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ASSESSMENT OF THE INFLUENCE OF CONTINUOUS AND INTERMITTENT IRRIGATION ON GREENHOUSE GAS EMISSIONS FROM PADDY RICE

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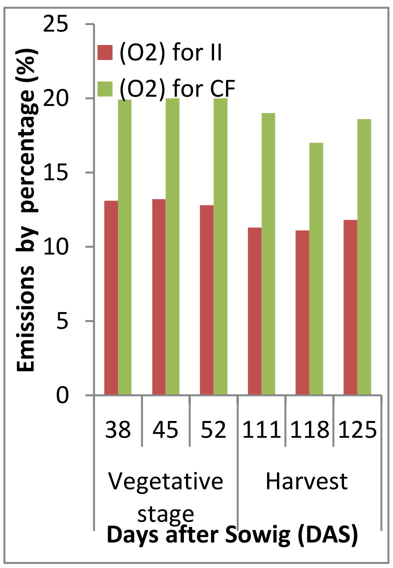
Graphical abstract



Abstract

The impact of two water management practises on Greenhouse Gases (GHGs) emissions from paddy rice fields was investigated. New Rice for Africa (NERICA 2) lowland variety was planted under intermittent irrigation (II) and continuous flooding (CF) water management practises. Two closed gas chambers (GCs) were developed and used for gas sampling from paddy fields and measurement was done conventionally in all the four growing stages of rice. Gas Chromatograph (GH200-9) was used analysing GHGs such as Methane (CH_4), Nitrous oxide (N_2O), Hydrogen Sulphide (H_2S) and Oxygen (O_2). Soil analyses were carried out to determine the presence of the following parameters viz: nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), Manganese (Mn) and calcium (Ca). Others are Organic Carbon (OC), Moisture Content (MC), Iron (Fe), Chloride (Cl) and Electrical conductivity (EC) using standard laboratory procedures and ascertain effects of their availability on GHGs concentration levels. From the study, no appreciable CH_4 emissions was detected during the four growing stages and under the two water management practises but other GHGs emitted were higher in CF compared with II. Soil nutrients such as N, OC, K and P also contributed considerably to emissions recorded on the two rice fields. The detection of H_2S was also an indication that other gases apart from the common GHGs were present in rice fields. Although, CH_4 was not detected, other GHGs emitted were more in CF when compared with II which suggested that II be encouraged as a mitigation strategy for reducing impacts of its emissions.

Keywords: Irrigation, water management, paddy rice, GHG emissions

1.0 INTRODUCTION

One of the most serious long-term challenges facing the world today is climate change and the most affected sector is agriculture since climate is the primary determinant of agricultural productivity [1]. Out of all the climatic factors such as temperature, wind speed, rainfall, relative humidity affecting agricultural yield decline [2], Atmospheric methane (CH_4), nitrous oxide, (N_2O) and carbon dioxide (CO_2) are major greenhouse gases (GHG) that had potential of contributing significantly to global warming [3]. Rice fields are considered as one of the major sources of methane (CH_4), nitrous oxide, (N_2O) gases [4]. Methane fluxes especially were strongly controlled by soil carbon content, soil electrical conductivity, and soil temperature [3]. It has been predicted that a fifth of World's population will face starvation and famine while millions will be forced by heat, drought and rising sea levels to abandon their land [5]. Sea levels have risen by an annual average of 3.1 mm since the last decade. Greenhouse gas (GHG) emission which is largely produced from Agricultural sector, deforestation and bush burning, livestock and humans deplete ozone layer, heats up the planet, increase land surface temperature. Methane (CH_4) and Nitrous oxide (N_20) have significant effect on yield as their emissions were the strongest in fields [6].

