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RESEARCH ARTICLE

PRECISION AGRICLTURE FOR SUSTAINABLE FARMING: DIGITAL TECHNIQUE TO ESTIMATE GREENHOUSE GAS EMISSIONS FROM WHEAT FIELDS AS INFLUENCED BY DIFFERENT TILLAGE PRACTICES IN BAMENDA, CAMEROON

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ABSTRACT

Tillage operations alter the intensity of greenhouse gas emissions from soils. Given the increasing concern of the impacts of agricultural practices on climate change, studies on the impact, and the mitigation potential of tillage practices on greenhouse gas emissions are required to enable widespread adoption. This study aimed to apply digital technology to accurately estimate tillage impacts on greenhouse gas emissions under wheat cultivation in Bamenda, Cameroon. A field study was executed during the 2023 and 2024 crop growing seasons in Bambili, at the research field of the College of Technology of the University of Bamenda, Cameroon. Five different tillage practices namely; disc ploughing followed by disc harrowing (mechanized tillage), burning in ridges ("Ankara"), and traditional ridge tillage (traditional tillage practices), no-tillage, and strip tillage (conservation tillage practices) were applied and replicated three times in a randomized complete block design. Greenhouse gas emissions (CO_2 and CH_4) emitted from the wheat field were measured insitu using a digital gas measuring device. Tillage practices influenced CO_2 and CH_4 emissions during both the 2023, and 2024 cropping seasons. Traditional ridge tillage and burning in ridges recorded the mean highest CO_2 and CH_4 emissions while no-tillage, and strip tillage emitted the lowest CO_2 emissions during both years. Equally, disc ploughing followed by disc harrowing emitted moderate CO_2 emissions, and least CH_4 emissions while no tillage released high amounts of CH_4. Thus, strip tillage with low emissions of both gases is a more sustainable, environmentally safe tillage practice recommended to wheat farmers in Bamenda.

KEYWORDS

Precision agriculture, Sensors, Farm machinery, Tillage practices, Greenhouse gas emissions

1. INTRODUCTION

In this era, agriculture has seen great transformation in technology due to digitization such as the greater focus on its technologies; precision agriculture, and smart farming (McFadden et al., 2022). Precision agriculture, an emerging technology in agriculture engages the efficient capabilities of intelligent agricultural machinery, thereby increasing agricultural productivity (e.g. through precise nutrient, weed and pest management), optimizing natural resources (such as water and land), and reducing environmental degradation through detection of greenhouse gases (Anand et al., 2022; Lingireddy et al., 2023; Tiwari, 2013). Precision agriculture applied for the detection and estimation of greenhouse gas emissions uses technologies such as sensors (Lingireddy et al., 2023; Tiwari, 2013). Smart farming on the other hand deals with data collection, monitoring, and analysis from within farms in order to improve on food productivity, while decreasing the negative impact of farming practices on the environment. Digital agriculture, thus, a combination of precision agriculture, and smart farming technologies (McFadden et al., 2022).applies digital tools to collect, combine, analyze, and share data along the entire agricultural value chain thereby enhancing agricultural productivity and providing a climate resilient environment (Dibbern et al., 2024; Lingireddy et al., 2023).

Climate change as a result of the emission of greenhouse gasses is one of the most severe global challenges (Feulner, 2016). In Africa, climate change is one of the most severe challenges in the 21st century (Olusegun et al., 2017). Africa contributes lowest (4%) of global greenhouse gas emissions due to low level of industrialization. However, extensive land use changes that occurs in many tropical African countries may significantly raise greenhouse emissions of the continent (Olusegun et al., 2017). Agriculture is directly responsible for 14% of annual greenhouse gas (GHG) emissions worldwide (Sapkota et al., 2014). Carbon dioxide (CO_2), and Methane (CH_4) are among the major climate trace gases (Oertel et al., 2016). Amongst these gases, CH_4 presents 25 times higher global warming potential than CO_2 (Munoz et al., 2010; Signor et al., 2013). However, CO_2 affects the processes of global warming and is considered an initiator of global climate change (Bilandžija et al., 2017; Robertson, 2014). Greenhouse gas emissions are said to come from agricultural soils (Lokupitiya Paustian, 2010; Munoz et al., 2010). And agricultural practices such as residue cover and tillage practices (Signor et al., 2013). Soil greenhouse emissions are thus influenced by tillage practices (Abdalla et al., 2013).

