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DEPARTMENT OF HORTICULTURE

ASSESSMENT OF THE QUALITY AND QUANTITY OF MAIZE, RICE AND SOYBEAN BIOMASS IN THE NORTHERN REGION OF GHANA

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DECLARATION

I hereby declare that, except for the references made to other people's work and quotations which I duly cited, this thesis is the result of my own research and no part of it has either been presented in part or in whole for another degree in this University or elsewhere.

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ABSTRACT

The efficient use of crop residues, including straw, stalks, and pods, plays a crucial role in achieving sustainable agricultural production. This research was aimed at evaluating the quantity and quality of maize, rice, and soybean biomass in the Northern Region of Ghana. Data was collected from 200 farmers in the Tolon and Kumbungu districts, as well as the Savelugu municipality using purposive sampling method and analyzed using the Statistical Package for Social Sciences (SPSS). Crop residue samples were obtained from farm fields and subjected to laboratory analysis to determine their nitrogen (N), phosphorus (P), potassium (K), and carbon (C) content. The average crop residue yield for the three crops were: 7020 kg/ha for maize, 4096 kg/ha for rice, and 2924 kg/ha for soybean. The percentage of crop residue used as fuel wood for each crop were 25.0% for maize, 9.6% for rice, 5.6% for soybean. Percentage of residue for animal feed were 8.9% for maize, 15.4% for rice, and 55.5% for soybean. Also, the percentage of residue for soil amendment were 12.5% for maize, 13.5% for rice and 25% for soybean straw. The larger portion of the residue were burnt on the field either by farmers or game hunters, with 53.6% for maize straw, 57.7% for rice straw, and 13.9% for soybean straw. The nitrogen content of the residue varied significantly ($p <. 001$). Soybean recorded the highest nitrogen content of 1.103 ± 0.34% followed by rice residue with a nitrogen content of 0.914 ± 0.25% whiles maize residue recorded the least nitrogen content of 0.825 ± 0.17%. The phosphorus content of maize, rice and soybean residue ranged from 0.0620 ± 0.02%, 0.0606 ± 0.02%, 0.0970 ± 0.16% respectively which were not significantly different ($p = 0.25$) from each other. The price of nitrogen in one (1) kg of maize residue was estimated to have a value price of GH₵ 0.0495 or US$ 0.0083. One kilogram of soybean residue can be estimated to have a value price of GH₵ 0.06618 or US$ 0.011. This price encompasses not only the value of nitrogen or phosphorus present in the crop residues but also includes the value of additional environmental benefits that go beyond simply substituting fertilizers. The research findings indicate that the practice of recycling crop residues for crop production in the Northern Region of Ghana is currently inadequate and should be promoted due to the numerous associated advantages.

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ABBREVIATIONS AND ACRONYMS

GDP…………………………………Gross Domestic Product

PRR…………………………………Product to Residue Ratio

IEA………………………………… International Energy Agency

SOC……………………………….... Soil Organic Carbon

SOM………………………… ……... Soil Organic Matter

CEC……………………………….... Cation Exchange Capacity

IPNI……………………………….... International Plant Nutrition Institute

BCSR………………………………Base Cation Saturation Ratio

GHG……………………………….. Green House Gas

EC………………………………….. Electrical Conductivity

ERS…………………………………Economic Research Service

UN………………………………… United Nations

EPACT…………………………….. Energy Policy Act

MoFA……………………………… Ministry of Food and Agriculture

FAO……………………………….... Food and Agriculture Organization

RAD……………………………….. Regional Agriculture Department

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Crop residues such as straws, stalks and pods have been associated with crop production and are noted for improving soil organic matter (SOM) content and soil structure (Andrews *et al*., 2021). According to Jain *et al.* (2014), agricultural residue(s) are the biomass left in the field following harvesting and processing of the economic components. Crop residues are important for improving soil structure and soil organic matter (SOM) while also sequestering carbon and reducing evaporation of water from the soil. Erosion control and reduction of weed growth on the field are added advantages of crop residues.

An estimated 3.8 billion metric tons of crop residue are generated worldwide (Hiloidhari *et al*., 2020) while an estimated 60-70% of crop residues are produced in Ghana yearly (Seglah *et al*., 2019). The northern parts of Ghana are considered as one of the major food baskets of Ghana and has attendant production of large quantities of crop residues. These crop residues are mostly used as animal feed, thatch for roofing residential and commercial properties, residential cooking fuel while the rest is left on the field to decompose. In some cases, these residues become a nuisance to land preparation and farmers resort to burning them before planting. Farmers also burn crop residues because, there is evidence that they harbour pests and/or diseases that could reduce harvest in the subsequent cropping season (Berazneva, 2013). According to Smil (1999), farmers in low-income countries who burn all their crop residues estimated that approximately 25% of their residues are lost through this practice. Conversely, retaining crop residue(s) on farm fields and implementing land fallowing and composting techniques are crucial methods for increasing organic matter in the soil. This is particularly important for maintaining soil fertility in various agricultural systems and conditions. In fact, it is widely believed that the primary cause of lessening food production in sub-Saharan Africa is inadequate fertility of the soil (Sanchez 2002; Antle and Stoorvogel, 2008). To address this issue, farmers have predominantly relied on the application of chemical fertilizers as the primary means of enhancing soil fertility and achieving high yields. Unfortunately, most farmers in Ghana and northern Ghana in particular do not have the financial might to purchase these chemical fertilizers. According to Place *et al*. (2003), continuous application of chemical fertilizer by resource-constrained smallholder farmers worsens the lack of nutrients in the soil. Sub-Saharan Africa (SSA) has limited soil fertility, which calls for mixed applications of synthetic and organic fertilizers to meet both the immediate nutrient requirements of crops and in the long run improvements in organic matter in the soil (Vanlauwe *et al*., 2014). Marenya and Barrett (2007) claim that by combining these two resources, farmers will be able to benefit from their economic complementarities.

1.2 PROBLEM STATEMENT

The large quantities of crop residues left on the farmers' fields are mainly burnt during land preparation contributing to global warming through the emission of CO_2, N_2O, CH_4 (Bhatia *et al*., 2013). This is problematic and derails the world's effort of achieving sustainable development Goal 13 which pushes for climate-smart production methods. That aside, burning residues of crops lead to the evaporation of some nutrients in the soil and also kills both micro and macro-organisms that aid in soil nutrient transformation (Okereke, 2021). The practice, if pervasive could destroy soil structure. Additionally, most farmers in northern Ghana are resource-constrained and are unable to purchase agro-chemicals. The benefits of crop residues as soil amendments therefore come in handy for such farmers.

1.3 JUSTIFICATION

Ghana, being largely agricultural, produces significant quantities of crop residues (Boon and Anuga, 2020). The increasing human population necessitates greater food production (Mohammed *et al*., 2013), leading to a rise in crop residue production per capita. Additionally, the Government's initiative, planting for Food and Jobs, is expected to boost yields through increased vegetative growth, resulting in more crop residues being generated (Timsina, 2018). Given this context, the question arises: should farmers continue burning these residues, despite the associated soil and environmental impacts, when they could be put to better use for their benefit?

To effectively utilize crop residues for soil improvement, a comprehensive quantification and assessment of their nutrient contents are required (Turmel *et al*., 2015 and Ali *et al*., 2019). Unfortunately, there has been a lack of such comprehensive assessments of nutrient contents and volumes of organic resources for soil improvement (Giller *et al*., 2011). Even though straw resources are predominantly in the world (Yang *et al*., 2015), especially in Ghana's northern area, are abundant, little is known about their various potential uses or the consequences of burning them. Policymakers need specific information to address the issue of burning of crop residues (Seglah *et al*., 2020).

Understanding the significance of crop residues for improving soil organic matter, structure, and other benefits, it becomes crucial to quantify their nutrient contents, particularly N, P, K, and C, to determine their potential in enhancing soil fertility and productivity. The current research holds particular importance, due to its economic importance in the northern Ghana. By undertaking this study, we can contribute, albeit in a small way, to achieving the Sustainable Development Goals set by the United Nations.

1.4 OBJECTIVES

1.4.1 MAIN OBJECTIVE

The primary aim of this study was to quantify and analyze the nutrient composition of biomass derived from maize, rice, and soybean crops in the Northern Region of Ghana.

1.4.2 SPECIFIC OBJECTIVES

i. To determine the quantity of crop residues generated from maize, rice and soybean farms.

ii. To determine the N, P, K, and C contents of the crop residues.

iii. To determine the uses of crop residues by farmers after harvest.

1.5 RESEARCH QUESTIONS

i. What is the quantity of crop residue generated from maize, rice and soybean farms?

ii. What is the quantity of N, P, K and C content in the crop residue?

iii. What is the uses of crop residues to farmers after harvest?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 CROP RESIDUES

Residues from crops are materials of organic origin that constitute parts of living crops and/or plants left on farmers' fields either deliberately or inadvertently after crops are harvested. Crop residues vary greatly in properties and decomposition (Lal, 2005a; Iqbal *et al*., 2013). They are important in maintaining long term soil fertility and supporting sustainable crop production. The production of agricultural byproducts or crop residues is predicted to be about 3.8 billion tons per year globally, with grains making up over 74 % of this total. On the other hand, legumes, petroleum plants, sugar plants, and root crops account for 8%, 3%, 10%, and (5%) respectively (Lal, 2005b; Hiloidhari *et al*., 2020). According to Smil, (1999) and Lal, (2005b), developing nations are estimated to produce 60% of crop residues while 40% is produced in the developed countries. In developing counties such as Ghana, roughly 50% of the feeds for livestock come from crop residues in addition to contributing to meeting the family power requirements for cooking and other domestic stuff (Herrero *et al.*, 2010). Crop residues are also used as substrates for mushroom cultivation, feedstock for biofuel generation and in the paper manufacturing industry (Liu *et al.*, 2014). Crop residue is essential for the management of soil organic carbon (SOC) due to its high concentration of 50% C content. Allowing crop residue to decompose in the soil helps to increase SOC concentration (Blanco-Canqui *et al*., 2013). Crop residues are also used as feed stocks in producing cellulosic ethanol. High residue removal from farm fields for off-farm uses could result in a reduction of crop residues and long-term low in SOC concentration (Anderson-Teixeira *et al*. 2009).

Evidence exist that a large quantity of crop residues is left in farmers' fields after harvesting (Franzluebbers, 2015). Unfortunately, most farmers may not be aware of the important roles crop residues play in maintaining and enhancing not only chemical but also biological and physical soil properties (Blanco-Canqui and Lal, 2009; Franzluebbers, 2015; Stavi *et al.*, 2016; Carvalho *et al.*, 2017).

2.2 ROLE OF CROP RESIDUES IN SOIL FERTILITY MAINTENANCE

2.2.1 PHYSICAL PROPERTIES

Physical degradation of agricultural soils is a serious problem in tropical nations (Lal, 2000). Indeed, as a result of climatic changes, erosion is becoming more aggressive and quicker, resulting in the formation of gullies, tree uprooting, crop loss, soil leaching, seed germination deregulation etc. (Brown *et al*., 2004). Intensive agriculture, uncontrolled logging, population increase, urbanization, and industry all contribute to the degradation of soil physical structure (Bhadauria and Saxena, 2010). Incorporation of residue into farming systems, however will help to regenerate soil structure by binding loose soils and also prevent washing away of soil nutrients (Mgolozeli *et al*., 2020). The application of chemical fertilizers more frequently than organic inputs, according to Miaomiao *et al*. (2009), enhances immediate yields but gradually degrades the soil. Furthermore, for small farms with limited/inadequate financial resources, these fertilizers are becoming progressively expensive. For farmers to successfully address the issues brought on by the use of chemical fertilizers, improved structural stability of soils with increased soil organic matter content are crucial (Fu *et al*., 2021). It is widely accepted that organic matter is essential for the restoration and stabilization of damaged soil structures (Cambardella *et al*., 2003). The use of crop residues in agriculture is related to their nutritional contents as well as to their capacity to decrease soil runoff and erosion while enhancing water retention, which is crucial for the growth of plants and microorganisms (Erenstein, 2002).

Crop residue decomposition also contributes in the formation of quality structure of the soil by increasing soil moisture content, decreasing bulk density, increasing total porosity, and improving aggregate stability (Lou *et al*., 2011; Brankatschk and Finkbeiner, 2015; Zhao *et al*., 2019). The soil's ability to hold water is increased by organic matter. Additionally, it influences the soil's dark colour (Krull *et al*., 2004; Bot and Benites, 2005; Broadbent, 2015). The soil temperature rises as a result of these two soil characteristics, boosting the soil's capacity to absorb heat (Fang *et al*., 2005).

Shaver's (2010) findings indicated that soil bulk density gradually decreases as crop residue quantities increase. According to Fu *et al*. (2001), soil bulk density (SBD) can serve as an indication of soil structural changes. Bulk density of the soil in 0–20 cm layer was found to have decreased by 5.7%, according to Zhao *et al*., (2018).

When crop residues are processed and added to the soil and plowed deeply, the soil becomes more porous (Fu *et al*., 2021). A study by Gao *et al*., (2020) found that the complete summer maize stalks ploughed into the soil as treatment boosted the soil's total porosity at the physiological stage by 23.0%. The root penetration of crops can therefore be improved by the application of crop residues to soil after harvest

2.2.2 CHEMICAL PROPERTIES

Residue decomposition may have a significant influence on soil pH, mainly in those soils with lesser buffering capacity (Tang and Yu, 1999; Xu *et al*., 2006). Pan *et al*. (2021) investigated the ameliorating effects of four (4) crop straw decayed products (SDPs) on an acidic ultisol in a thirty (30) day incubation experiment, and the findings revealed a 55% to 75% improvement in soil pH. A study by Butterly *et al*. (2013) discovered that adding agricultural residue to the soil improved the pH of the top-soil (0–10 cm) and sub-soils, with the effects persisting for up to two (2) years. The changes in soil pH can be attributed to several factors, including excessive cation concentration, cycles of carbon (C) and nitrogen

(N), variations in crop residue types, and soil characteristics (Lal, 2005a; Butterly *et al*., 2013; Shen *et al*., 2015). Effective management of crop residues has a significant impact on the cation exchange capacity (CEC) of the soil. Accumulation of soil organic matter (SOM) in crop residues can lead to an increase in negative charges, thus enhancing CEC (Abbasi *et al*., 2009; Rezig *et al*., 2013). Malobane *et al*. (2020) conducted a three-year field study using sweet sorghum and observed that retaining 30% of the crop residue, compared to removing it entirely, resulted in an 11.3% and 27.32% increase in CEC based on the total harvested fresh biomass. Furthermore, the Cation Exchange Capacity (CEC) showed significant increases of 85% and 102% during the first and second cropping seasons in a five (5) season wheat-guard rotation experiment. These improvements were observed when the researchers incorporated mulched residues, with a continuous integration of only wheat residues (Mbah and Nneji, 2011).

Cation exchange capacity increased by 9.39-21.59 percent on the surface (0-20 cm) compared to the control (Rezig *et al*., 2013). Additionally, after the application of peanut, pea, canola, and rice decaying products (SDPs), The CEC (cation exchange capacity) of the sandy ultisol exhibited increments of 0.72, 1.09, 0.99, and 1.05 cmol/kg respectively, according to Pan *et al*., (2021). The buildup of soil organic matter mostly regulates the rise in CEC (Fu *et al*., 2021).

2.2.3 BIOLOGICAL PROPERTIES

In the soil ecosystem and the biogeochemical cycle of essential components like nitrogen and carbon, microbial communities are essential contributors (Fu *et al*., 2021). Returning crop residue to the soil can improve the soil organic matter content and provide a conducive habitat for the growth, development and proliferation of microorganisms (Shen *et al*., 2015; Su *et al*., 2020; Zhang *et al*., 2021). In addition to their impact on nutrient cycling, microbes also have an impact on the soil's physical attributes because they produce extracellular polysaccharides, which act as cementing agents to stabilize soil aggregates, as well as other cellular waste that is necessary for preserving and improving soil structure (Golchin *et al*., 2018).

An early indicator of soil fertility is a change in the microbial biomass, which can indicate improvement or degradation for several of the aforementioned qualities (Kushwaha *et al*., 2000). Straws of sugarcane kept for a period of 14 months can improve the diversity and quantity of fungus in the 0-10 cm soil depth (Zhang *et al*., 2021). The richness of the fungal population and the risk of fungal pathogenicity in corn straw returns were both lower than in wheat straw returns. This was mostly caused by the fact that after maize straw returned, specific fungal species eventually took over. (Su *et al*., 2020). Additionally, research by Ali *et al*., (2020) shows that substrates of garlic boosted the variety and quantity of helpful microorganisms for plants. Crop residues regenerate weak soil through decomposition of crop residues into organic manure which contains various organic nutrients and soil properties (Bationo *et al*., 2019; Seglah *et al*., 2019). According to Tejada *et al*., (2009) restoring crop residues back to soil facilitates; soil reestablishment, sustaining soil organic matter, recovering degraded soils, and contributing plant nutrients. A study according to Fu *et al*., (2021) also said the diversity and population of fungi in paddy soils, as well as their functions, were found to be greatly benefited by the prolonged use of inorganic fertilizers and rice straw.