With the burgeoning population and increasing scarce land and water resources for increasing food production due to urbanization, irrigated agriculture was seen as a way out of food security. Irrigated agriculture is the dominant use of water, accounting for about 80 % of global and 86% of developing countries water consumption as at 1995 [4]. Irrigation was responsible for about 75% of the world's total rice production [6]. In Nigeria, Irrigation has the capability to play a crucial role in helping to achieve its goal of food security through increased food production and poverty reduction but has largely been ineffective due to myriads of problems confronting its operations [7]. Rice, the major staple food in Nigeria and the most important source of employment and income generation is being threatened by yield reduction occasioned by the global effect of climate change. The potential land area for rice production in Nigeria is between 4.6 million and 4.9 million ha. Out of this, only about 1.7million ha—or 35 % of the available land area—is presently cropped to rice. Rice fields contribute 9-13% to global methane emissions [8]. Previous studies [9-12] have shown that irrigated systems have the highest potential for methane emission because of assured or continuous water supply which causes anaerobic condition in the paddy soil but to what extent is unknown [13]. Wetland soils have been shown to be an important methane source at the global scale and an attempt to reduce GHG emission is likely to mitigate such impacts on food production especially rice. Considering the impacts of different irrigation practises on GHG mitigation while ensuring sustained yield increase to meet growing population demand becomes inevitable. Therefore, an attempt was made to investigate the influence of water management practises on emissions of GHGs from paddy rice fields in Nigeria

2.0 MATERIALS AND METHODS

2.1 Study Site and Soils

The study site was located at a Jolly rice irrigation farm at Ilara Mokin, Ondo state Nigeria on longitude 5°6'19.4'' East and latitude 7°22'5.5'' North. High-yielding lowland variety of the new rice for Africa (NERICA 2) [14] were raised in nursery in November 15, 2013 and manually transplanted into the field 30 days after planting (DAP), i.e., 14 December, 2013 following standard planting procedures. Urea 40 Kg ha^{-1} was applied after transplanting and weeding control practises were carried out to ensure optimum yield. Prior to fertilization and transplanting, soil analyses were conducted to ascertain the nutrient status of the soil. Soil samples were collected at 0-10 cm, 10-20 cm layers at the beginning of the growing season to perform chemical characterization and the parameters analysed include; nitrogen, phosphorus, potassium, magnesium, calcium,, chloride, iron, pH and organic compounds. The pH was measured using Digimed digital pH meter, Kejldahl method for measuring nitrogen, Walkley-Black method was used in measuring organic C while the rest were determined in the laboratory using the standard procedures recommended by [15].

2.2 Irrigation Water Management

Two management practices used by [3] were considered and adopted for the studies which were continuous flooding (CF) and Intermittent Irrigation (II) in the two paddy fields. For both CF and II, running water (flood) was left on the field and water level of 6 cm was maintained throughout until 10 days prior to harvest. In II, alternate wetting and drying (AWD) technique was used, meaning the first interruption in water supply took place 30 days after transplanting (DAT) and lasted 7 days, followed by another 30-day flooding period. This was again followed by another 7 days interruption and 11 day-flooding period.

2.3 Sampling and Analysis

A closed-chamber method [16] was used to collect gas from the rice fields. Two transparent, rectangular gas-sampling chambers (51cm x 51cm x 100cm) were constructed using 4mm transparent Polyvinyl Chloride (PVC) and installed in the rice fields. Thermometer was installed inside the chamber to measure the internal temperature; meter rule was also attached for water level measurement while an electronic fan was attached to promote air circulation during in-situ measurements and sampling.

In-situ greenhouse gas (GHG) measurement within the two gas chambers (GCs) were carried out for 6 hours (8am through 12 noon at 2 hours intervals) under the two water management practises which were II and CF weekly throughout the growing stages of paddy rice. Gas samples were taken from the GCs, stored in sampling bags and moved to the laboratory for further analysis. At the end of each measurement, the GCs were removed from sites and re-installed before measurement to allow for respective scheduled agricultural practices to take place [17]. Methane, Carbon dioxide and Nitrous oxide gases (CH_4, CO_2 and N_2O) were measured in the laboratory using the use of static (closed) chamber technique described. CH_4 was analyzed using a gas chromatograph (Shimadzu GC-14B) with a detector (FID) operated at 200^0C.The injecting port temperature was 100°C while the carrier gas was N_2. Nitrous oxide (N_2O) was analysed by using gas chromatograph (Shimadzu GC-14A) with a detector (ECD) operated at 300^{0}C while the injecting port temperature was 100^{0}C while the carrier gas was Ar-CH_4 [17].