The intensive use of agricultural machinery for farming operations such as tillage practices has led to adverse effects on the environment including the emission of greenhouse gases (Anand et al., 2022; Tiwari, 2013). Tillage operations can alter the intensity of greenhouse gas emissions from soils (Li et al., 2023). Mechanized tillage which involves mechanical soil manipulation affects soil structure, which could influence soil water holding capacity, and greenhouse gas emissions while conservation tillage with at least 30% of the soil surface covered with crop residue improves soil moisture content, CH_4 absorption, and a reduction of net CO_2 flux (Alhassan et al., 2021). Due to the potential of tillage practices to affect greenhouse gas emissions, there is a growing interest in applying environmentally friendly tillage systems that are capable of improving soil quality while reducing greenhouse gas emissions from the soil (Valujeva et al., 2022). Given the increasing concern of the impacts of agricultural practices on climate change, studies on the impact, and the mitigation

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potential of tillage practices the study on greenhouse gas emissions are required to enable widespread adoption (Abdalla et al., 2013). Also, detailed scientifically proven knowledge on the effects of tillage systems on greenhouse emissions is necessary for recommending low emission practices (Feng et al., 2018). Thus contributing to the global fight against climate change. However, field studies estimating greenhouse gas emissions from the agricultural sector are still very few in Sub Saharan Africa thereby leading to a high level of uncertainty in greenhouse gas budgets in the continent (Wachiye et al., 2020). This study thereby aimed at estimating the impacts of five different tillage practices on the emission of greenhouse gasses (CO_2 and CH_4) from soils under wheat cultivation in Bamenda, Cameroon.

2. Materials and Methods

2.1 Experimental area

An experiment was executed in Bambili, Tubah Subdivision (5.45°N-9.9°N and 9.13°E-11.13°E) located in Bamenda, Cameroon during the 2023 and 2024 crop growing seasons (starting in March of each year, and ending in June), with the cultivation of wheat. The climate of the area is divided into a minor dry season (which starts from November and ends in March), and a major raining season that commences from April and ends in November (Magha et al., 2021). The maximum rainfall during the experiment was 850 mm recorded in June of 2023, and the minimum rainfall was 160 mm recorded in May of 2024. The average daily temperatures were 22^{o}C in 2023, and 22.3^{o}C in 2024 (Department of National Meteorology, Ministry of Transport, Yaounde, Cameroon). The soils at the experimental field were classified as clay loam (40.5% sand, 30% silt, and 29.5% clay), with 5.10% organic carbon content, 0.079% Nitrogen content, 12% moisture content, and a pH of 6.4 (measured from 0 - 30cm soil depth).

2.2 Experimental design and treatments

The study field was partitioned into plot sizes of 25m^2 (5m x 5m), laid out in a randomized complete block design with five different tillage treatments, replicated three times. The tillage treatments were; disc ploughing followed by disc harrowing (mechanized tillage), burning in ridges ("Ankara"), and traditional ridge tillage (traditional tillage practices), no-tillage, and strip tillage (conservation tillage practices). Disc ploughing was applied first using a tractor mounted standard three-disc right-handed disc plough, with the intension to cut and break the soil structure, invert soil and control weeds. Disc harrowing followed using a tractor mounted offset disc harrow, aimed at soil pulverization and aeration. Crop residues were left on the surface of the no tillage, and strip tillage plots (at least 30%). Dried grasses were burned underneath the soil in the burning in ridges tillage plots while vegetation was covered with soil and allowed to decompose underneath the soil in the traditional ridge tillage plots (Mbachan and Ngwabei, 2024).