The composition of microbial populations for degradation can be influenced by the quality of crop wastes that are returned to the soil (Gonzalez, 2002). According to Wardle *et al*., (1999), the type of microorganisms in the soil may also change depending on the plant community. Some results shown that, soybean residue promoted the growth of more cellulolytic bacteria (Escobar Ortega *et al*., 2021).The location of residues has a substantial impact on both the level of disintegration and the ecological successions seen in the population structure and taxonomic diversity of the bacterial communities occupying those residues (Pascault *et al*., 2010).

Through indirect actions like disintegrating crop residues, blending them with soil, and grazing on decomposers, mesofauna and macrofauna are crucial for the breakdown of organic materials and the cycling of nutrients (Murungu *et al*., 2011; Ojha and Devkota, 2014; Khatoon *et al*., 2017). Among soil organisms, earthworms, termites, and ants have been recognized as significant contributors to soil engineering (Mora et al., 2005; Jouquet *et al*., 2006; Bottinelli *et al*., 2015). These organisms play a crucial role in creating biogenic structures such as casts, pellets, galleries, chambers, and nests. These structures establish distinct pathways for decomposition, extending beyond the lifespan of these organisms, thus influencing decomposition processes on broader temporal and spatial scales (Lavelle *et al*., 2016).

2.2.4 CROP RESIDUE AS SOURCE OF FERTILIZER AND SOIL FERTILITY IMPROVEMENT

There are two types of manuring that can be done with crop residues: direct manuring and indirect manuring (Watson *et al*., 2002). According to Zaniewicz-Bajkowska *et al*., (2009), direct manuring refers to the practice of mulching or incorporating waste into the soil. However, the manufacture of biochar or composting are the two alternatives for indirect soil nutrient management. Crop residue is managed for soil nutrients in one of four ways: integration, surface mulching, composting, and fertilization, according to McIntire *et al*., (1992).

According to Aggarwal and Power (1997), India produces 236 million Mg of straw annually from its five main cereal crops, of which well over one hundred (100) million Mg can be recycled through soil fertility.

Quansah *et al*. (2001) conducted a study across six regions of Ghana and discovered that farmers believe in the positive impact of mulch application and the use of crop straw-based fertilizers such as compost or biochar on enhancing soil organic matter content. Similarly, a study by Seglah *et al*. (2019) in the Savannah region demonstrated that farmers who practiced composting using crop residue agreed that straw compost had improved their soil quality (Seglah *et al*., 2019).

According to research by Dugan *et al*., (2010), maize stover biochar can be utilized as a soil amendment material at a rate of five tonnes per hectare to help Ghanaian soils keep their moisture content, which ranges from 349% to 481%, especially in sandy textured soils. Locally accessible straw that is added to the soil enhances the soil's ability to boost yield (Zhao *et al*., 2016). According to research by Issaka *et al*., (2012), the 366,975.2 Mt of rice straw produced had a nitrogen content of 1834.9 Mt, a phosphorus content of 587.2 Mt, and a potassium content of 5137.7 Mt, with other nutrients like calcium and magnesium possibly present. The significant amounts of rice straw produced in Ghana's Northern area contain more than 50% of these nutrients (Issaka *et al*., 2012). The findings of Logah (2011), adding chemical fertilizer to maize straw could raise its levels of the nutrients nitrogen and phosphorus while lowering its polyphenol content. This would boost the production of crops. The use of straw aids in preserving the soil's nutrition and moisture levels. (Seglah *et al*., 2019). Sustainable agricultural systems in Ghana have a very bright future as a result of the production and use of biochar in soils. This is due to the country's availability to biomass resources, which could serve as a possible feedstock for the production of biochar (Duku *et al*., 2011). Issaka *et al*. (2012) state that for Ghanaian soils, which are generally acidic, the utilization of ashed straw with a pH exceeding 11.0 can provide benefits. This straw contributes to the improvement of the soil's physical and chemical qualities, especially in soils in the Northern region that are deficient in phosphorus (Zhang *et al*., 2016). Using rice straw as a mulching material for cultivating "white Creole" onions resulted in a higher yield and improved productivity compared to not using any mulch (Baba *et al*., 2013). This is due to moisture's impact on mineralization, which in soils enhanced with maize and groundnut straw is 50% effective. The temperature in Northern Ghana is largely constant despite some variance in rainfall patterns, due of this, placing greater emphasis on the moisture levels of the soil and the specific type of straw being utilized is crucial when implementing soil management strategies (Mohammed *et al*., 2014). On cultivated fields, mulching with crop residue, especially rice straw and maize stovers, aids in reducing weed infestation, erosion, and soil temperature loss (Eagleton, 2017). Ghana is projected to have an annual surplus of 367,000 tonnes of rice straw, according to Tobita and Nakamura (2018). It is thought of as a substantial source of organic matter when rice straws are left to decompose in the soil (Lin *et al*., 2010). Crop residue amendment increases the soil's NPK concentration by 50% over time compared to inorganic fertilizer (Kumar *et al*., 2008). Depletion of soil organic matter is cited as the primary factor in Africa's low agricultural productivity (Sanchez, 2002; Antle and Stoorvogel, 2008). The need for a combination of chemical and organic fertilizer to solve the nutrient deficit in Sub-Saharan Africa's soils in the short and long terms is becoming more widely acknowledged (Vanlauwe *et al.*, 2014).

Numerous authors have suggested that the quality of soil in developing countries has been steadily diminishing over the period, and Ghana's soil is no different (Salaam, 2016). The majority of hot, humid soils are not very productive, according to Place *et al*., (2003), due to insufficient moisture content, the loss of crucial minerals, and the toxicity of aluminum and iron, and low organic matter, all of which have an impact on the soil's capacity to retain nutrients (Ekboir *et al.*, 2005). Residues from crops are a rich source of carbon that also contain considerable amounts of NPK as well as other nutrients necessary for crop growth (Li *et al*., 2019). It is important for balancing nitrogen, phosphorus, and potassium proportions in farm soil, as well as compensating for phosphorus and potash fertility deficits, according to (Dawson and Hilton, 2011).

Simultaneously, the nutrients released by straw decomposition can be used to boost crop yields, improve soil fertility, and create a conducive habitat for microbial activity (Li *et al*., 2021). According to Singh and Sharma (2002), it is strongly encouraged to return crop residue to the soil rather than burn it to prevent air pollution because it is nutrient-rich and can be digested by microorganisms. Because it promotes soil microbial activity and growth, which leads to the subsequent mineralization of plant nutrients (Nelson and Mele 2006), and because it increases soil fertility and quality, according to Randhawa *et al.* (2005), applying crop residue to soil is a beneficial management technique. This makes them potential application in the repair of soil damaged zones. However, the type, quantity, and size of organic materials added also have an impact on soil qualities. The major component of a given plant residue determines how it affects the qualities of the soil (Chaves *et al*., 2004).

Several enzymes have the potential to serve as indicators of soil quality as they respond to changes in soil fertility status (Garcia-Ruiz et al., 2009). Enzymes, in comparison to physical or chemical variables, can exhibit quicker reactions to alterations in soil management practices, making them valuable as early indicators of biological changes (Bandick and Dick, 1999).

For crop growth, essential elements including carbon (40%-45%), nitrogen (0.6%-1%), phosphorus (0.45%-2%), potassium (14%-23%), and micro-elements are all necessary (Wang *et al*., 2019).

These nutrients in the residue help to correct nutritional imbalances in farm soil while also compensating for the disadvantages of inorganic fertilizers (Mohammadi *et al*., 2011). The rate and quantity of nutrients released are influenced by the carbon and nitrogen ratio and chemical structure of crop residue(s), climate (precipitation or temperature), soil properties and how crop residues are applied to the soil (Grzyb *et al*. 2020). According to Zhao *et al*. (2019), the presence of crop residues can positively impact the physical properties of soil. It can enhance soil moisture content, reduce bulk density, and contribute to increased total porosity and improved aggregate constancy.

2.4 ORGANIC CARBON AND OTHER NUTRIENTS

Decomposing crop residues play a vital role in the nutrient cycle, as highlighted by Grzyb *et al*. (2020). The incorporation of agricultural byproducts or crop residue(s) into the soil can have multiple benefits, including an increase in soil organic carbon, nitrogen, available phosphorus, and potassium levels (Tan *et al*., 2015; Zhao *et al*., 2019; Ali *et al*., 2020). Furthermore, the addition of crop residues can improve the availability of essential nutrients in the soil while reducing nutrient loss (Zhang *et al*., 2021; Abbasi *et al*., 2009). It is important to note that extensive rainfall prior to residue application can affect in leaching of potassium from the residue (Gelderman *et al*., 2011). Each crop possesses a range of nutrients in its residues, with nitrogen and potassium being the predominant ones (Torma *et al*., 2018).

The percentage of SOC in crop residues is about 40%, which can be used to manage soil characteristics and improve soil stability by forming large aggregates (Fu *et al*., 2021). Returning crop residue can also help to prevent organic carbon loss (Wang *et al*., 2020). Through mineralization and nitrification, it is possible to transform the nitrogen in agricultural residue into NH_4^+ and NO_3^-. According to Zhao *et al*., (2019), adding straw and partial fertilizers increased the amount of nitrogen that was readily available in the soil by an average of 64% at soil depths of 0 to 20 cm. However, according to Fu *et al*., (2021), crop residues contain a high carbon and nitrogen ratio (60–100:1). Consequently, a rise in returning residues can improve nitrogen immobilization, which might call for the application of additional nitrogen fertilizer (Chen *et al*., 2014). For energy processes and cell division, phosphorus is a necessary component. In crop residue, phosphorus can be broken down by microorganisms into $H_2PO_4^-$ and HPO_4^{2-} (Fu *et al*., 2021). The soil's 0–20 cm layer's accessible phosphorus level increased as a result of long-term crop straw integration (30 years). Parallel to this, phosphorus utilization efficiency rose from 43% in 1983 to 72% in 2012 when mineral fertilizer was coupled with 3750 kg/ha wheat straw treatment (Guo *et al*., 2018).

The addition of crop residues to the soil aids the accumulation of potassium (Cherubin *et al*., 2018). When raw garlic stalks were applied in dosages of 1%, 3%, and 5%, respectively, Ali *et al*., (2020) found that the level of accessible potassium increased by 4.4%, 6.5%, and 3.8%. Furthermore, according to Yadav *et al*., (2021), maintaining 90% (7.0 t) of soybean residue resulted in 89.7kg of potassium being supplied to the soil and 90% (13.8 t) wheat residue(s) added 232.2 kg potassium in 5 years.

Some plant nutrients may be present in crop residue as soluble inorganic compounds (such as K^+, SO_4^{2-}) or organic compounds with easily mineralizable elements such as amino-bond S, protein-bound S, and phosphate esters (Salas *et al*., 2003; Bhupinderpal-Singh *et al*., 2006). Following the return of agricultural residues to soil, these nutrients are easily mineralized in microbial biomass (Fu *et al*., 2021).

2.5 CARBON

2.5.1 SOIL CARBON DYNAMICS

For SOC change to occur, there must be a stability between carbon (C) inputs and outputs. Crop residues from above- and below-ground levels, animal manure, compost, and other materials are used as inputs. The outputs include deep leaching, losses caused by erosion from water and wind, and gas fluxes related with microbial and plant respiration (Blanco-Canqui *et al*., 2013). Using the renowned exponential decay function, the quality of the residues, how they are managed (including their management in the soil, water, and air), the type of soil, and the climate all affect how quickly they degrade (Blanco-Canqui and Lal, 2009). The decomposition rates of residues are influenced by the characteristics of the residues themselves, including their carbon-to-nitrogen ratio, cellulose content, as well as lignin and polyphenol levels (Lin *et al*., 2013). According to Blanco-Canqui *et al*., (2013), Higher C:N ratio residues, such those from *Zea mays L.* and *Triticum aestivum L*. wheat, may decompose more slowly than residues from legumes, which have lower C:N ratios. SOC dynamics are also impacted by the practices of residue management for instance, cutting, shredding, absorbing into the soil, and removal (Guerif *et al*., 2001).

When compared to levels when the land was primarily covered by native perennial vegetation, SOC levels have fallen by almost 50% as a result of excessive tillage and vegetation modifications (Paustian 2000; Blanco-Canqui *et al*., 2013). In comparison to coarse-textured and sloping soils, changes in SOC content can occur more slowly on soils that are tight, clayey, and poorly drained (Fissore *et al*., 2008). Some agricultural soils allow for just a 10% conversion of crop wastes into SOC, based on the aforementioned parameters (Duiker and Lal, 1999).

2.5.2 SOIL ORGANIC CARBON AND SOIL PHYSICAL PROPERTIES

Studies evaluating SOC sequestration and C emissions in agriculture fields that are under strict management are widely available in the recent literature, and the importance of SOC is frequently linked to preventing climate variation (Smith *et al*., 2020). The prominence of SOC in enhancing physical, chemical, and biological processes and qualities should not be underestimated (Blanco-Canqui *et al*., 2013). In order to improve numerous soil processes and qualities for productive agriculture, SOC must be increased from existing levels, regardless of its capacity to mitigate climate change (Lal, 2004). Physical, chemical, and biological qualities are only a few of the properties and processes that are simultaneously impacted when one soil property is improved by SOC (Blanco-Canqui *et al*., 2013). According to Guo *et al*. (2020), an increase in soil aggregate stability, for instance, can improve macro-porosity, boost water infiltration, and encourage soil microbial activity. SOC and soil characteristics are related to one another (Yang *et al*., 2017). The paper published by Blanco-Canqui *et al*., (2013) explained that the amount of SOC effects on soil properties may differ based on a number of variables, including clay content and mineralogy, the components of the soil's carbon pool (labile and stable C), and climate. For instance, silt loams may benefit more from an increase in SOC than clayey soils do. The presence of a high clay content can diminish the benefits of increased SOC because the organic and clay mineral components exhibit certain similarities, such as a high specific surface area (Liu *et al*., 2014). When assessing the effects of SOC on soil parameters, these considerations should be taken into account, according to Blanco-Canqui *et al*. (2013).

An increase in SOC encourages macro aggregation, lowers the dangers of soil compaction, and boosts water retention capacity (Blanco-Canqui *et al*., 2013). According to Baldock (2002), organic elements create binders that enable soil granules to combine to form aggregates. Enhancing the steadiness of soil aggregates can have an impact on near-surface soil processes that control water infiltration and runoff, including splash detachment, surface sealing, and crusting (Liu *et al*., 2019). The clogging of soil pores by aggregate detachment and surface sealing increases water runoff (Sajjadi and Mahmoodabadi, 2015). According to Lado *et al*., (2004), soils with high organic carbon content are less likely to experience surface seal formation or soil aggregate slaking. In order to promote water infiltration, precipitation capture, and reduced runoff, stable aggregates can preserve the integrity of surface-connected macropores in conjunction with an abundance of surface residue cover. Sometimes a rise in SOC causes a reduction, and can lead to soil compactibility (Unger and Kaspar, 1994; Blanco-Canqui *et al*., 2013), In contrast to soils with higher SOC concentration, soils that have a lower concentration of SOC tend to experience compaction at a lower water content level and under the same force of compaction.

The ability of SOC to retain water is another advantage. According to Wang *et al*., (2019), organic C enhances soil matrix water absorption and retention. The availability of plant-accessible water in 1 gram (0.0022 pounds) of carbon (C) can vary from 1 to 10 grams (0.0022 to 0.022 pounds), depending on the soil's textural class, according to Emerson (1995). The presence of organic carbon (C) improves soil water retention by increasing the precise surface area for a given amount of soil. (Petersen *et al*., 1996). More water is absorbed by soil with a higher specific surface area, and it releases water more gradually when compared to soil with a lower precise surface area (He and Walling, 1996). In times of drought, the gradual discharge of water can prevent extreme water losses (Blanco-Canqui *et al*., 2013). As a result, boosting SOC is one method for encouraging water retention in the soil and raising plant accessible water.

2.5.3 SOIL ORGANIC CARBON AND SOIL BIOCHEMICAL ATTRIBUTES

Variations in soil chemical and biological characteristics are closely associated with variations in SOC content. SOC accounts for approximately 58% of soil organic matter and influences soil respiration, microbial biomass, and community structure (You *et al*., 2014; Massaccesi *et al*., 2020). The agriculture field practices like zero-till, which increase SOC concentration, can promote microbial growth in the upper layers of the soil. Iqbal et al. (2021) found a strong correlation between SOC and enzyme (invertase) activity throughout the soil profile, comparing zero-till and normal-till practices over an extended period. Grigera *et al*. (2006) also detected a relationship between soil microbial biomass and SOC across different fields, noting that concentrations of fungal and mycorrhizal biomarkers were mainly associated with coarse particle organic matter, while concentrations of soil-borne bacteria and actinomycete biomarkers were more significantly correlated with fine particulate organic matter. Furthermore, variations in SOC impact nutrient availability, organic material decomposition, and overall soil capacity and conditions, as highlighted by Rasche and Cadisch (2013).

