log of nitrous oxide, LCD - log of carbon dioxide, LMTN - log of methane

Table 3: Long-run test using Johansen-Juselius cointegration test

Null hypothesis	Test statistics		Critical value at 5%	
	Trace	Max-Eigen	Trace	Max-Eigen
None	69.98	24.89	47.86	27.58
At most 1	45.09	24.29	29.80	21.13
At most 2*	20.80	17.88	15.49	14.26
At most 3	2.92	2.92	3.84	3.84

While the trace test indicates 3 cointegrating equations, the maximum-Eigen test indicates no cointegration at the 0.05 level.

* - non-rejectable null hypothesis

Table 4: Lag order selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	535.7720	NA	3.86e-18	-28.74443	-28.57028	-28.68303
1	628.7102	160.7581	6.07e-20*	-32.90326	-32.03249*	-32.59627*
2	639.3042	16.03406	8.41e-20	-32.61104	-31.04366	-32.05846
3	662.4418	30.01638*	6.22e-20	-32.99685*	-30.73286	-32.19869

* - lag order selected by the criterion, FPE - final prediction error, AIC - Akaike information criterion, SC - Schwarz information criterion, HQ - Hannan-Quinn information criterion; LogL - loglikelihood, LR - likelihood ratio, NA - not applicable

Table 5: Causality between gas emissions from crop residue burning and rice yield in Nigeria

Null hypothesis	F-Statistics	Probability	Type of causality
LNO does not Granger cause LRYD	0.56084	0.645	No causality
LRYD does not Granger cause LNO	3.88780**	0.0185	Uni-directional
LCD does not Granger cause LRYD	0.54858	0.653	No causality
LRYD does not Granger cause LCD	3.91539**	0.018	Uni-directional
LMTN does not Granger cause LRYD	0.54834	0.6531	No causality
LRYD does not Granger cause LMTN	3.91742**	0.0179	Uni-directional

** - statistical significance at 5%, LRYD - log of rice yield, LNO - log of nitrous oxide, LCD - log of carbon dioxide, LMTN - log of methane

DISCUSSION

The mean rice yield in this study was less than 4 mt ha⁻¹ for Madagascar and 5.3 mt ha⁻¹ for Mauritania (Felix and Sophia, 2018; Abiola *et al.*, 2021). The mean figures for Madagascar and Mauritania were even higher than the maximum yield of 2.67 mt ha⁻¹ for the period of this study. Between 1981 and 2020, rice yield declined by 5.08%, thereby contributing to food insecurity in Nigeria. Against the backdrop of the financial policy interventions of the government in the rice subsector such as the ABP (Aiyede, 2021; Okeke *et al.*, 2019; Saheed *et al.*, 2018), ACGSF (Sulaimon, 2021; Zakaree, 2014) and the efforts of IFAD in Nigeria's rice value chain (Attah, 2012; Ayinde *et al.*, 2020), the result suggests that the rice subsector has been resistant to changes. This increases the sector's vulnerability to climate change precipitators.

Between 1981 and 2020, N₂O, CO₂ and CH₄ emissions from CRB increased by 1,236.35, 1,234.53, and 1,234.40%. These changes are massive, with implications for global warming. The results suggests that climate change mitigation efforts in Nigeria have not yielded the desired result in drastically reducing the contribution of GHG to global warming or that climate-smart agricultural practices have not focused enough attention on GHG emissions, especially from anthropogenic sources. In particular, N₂O is among the gases that cause a catastrophic rise in global temperature (Agba *et al.*, 2017). Notwithstanding the various climate change policy interventions and frameworks, nitrous oxide emissions from agricultural practices continued unabated. The results conformed with Eregha (2014), Lynch *et al.* (2021) and Siamabele (2021). Rising climatic conditions may not augur well for crop production since according to Kralovec (2020) food production depends on steady climatic conditions, particularly in developing countries with weak institutional capacity to combat the menace of climate change and food shortages. LRYD Granger-causes LNO, LCD and LMTN, respectively, without feedback. Hence, past values of rice yield can be used to predict the quantity of N₂O, CO₂ and LMTN emissions from CRB. Rice production generates substantial biomass, which is often burnt by peasant farmers. This finding is in line with the Federal Ministry of Environment (2014) and Win and Win (2020) that nitrous oxide

emissions came from the burning of agricultural residues. Findings on CO₂ and CH₄ validate Eregha (2014) who found that CO₂ significantly affected rice production and Lynch *et al.* (2021) that methane constitutes a large share of agricultural emissions, respectively. Furthermore, Win and Win (2020) found that the emission of nitrous oxide comes from rice farms in Myanmar.

CONCLUSIONS

The study determined the nexus between rice productivity and greenhouse gas emission in Nigeria between 1981 and 2020. The study found that the emissions of nitrous oxide, carbon dioxide and methane from CRB increased massively, thereby heightening the tradeoff between global warming and the current agricultural practice. However, rice yield decreased thereby aggravating food insecurity. These emissions can be predicted more accurately with the past values of rice yield. Hence, climate-smart agriculture is yet ineffective in curbing GHG emissions from agricultural practices, especially CRB.

Therefore, the study recommends that, farmers should fully adopt climate-smart agricultural practices especially on-farm crop residue retention to reduce anthropogenic gas emissions and increase soil fertility for sustainable rice productivity; and the Federal Ministries of Agriculture/Rural Development and Environment, in conjunction with designated centres for climate change in Nigeria should train rice farmers on efficient crop residue management to curb global warming and reduce poverty among peasant farmers.

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