2.3 Cultural practices

Wheat seeds obtained from the Department of Crop Production Technology, of the College of Technology of the University of Bamenda, Cameroon were planted at a sowing depth of 2.5 cm using a hand dibbler (Reagan et al., 2018) at a seeding rate of 500 seeds in a square meter (Wozniak and Rachon, 2020). The distance between crops and rows was 25 cm (Buck and Keys, 2019). Weed control was done using the hand hoe on all plots, except the no tillage plots whereby chemical herbicide Glyphosate (Round-up) was sprayed at an application rate of 4 L/ha to control weeds.

3. Data Collection

Compared to the costly and work intensive Mechanized greenhouse gas data collection methods, the digital technique using digital devices (sensors) was used for greenhouse gas monitoring from the different tillage plots on the wheat field. The digital technique provided for a low cost, easy, fast, precise, and insitu method for estimating greenhouse gas emissions from the soil (Heger et al., 2020).

3.1 Digital gas measuring device description, and field application

The prototype of a low cost digital greenhouse gas measuring device is shown on Figure 1. It consisted of electronic components which were:

- **Sensors:** The precise MG811 CO_2 sensor fabricated by Zhengzhou Winsen Electronics Technology Co., Ltd, and the low cost, highly accurate, and sensitive semiconductor type MQ4 CH_4 sensor manufactured by Hanwei Electronics (Mukhtarov et al., 2024).
- **Arduino mega microcontroller**, the central processing unit of the digital device, handling inputs from the sensors, processing the data, and controlling the system (Heger et al., 2020; Thongleam et al., 2024).
- **Main board**, where the CO_2 and CH_4 sensors were connected by wiring to the Arduino mega microcontroller (Heger et al., 2020).
- **Data acquisition SD card,** inserted into the Arduino system for storing data from the microcontroller in a readable format, enabling easy access and usage (Thongleam et al., 2024).
- **Power supply:** A rechargeable battery serving as a source of power to provide energy for the sensors and the microcontroller.

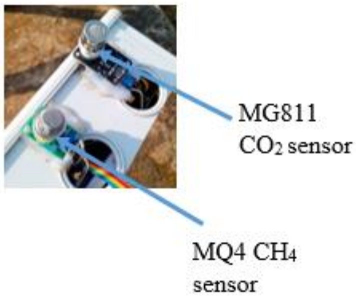

Figure 1: Digital gas measuring device showing CO_2 and CH_4 sensors

Figure 2 presents the field application of the digital gas measuring device for greenhouse gas (CO_2 and CH_4) data collection from the different tillage plots. Spots on the tillage plots where gas measurements were to be collected were kept undisturbed and flux chambers fixed and installed to the ground (Figure 2a). The digital gas measuring device was positioned on the lid of the flux chambers (Figure 2b). Water was placed around the open chamber lids for sealing to make them airtight. Immediately the flux chambers were covered with its lids (Figure 2c), the stop watch was switched on and gas concentrations at intervals of 5 minutes over a 60 minutes period were recorded by the device and stored in the data acquisition SD card (Mendes et al., 2015).

a) b) c)

Figure 2: Field application of digital gas measuring device

a) Base of the chamber permanently placed in the field

b) Digital gas measuring device fitted to chamber lid

c) Covering of the chamber with chamber lid for commencement of measurements

The slope of the regression (plots of greenhouse gas concentration against time), volume of chamber, and chamber area were used in determining the greenhouse gas flux according to the model developed by Collier et al. (2014) given by;

$$F = \frac{S \, x \, V}{A}$$

Where;

F = Greenhouse gas flux (mg m^{-2} hr^{-1}),

S = Slope of the regression (mg L^{-1} hr^{-1})

V = Volume of chamber (L)

A= Chamber area (m^2)

3.2 Data Analysis

CO_2 and CH_4 fluxes collected were subject to the One-Way ANOVA procedure for Randomized Complete Block Design using the Minitab Statistical Software 22. Tukey Pairwise Comparisons (Turkey Simultaneous Tests for Differences of Means) were used to determine significant differences (P<0.05) between the different tillage treatments.

4. Results and Discussions

4.1 Impact of tillage practices on CO_2 emissions

Table 1 and Table 2 show the impacts of tillage practices on CO_2 emissions during the 2023 and 2024 crop growing seasons respectively.