The relationship between SOC and other soil properties processes is well-established (Ukalska-Jaruga *et al*., 2019). SOC influences microbial activity, biomass, and processes by providing a habitat (e.g., stable aggregates) and substrate, while microbial activity, in turn, controls SOC turnover (Six *et al*., 2006). SOC also has a positive effect on soil pH and cation exchange capacity (Sumner and Miller, 1996). According to Yi *et al*. (2021), increased SOC concentration has two favorable effects: it acts as a buffer for pH, stabilizing soil acidity or alkalinity, and enhances cation exchange capacity. Additionally, SOC plays a crucial role in filtering and absorbing runoff contaminants, reducing pollution from external sources and improving water quality (Yi *et al*., 2021). Due to its large surface area and negative charge, organic matter has the ability to interact with cations and organic contaminants, such as herbicides and pesticides (Blanco-Canqui *et al*., 2013). Organic carbon exhibits a higher capacity for pollutant adsorption compared to clay minerals, attracting cations from pollutants more effectively (Yuan *et al*., 2013). Blanco-Canqui *et al*. (2013) emphasize that organic matter affects all chemical and microbiological activities that influence soil behavior and water quality.

2.6 CROP RESIDUES AND SOIL NITROGEN

Mineralization is described as the transformation of an element owing to microbial activity from an organic state to an inorganic state (Ginovart *et al.*, 2005). It has been recommended that nitrogen is the most common nutrient in crop residues, and a high proportion of it is in crop residues (in inorganic forms) that cannot be used for plant uptake (Steiner *et al*., 2008). Throughout the process of nitrogen mineralization, the organic nitrogen present in the soil's organic matter, including recently incorporated crop residues, undergoes a conversion into an inorganic form that is readily available for plant(s) uptake (Olk, 2006). The main technique for nitrogen is the ammonification process, which converts organic nitrogen (N) in soil organic matter (NH_4^+) into ammonium (Sahrawat *et al*., 2010). Frequently, the microbial nitrification process converts the ammonium rapidly to nitrate (NO_3^-). N mineralization (NM) refers to the amount of inorganic nitrogen (N), such as NH_4^+ and NO_3^- that results from SOM. (Gilmour and Mauromoustkos, 2011).

Accessibility of nitrogen (N) from plant residues is highly dependent on the amount of nitrogen mineralized or immobilized by decomposition (Hadas *et al*., 2004).

The act of integrating plant residue(s) into the soil as a method of enhancing soil quality can be a valuable recycling strategy that affects the processes of nitrogen and carbon cycling in soil-plant interactions. (Kaleem Abbasi *et al*., 2015).

2.7 CROP RESIDUES AND SOIL PHOSPHORUS

In order for phosphorus (P) to be available from organic materials, microbial biomass must mineralize it (Hayes *et al.*, 2000). As agricultural production(s) changes to meet anticipated future global food production targets, optimizing the use of phosphorus (P) will have an impact on the economy, agronomy, and environment. The quantity and types of phosphorus present in residue(s) have a significant impact on both the direct bioavailability of phosphorus in the residue material and the following interactions of phosphorus with soil constituents. The soil and environmental factors, as well as the physiological age of the crop from which they are generated, have a significant impact on the P properties (Damon *et al*., 2014). Research has shown that although reported threshold values range from 2 to 3 mg g-1, phosphorus in residues will be immobilized if it is less than 3 mg g-1 or will be mineralized if it is larger than 3 mg g-1 (Iqbal, 2016).

According to Reddy *et al*. (1997), the introduction of soybean (Glycine max) and wheat residues into the soil increased the accumulation of labile inorganic and organic phosphorus (P) while decreasing recalcitrant P levels. Field studies conducted by Waigwa *et al*. (2003) and Lupwayi *et al*. (2007) demonstrated that when crop residues and rock phosphate were applied together, there were more significant improvements in soil P levels, cereal P uptake, and cereal yields compared to the application of rock phosphate alone.

The decomposition of organic phosphorus (P), similar to organic nitrogen (N), is facilitated by soil microorganisms and influenced by environmental factors and residue quality. Kabba and Aulakh (2004) noted that changes in soil moisture and temperature impact microbial activity, thus affecting phosphorus mineralization.

In their study, Lupwayi *et al*. (2007) observed that green manure residues released higher percentages of phosphorus (P) compared to other residue types. The timing of residue addition throughout the year contributed to variations in P release patterns, partially attributed to seasonal fluctuations in soil temperature and moisture conditions.

During mature grain harvests, a significant portion of phosphorus, like nitrogen, is stored in the grain and subsequently removed during harvesting, resulting in minimal phosphorus remaining in the crop residue (Whitbread *et al*., 2000).

2.8 CROP RESIDUES AND SOIL POTASSIUM

Potassium (K) is the third major nutrient for plants after nitrogen (N) and phosphorus (P). It is involved in a wide range of biological processes that support or even enhance photosynthesis, protein synthesis, enzyme activation, crop development, and grain quality (Das and Pradhan, 2016). Activating different enzymes in plants is one of the uses of potassium (Prajapati and Modi, 2012), which leads to photosynthesis, stomata regulation, protein synthesis, water relationships, translocation of assimilates, and improvement of crop quality such as fruit size, taste, color, and quality of storage.

Potassium (K) is transferred from crop residue and is quite soluble and returned to the soil (Mikkelsen, 2007). Potassium allows the plants to convert nitrogen into proteins (Xu *et al*., 2020). Potassium deficiency in plants results in yellowing of the leaf margins, giving them a burnt look. Incomplete root development and delayed growth are further potential effects. K plays a role in a variety of biochemical and physiological functions in plants, such as stomatal control (Das and Pradhan, 2016).

Non-exchangeable K is converted to exchangeable forms when the concentration of exchangeable and solution K decreases due to crop removal or leaching (Das and Pradhan, 2016). Potassium is required by plants in larger amounts and is absorbed faster than how plants accumulate dry matter (Xu *et al*., 2020). Potassium is transferred to grain from leaves and stalks as the plant grows older. Soybeans transfer a higher percentage of potassium to the grain than cereal crops, such as sorghum, wheat, or maize. In other words, more potassium is taken from soybeans harvested per bushel than from cereal crops (Cox *et al*., 2002). Nonetheless, due to the higher potassium (K) content in crop residues compared to grains, all types of crop residues were found to contribute significantly to the regeneration of agronomically relevant levels of potassium (K) (Lupwayi *et al*., 2007). Additionally, it has been demonstrated that significant organic K fertilizer sources, such as crop residue, can successfully replace inorganic K fertilizers, enhancing soil K supply capacity and crop yields (Jiang *et al*. 2019). The amount and kind of crop residue employed have a significant impact on the effectiveness of replacing inorganic K fertilizer. For instance, it has been demonstrated that residue from agriculture works better as a substitute for chemical K fertilizers the more it is available (Sui *et al*., 2016).

2.9 BURNING OF RESIDUES

2.9.1 EFFECT OF BURNING ON SOIL

Most of the farmers understand that burning of residues as a means of preparing the land for farming causes severe damage to the soil (Kumar *et al*., 2015). This practice is, however, still being practiced by farmers due to unknown affordable alternative (Derpsch, 1998). Burning residue to prepare land for farming still remains the most affordable choice for rural farmers (Snapp *et al*., 2002).

In Africa, the traditional farming system often involves the use of the slash and burn method for land preparation, as noted by Dennis *et al*. (2013). However, this practice has significant consequences for soil nutrients. The burning of straw releases heat that can lead to accelerated soil erosion and infertility (Smith *et al*., 2016).

Several studies have proposed that agricultural practices such as no-till and residue retention can promote higher populations of soil micro-arthropods, including fungi consumed by collembolans, mites, and earthworms, compared to conventional cultivation methods (Pankhurst *et al*., 1995; House and Parmele, 1985; Doube *et al*., 1994). When crop residues or agricultural byproducts are removed or burned, it has the potential to decrease microbial biomass and activity in comparison to soils where residues are retained and incorporated back into the soil, as indicated by basal soil respiration (Biederbeck *et al*., 1980; Rasmussen *et al.*, 1980; Gupta *et al*., 1994; Hoyle *et al*., 2006).

According to Doube *et al*. (1994), the residues resulting from burning crops can have a negative impact on the density and activity of microorganisms. Val'kov *et al*. (1996) observed a reduction in the density of mites and Collembola (plant faunas) in the top layer of soil after the burning of barley residues. The studies conducted by Biederbeck *et al*. (1980) and Val'kov *et al*. (1996) indicate that the swift removal of substrates after burning leads to a decline in soil microbial activity. This reduction in microbial activity negatively affects plant growth in the field. The impacts on microbial biomass, activity, and community structure in relation to alterations in residue management techniques are particularly evident during the planting season (Drijber *et al*., 2000; Feng *et al*., 2003). However, human activities interfere with the circulation of matter in the agro ecosystem not only by removing biomass from the areas but also by other non-conscious undertakings (burning of crop residues on the ground) (Kastori *et al.*, 2012). The burning of crop residues leads to the loss of a substantial quantity of nitrogen, which has immediate adverse effect on soil fertility (Mandal *et al*., 2004). For instance, plant nutrient like sulphur can be lost even it has less ecological importance (Kastori *et al*., 2012). According to Van Loo and Koppejan (2002), combustion results in the release of potassium (K), chlorine (Cl), and sodium (Na). These elements are found in flying ash or salt as KCl, NaCl, and K_2SO_4, respectively.

2.9.2 EFFECT OF BURNING ON CLIMATE

Cereal straws particularly maize residue is recorded to be the highest burnt crop residue in Ghana followed by rice (Seglah *et al*., 2019). According to an FAO (2018), between 1961 and 2017, a total of 36,099,878 tons of crop residues (specifically maize and rice straws) were subjected to burning in Ghana. Despite the negative effect of the practice on soil health, air quality and climate, farmers across the globe continue to burn crop residue (Turmel *et al*., 2015). The open residue burning releases a range of air pollutants that are harmful to the environment (Pasukphun, 2018). According to an Environmental Scientist's observation in a study by Ubuoh *et al*. (2017), burning the soil leads to the destruction of its nutrients and overall depletion. Additionally, burning grass releases carbon dioxide into the atmosphere, contributing to the depletion of the ozone layer and climate change. The use of "slash and burn" farming techniques is considered detrimental to both local agriculture and the environment. According to Aruya *et al*., (2016) the practice of burning crop residue is viewed as a waste of precious resources because it frequently degrades the environment and pollutes human health. According to a poll by Seglah *et al.*, (2020), 15% of farmers do not burn crop residue, whereas 85% do it either deliberately or unintentionally. Eriksen (2007), also discovered that field burning can result from the yearly bushfires that are started by both farmers and game hunters in the area.

The practice of burning crop residue after harvest not only contributes to atmospheric pollution but also leads to soil degradation (Bhuvaneshwari *et al.*, 2019; Saxena *et al.*, 2021). Residue burning releases various air pollutants, including carbon monoxide(CO), volatile organic compounds (VOCs), nitrogen oxides(NOx), ammonia (NH_3), sulfur dioxide(SO_2), carcinogens such as polycyclic_aromatic_hydrocarbons(PAHs), and other toxic compounds (Yin *et al.*, 2019). Additionally, residue burning releases greenhouse gases (GHGs) such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), which are major contributors to climate change and have adverse effects on the ozone layer (Jamala *et al.*, 2012).

2.10 CROP RESIDUE UTILIZATION

In comparison to other countries, Ghana's use of crop residue is not highly competitive (Seglah *et al.*, 2019). Notwithstanding the fact that crop leftovers are utilized for a variety of reasons across the nation, traditional use is more prevalent than industrial use, which is the case in advanced countries (Zeng *et al.*, 2007; Seglah *et al.*, 2019). According to Bakker *et al*. (2013), there are two categories of uses for crop residues: agricultural and non-agricultural. Crop residues are utilized for a variety of local purposes, such as burning, in addition to being used as fuel for cooking, a source of fertilizer to improve the soil, a substrate for the growth of mushrooms, and as feed for cattle. Despite the fact that the most of these methods of usage have been there for a while, they haven't yet been used to their fullest extent (Seglah *et al.*, 2019).

2.10.1 CROP RESIDUE AS FEED FOR LIVESTOCK

Cattle, sheep, goats, pigs, and poultry make up the majority of the livestock farmed in Ghana, accounting for 6.2% of the country's gross domestic product (Seglah *et al*., 2019). Notably, livestock production promotes food security and greatly improves farmer livelihood in Northern Ghana (Amankwah *et al*., 2012). Access to a reliable source of feed is a significant barrier to the growth of the livestock business in northern Ghana, where 60% of rural residents are involved in raising livestock (Partey *et al*., 2018). Cattle, sheep, and goats are the most frequent animals maintained using one of three different management techniques: herding, tethering, or confinement (Taye and Abebe, 2000). Animals used for livestock production typically feed on leftover residues that have been left on the field in farm fields. In some regions of the country, crop residues have developed into a plentiful resource that is utilized as animal feed. Since agricultural leftovers are readily accessible after harvest, using them as livestock feed is preferable since it minimizes the cost of feeding animals (Seglah *et al*., 2020) The northern region of Ghana is where the majority of livestock is grown (Adzitey, 2013). In rural locations where ruminants are typically housed in an extended system, over the years, the practice of using crop residues as livestock feed has been a common practice. In contrast, ruminants in urban areas are enclosed and fed with a variety of crop residues, such as plantain and cassava peels (Tonamo, 2016; Wilson, 2018). Ruminants eat crop residue, which is non-nutritional to people, and use it to produce beneficial byproducts like milk and meat for people (Mottet *et al*., 2017; Salami *et al*., 2019). Seglah *et al*. (2019) estimate that the northern region of Ghana produces roughly 5.2 million tonnes of residue per year. In the dry season, the produced residue only makes up 20% to 30% of the additional feed (Karbo and Agyare, 2002; Obi *et al*., 2016). Rice straws and other unprocessed cereal straws have a low nutritional value in terms of proteins, calories, minerals, and vitamins. Additionally, it is not very palatable (Sarnklong *et al*., 2010; Idan *et* *al*., 2020). Another way to increase the nutritional value of straw used as livestock feed is to supplement cereal straw with legume straw (keftasa, 1987; Yulistiani *et al*., 2003).

2.10.3 CROP RESIDUE AS FUEL FOR COOKING

Karbo and Agyare (2002) stated that the stalks of the majority of grains are utilized as fuel. Most of these crop residues are used as cooking fuel, especially when there is a firewood shortage. In some parts of Ghana's northern region, sorghum straw in particular, is used as a fuel source in addition to firewood, which is the predominant source of fuel used for cooking in rural communities (Seglah *et al*., 2019). According to research by Seglah *et al*. (2019), sorghum straw stands out from other crop straws due to its exceptional durability, superior combustion properties, and extended lifespan. However, millet, maize, and rice straw are often utilized as a substitute when sorghum straw is not easily accessible (Devi *et al*., 2017). In Ghana, crop straw usage as a percentage of other cooking fuels was 1.4%, 1.6%, and 1.2% in 1990, 2000, and 2010 accordingly (Ahiataku-Togobo, 2013). While rice, sorghum, and maize straw all contribute to the utilizing biomass as cooking fuel, biomass still accounts for 50% of Ghana's energy source at the household level (Seglah *et al*., 2019). In accordance with Akolgo *et al*.'s (2018) research, 74% of the population in Ghana's then 10 regions cooks using biomass, 2% of which is maize stalk. This biomass includes charcoal, firewood, sawdust, and maize stalk. According to Akolgo *et al*. (2018), maize stalk was the fourth most popular cooking fuel nationwide. With a percentage utilization of 0.80% and 1.30% respectively, maize stalks are mostly utilized as fuel in Ghana's northern regions, notably the Upper East (UER) and Upper West regions (UWR), indicating that these two regions use maize stalks more frequently than the other eight regions (Seglah *et al*.,2019). The usage of maize straw as fuel in the northern region of Ghana was also noted by Ansah and Issaka (2018). Straw is still being used as a fuel for cooking, and it hasn't advanced much through time (Seglah *et al*., 2019).

2.10.4 SALE OF RESIDUES

The use of residue is progressively becoming competitive in the world (Fischer *et al*., 2010). Crop straw is valued as a substantial farm asset and a source of income for farmers in various parts of Ghana. We must therefore better understand how farmers make decisions about biomass management and practices that improve agricultural food production without endangering long-term environmental sustainability in order to balance these challenging demands and contribute to addressing the pressing need to increase present on-farm production and efficiency (Berazneva, 2013).