3.0 RESULTS AND DISCUSSION

3.1 Soil Analysis Results

Table 1 contained physicochemical properties of the soil in the study area during the four identified stages of crop development. The pH ranged between 6.5 and 7.2 which is suitable for rice growth as it is still within the 6.5-8.5 recommended range for optimal production. EC test for salinity ranged between 88.00±3.61 dS/m which was obtained during emergence and 91.00±4.00 ds/m, a value recorded during sowing stage. These values were far above the maximum permissible range of 2.56 - 4.21 dS/m, meaning that the soil was saline which would be one major factor responsible for decline in yield or inadequate development of the paddy rice during the growing season. This agreed with the findings of [18]. Nitrogen ranged between 0.75±0.17% (emergence) and 0.81±0.13% (vegetative). This was expected because within the first two stages of crop development, nitrogen depletion was expected but during the peak of development, at mid-season stage, nitrogen fixation in the soil normally occurred which increased the quantity of nitrogen in the soil and agreed with the observations of [18]. Phosphorus had the following values; 10.22±0.48 (mg/kg) during sowing, 9.62±2.36 (mg/kg) during emergence, 11.33±1.83 (mg/kg) during vegetative and 9.95±1.49 (mg/kg) reordered at harvest stages respectively. The permissible P-range for optimum production is between 5.45 and 22.7(mg/kg) which inferred that the mineral's composition within the soil would contribute positively to crop development. This was also similar to the findings of [19]. Other analysis of the remaining parameters such as Potassium (K), Calcium (Ca), Magnesium and Sodium (Na) showed that their constituents were in sufficient quantities to sustain rice development and growth in the study area. The contributions of these soil nutrients to greenhouse gas emissions irrespective of the type of irrigation practised was also significant due to the values recorded and supported the findings of [20-22].

Table 1 Soil physicochemical properties at every stage of paddy development

Physicochemical properties	Sowing	Emergence	Vegetative	Harvest
N (mg/kg)	0.75±0.18^a	0.74±0.17^a	0.81±0.13^a	0.80±0.04^a
P (mg/kg)	10.22±0.48^a	9.62±2.36^a	11.33±1.83^a	9.95±1.49^a
K (mg/kg)	18.83±0.76^b	11.17±2.65^a	17.16±1.37^b	17.32±2.83^b
Mg (mg/kg)	3.38±0.88^a	2.43±1.06^a	2.74±0.51^a	3.00±0.58^a
Ca (mg/kg)	69.33±17.16^a	81.90±9.95^a	76.07±11.43^a	71.17±5.92^a
Mn (mg/kg)	0.17±0.03^a	0.17±0.04^a	0.19±0.04^a	0.20±0.02^a
Cl (mg/kg)	6.28±1.55^a	7.37±0.86^a	6.50±0.74^a	7.53±0.85^a
Fe (mg/kg)	1.33±0.06^a	1.33±0.09^a	1.28±0.16^a	1.37±0.03^a
pH	6.5	6.8	7.1	7.2
Organic Content (%)	3.30±0.17^a	2.45±1.18^a	2.48±1.11^a	3.32±0.01^a
Electrical Conductivity	91.00±4.00^a	88.00±3.61^a	86.33±3.21^a	86.33±4.16^a
Moisture Content (%)	16.57±0.78^a	18.20±2.72^a	17.33±17.33^a	18.07±18.07^a

Means with the same letter in same column are not significantly different from one another

3.2 Greenhouse Gas (GHG) Emissions from Paddy in the Two Water Management

3.2.1 Methane

Methane gas was not detected at all in all the growing stages and in the two water management strategies (II and CF) throughout the period of study. The most probable reason given for this observation could be due to gas diffusion during transportation from field to laboratory for analysis and that lack of support for gas accumulation in the water body which was supported by [17]. Also, absence of CH_4 might be theoretically correct as 90% of the methane gas was transported via rice stalks [16, 23]. The ebullition and diffusion only contribute a small amount of methane emissions from paddy soils which agreed with the findings of [6, 24-26]. As for II, the non-flooding conditions during the period of water withdrawal may be responsible for low methane production, the observation agreed with the findings of [27] in a similar study. [28] further remarked that some of the methane produced via *methanogensis* in flooded soils were consumed and oxidized to CO_2 at the interface of the anaerobic-aerobic zones and this occurred by a group of bacteria known as *methanotrophs*. [28] further reported that the microbes could be found in the surface layers of wetland soils and unsaturated upland soils, and may be exposed to very high concentrations of methane gas, sometimes amounting to 10% or more of the dissolved gases. Methane is thought to be the only source of C and energy for these bacteria [29]. The time of measurement could also partly be responsible for absence of CH_4 during the experiment as temperature could have caused changes in the gas nature [30]. Similarly, water level, soil type, fertilizer type and pesticides applied had been proved to have considerable effect on emission of CH_4 and other gases from the rice fields [31].