Table 1: Effects of tillage practice on CO_2 emissions in 2023

Tillage practice	Mean CO_2 flux (mg m^{-2} hr^{-1})	Standard Deviation
Burning in ridges	46.2	36.3
Strip tillage	8.17	7.32
No tillage	11.92	10.86
Disc ploughing followed by disc harrowing	19.07	10.90
Traditional ridge tillage	47.50	43.1

Table 2: Effects of tillage practice on CO_2 emissions in 2024

Tillage practice	Mean CO_2 flux (mg m^{-2} hr^{-1})	Standard Deviation
Burning in ridges	44.5	41.6
Strip tillage	29.1	22.4
No tillage	7.41	6.47
Disc ploughing followed by disc harrowing	23.30	11.46
Traditional ridge tillage	29.3	25.4

Tillage affected CO_2 emissions for both 2023, and 2024 crop growing season. The traditional ridge tillage practice produced the mean highest CO_2 emissions (47.50 mg m^{-2} hr^{-1}) in 2023 followed by burning in ridges (46.2 mg m^{-2} hr^{-1}), while in 2024, burning in ridges rather emitted higher CO_2 emissions (44.5 mg m^{-2} hr^{-1}) followed by traditional ridge tillage (23.30 mg m^{-2} hr^{-1}). These results align with (Jain et al.,2014) who obtained highest CO_2 emissions from the burning of crop residues in India, and (Dung et al., 2022) who recorded highest CO_2 emissions from the decomposition of vegetation in Vietnamese Mekong Delta region. Combustion of plant residues and other organic materials in the burning in ridges tillage practice directly releases high amounts of CO_2 which contributes to global warming. Also, the decomposition of vegetation underneath the soil in the traditional ridge tillage practice leads to the oxidation of carbon stored in the soil, contributing to CO_2 emissions over time (Dung et al., 2022). Disc ploughing followed by disc harrowing produced the third highest emissions of CO_2 during both years (19.07 mg m^{-2} hr^{-1} in 2023 and 23.30 mg m^{-2} hr^{-1} in 2024). Generally, mechanized tillage disrupts the soil mechanically thereby breaking the soil structure, increasing soil aeration, and microbial activity, as well as acceleration of organic matter decomposition thus, the release of CO_2 into the atmosphere (Krištof et al., 2014; Reda, 2016). The study also found that the use of farm machineries in disc ploughing followed by disc harrowing caused increased CO_2 emissions. Although disc ploughing followed by disc harrowing contributes to significant CO_2 emissions, its impact is generally less damaging compared to traditional ridge tillage and burning in ridges due to the fact that it does not directly release large amounts of CO_2 as it is with biomass decomposition and vegetation burning (Afzalinia .,2020). Lowest CO_2 emissions were recorded in strip tillage in 2023 (8.17 mg m^{-2} hr^{-1}), and in no tillage in 2024 (7.41 mg m^{-2} hr^{-1}). This study is similar to (Afzalinia.,2020; Krištof et al., 2014; Reda., 2016) who found out that conservation tillage practices (no tillage, and strip tillage) produced far lesser CO_2 emissions than Mechanized moldboard ploughing. This is due to the presence of crop residues, and absence of soil disturbance in these conservation tillage practices which maintains soil organic carbon levels, thus a reduction in the release of CO_2. No tillage practice particularly promotes long term carbon sequestration due to the preservation of soil organic matter (Reda, 2016). It also keeps the soil structure intact, reducing soil aeration and microbial activity thus the reduction of CO_2 emissions from the soil. By tilling only narrow strips of soil, strip tillage also minimizes soil disturbance which limits the exposure of organic matter to oxidation.

4.1.1 Tillage effects on CH_4 emissions

Impacts of tillage practices on CH_4 emissions during the 2023 and 2024 crop growing seasons are presented on Table 3 and Table 4 respectively.