According to Karbo and Agyare (1998) crop straw is a key source of income in the bulk of Ghana's highly populated districts, particularly in the Upper East region. These places earn money by selling or trading crop straw for other items. The most significant straws come from the stalks of legumes and grains, particularly the stalks of peanut and soybean (Seglah *et al*., 2019). Additionally, their research revealed that in the southern region of Ghana, the cost for a 100 kg bale of sorghum or millet straw was 50 Ghana cedis (equivalent to 9 US dollars), whereas rice straw was often priced at 10 Ghana cedis (equivalent to 2 US dollars) per 100 kg bale. The haulms from pigeon pea was part of the most popular straws, according to Amole and Ayantunde (2015), and they were offered for 150 kg for 0.50 Ghana cedis (0.08 USD). Feed markets have expanded in Ghana's Northern, Upper East, and Upper West regions, which is crucial for solving the feed deficit in urban areas (Konlan *et al*. 2015). This has led to feed merchants selling straw from potato vines and legume vines all year long, according to Seglah *et al*. (2019). They traded straw primarily to generate cash due to a feed scarcity (Duguma and Janssens 2016).

2.11 CROP AREA ESTIMATION

The management of natural resources and agricultural statistics both rely heavily on accurate crop area estimates. The development of agricultural policy and the strategy for agricultural research both depend on accurate agricultural statistics, especially surface area and production data, which are crucial for understanding rural communities. (De Groote and Traore, 2005; Perfecto and Vandermeer, 2010).

2.11.1 CROP RESIDUE YIELD ESTIMATION IN GHANA

From Duku *et al*. (2011) and Ayamga *et al*. (2015), there hasn't been much study done in Ghana on how much crop residue is produced from agricultural areas. The Ghanaian Ministry of Food and Agriculture has not yet published the methods used to estimate residue yield. But, the Savanna Agricultural Research Institute (SARI) has been using a methodology for estimating residue yield called the crop cutting procedure. An Enumeration area (EA) must be chosen for the exercise. A random selection is made from a list of every farmer in the area to choose some of them for the crop cutting estimation. To measure farm locations and crop specifics for the estimation of agricultural residues, the enumerators/field officers employ GPS, tape measurement, programmable calculators, and ranging poles.

Each farm is divided into three 5 m by 5 m plots, and each plot's plant population is then counted. To track the performance of the crops, the enumerators make frequent trips.

Depending on the intended use of the crops, straws and seeds are sorted after harvest and then weighed. The recorded weights from different enumeration areas are utilized in calculating farm-level yields up to the district level.

2.11.2 CROP CUTTING METHOD OF YIELD ESTIMATION

Crop cutting is an estimation method for maize yields that was developed long ago, after the World War II, by soil surveyors including other Indian professionals (Hoskinson *et al*., 2007). The approach involved collecting samples from small plots with in the cultivated site or field using a randomized design. The FAO-United Nations was able to employ the same technique ten years later once it had gained widespread acceptance (Greenfield and Southgate, 2003).

Estimation for the crop cutting was done using data from various sub-plots within the planted fields. The production or yield achieved was determined by multiplying the total yield of the sub-plot (measured during crop cutting) by the area of the crop cutting portion, multiplied by a unit farm size of typically one hectare.

$$\text{Crop yield (kg)} = \frac{\textbf{crop cut yield (kg) x 1ha}}{\textbf{crop cut area(square meters)}}$$

where, 1 ha =10000 m^2

The approach also suggests conducting a pre-survey to identify the optimal sites ideal for harvesting. For example, areas of the farms characterized by weak stalks, potentially containing weak or empty cobs or pods, affected by diseases, or not yet fully mature were deliberately avoided. This was done in order to lessen sampling biases. Initially, each farm had a single subplot for crop cutting. As recommended by Spencer (1972), the subplot portions were normally chosen at random. Either a square or a triangular plot shape was preferred. Once gathered from these specific locations, the product would undergo standard procedures of drying, shelling, and weighing before being utilized to determine the yields. Another approach entails marking out a specific portion of the crop in the subplot, intentionally leaving it unharvested while continuing with the regular harvesting of the main field (Spencer, 1972). Afterward, the unharvested section would be collected and measured at a later time, thereby minimizing any potential issues that could arise from keeping the entire farm waiting.

2.11.2.1 CROP CUT YIELD ESTIMATION IN GHANA

The maize harvest is often cut from specific farm areas, according to the Ministry of Agriculture (MoFA). The UN's Food and Agriculture Organization was responsible for creating the protocol. Since the beginning of MoFA, this strategy has been used. An area of each farm is chosen for crop cutting after choosing the farmers and their farms. When evaluating accuracy and precision, an equal-randomization approach is typically taken into account. According to Atlin *et al*. (2001), the farm portion's selection and sampling should be randomly chosen, with the performance of the intermediate crops being required to be representative of other farms. Typically, the MoFA designates a 5 m by 5 m crop space to demarcate the farm areas. Depending on the farm, the sections are either harvested to determine crop production or residual. After being removed from the stovers during harvest, the cobs are weighed after being dried for a while to a moisture level of 16%. For the purpose of estimating crop output and residue production after harvest, MoFA has adopted the crop-cutting method (Masika, 2016).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 DESCRIPTION OF THE STUDY AREA

3.1.1 Location and Population Size

This study was conducted in the Tolon, Kumbungu and Savelugu Districts (Figure 3.1) of the Northern Region of Ghana. The research was conducted within longitude and latitude (09.43034N, 0.06577W), (09.56027N, 0.94967W) and (09.62824N, 0.82754W) of Tolon, Kumbungu and Savelugu respectively. The two Districts Tolon and Kumbungu shares boundaries to the North with Mamprugu/Moagduri district, and North Gonja districts to the West, Sagnarigu District to the South. The Kumbungu District share boundary with Savelugu Municipal to the East. The experimental areas are within Ghana's Guinea savanna Agro-ecological Zone. The population of the three districts according to the 2010 population and housing census stands at 72,990, 39,341 and 92,717 for Tolon, Kumbungu, and Savelugu respectively.

3.1.2 Topography and Drainage

Generally, the land is undulating with a number of scattered depressions. According to FAO (2001), the soils are Plinthic Lixisols. They have a shallow, sandy loam texture with medium and coarse quartz stones as well as iron pan boulders that are frequently visible on the surface. The Districts are drained by a number of rivers and streams, most prominent being the White Volta. The major rivers and their tributaries exhibit dendrite drainage patterns. Most of these tributaries dry up during the dry season.

3.1.3 Climate and Vegetation

From May to October, the zone sees a mono-modal rainfall pattern lasting roughly 5 to 6 months, with a mean annual rainfall of 1120mm. Average yearly temperatures are high, with maximum and lowest values at 34.3 °C and 23.4 °C, respectively. The region is affected by the North-East Trade Winds (Harmattan) from November to April, which causes the relative humidity to drop to around 16% in January (Dietz *et al*., 2004). The vegetation of these locations is mainly the grassland type with scattered Guinea Savannah woodland which includes dawadawa (*Parkia biglobosa*), baoba (*Adansonia digitata*), neem (*Azadirachta indica*), shea (Vitellaria paradoxa), acacia (Acacia longifolia). Some of the most common arable crops grown in the area are groundnuts (*Arachis hypogaea L.*), cowpeas (*Vigna unguiculata*) and soybeans (*Glycine max*), as well as cereals (corn (*Zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor* L.), and millet (*Pennisetum glaucum* L.)). Continuous cultivation, slash and burn and mixed farming involving plants and ruminants (e.g., cattle, sheep and goat) production are predominant agricultural system typical of the study area.

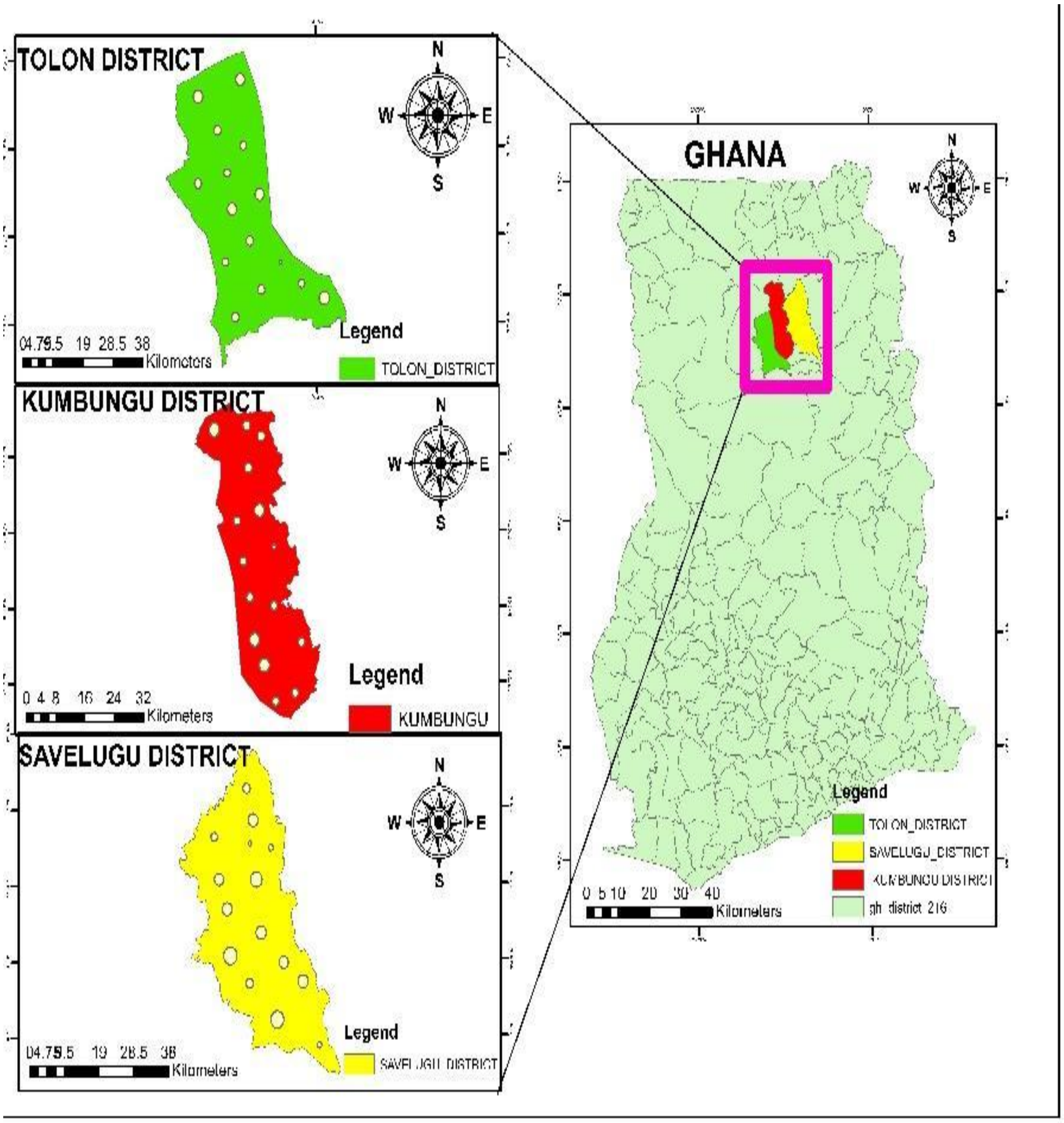

Figure 3. 1 Map of the study area

3.2 DATA COLLECTION PROCEDURE

3.2.1 Field survey and sampling

Farmers in these three districts of study (Tolon, Kumbungu and Savelugu) were found growing different kinds of crops, but were on diverse parcels of land that were close to each other. This method of cropping on separate farm lands that are far from each other is termed spatial diversification (Avornyo *et al.*, 2014). Due to the cropping method adopted by the farmers, data was collected based on the spatial diversification system of cropping. Field data on the land size of farmers, allocation of crop residue after harvest, major crops grown and on-farm crop residue were also collected.

The study was conducted in the Northern region of Ghana. A multi-stage sampling technique was used to select participant farmer from the three study areas (Tolon, Kumbungu, and Savelugu). These districts were purposively selected due to their engagement in cultivating maize, rice and soybean as part of their major crops in the region. In addition, the districts were selected for their closeness and easy accessibility.

In the third stage, the study used simple random selection to select 10 communities from each district Tolon (Kpalsogu, Kukuo, Vingoni, Wariborgu, Nlalayili, Tali, Tingoli, Dasoyili, Wantugu, Nyankpala) Kumbungu (Cheyohi, Gbulon, Gingani, Logshegu, Nagpatua, Silinboma, Zangbalun, Gbugli, Saakuba, Botanga) and Savelugu (Diko, Bunlun, Bihiinaa yili, Libga, Tibali, Tooteli yili, Damonkunyili, Nyorilo, Kpaliyogu, Naabogu). The Extension Divisions of the relevant Ministry of Food and Agriculture (MoFA) district directorates provided the researcher with a list of the maize, rice, and soybean producers in these localities. In the final stage, respondents were drawn from the sampling frame with considerations made for equitable representation of the crops of interest and the proportion of farmers available in each community. In Tolon, 66 farmers were sampled, while in Kumbungu, 68 were included, and in Savelugu district, 66 farmers were also sampled. A total sample size of 200 farmers from the three districts was obtained through this process.

The study used organized questionnaires to guide interviews with the sampled farmers and elicited in-depth information through face-to-face key informant interviews to gather primary data from 2019 farming season on such parameters as major crops, cultivated land area, residue allocation, etc. Information on residue usage was assessed to determine farmers' perceptions on the usage of biomass based on gender. Also, secondary data for 2019 farming season on the (maize, rice and soybean) cropping area from the Ministry of Food and Agriculture (MoFA) Regional Directorate was used to determine the total residue generated in the districts at the end of 2019 season. The data was also used to calculate the quantity of soil nutrients (N.P.K.) generated in each district.

3.3 RESIDUE QUANTIFICATION

The same number of farms, 15 for each crop (maize, rice, and soybean), were selected. Consequently, a combined total of 45 farms, representing all three crops, were chosen from these communities. On-farm residues for each crop were quantified using the crop cutting method. The crop cutting method is a technique used in agricultural research and crop yield estimation. It involves physically harvesting a sample area of a crop field in a systematic manner to measure its yield (Fermont and Benson, 2011). Typically, a designated portion of the field is harvested, and the harvested crop is then weighed to determine its yield per unit area. Communities that were within 5 km range from each other during the selection process were considered.

An area of 5 m × 5 m was demarcated with the aid of a tape measure. The portions were harvested for biomass estimation on each farm, and all residues in the quadrant above 5 cm from the ground were cut and weighed with a spring balance. Upon harvest, food produce (seeds) was separated from the stovers. This was repeated three times in every field and the average was used to estimate the quantity of residue generated on a field. Biomass yield was expressed as:

$$\text{Biomass yield (kg)} = \frac{\textbf{crop cut yield (kg) x 1ha}}{\textbf{crop cut area(square meters)}} \quad \text{…………. eqn.1}$$

Where, 1 ha =10000 m^2

3.4 LABORATORY ANALYSIS ON CROP RESIDUES

3.4.1 Preparation of samples

The residues from the three crops sampled for the analyses included maize leaves and stalk, rice straw and soybean straw (leaves and pods). The residues were parked into an envelope and oven dried at a constant temperature (70 °C, 72 hours) at the Savanna Agriculture Research Institute (SARI) Soil Science Laboratory. Thereafter, they were cut into pieces with the aid of secateurs, ground in a milling machine and were sieved through a 0.5mm mesh to obtain a fine consistency. The samples were tested for N, P, K and C contents at the Faculty of Agriculture laboratory, Kwame Nkrumah University of Science and Technology (KNUST).

3.4.2 Dry ashing of plant tissues.

A prepped plant sample weighing 2.00 grams was meticulously transferred into a clean ceramic crucible using a spatula. The weight was meticulously measured to the closest 0.001 grams. Moreover, an empty crucible was included separately as a reference point for comparison. The samples were kept in the crucibles, which were then placed in a cool muffle furnace, and the temperature was gradually increased over the course of two hours to 500^{o}C. For full ashing, samples were kept at 500^{o}C for an additional two hours. After the ashing was finished, the crucibles were left to cool in the oven for about 12 hours after ashing was done. The samples were removed from the furnace making sure that the environment was free from breeze. The samples that underwent the ashing process were transferred to centrifuge tubes with a volume of 50 ml. Following that, the crucible(s) were washed with 10ml of distilled water, and the resulting washings were combined with the same set of centrifuge tubes. A 10 ml solution of aqua regia was then used to rinse the crucibles again, and the contents were added to each tube. The samples were vigorously vortexed (shaken) for 5 minutes to ensure thorough, complete, and consistent mixing. Afterwards, the samples underwent centrifugation at 3000rpm for 10 minutes. The resulting supernatant was carefully transferred into fresh vials to determine the macro nutrients.