3.2.2 Carbon Dioxide

Figure 1 showed CO_2 emissions during sowing and emergence stages in both CF and II scenarios. In both water management practises, concentrations of CO_2 emitted was higher during II when compared with CF at the two early stages of crop development. The percentage emitted ranged between 2 to 9% with the 9% experienced at 18 DAT while all the CO_2 emitted at CF were under 1% (actually between 0 and 0.3%). Similar scenario played out during vegetative and harvest stages as shown in Figure 2. CO_2 emitted ranged between 2 and 9% in II while the maximum emission was recorded on 118 DAT. In actual fact, highest emissions were recorded during the harvest stage when all vegetative activities in paddy had been completed. Oxidation of CO being responsible for the CO_2 emitted at this stage was a strong possibility and [32] made similar observation in his research. As for CO_2 emissions in CF, none was detected during vegetative stage but slightly higher values were recorded during harvest which ranged between 1 and 3%. Non detection of CO_2 during vegetative stage in CF may be strongly connected with the super saturation state of soil due to continuous flow of water in the rice fields up to 7cm level making it difficult for chemical reactions within pore spaces between oxygen and organic compounds to take place. [33] remarked that during II, carbon was dispelled due to the release of trapped carbon in root zone through rice tiller or stalks into the gas collection chamber while during CF, most of the carbon reacted with other gases during ebullition, oxidation and diffusion thereby causing low carbon emission. Several adverse conditions occur in the root zone when plants germinate under water, oxygen is scarce hindering root respiration and growth while gases such as CO_2 and ethylene build up. Low oxygen causes a reduction in root growth and function, thus reducing nutrient and water uptake [34].

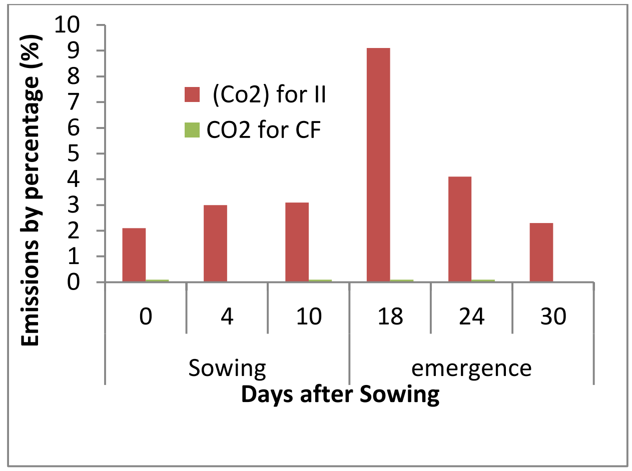


Figure 1 Carbon dioxide (CO_2) emissions at the sowing and seed emergence stage of CF and II practices

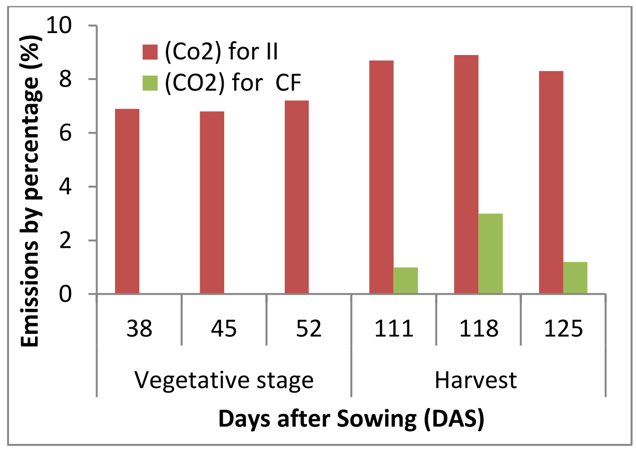


Figure 2 Carbon dioxide (CO_2) emissions at the tillering and harvest stage of CF and II practises

3.2.3 Oxygen

Figure 3 showed O_2 emissions during sowing and emergence stages in II and CF respectively. Emissions ranged between 10 and 20% in the two water management practises which is a sharp contrast to CO_2 emissions at the same stage. For II, O_2 emissions ranged between 10 and 19% while during CF, it was almost fairly 20% (Figure 3). The story was not particularly different during vegetative and harvest stages in Figure 4. O_2 emission during II ranged between 12 and 13% while the value during CF was between 17 and 20% respectively. From the two scenarios described, water level on the field does not significantly affect oxygen emissions since it is present both in water and air always. Rice crop uses CO_2 to produce oxygen anaerobically which was what [12, 35] reported in their different studies.