Table 3: Impacts of tillage operations on CH_4 emissions in 2023

Tillage practice	Mean CH_4 flux (mg m^{-2} hr^{-1})	Standard Deviation
Burning in ridges	0.02150	0.01517
Strip tillage	0.01625	0.00527
No tillage	0.02150	0.01717
Disc ploughing followed by disc harrowing	-0.00350	0.01602
Traditional ridge tillage	0.01475	0.00263

Table 4: Impacts of tillage operations on CH_4 emissions in 2024

Tillage practice	Mean CH_4 flux (mg m^{-2} hr^{-1})	Standard Deviation
Burning in ridges	0.0353	0.0336
Strip tillage	0.0250	0.0271
No tillage	0.0554	0.0411

Table 4 (cont): Impacts of tillage operations on CH_4 emissions in 2024		
Disc ploughing followed by disc harrowing	0.0273	0.0232
Traditional ridge tillage	0.0569	0.0406

Tillage practices influenced CH_4 emissions during both 2023 and 2024 crop growing seasons but from turkey simultaneous tests for differences of means, their effect was statistically the same. However, the burning in ridges, and no tillage practices produced the mean highest CH_4 flux in 2023 (both emitting 0.02150 mg m^{-2} hr^{-1}), while traditional ridge tillage emitted the highest CH_4 emissions in 2024 (0.0569 mg m^{-2} hr^{-1}) followed by no tillage (0.0554 mg m^{-2} hr^{-1}). The incomplete burning of vegetation underneath the soil as well as the presence of methanogenic microorganisms that anaerobically decompose partially burnt biomass remaining in the soil could lead to increased emissions of methane in the burning in ridges tillage practice. Also, covering biomass with soil in the traditional ridge tillage practice enhances anaerobic conditions in the soil, promoting methane production by methanogenic bacteria which thrive in low oxygen environments (Dung et al., 2022). No tillage on the other hand with no soil disturbance provides for little exposure of organic matter to aerobic microbes, thereby enhancing activities of anaerobic microbes which produce high amounts of methane (Lenka et al., 2022). Mechanized tillage through disc ploughing followed by disc harrowing produced negligible CH_4 flux in 2023 (-0.00350 mg m^{-2} hr^{-1}), while strip tillage produced the lowest CH_4 flux in 2024 (0.0250 mg m^{-2} hr^{-1}). This agrees with studies by (5Lenka et al.,2022). Who also obtained reduced CH_4 emissions in Mechanized tillage compared to no tillage in Madhya Pradesh, India. The presence of high intensity soil disruption in disc ploughing followed by disc harrowing leads to increased soil aeration and reduced anaerobic conditions. This causes a reduction in CH_4 emissions as aerobic microbes rather cause methane oxidation leading to very low CH_4 emissions (Zhao et al., 2024). Tilling only narrow strips of soil in the strip tillage practice allows for litttle soil disturbance and the preservation of soil organic matter which maintains a balance of soil aeration and microbial activity, limiting the degree of anaerobic conditions in the soil, thus a decrease in the emissions of methane.

5. Conclusion

This study effectively applied digital technology in quantifying greenhouse gas emissions (CO_2 and CH_4) in wheat fields in Bamenda. Tillage practices affected and contributed to CO_2 and CH_4 emissions. The traditional tillage practices (traditional ridge tillage and burning in ridges) recorded the highest emissions of CO_2 and CH_4. This was due to the fact that traditional ridge tillage exposes vegetation to decomposition resulting in high CO_2 emissions, as well as provides anaerobic conditions in the soil which increase methane production by methanogenic bacteria which thrive in low oxygen environments. Also, burning in ridges through the direct combustion of vegetation, and the anaerobic decomposition of partially burnt biomass remaining in the soil led to high CO_2 and CH_4 emissions. Mechanized tillage (disc ploughing followed by disc harrowing) produced the second highest CO_2 emissions due to increased soil aeration, as well as very little CH_4 fluxes due to the lack of anaerobic conditions that favour methanogenic bacteria. Conservation tillage practices (strip tillage and no tillage) recorded the lowest CO_2 emissions while no tillage rather produced higher CH_4 emissions. Strip tillage, recording a lower emission of both CO_2 and CH_4 gases thus is an environmentally friendly tillage practice for adoption by farmers in Bamenda.

Conflicts of Interest

The authors declare no conflicts of interest.

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