3.4.3 Analysis of phosphorus (p)

Phosphorous content was determined using vanadium-phosphomolybdate (Benton *et al.*, 1990). Standards were prepared using the vanadium phosphomolybdate solution to draw the standard curve. The digestion solution was carefully transferred into a 50ml volumetric flask in an exact amount of 5ml. Afterward, 10ml of vanadomolybdate reagent was introduced, and then distilled water was added. The flask was then vigorously shaken for a duration of 30 minutes. On a UV-Visible spectrophotometer, a yellow color emerged and was detected at 600 nm. The value of the percent transmittance obtained from the blank and samples was noted. Then, it was determined what the absorbance and P content of the blank and sample were from the standard curve.

3.4.4 Analysis of potassium (K)

Instrument: The flame photometric method was used to assess the concentration of potassium (K) by comparing the strengths of the emitted radiation from potassium atoms to a set of standard solutions (Hunter *et al.*, 1984).

3.4.5 Total nitrogen determination

The determination of the total nitrogen (N) percentage was conducted using the Kjeldahl method of analysis, as described by Bremner and Mulvaney (1982). In this method, 1.00 g of plant material was dried in an oven and then ground to pass through a 0.5 mm sieve. The ground material was weighed and transferred to a 500 ml long-necked Kjeldahl flask. To moisten the sample, 10ml of distilled water was added and allowed to stand for 10 minutes.

A spatula full of Kjeldahl catalyst, which is a mixture of 1 part Selenium, 10parts $CuSO_4$, and 100 parts Na_2SO_4, was added to the flask. Additionally, 10 ml of concentrated H_2SO_4 was included. The digestion process continued until a clear, light greenish solution was observed, typically taking around 1-2 hours. The flask was left to cool down. The contents of the digestion were transferred into a volumetric flask with a volume of 50 ml and then filled to the desired level with distilled water, utilizing the remaining liquid in the digestion flask to rinse it. A blank digest was included using distilled water instead of sample.

A portion of 10ml from the digest was transferred into the Kjeldahl distillation apparatus using a pipette, and then an extra 90ml of distilled water was included. Same was done for the blank using separate Kjeldahl flask. An amount of 20ml of a 40 % NaOH solution was dispensed into the Kjeldahl flask.

The distillate was collected above 10 ml of a 4% Boric acid solution. Then, three drops of a combined indicator were added to a 500 ml conical flask, and the mixture was left undisturbed for 5 minutes. About 100 ml of distillate was collected.

The collected distillate (about 100 ml) was titrated with 0.l N HCl until the blue colour changed to grey and then suddenly flashes to pink.

$$\% N = \frac{(a-b) \times 1.4 \times N \times V}{S \times t}$$

Where:

a = ml hydrochloric acid (used in the sample titration)

b = ml hydrochloric acid (used in the blank titration)

N = Normality of standard HCl

V = total volume of digest

S = mass of oven dried sample taken for digestion

t = volume of aliquot taken for distillation (10ml)

1.4 = correction factor

3.4.6 Determination of carbon

The Walkley and Black wet oxidation technique was employed to determine the quantity of organic carbon derived from plants (Nelson and Sommers, 1982).

An Erlenmeyer flask with a volume of 500 ml was filled with a 0.5g plant sample. Before weighing, samples were ground to pass through a sieve with a mesh size of 0.5 mm In order to ensure consistency, the samples were meticulously blended prior to the weighing process. A burette was used to add 10 ml of 1.0 N $K_2Cr_2O_7$ solution, and then 20 ml of concentrated H_2SO_4 was added. To make sure that the solution came into contact with every plant particle, the mixture was swirled. Afterward, a cooling period of 30 minutes was provided for the flask and its contents on an asbestos sheet. 10ml of orthophosphoric acid was added after 200 ml of distilled water. The diphenylamine indicator was added in 2.0 ml drops. With 0.5 N ferrous sulphate solution, titration was carried out until the endpoint turned green and then dark blue. The titer value was noted and adjusted to (≥10.5) for the blank solution.

Calculation:

$$\%C = \frac{M \times \langle V_{bl} - V_s \rangle \times 0 \cdot 003 \times 1 \cdot 33 \times 100}{g}$$

Where;

"M" refers to the molarity of $FeSO_4$.

"Vbl" represents the volume of $FeSO_4$ used in the blank titration, measured in milliliters.

"Vs" denotes the volume of $FeSO_4$ utilized in the titration of the plant sample, measured in milliliters.

"g" represents the weight of the plant sample used, measured in grams (g).

The value "0.003" corresponds to the weight of carbon (C) in milli-equivalents, which is calculated as the ratio of 12 to 4000 and expressed in grams.

"1.33" represents the correction factor employed to convert the wet combustion carbon (C) value to the true carbon value. This correction factor is utilized because the wet combustion method provides an estimation of the C value with an efficiency of approximately 75%. In simpler terms, this efficiency ratio is derived from 100 to 75, resulting in a value of 1.33.

The given formula was employed to calculate the organic matter content;

The organic carbon percentage was multiplied by the Van Bemellean factor of 1.724 to obtain the result.

3.5 DATA ANALYSIS

The survey data was analyzed using the IBM Statistical Package for Social Sciences (SPSS version 22). The laboratory examination results of the plant samples were subjected to statistical descriptive analysis and analysis of variance using Genstat (12^{th} edition). Descriptive statistics techniques, including frequencies, percentages, and proportions, were employed to summarize the data. The findings were presented using tables and graphs to provide further explanation. To determine the differences between means at a 5% significance level, the Tukey's test was applied.

CHAPTER FOUR

4.0 RESULTS

4.1 Demographic characteristics of respondents

4.1.1 Demographic characteristics

Demographic characteristics of the three districts considered in the study area are indicated in table 4.1. Across the three districts, male farmers were 18% more than the female farmers. The Kumbungu District recorded the least number of female (21.9%) farmers, while it had the highest number of male (39.8%) farmers.

The age group 46-55 years recorded the highest (47.5%) number of farmers in the three districts. The least number of farmers were found in age group 15-25 years (3.5%). The age group 46-55 years was 44% more than 15-25. This could be that there is no motivational package to support the youth in agriculture. Also, the Tolon district had a youthful number of farmer population and the Savelugu district recoded more aging farmer.

Within the three districts, 56% of the farmers lack any kind of formal education. Following Savelugu (19.5%) and Kumbungu (16%), the Tolon district had the greatest proportion of uneducated farmers (20.5%). Farmers who have completed a formal education make up 16.5% of the population in the Kumbungu district. Tolon had the fewest farmers with at least a primary school level (13.5%) of any district. The number of farmers in the three districts with no educational level is 12% more than the number of farmers with at least primary level of education.

In terms of the household sizes, households with 6-10 and 11-15 occupants scored 40 % and 37% respectively. On the other hand, the least household size (0.5%) was observed in households with 21 and above occupants.

The findings from this study indicate that 98% of the farmers relied solely on farming as their primary means of earning a livelihood, whereas 2% were involved in farming as well as other economic pursuits.

Table 4. 1: Differences in demographic characteristics

	District				
Variable	**Tolon**	**Kumbungu**	**Savelugu**	**Total**	**Pearson Chi^2 (sig.)**
Gender					7.121^a (.028)
Male	35	47	36	118	
Female	33	18	31	82	
Age					15.739^a (.046)
15-25	1	2	4	7	
26-35	2	8	5	15	
36-45	20	12	23	55	
46-55	37	36	22	95	
56 above	8	7	13	28	
Education					16.960^a (.031)
Primary	10	21	19	50	
Junior high	7	9	3	19	
Secondary	2	2	4	8	
Tertiary	8	1	2	11	
No schooling	41	32	39	112	
Household size					17.805^a (.023)
0-5	12	13	14	40	
6-10	34	29	17	80	
11-15	18	23	33	74	
16-20	4	0	1	5	
21 above	0	0	1	1	
Occupation					7.923^a (.019)
Yes	64	65	67	196	
No	4	0	0	4	
Major crop cultivated					7.995^b (.092)
Maize	45	33	34	112	
Rice	11	23	18	52	
Soybean	12	9	15	36	

4.2 THE QUANTITY OF CROP RESIDUES GENERATED FROM MAIZE RICE AND SOYBEAN

4.2.1 Fertilizer (NPK) application on crop

From the study it was revealed that among the three major crops cultivated in the districts, maize farmers were the highest (56%), followed by rice (26%) and then soybean (18%). Regarding fertilizer application, 82.5% of farmers used NPK fertilizer, of which 67.9% were maize farmers, 31.5% were rice farmers, and 0.6% were soybean farmers. However, 17.5% of farmers do not use NPK fertilizer (Table 4.2).

Table 4.2: Fertilizer (NPK) application on crops

		Crop			
Variable	**Maize**	**Rice**	**Soybean**	**Total**	**Pearson Chi^2 (sig.)**
Fertilizer application (NPK)					
Yes	112	52	1	165	193.266[a] (.000)
No	0	0	35	35	

[a] indicate statistical significance at 5% level

4.2.2 Period of field burning of crop straws

The occurrence of straw burning was more common in the later stages of the dry season (February to April) compared to the early dry season (November to January) and the initial period of the wet season (May to July). During this period, there is a decrease in humidity in the atmosphere which causes residues to dry faster (Table 4.3).

Table 4.3: Period of field burning of crop straws

Season	**Frequency**	**Percentage (%)**
Early dry season (Nov-Jan)	75	37.5
Late dry season (Feb-April)	110	55.0

Early wet season (May-July)	15	7.5
Total	**200**	**100**

4.2.3 Cultivated land area for maize, rice and soybean

The total land area for the Tolon district is 135,366 ha (Table 4.4). Maize cultivation in the Tolon District covered 6.55 % out of the total land area in the 2019 farming season, recording the highest among the three districts. Rice cultivation in the Tolon district covered about 5.65 % cultivable land in 2019. Soybeans had the least amount of cultivated land among the three crops in the Tolon district (2.56%).

The total land area of the Kumbungu district is 159,900 ha (Table 4.4). Maize farming recorded the highest cultivable land (3.63 %) among the three crops. Soybean farming recorded the least cropping area (0.70 %) among the three crops in the district.

In the Savelugu district the total land area is 179,070 ha. Maize cultivation covered an area of 4.11 ha recorded as the highest among the three crops, soybean recording the least cropping area of 2,28 ha.

Table 4.4: The total cultivated land area for maize, rice and soybean farms in Tolon, Kumbungu and Savelug districts

District	Crop	Area cropped (%) 2019	Total land Area of District (ha)
Tolon	Maize	6.55	135,366
	Rice	5.65	
	Soybean	2.56	
Kumbungu	Maize	3.63	159,900
	Rice	3.33	
	Soybean	0.70	
Savelugu	Maize	4.11	179,070
	Rice	3.73	
	Soybean	2.28	

Source: Northern Regional Agricultural Directorate annual report (2019).

4.2.4 Quantities of residues and nutrients (NPK) estimated from maize, rice and soybean farms

The table 4.5 represents the average quantities of residues that have been generated from maize, rice and soybean and the quantity of nutrients in the three districts; Tolon, Kumbungu and Savelugu. Maize generated the highest quantity of residue among the three crops (7020 kg/ha). The average straw weight for rice was 4096 kg/ha. Soybean recorded the least quantity of residue (4096 kg/ha) generated among the three crop (Table 4.5).

From the results, a hectare of maize residue could generate a quantity of 57.92 kg of nitrogen (Table 4.5). Soybean producing the least quantity 32.25 kg of nitrogen. Phosphorus produced from a hectare of maize residues recorded the highest 4.354 kg. Rice residue recorded the lowest (2.48%) quantity of phosphorus from a hectare. Also, the quantity of potassium generated from a hectare of maize, rice and soybean land was 55.32 kg, 25.27kg and 42.05 kg respectively.

Table 4.5: Quantities of plant nutrients estimated from a hectare of crop residue

	Crop residue (kg/ha)	**Nitrogen (kg/ha)**	**Phosphorus (kg/ha)**	**Potassium (kg/ha)**
Maize	7020	57.92	4.35	55.32
Rice	4096	37.44	2.48	25.27
Soybean	2924	32.25	2.84	42.05

Source: Field survey 2019.

4.3 ASSESSING THE QUANTITY OF NUTRIENT (NPK) IN MAIZE, RICE AND SOYBEAN RESIDUE

4.3.1 Nutrients estimated from crop residues by Districts

The results show the estimated quantity of nutrient (NPK) generated from the crop residues of Tolon, Kumbungu and Savelugu districts using the cultivated land area for maize, rice and soybean crop obtained from the regional MoFA office, 2019 (Table 4.6). Among the three crop residues in the Tolon district, maize residue (513,545.94 kg) was estimated to produce the highest quantity of nitrogen fertilizer (Table 4.6). The quantity of nitrogen fertilizer estimated from the soybean residue (111,758.18kg) was the least among the three crops in the Tolon district. Again, maize residue (38,569.15 kg) had the greater quantity of phosphorus fertilizer from the estimated residue than rice (18,967.49 kg) and soybean (9,841.65 kg) residues in the Tolon district. The potassium content in the maize residue (490,493.12 kg) was also higher than both rice and soybean (Table 4.6).

The total quantity of maize residue generated from the cultivable lands area in the Kumbungu district was estimated to produce 336,189.11kg of nitrogen fertilizer. In comparison to soybean residue, which had the lowest nitrogen content of the three crop residues in the district, rice residue (199,355.65kg) was estimated to contain the second highest nitrogen content in the district (Table 4.6). The estimated phosphorus nutrient in maize residue (25,249.01kg) in the district was also high than rice (13,205.18kg) and soybean (3,178.81kg) residues. The maize residue again recorded the larger quantity of 321,097.75kg of potassium in the district. Potassium content in the soybean residue (47,066.57kg) was estimated to produce the least quantity of potassium in the Kumbungu district. The nitrogen content estimated from the maize residue (426,278.46kg) emerged the highest among the three residues in the Savelugu district. Soybean residue (131,670.30kg) was estimated the lowest nitrogen content among the three crop residues in the district. The maize residue generated from the Savelugu district was estimated to produce 32,015.04kg of phosphorus. The phosphorus content estimated from the soybean residue (11,595.15kg) also recorded the lowest quantity among the three crops residue in the district. Again, the maize residue generated from the Savelugu district was estimated to produce the highest (407,143.03kg) potassium content among the three crop residues. The potassium quantity in the rice residue recorded the least quantity of 168,786.16kg potassium among the three residues.

Table 4.6: Quantities of nutrients (NPK) estimated from residues in each district in 2019 season

			Nutrient Quantity		
District	**Crop Residue**	**Quantity (kg/ha)**	**Nitrogen (kg)**	**Phosphorus (kg)**	**Potassium (kg)**
Tolon	Maize	7020	513,545.94	38,569.15	490,493.12
	Rice	4096	286,347.86	18,967.49	193,269.51
	Soybean	2924	111,758.18	9,841.65	145,718.80
Kumbungu	Maize	7020	336,189.11	25,249.01	321,097.75
	Rice	4096	199,355.65	13,205.18	134,554.41
	Soybean	2924	36,097.43	3,178.81	47,066.57
Savelugu	Maize	7020	426,278.46	32,015.04	407,143.03
	Rice	4096	250,073.37	16,564.69	168,786.16
	Soybean	2924	131,670.30	11,595.15	171,681.74

Source: Regional Agricultural Directorate N/R annual report 2019

4.3.2 Comparative analysis of nitrogen, phosphorus, potassium and carbon content of the crop residues

The amount of nitrogen generated in the three crops residue differ significantly ($p = 0.008$) from each other for the three districts in which the samples were taken. Soybean residues sampled from Savelugu recorded the highest nitrogen contents of 1.37% as compared to those sampled from Kumbungu and Tolon with the value of 0.93% and 0.99% respectively (Table 4.7). Also rice residues obtained from Savelugu had the highest nitrogen contents (1.06%) followed by those from Kumbungu (0.93%) while the least was recorded (0.75%) in residues picked from Tolon. Also, maize residues sampled from Savelugu had the highest nitrogen contents of 0.88% followed by residues sampled from Kumbungu (0.80) (Table 4.7). Residues from Tolon district had to have the least nitrogen content of 0.79%. Generally, residues sampled from Savelugu contained the highest amount of nitrogen (Table 4.7).

Table 4.7: Nitrogen content in crop residues from the three districts

District	Maize (%)	Rice (%)	Soybean (%)
Tolon	0.79	0.75	0.99
Kumbungu	0.80	0.93	0.93
Savelugu	0.88	1.06	1.37

P-Value <.008 ***Lsd = 0.1699***

The phosphorus content of the residues obtained from the three districts were not statistically different (p=0.35). However, soybean residues sampled from Kumbungu recorded the highest phosphorus content (0.145%) followed by those sampled from Tolon which recorded phosphorus content of 0.079% (Table 4.8).

Table 4.8: Phosphorus content in crop residues from the three districts

District	Maize (%)	Rice (%)	Soybean (%)
Tolon	0.055	0.062	0.079
Kumbungu	0.074	0.050	0.145
Savelugu	0.057	0.069	0.067

P-value <.0.35 ***Lsd = 0.068***

The potassium (K) levels in the three crop residues differ significantly (p = 0.002) amongst the three districts. Soybean recorded the highest potassium level; Tolon (1.489%), Savelugu (1.445%) and Kumbungu (1.380%). Rice residue recorded the least K level amongst the residue in three districts; Tolon (0.677%), Savelugu (0.587%) and Kumbungu (0.567%) (Table 4.9).