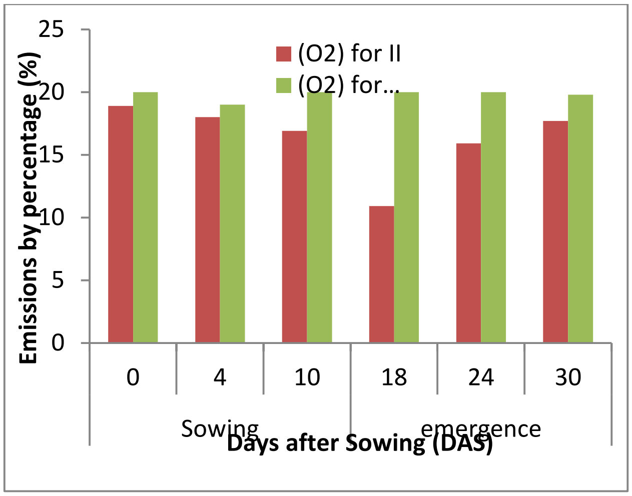


Figure 3 Oxygen (O_2) emissions at sowing and seed emergence stage of CF andII practises

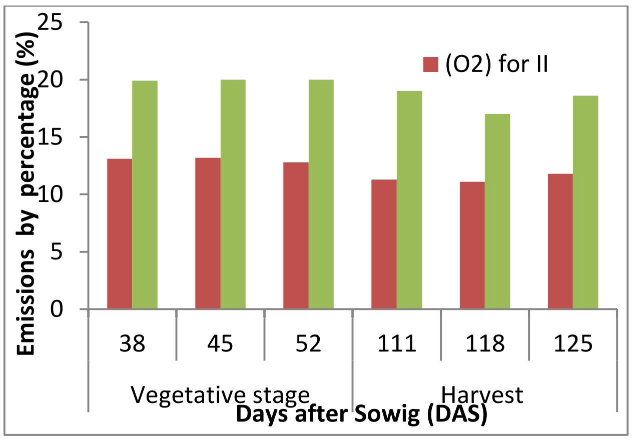


Figure 4 Oxygen (O_2) emissions at the vegetative and harvest stage of CF and II practises

3.2.4 Hydrogen Sulphide and Other Gases

Table 2 showed H_2S emission from the rice fields under the two management practises. There was a relation between sulphate concentration in soil and CH_4 production rate meaning higher sulphate concentration resulted in lower CH_4 production because H_2S production was based on reduction of concentrated sulphate. Therefore, CH_4 was oxidized during the sulphate reduction by bacteria [36]. Although, ammonium sulphate (NH_4SO_4) causes root rot by production of H_2S, it may effectively affect rice production and CH_4 emission [37]. Hydrogen sulphide (H_2S) toxicity may occur in soils low in active iron, and in parts of fields which have been enriched by organic substrate [38]. Other toxic substances produced during the decomposition of organic matter at low redox potentials were thiols, organic sulphides, H_2S and C_2H_4 [39-40].

Table 2 H_2S gases emission from Rice field

Days after sowing(DAS)	H_2S (ppm)
0	5
4	14
10	13
18	13
24	14
25	13
30	13
38	13
45	13

4.0 CONCLUSION

Effects of two water management practises (II and CF) on GHG emissions were considered and from the study, there was no appreciable methane emission was detected during the four growing stages and under the two set of water management strategies. However, CO_2 was detected in an appreciable quantity in three of the four rice growing stages in II and CF with the exception of vegetative stage. Similarly, high O_2 values were detected in all the growing stages during CF while slightly lower values were recorded in II when compared with CF at the vegetative and harvest stages. During harvest at CF, increase in CO_2 was detected was due to respiration from the photosynthetic reaction that occurred in a fully grown stalks around the rice *aerenchyma*. The $CO_2$was higher in II while $O_2$was relatively higher in CF as compared II in the study. The detection of H_2S was also an indication that other gases apart from GHGs were present in rice fields. Water management practices were observed to have profound effect on the GHGs emergence at all growing stages of rice. Although, CH_4 was not detected, other GHGs emitted were more in CF when compared with II which suggested that II be encouraged as a mitigation strategy for reducing impacts of its emissions.

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