Table 4.9: Potassium content in crop residues from the three districts

District	Maize (%)	Rice (%)	Soybean (%)
Tolon	0.602	0.677	1.489
Kumbungu	0.700	0.587	1.380
Savelugu	1.061	0.587	1.445

P-Value <.0.002 ***Lsd = 0.1998***

The carbon content was highly impacted (P <.001) by the three districts where the samples were taken from. Rice residues sampled from the Tolon district recorded the highest carbon content of 39.58% (Table 4.10).

Table 4.10: Carbon content in crop residues from the three districts

District	Maize (%)	Rice (%)	Soybean (%)
Tolon	35.43	39.58	39.42
Kumbungu	38.38	35.35	36.15
Savelugu	35.03	36.39	36.79

P-Value <.001 ***Lsd = 0.957***

4.3.3 Laboratory analysis of crop residues

The nitrogen content varies significantly (p <. 001) for all the three residues (maize, rice and soybean) sampled from the three districts (Table 4.11). Soybean recorded the highest nitrogen content of 1.103 ± 0.34% followed by rice 0.914 ± 0.25% whiles maize residue recorded the least nitrogen content of 0.825 ± 0.17%. The carbon content ranged from 36.28 ± 1.73 to 37.45 ± 2.23. However, the phosphorus content of maize, rice and soybean were not statistically different from each other. (p = 0.25).

Table 4. 11: Laboratory analysis of crop residues

Crop residue	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Carbon (%)
Maize	0.825 ± 0.17	0.0620 ± 0.02	0.788 ± 0.33	36.28 ± 1.73
Rice	0.914 ± 0.25	0.0606 ± 0.02	0.617 ± 0.18	37.11 ± 2.10
Soybean	1.103 ± 0.34	0.0970 ± 0.16	1.438 ± 0.33	37.45 ± 2.23
P-Value	**<.001**	**0.251**	**<.001**	**<.001**
LSD	**0.11**	**0.15**	**0.05**	**0.64**

Source: Field survey (2020)

4.4 ASSESSING THE USES OF CROP RESIDUE AFTER HARVEST

4.4.1 Crop residue usage based on gender

Hypothesis testing

H_0: *There are no significant differences in the perception of crop residue usage based on gender*

H_1: *There is a significant difference in the perception of crop residue usage based on gender*

Table 4.12: Group statistical independent T- test for crop residue usage based on gender

Sex	Mean	Std. Deviation	Df	T-cal
Male	2.38	1.078	198	2.59
Female	1.93	1.395		

At an alpha level of 0.05, T-critical value is 1.962

The mean scores and standard deviations for male and female respondents are shown in table 4.12. The results show that the mean score for male is greater than that of the female. In favor of males, there was a significant difference in perception of crop residue use ($P < 0.05$).

4.4.2 Allocation of crop residues after harvest

The various allocations were conducted on the major crop cultivated by farmers. This was categorized into fuel wood, soil fertility management, burning, miscellaneous purposes and feeding animals regarding maize, rice and soybean residue. From the total farmers interviewed, 53.6% of the maize farmers had their residue burnt in their farm (Table 4.13). Soil fertility management with maize residue recorded 12.5%. The least allocation of the maize residue was for animal feed (8.9 %).

Table 4. 13: Allocation of crop residues by farmers after harvest.

	Maize residue	
Residue utilization	**Frequency**	**Percentage (%)**
Fuel wood	28	25.0
Feed	10	8.9
Soil fertility management	14	12.5
Burning	60	53.6
Miscellaneous	0	0
Total	**112**	**100**
	Rice residue	
Fuel wood	5	9.6
Feed	8	15.4
Soil fertility management	7	13.5
Burning	30	57.7
Miscellaneous	2	3.8
Total	**52**	**100**
	Soybean residue	

Fuel wood	2	5.6
Feed	20	55.6
Soil fertility management	9	25
Burning	5	13.9
Miscellaneous	0	0
Total	**36**	**100**

Source: Field survey, 2019.

The quantity of rice residue after harvest that are burnt after harvest was 57.7 % (Table 4.13). Rice residue for miscellaneous purposes recorded the least usage of residue (3.8 %).

A total number of 36 soybean farmers were interviewed for residual allocation after harvest. Animal feed recorded as the highest (55.6%). The least used residue was fuel wood (5.6 %). There has been several evidence of farmers burning crop residues after harvesting (Plate 4.1). Most of these farmers stated that burning crop residues helps clear the land and makes it easier to prepare for the next planting season.

Plate 4.1: Burning maize residues at Tingoli.

Plate 5. 1: Maize Stover's for fuel wood at Gingani.

Plate 4. 2: Burning rice straws after harvest at Nyankpala

CHAPTER FIVE

5.0 DISCUSSION

5.1 DEMOGRAPHIC DATA

5.1.1 Gender and age of farmers in the crop production

An enormous majority of about 60 % of the population works in crop production in the Northern Region of Ghana, where agriculture is a substantial economic activity. Despite differences in their commitment and duties, men and women both play crucial roles in agricultural activities.

Women have long played a significant role in agriculture in Ghana, especially in subsistence farming on a small scale (Quansah, 2012). Weeding, planting, harvesting, and processing of crops are among their responsibilities. Plowing and selling of agricultural products are tasks frequently performed by men and women. The distinction between men and women in agriculture can change depending on cultural, societal, and economic variables, it is crucial to highlight.

In the current study, there were more men (59%) than women (41%). Male farmers were mostly the head of almost all the farmers household and are entitled to owning land for farming. It was also observed that some female farmers were performing the duty as head of their households in the absence of their husbands due to divorce and widowhood. From the results, gender had influence on the parameters considered in the current study. Older individuals, those in their middle years, and younger farmers were all frequently involved in agriculture in the Northern region. While younger farmers may provide fresh perspectives and innovations, older farmers often have more conventional knowledge and expertise in farming techniques (Lobley, 2010). The sustainability of the agricultural sector and the safety of the food supply in the country depend on young participation in agriculture (Ingram and Kirwan, 2011; Wójcik *et al*., 2019).

Despite males being the higher number of farmers in the region, on the other hand, women are essential to the farming system in many ways, including production, processing, marketing, and household duties. Their contribution to the development of these systems is crucial. This study aligns with the findings presented in the report by Dixon *et al*. (2001) who emphasized that more females are involving themselves in arable crop production in order to help sustain their family livelihood.

The labour force in the study was much dominated by farmers within 46 years and above (61.5%) comparable to the youthful labour force of 15–45 years (38.5%). Modern youth are rapidly urbanizing in search of better employment prospects and have no desire to return to the agricultural sector (Todes *et al*., 2010; Peou, 2016). This could also be the fact that there is no proper motivation and policy for the youth involvement in agriculture in the region. These results have effect on low production of agriculture produce and how the resources (agriculture products and by-products) should be utilized effectively in our parts of the country. Earlier, it was suggested that the increase in number of the aged in the agricultural labour force are trending in many parts of the globe and this has a significance effect on agricultural production as well as sustainability of the soil fertility and improving the ecosystem (Bloom *et al.,* 2010).

5.1.2 Farmers educational status

Several factors, including access to formal education, cultural practices, and individual circumstances, contribute to a wide variation in the educational status of farmers in the Northern region of Ghana (Abdulai and Huffman, 2000). Agricultural operations are being significantly influenced by recent advancements in technology, business management, and various related fields. However, lack of formal education is one of the major factors impinging farmers' inability to read and write and has contributed to the poor farming practices like fertilizer and pesticides application, soil fertility management etc., (Ntow *et al*., 2006; Moise *et al*., 2013). This has made farmers to be restricted to the primitive way of farming which has left adverse effect on crop yield. The survey conducted regarding educational level farmers revealed that those with no formal education (52.5%) are the highest. The findings also shows that farmers without little or no education were more than those who have had the opportunity to attain some level of education (44%). Out of the total farmers sampled from the three districts, only 19% are able to read, write and understand the English language. These are farmers who have attained junior high to tertiary education. Meanwhile, the level of farmer's education has a direct impact on the various modernizations of managing the soil and obtaining good yield whiles increasing their income levels (Nkonya *et al*., 2005; Swanson *et al*., 2008) This this agrees with Davis *et al.* (2012) who stated that most farmers who have acquired higher education are likely to adopt new technologies than others with low or no educational level. According to Abdallah and Abdul-Raman (2017), although agricultural extension officers have been engaged to in parts of Northern Ghana to educate farmers on new and emerging agricultural practices, their numbers are woefully inadequate to deal with the prevailing challenge of farmers engaging in outdated practices which have not helped to boost their yields.

5.1.3 Household size and occupation

The mindset of farmers in the rural areas is to have larger family size to assist in the farming business and this has led to farmers giving birth to many children. The rural areas in Ghana have become predominantly featured in large family size (Naab, *et al.*, 2013). Farmers' household size is a major factor that contributes significantly to agriculture in Ghana. Large family sizes are common in the northern region, and family members frequently provide extra unpaid labour for farming tasks (Ansah and Issaka, 2018). From the results, majority of famers' household sizes in the northern region was between 6-10 and 11-15 people. This clearly supports the claim by Maharjan and Khatri-Chhetri, (2006) who reported that, large household size is the main feature in rural areas. The large household size practiced by these rural farmers is for their family to assist in farming. This increase in household number, according to Joshi and Joshi (2017), can also affect the household food security.

The results indicated that for 98% of the respondents, farming is their primary line of work, while 2% are traders or work for governmental or Non-Governmental Organizations (NGO). The majority of farmers indicate that farming is their main source of income, which supports their economic well-being. This result supports Seglah *et al*., (2020) who said that the northern region is an agricultural dominated region and majority of the people engage in farming as their main source of income.

5.2 THE QUANTITY OF CROP RESIDUES GENERATED FROM MAIZE RICE AND SOYBEAN

5.2.1 Major crop cultivated by farmers

The northern region of Ghana is an agricultural zone in which farmers show interest in cultivating different types of crops for sale and consumption. Despite the fact that farmers cultivate different types of crops, farmers in this region show interest in cultivating one type of crop more than the others. This could possibly be the nature of the land, market demands, household food security, etc.

Amongst the three major crops cultivated in the region, results from the survey indicate that maize is the most dominant (56%) and is cultivated by almost all the farmers in the region. A significant number of the farmers concluded that maize has been their main crop of cultivation. The reason is that maize is a staple crop used in every major local food preparation ("kenkey," "TZ," "Banku,") and can easily be marketed to other industries like the poultry (Kusi *et al*., 2015; Murdia *et al*., 2016).

Rice is considered as one of the cash crops especially in the Northern part of Ghana and this explains why it is the second most cultivated crop; cultivated by 26% of the respondents. Unlike maize and soybean, rice cultivation requires a lot of water or waterlogged areas which in the dry season are limited. According to Laube *et al*., (2012) in some part of the Northern Region of Ghana, most farmers rely solely on highly unpredictable and intermittent seasonal rainfall. Moreover, during the rainy season, some areas within the region do not support the growth of other crops due to flood/muddy areas, making rice the only optional crop to be cultivated. Farmers then take advantage of this and cultivate crops that could survive in those areas of which rice crop is one of these crops.

Soybean has a very significant influence on the livelihood of the people in the study area as 18% of the farmers did plant soybean as one of their major crop Soybean according to the farmers has a lot of nutritional benefits and can be used to prepare a wide range of dishes that are consumed by people in the study area. This affirms the conclusions of Mbanya (2011) who reported that, soybean has been identified as the crop with the highest documented nutritional value for cultivation in all suitable regions of Ghana. It is also considered as a cash crop that fetches the farmer some income to manage their expenses (Gladwin *et al*., 2001; Franke *et al*., 2014).

5.2.2 Fertilizer application

The type and quantity of fertilizer to be used are determined by a number of variables, such as the crop's nutrient needs, the fertility of the soil, and particular growth stages (Stoop, Uphoff and Kassam, 2002; Hofman and Van Cleemput, 2004). To avoid misuse or nutrient imbalances that could impair the environment or crop health, it is crucial to take into account soil testing and adhere to suggested fertilizer application rates (Roy *et al*., 2006; Vanlauwe and Giller, 2006). Optimizing crop yields, enhancing plant health, and guaranteeing sustainable agricultural practices all depend heavily on using fertilizer correctly.

Soil organic matter depletion is said to be the main cause of low production of agriculture in Africa (Sanchez, 2002; Antle and Stoorvogel, 2008). From the results, 82.5% apply chemical fertilizer (NPK) as the major nutrient to increase yield. About 17.5% of the total farmers used for the current study do not use chemical fertilizer with majority being soybean farmers. The paper published by Place *et al*. (2003), restricted use of chemical fertilizer on a particular piece of land by middle income farmers worsen the nutrient deficiency (in the soil). Therefore, the application of both inorganic and organic fertilizer to address nutrients needed by plants for short term and long-term needs will help maintain soil fertility level (Vanlauwe, *et al*. 2014).

5.2.3 Quantity of residues estimated from maize rice and soybean farms

The amount of residual biomass or waste materials created during various farming activities is used to estimate the quantity of leftovers generated in methods of agriculture (Florindo *et al*., 2022, Howari *et al*., 2023). The variation in residue levels can be influenced by factors including the type of crop that is cultivated, harvesting practices, and post-harvest processing methods (Fennell *et al*., 2004). As a significant producer of grains and legumes in Ghana, the Northern area has an abundance of crop straw resources (Seglah *et al*., 2020). The study conducted by Seglah *et al*. (2020) regarding the utilization of crop straw in Ghana has not received much attention and lacks thorough documentation. In Ghana, the majority of crop straw is used in a traditional manner, and a significant amount is burned on farms. Maize farming is currently the most predominant crop cultivated in Ghana's northern region

(MacCarthy *et al*., 2017). The current study revealed that the Tolon district was the leading producer of maize from 2018 to 2019 cropping season indicating that maize has become the most widely produced and consumed cereal crop in Ghana (Wood, 2013). Maize crop has been found to have a lot of beneficial nutrients including protein, carbohydrate and other nutritional components beneficial to human and animal (Murdia *et al*., 2016). As a results of the high demand and utilization of maize, its production has gained a considerable attention which might have contributed to the higher level of residues recorded in the current study. This is of interest because, evidence suggest that a large quantity of crop residues is left in farmers' fields after harvesting (Franzluebbers, 2015). Unfortunately, most farmers may not be aware of the important role crop residues play in maintaining and enhancing biological, chemical and physical characteristics of the soil (Blanco-Canqui and Lal, 2009; Lal, 2009; Franzluebbers, 2015; Stavi *et al.*, 2016; Carvalho *et al.*, 2017). Due to the inadequate knowledge about the significant of the crop residues, most farmers burn them after harvest as indicated in this study. Cereal straws particularly maize residue is recorded to be the highest burnt crop residue in Ghana followed by rice (Seglah *et al*., 2019). Despite the negative effect of the practice on soil health, air quality and climate, farmers across the globe continue to burn crop residue (Turmel *et al.*, 2015). The open residue burning releases a range of air pollutants that are harmful to the environment (Pasukphun, 2018). Crop residue burning is regarded as a waste of precious resources that frequently leads to environmental deterioration and human contamination (Aruya *et al*., 2016).

Meanwhile, the erosion of soil in the three selected district for this study has become more aggressive and quicker, resulting in crop loss, soil leaching and poor yield (Brown *et al*., 2004). Incorporating crop residue left after harvest into farming systems, however will help to regenerate soil structure by binding loose soils and also prevent washing of soil nutrients (Shaxson and Barber, 2003; Bot and Benites, 2005). The great potential of crop residues generated after harvest cannot be underestimated because their usage in agriculture is linked not only to their nutrient content, but also to their ability to reduce soil runoff and erosion while increasing water retention and promoting essential plant nutrients and microorganism (Erenstein, 2002). Gao *et al*. (2020) investigation revealed that the total soil porosity, water holding capacity and physiological characteristics of the soil were improved with the application of maize straw treatment enhancing the root penetration of crop.

Aside maize being the most cultivated crop, another interesting observation made in this study was rice residues also recording a high number of residues generated. Crop straw is said to be a source of income in several Northern Ghanaian regions, particularly in the Upper East region, where it is sold or exchanged for other items (Seglah *et al*., 2019). In some parts of Ghana, crop residues are considered a valuable farm asset and serve as a source of income for farmers. Most important among the residues are those of cereal stalks like rice. Crop residues are most commonly sold in bundles that are wrapped in bags during the dry seasons to accommodate the demand for feed needed for animal fattening and feed shortages wiles others are used as fuel during shortage of firewood (Karbo and Agyare, 2002).

Straw is still in its infancy as a fuel wood source, and it has gotten less attention over time. Maize farming accounts for the majority of rural livelihoods in Ghana, and local maize production satisfies 90% of the country's food demands (Otchere-Appiah and Hagan, 2014). Elsewhere, Adjapong *et al*., (2015) reported that maize straw had a higher yield than rice straw. This study found that maize, rice, and soybeans were the three main crops grown for making straw in Ghana, producing 7020, 4096 and 2924 kg/ha of residues in the three districts that were chosen in the country's northern region, respectively. Similarly, Li *et al*. (2017) demonstrated that maize and rice straw resources have more records in terms of the collectable amount of residues than any other straw. The disparity in the amount of crop residues produced may be attributed to low yields caused by traditional agricultural techniques involving the use of hoes and cutlasses, as well as reliance on rainfall, especially in the northern region of Ghana. The current study's findings support the existence of crop residue resources in Ghana, particularly in the north, and call for additional investigation. This quantity of residues generated by the districts can produce highly significant amount of nitrogen, phosphorus and potassium fertilizer when utilized properly in the soil. Consequently, wise use of these resources is essential to advancing national sustainable development.

Generally, soybean residues decreased for all the three districts even though there has been an increase of 0.05% from 2018 to 2019 cropping season for Savelugu district (Table 4). The least value recorded for soybean across the three districts could be attributed to the harvesting practices of the crop which could lead to low residue yield. During the harvesting time, famers allow the soybean plant to undergo complete dryness where the leaves are shared off the stalks of the plant. This practice was common to all the famers in the three districts sampled for the study. To increase cash revenue and better meet the nutritional needs of rural households, the Ministry of Food and Agriculture (MoFA) has promoted the production of soybeans (Mbanya, 2011). However, there hasn't been much of an increase in soybean farming. It is mostly grown for food and is a strong source of protein and oil (Singh *et al*., 2008). Although soybean is comparatively a recent crop in Ghana (Asodina *et al*., 2021), the crucial role that the crop is playing in the rural economy of farmers' households in northern Ghana cannot be overstated, given its growing significance. Despite the numerous benefits of the soybean, the yield grain per unit area is lesser in Ghana, with an average of 1.3 tons per hectare (Sarkodie and Mahama, 2012).

An interview conducted on a soybean farmer, Mr. Ibrahim Alhassan indicated that;

"Due to poorly organized processing and marketing channels, soybean farmers are experiencing lower-than-expected incomes from the crop compared to other crops. This has resulted in reduced prices for soybean in the market".

This demonstrates that farmers produced the crop primarily for financial gain, but that they were unwilling to expand their output levels because the crop's production was being negatively impacted by the low pricing. Moreover, low level of technology during harvesting has also limited the production of soybean especially in Ghana.

The ability to access improved seed cultivars, prepare the land properly for planting, weeding, controlling pests and diseases, marketing, and product utilization are just a few of the technically demanding factors that affect soybean production and are typically challenging to meet (Mbanya, 2011). These factors might have contributed to the low level of soybean residues recorded for this study.

5.3 ASSESSING THE QUANTITY OF NUTRIENT (NPK) IN MAIZE RICE AND SOYBEAN RESIDUE

5.3.1 Nitrogen, phosphorus, potassium and carbon content of the crop residues estimated by district

The nitrogen (N), phosphorus (P), potassium (K), and carbon (C) content of crop residues can vary depending on several factors, including the type of crop, plant part (e.g., leaves, stems, roots), and stage of maturity (Aulakh and Malhi, 2005). The amount of nitrogen generated in the three crop residues differs significantly from each other for the three districts in which the samples were taken. This seems like the geographical location affected the nitrogen contents in the residues sampled for the study. The paper by Malhi *et al*. (2006) indicated that in agro-ecosystems, nitrogen can be taken up by plants (crops), retained in the soil, or lost from the soil-crop systems by leaching and other means. Soybean residues sampled from Savelugu recorded the highest nitrogen contents of 1.37% as compared to those sampled from Kumbungu and Tolon with the value of 0.93%. This might be due to soybean's capacity to absorb nitrogen from the environment, fertilizers, and soil reserves while coexisting with microorganisms (Rymuza, 2020).

Moreover, soybean can absorb nitrogen from different sources as compared to other crops (Ohyama *et al*., 2017). According to Baldani and Baldani (2005), the nitrogen fixation process in nature involves the participation of microorganisms with varying morphological and physiological characteristics, as well as their habitat needs and the complexity of the system in which the nitrogen assimilation process takes place. In the soil environment, certain bacteria can fix nitrogen on their own, while others do it in symbiosis.

Leguminous plants are among the most important agricultural plants that coexist in symbiosis with bacteria that fix free atmospheric nitrogen, with soybean being the most notable example (Rymuza *et al*., 2020). This could have accounted for the high level of nitrogen content recorded for soybean. Generally, the nitrogen content for the three crops residues sampled appeared to be high for samples selected in the Savelugu district. This could be attributed to farmers burning more crop residues in Tolon and Kumbungu than in the Savelugu district, which could possibly result in a loss of N nutrient. According to Therefore, bush burning causes the transfer of functional plant nutrients (such as Na) and necessary plant nutrients (N, P, K, Ca, and Mg) into the atmosphere, which is thought to be the reason of the reduction in soil fertility throughout Ghana's northern area (Grillo *et al*, 2020).

A different scenario was observed in the phosphorus content of the residues generated in the three districts. The phosphorus content did not show any variations in the three districts. However, soybean residues recorded the highest phosphorus as compared to the other residues. This could be as a result of continuous burning of crop residues by farmers attributing to low organic matter content in the soil. Most Ghanaian soils are low in available phosphorus, and the problem becomes more serious when the organic matter content of the soil is low (Dakpalah *et al*., 2018). It was interesting to find that; maize residue sampled from Kumbungu had similar phosphorus content with soybean sampled from Tolon. This could be as a result of the proximity of these two districts to each other which might have contributed to the uniformity of the distribution of the phosphorus content in the two crops. Moreover, rice residues sampled from Savelugu also had similar phosphorus content with that of the phosphorus content of soybean residues sampled from the same district. It appears that all the three crop residues sampled have similar phosphorus content which is lower than the remaining nutrients obtained from the three residues sampled from the study area. This could be as a result of the low phosphorus content in the northern region as reported by Tetteh *et al*. (2016) who found that over 60% of the sites have soil with very low phosphorus content (<10ppm).

Potassium is normally available as an ionic form in plants. Chhibba, (2010) reported that approximately 75-80% of K had been abandoned in cereal residues, allowing them to be the main source for farmers. Potassium content in the residues sampled from the three districts varies. Soybean residues sampled in Tolon appeared to have the highest potassium content, followed by Savelugu and Kumbungu respectively. For maize residues, samples selected from Savelugu recorded the highest potassium content of 1.06% followed by samples taken from Kumbungu. The least potassium content recorded for maize was samples taken from Tolon. It was obvious to find out that, rice residues sampled from the three districts have similar potassium content.

A rise in the decomposition of crop residues may result in increased CO_2 emissions and less C in the soil (Ntonta *et al*., 2022). Concerns about how various management techniques can boost soil levels, organic carbon, and guarantee better agricultural sustainability are raised by the loss in soil organic carbon (SOC) and the effects of crop output in conventional farming (Ghimire *et al.*, 2017). The carbon contents of all the residues sampled show a higher variation among the three districts. These variations could be a result of the different geographical locations and the soil types from which these residues were taken from. The findings of previous authors indicate that the arrangement of land can affect the quantity of residues produced due to water availability. The movement of soil and organic substances downhill due to erosion can lead to an augmentation of soil organic matter reserves in the lower regions of the land. This could slow the amount and transformation rate of organic matter moving into more stable fractions. Soil type affect the decomposition rate of organic residue for carbon sequestration and this might have brought about the variations exhibited in the carbon content (Powlson *et al*., 2011). Moreover, soils that are naturally higher in clay content generally retain more organic matter, and therefore retain more organic carbon than sandy soils (Nath, 2014). Other farming practices could also contribute to the differences exhibited among the crop residues sampled from the three districts. The majority of farmers employ a crop residue management practice where the residues remaining on the field are primarily incorporated back into the soil through plowing in the subsequent planting season. Some of the farmers practice burning before plowing. Although burning of residues are not encouraged, but the burnt residue serves as biochar to sequestrate carbon to the soil. Rice and soybean residues sampled from Tolon had more carbon contents followed by maize residues sampled from Kumbungu. Rice and soybean samples obtained from Savelugu have a similar carbon content. Maize residues sampled from Savelugu and Tolon also had similar carbon contents.

Based on the overall analysis of nitrogen, phosphorus, potassium and carbon for all the residues, pointed out that soybean recorded the overall average mean of 1.103 ± 0.34%

followed by Rice residues with the value of 0.914 ± 0.25% whiles maize residues was the lowest with the value of 0.825 ± 0.17% (Table 4.15).

5.4 ASSESSING THE USES OF CROP RESIDUES AFTER HARVEST

5.4.1 Farmers uses of crop residues

Both middle and low-income countries have agricultural zone for farming different crops. Residue generation is very high in abundance due to its high farming rate. As reported by Smil (1999), the tropics account for over 40% of agricultural residues, with low-income nations producing more than 60% of all crop residue (s).

In Ghana, the effective use of crop residue (s) is limited despite its availability. Burning has been the cheapest option farmers use to remove residues that are not used for fuel, feed for animals, thatch for roofing building etc., (Long *et al.,* 2016).

Five main uses were identified for crop residues which were cooking fuel, animal feed, fertility management, burning and miscellaneous (Seglah *et al*., 2019). Observations have indicated that the production and utilization patterns of biomass differ based on factors such as the agricultural season, farm size, soil fertility, and household size and socioeconomic features, as well as other prevalent cultural traditions (Adjapong *et al*., 2015).

Maize residue is one of the key residues produced in the northern region. Results from the current study show that most of the farmers' households use maize stovers to complement cooking fuel after harvesting as compared to rice and soybean.

Fuel wood in the northern region is very scarce, especially in the dry season, farmers then rely on the harvested crop/plants residue as cooking fuel for their household. Some farmers stated that apart from the limited shrubs or trees that are available and sometimes used for fuel wood during the dry season, more of their attention is shifted onto the utilization of maize residues. Literature discusses the advantages of using biomass as a source of home energy. The results of this study are in line with those of Amacher *et al*. (1993), who discovered that crop residues and fuel wood are complements in one district and substitutes in the other, with crop residues serving as a more significant substitute for low-income households in both districts.

From the interview conducted in the three districts, it was found that all the farmers' households keep farm animals. Crop straw is a crucial component of crop-livestock farming systems (Moraine *et al*., 2014), and households that own livestock have a higher probability of utilizing crop straw as animal feed (Jaleta *et al*., 2015).

The findings of current research indicate that farmers have a preference for feeding their animal's soybean straw rather than cereal straws, such as rice and maize straws. This preference is primarily based on the attributes of legume straw, including palatability, high nutritional value, and enhanced digestibility (Seglah *et al*., 2020; Islam and Khan, 2021). Two studies, namely Illo *et al*. (2018) and Ayantunde *et al*. (2019), provide insights into the reasons behind this preference. According to Illo *et al*. (2018), farmers prefer soybean straw as cattle fodder because it is more palatable. The term "palatability" relates to the feed's flavor, aroma, and texture, all of which have an impact on the animals' willingness to eat it. Animals are more likely to consume more feed when it is soybean straw because it has enticing properties that make it more tempting to them (Mathis and Sawyer, 2007). Contrarily, cereal straws frequently have a gritty texture and are less appetizing, which results in decreased consumption and possible feed waste (Cork *et al*., 2022). A key element influencing farmers' preferences is the nutritional value of soybean straw. According to Ayantunde *et al*. (2019), compared to cereal straws, legume straws including soybean straw have higher levels of crude protein, essential amino acids, and minerals. The development, reproduction, and general health of animals depend on protein. Animal weight increase and feed efficiency are both enhanced by the higher protein content of soybean straw (Ahmed *et al*., 2002). Soybean straw's nutritional value is also improved by the important amino acids and minerals that it contains (Sopanrao *et al*., 2010). The effective utilization of the nutrients in feed by animals depends greatly on digestibility as well. Comparing soybean straw to cereal straws like rice and maize straws, Ayantunde *et al*. (2019) found that soybean straw is more digestible. Animals' capacity to digest and absorb nutrients from the feed they eat is referred to as their digestibility. The decreased lignin concentration of soybean straw contributes to its increased digestibility by making nutrients more accessible for microbial fermentation in the rumen (Malik *et al*., 2015). Animals given soybean straw as a result have better nutrient uptake and utilization, which enhances productivity and growth (Beigh *et al*., 2017).

Crop productivity is significantly increased by improving soil fertility. Soil erosion is a significant issue in Sub-Saharan Africa that has an impact on plant growth (Yageta *et al*., 2019). Data collected for this study indicate that only a few farmers use residues for fertilizing their soils. The results contradict with that of Ansong Omari *et al*. (2018) and Seglah *et al*. (2020) a considerable percentage of farmers return straw to the field, according to study in Ghana's Guinea Savannah region. Despite the benefit crop residue contributes to the soil, farmers in the northern region do not utilize these residues and therefore rely on chemical fertilizers. The combination of both organic and inorganic fertilizer by northern farmers would have enriched the soil by holding nutrients from leaching and also reduce the quantity of chemical fertilizer as described by Vanlauwe *et al*., (2014). According to Marenya and Barrett, (2007) this practice will let farmers take advantage over the two resource, economic complementarities.

Results indicate that crop residues are burnt on farm field while other farmers abandon the residues on the farm without the intention of fertilizing the soil. Residues left on the field are later burnt by game hunters during their hunt for rodents in people's farm. The findings support Quartey and Chlkova's (2012) assertion that bush burning typically destroys significant volumes of agricultural straw on farms. The act of burning straw is associated with demographic factors, according to Seglah *et al*. (2020), and respondents' low levels of education make it a prevalent occurrence in the study area. Based on the findings of Parker *et al*. (2010), the practice of field burning of straw is considered unsustainable due to the observed decrease of 21% in soil organic carbon, leading to the emission of 1446 kg ha^{-1} of CO_2. The areas studied are prominent districts in the Northern region that are known for their dominance in supplying agricultural produce. As a result, a decrease in food imports from these regions will have a detrimental impact on food supply in Ghana, posing a risk to food security, and worsen hunger and poverty among farmer households. In order to prevent pathogens from spreading diseases to the following farming season, farmers have a mentality of burning waste after harvesting (Cooperband, 2002).

Burning of crop residues in the dry season is an annual experience in the northern region due to the climatic condition. The absence of rainfall and low atmospheric humidity during the dry season causes severe dryness to the crop residues, making it to burn easily during burning. The primary causes of bush fires in the area are due to human actions meant to promote regeneration of grass for cattle grazing, clear land for agricultural use, and engage in animal hunting (Kugbe *et al*., 2012). According to Singh and Sidhu (2014), farmers also rely on burning as the cheapest way of disposing crop residues.

5.4.2 Determining the economic value of crop residues to farmers after harvest

The increase in the cost of fertilizer in the market is becoming alarming and farmers find it problematic to apply the recommended amount of fertilizer to their crops due to price increase. The application of organic manure or compost as a soil fertility amendment are no longer practiced by farmers due to the slow process of releasing nutrients for plant growth. Farmers have restricted to the use of chemical fertilizers as the only source of plant nutrients.

When smallholder farmers with limited resources are forced to apply only chemical fertilizer, this exacerbates the lack of soil nutrients (Place *et al*., 2003). The paper by Vanlauwe *et al*. (2006) suggest that in Sub-Saharan Africa (SSA), addressing both the gradual enhancement of soil organic matter over an extended period of time and the short-term increase in crop nutrient demands requires the combined application of chemical fertilizer and organic resources. This is also necessary to take advantage of the economic complementarities between the two resources (Marenya and Barrett, 2009). Moreover, there are also equally economic importance in terms of money associated with on-farm residue generated after harvest. Results from the field analysis indicates that maize, rice and soybean residues contain NPK (Table 4.15). Using the estimated nitrogen content from 1kg of maize, rice and soybean residues (0.825%, 0.914% and 1.103%) respectively, the value price of maize, rice and soybean residue could be estimated to produce an amount of (GH₵ 0.0495, GH₵ 0.05484, and GH₵ 0.06618 respectively. A study conducted by Berezneva, (2013) indicate that one (1) kg of residue could produce 0.7% of nitrogen at a cost KES 2.45. This provides a very good potential of income generation from the residues sampled for the study. Crop residues especially maize, rice and soybean residues contain a significant amount of nutrients in its residues. The results of this research for instance the nitrogen content is higher than the one recorded by Berazneva (2013) who indicated in research that the average maize residue retention was approximately 1,046 kg/acre, corresponding to 7 kg/acre of nitrogen. Therefore, the average crop residue estimated for the three crops (maize, rice and soybean) could generate as much quantity of nutrient (NPK) to support plant growth. The possibility of the soil getting access to these nutrients is for the farmer to incorporate these residues back into the soil. This practice could subsidize the cost of fertilizer purchased by farmers every year. The estimated value of 1 kg of maize, rice and soybean residues (GH₵ 0.0495, GH₵ 0.05484, GH₵ 0.06618) respectively left on the fields were lower as compared to the market price of 1 kg of chemical fertilizer in the market, this highlights the significance of additional environmental advantages that extend beyond simply replacing fertilizers. These benefits encompass the provision of various micro- and macronutrients, enhancements in soil moisture levels, reduction in soil-borne pests and diseases, and more (Place *et al*., 2003). Organic inputs contain carbon, which powers the majority of soil activities and replenishes the organic matter pool, improving soil fertility over the long run (Pikula and Ciotucha, 2022). In a meta-analysis comprising 57studies conducted in Sub-Saharan Africa, Chivenge *et al*. (2011) discovered that the utilization of organic resources in a particular season leads to enduring impacts in the following season. This resulted in a significant crop yield response of 38% compared to the no input control. Considering this finding, it is likely that the predicted values also account for the residual benefits of treatments involving maize residue.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Crop residues are readily available and are already being used to meet a variety of household needs and constitute essential productive resources for small-scale farmers in developing countries. From the study it could be concluded that about 7020 kg/ha, 4096 kg/ha and 2924 kg/ha of maize, rice and soybean residue respectively are generated by maize, rice and soybean farmers in the Northern Region. Additionally, the activities of organic resource management are an integral component of future economic and environmental protection of smallholder systems.

The results from the laboratory analysis of crop residues indicated a significant amount of nutrients (NPK) and carbon content in harvested crop residues of maize, rice and soybean. Maize as the major crop cultivated contains 0.825 ± 0.17%, 0.0620 ± 0.02%, 0.788 ± 0.33% of nitrogen, phosphorus, and potassium respectively. Carbon content in maize residue was 36.28 ± 1.73%. The collective understanding of farmers' disposal and misuse of crop residues particularly in the northern region of Ghana is due to the lack of education on crop residue returns to the soil for soil fertility.

The estimated economic worth of maize, rice, and soybean residues that remain on the fields ranges from GH₵ 0.01-0.05 or US$ 0.002-0.04 per kg. This valuation takes into account not only the value of nitrogen, phosphorus, and potassium present in the residues but also factors in the value of additional environmental benefits that surpass mere fertilizer substitution. From the various works done in the areas of soil fertility management and other related field activities carried out in the past, it is clear that when farmers are encouraged to adopt the practice of allowing crop residues to decompose on the field, they could help improve soil fertility which will in turn minimize the cost of applying fertilizers to the soil.

6.2 RECOMMENDATION

Based on the findings of this research, it is recommended that:

1) Farmers should incorporate harvested crop residues into the soil since they contain significant quantities of nutrients that can help improve the fertility level of the soil.
2) Similar experiments should be done in other districts in the region and possibly in the country.

REFERENCES

Abbasi, M. K., Mushtaq, A., & Tahir, M. M. (2009). Cumulative effects of white clover residues on the changes in soil properties, nutrient uptake, growth and yield of maize crop in the sub-humid hilly region of Azad Jammu and Kashmir, Pakistan. *African Journal of Biotechnology*, 218*4-2194*

Abdallah, A. H., & Abdul-Rahman, A. (2017). Technical efficiency of maize farmers in Ghana: A stochastic frontier approach. *International Journal of Innovation and scientific research*, *29*(2), 110-118.

Abdulai, A., & Huffman, W. (2000). Structural adjustment and economic efficiency of rice farmers in northern Ghana. *Economic Development and cultural change*, *48*(3), 503-520.

Adjapong, A. O., Ansah, K. D., Angfaarabung, F., & Sintim, H. O. (2015). Maize residue as a viable substrate for farm scale cultivation of oyster mushroom (Pleurotus ostreatus). *Advances in Agriculture*, *2015*.

Adzitey, F. (2013). Animal and meat production in Ghana-An overview. *The Journal of World's Poultry Research*, *3*(1), 1-4.

Aggarwal, R. K., & Power, J. F. (1997). Use of crop residue and manure to conserve water and enhance nutrient availability and pearl millet yields in an arid tropical region. *Soil and Tillage Research*, *41*(1-2), 43-51.

Ahiataku-Togobo, W. (2013). National cooking energy strategies—Lessons from Ghana. In *Presentation at the WACCA workshop, Ouagadougo, April*. pp. 23-25

Ahmed, S., Khan, M. J., Shahjalal, M., & Islam, K. M. S. (2002). Effects of feeding urea and soybean meal-treated rice straw on digestibility of feed nutrients and growth performance of bull calves. *Asian-australalasian journal of animal sciences*, *15*(4), 522-

527.

Akolgo, G. A., Essandoh, E. O., Gyamfi, S., Atta-Darkwa, T., Kumi, E. N., & de Freitas Maia, C. M. B. (2018). The potential of a dual purpose improved cookstove for low income earners in Ghana–Improved cooking methods and biochar production. *Renewable and Sustainable Energy Reviews*, *82*, 369-379.

Ali, A., Ghani, M. I., Haiyan, D., Iqbal, M., Cheng, Z., & Cai, Z. (2020). Garlic substrate induces cucumber growth development and decreases Fusarium wilt through regulation of soil microbial community structure and diversity in replanted disturbed soil. *International journal of molecular sciences*, *21*(17), 6008.

Ali, M., Saleem, M., Khan, Z., & Watson, I. A. (2019). The use of crop residues for biofuel production. In *Biomass, biopolymer-based materials, and bioenergy* (pp. 369-395). Woodhead Publishing.

Amacher, G. S., Hyde, W. F., & Joshee, B. R. (1993). Joint production and consumption in traditional households: fuelwood and crop residues in two districts in Nepal. *The Journal of Development Studies*, *30*(1), 206-225.

Amankwah, K., Klerkx, L., Oosting, S. J., Sakyi-Dawson, O., Van der Zijpp, A. J., & Millar, D. (2012). Diagnosing constraints to market participation of small ruminant producers in northern Ghana: An innovation systems analysis. *NJAS-Wageningen Journal of Life Sciences*, *60*, 37-47.

Amole, T. A., & Ayantunde, A. A. (2015). Assessment of existing and potential feed resources for improving livestock water productivity in communities around small reservoirs in Yatenga province, Burkina Faso. Report for managing water and food systems in the Volta and Niger basins project. *Report for managing water and food systems in the Volta and Niger basins project. International Livestock Research Institute, Nairobi, Kenya*. pp. 1-26.

Anderson-Teixeira, K. J., Davis, S. C., Masters, M. D., & Delucia, E. H. (2009). Changes in soil organic carbon under biofuel crops. *Gcb Bioenergy*, *1*(1), 75-96.

Andrews, E. M., Kassama, S., Smith, E. E., Brown, P. H., & Khalsa, S. D. S. (2021). A review of potassium-rich crop residues used as organic matter amendments in tree crop agroecosystems. *Agriculture*, *11*(7), 580.

Ansah, T., & Issaka, A. C. (2018). Ruminant livestock feed resources in the Kumbungu District of Ghana. pp. 41-45.

Ansong Omari, R., Bellingrath-Kimura, S. D., Sarkodee Addo, E., Oikawa, Y., & Fujii, Y. (2018). Exploring farmers' indigenous knowledge of soil quality and fertility management practices in selected farming communities of the guinea savannah agro-ecological zone of Ghana. *Sustainability*, *10*(4), 1034.

Antle, J. M., & Stoorvogel, J. J. (2008). Agricultural carbon sequestration, poverty, and sustainability. *Environment and Development Economics*, *13*(3), 327-352.

Arjmand Sajjadi, S., & Mahmoodabadi, M. (2015). Aggregate breakdown and surface seal development influenced by rain intensity, slope gradient and soil particle size. *Solid Earth*, *6*(1), 311-321.

Aruya, E. I., Yusuf, R. O., & Yusuf, Y. O. (2016). An assessment of crop residue characteristics and factors militating against efficient management in the Ikara local government area of Kaduna state, Nigeria. *Waste Manag Environ VIII*, *1*(Wm), 333-344.

Asodina, F. A., Adams, F., Nimoh, F., Asante, B. O., & Mensah, A. (2021). Performance of smallholder soybean farmers in Ghana; evidence from Upper West Region of Ghana. *Journal of Agriculture and Food Research*, *4*, 100-120

Atlin, G. N., Cooper, M., & Bjørnstad, Å. (2001). A comparison of formal and participatory breeding approaches using selection theory. *Euphytica*, *122*, 463-475.

Aulakh, M. S., & Malhi, S. S. (2005). Interactions of nitrogen with other nutrients and water: Effect on crop yield and quality, nutrient use efficiency, carbon sequestration, and environmental pollution. *Advances in agronomy*, *86*, 341-409.

Avornyo, V. K., Ito, O., Kranjac-Berisavljevic, G., Saito, O., & Takeuchi, K. (2014). Cropping systems in some drought-prone communities of the Northern region of Ghana: Factors affecting the introduction of rice. *Journal of Disaster research*, *9*(4), 475-483.

Ayamga, E. A., Kemausuor, F., & Addo, A. (2015). Technical analysis of crop residue biomass energy in an agricultural region of Ghana. *Resources, Conservation and Recycling*, *96*, 51-60.

Ayantunde, A. A., Boubacar, H. A., Adamou, K., Moumini, O., & Umutoni, C. (2019). Evaluation of feed resources in the mixed crop-livestock systems of the Sahelian zone in Burkina Faso and Niger. 1-21

Baba, I. I. Y., Wiredu, A. N., Yirzagla, J., Mawunya, M., & Haruna, M. (2013). The effects of different mulches on the yield and productivity of drip irrigated onions under tropical conditions. *1, 133-140.*

Bakker, R. R. C., Elbersen, H. W., Poppens, R. P., & Lesschen, J. P. (2013). *Rice straw and wheat straw-potential feedstocks for the biobased economy*. NL Agency.

Baldani, J. I., & Baldani, V. L. (2005). History on the biological nitrogen fixation research in graminaceous plants: special emphasis on the Brazilian experience. *Anais da Academia Brasileira de Ciências*, *77*, 549-579.

Baldock, J. A. (2002). 3 Interactions of Organic Materials and Microorganisms with Minerals. *Interactions between soil particles and microorganisms: impact on the terrestrial ecosystem*, *7*, 85.

Bandick, A. K., & Dick, R. P. (1999). Field management effects on soil enzyme activities. *Soil biology and biochemistry*, *31*(11), 1471-1479.

Bationo, A., Wani, S. P., Bielders, C. L., Vlek, P. L. G., & Mokwunye, A. U. (2019). Crop residue and fertilizer management to improve soil organic carbon content, soil quality and productivity in the desert margins of West Africa. In *Global climate change and tropical ecosystems* (pp. 117-145). CRC Press.

Beigh, Y. A., Ganai, A. M., & Ahmad, H. A. (2017). Prospects of complete feed system in ruminant feeding: A review. *Veterinary world*, *10*(4), 424.

Berazneva, J. (2013). Economic value of crop residues in African smallholder agriculture. 1-25.

Bhadauria, T., & Saxena, K. G. (2010). Role of earthworms in soil fertility maintenance through the production of biogenic structures. *Applied and environmental soil science*, *2010*.

Bhatia, A., Jain, N., & Pathak, H. (2013). Methane and nitrous oxide emissions from Indian rice paddies, agricultural soils and crop residue burning. *Greenhouse Gases: Science and Technology*, *3*(3), 196-211

Bhupinderpal-Singh, Rengel, Z., Bowden, J.W. (2006). Carbon, nitrogen, and sulphur cycling following incorporation of canola residue of different sizes into a nutrient-poor sandy soil. *Soil Biology and Biochemistry*. 38(1):32-42. Available at: https://doi.org/10.1016/j.soilbio.2005.03.025.

Bhuvaneshwari, S., Hettiarachchi, H., & Meegoda, J. N. (2019). Crop residue burning in India: policy challenges and potential solutions. *International journal of environmental research and public health*, *16*(5), 832.

Biederbeck, V. O., Campbell, C. A., Bowren, K. E., Schnitzer, M., & McIver, R. N. (1980). Effect of Burning Cereal Straw on Soil Properties and Grain Yields in Saskatchewan 1. *Soil Science Society of America Journal*, *44*(1), 103-111.

Blanco-Canqui, H., & Benjamin, J. G. (2013). Impacts of soil organic carbon on soil physical behavior. *Quantifying and modeling soil structure dynamics*, *3*, 11-40.

Blanco-Canqui, H., & Lal, R. (2009). Crop residue management and soil carbon dynamics. *Soil carbon sequestration and the greenhouse effect*, *57*, 291-309.

Blanco-Canqui, H., Shapiro, C. A., Wortmann, C. S., Drijber, R. A., Mamo, M., Shaver, T. M., & Ferguson, R. B. (2013). Soil organic carbon: The value to soil properties. *Journal of Soil and Water Conservation*, *68*(5), 129A-134A.

Bloom, D. E., Canning, D., & Fink, G. (2010). Implications of population ageing for economic growth. *Oxford review of economic policy*, *26*(4), 583-612.

Boon, E. K., & Anuga, S. W. (2020). Circular economy and its relevance for improving food and nutrition security in Sub-Saharan Africa: the case of Ghana. *Materials Circular Economy*, *2*, 1-14.

Bot, A., & Benites, J. (2005). *The importance of soil organic matter: Key to drought-resistant soil and sustained food production* (No. 80). Food & Agriculture Org.

Bottinelli, N., Jouquet, P., Capowiez, Y., Podwojewski, P., Grimaldi, M., & Peng, X. (2015). Why is the influence of soil macrofauna on soil structure only considered by soil ecologists?. *Soil and Tillage Research*, *146*, 118-124.

Brankatschk, G., & Finkbeiner, M. (2015). Modeling crop rotation in agricultural LCAs—challenges and potential solutions. *Agricultural Systems*, *138*, 66-76.

Broadbent, F. E. (2015). Soil organic matter. *Sustainable options in land management*, *2*, 34-38.

Brown, G. G., Moreno, A. G., Barois, I., Fragoso, C., Rojas, P., Hernández, B., & Patrón, J. C. (2004). Soil macrofauna in SE Mexican pastures and the effect of conversion from native to introduced pastures. *Agriculture, ecosystems & environment*, *103*(2), 313-327.

Butterly, C. R., Baldock, J. A., & Tang, C. (2013). The contribution of crop residues to changes in soil pH under field conditions. *Plant and soil*, *366*(1), 185-198.

Cambardella, C. A., Richard, T. L., & Russell, A. (2003). Compost mineralization in soil as a function of composting process conditions. *European Journal of Soil Biology*, *39*(3), 117-127.

Cao, Q., Li, G., Yang, F., Kong, F., Cui, Z., Jiang, X., & Zhang, E. (2021). Eleven-year mulching and tillage practices alter the soil quality and bacterial community composition in Northeast China. *Archives of Agronomy and Soil Science*, 1-16.

Carvalho, J. L. N., Nogueirol, R. C., Menandro, L. M. S., Bordonal, R. D. O., Borges, C. D., Cantarella, H., & Franco, H. C. J. (2017). Agronomic and environmental implications of sugarcane straw removal: a major review. *Gcb Bioenergy*, *9*(7), 1181-1195.

Chaves, B., De Neve, S., Hofman, G., Boeckx, P., & Van Cleemput, O. (2004). Nitrogen mineralization of vegetable root residues and green manures as related to their (bio) chemical composition. *European Journal of Agronomy*, *21*(2), 161-170.

Chen, B., Liu, E., Tian, Q., Yan, C., & Zhang, Y. (2014). Soil nitrogen dynamics and crop residues. A review. *Agronomy for sustainable development*, *34*(2), 429-442.

Cherubin, M. R., Oliveira, D. M. D. S., Feigl, B. J., Pimentel, L. G., Lisboa, I. P., Gmach, M. R., & Paiva, S. R. D. (2018). Crop residue harvest for bioenergy production and its implications on soil functioning and plant growth: A review. *Scientia Agricola*, *75*(3), 255-272.

Chhibba, I. M. (2010). Rice-wheat production system: soil and water-related issues and options. *Journal of the Indian Society of Soil Science, 58*(1), 53-63.

Chivenge, P., Vanlauwe, B., & Six, J. (2011). Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant and Soil*, *342*(1-2), 1-30.

Cooperband, L. (2002). Building soil organic matter with organic amendments. *Center for Integrated Agricultural Systems (CIAS), College of Agricultural and Life Sciences, University of Wisconsin-Madison*.

Cork, S. D., Blanchard, C., Mawson, A. J., & Farahnaky, A. (2022). Pulse flaking: Opportunities and challenges, a review. *Comprehensive Reviews in Food Science and Food Safety*, *21*(3), 2873-2897.

Cox, T. S., Bender, M., Picone, C., Tassel, D. V., Holland, J. B., Brummer, E. C., ... & Jackson, W. (2002). Breeding perennial grain crops. *Critical Reviews in Plant Sciences*, *21*(2), 59-91.

Dakpalah, S. S., Anornu, G. K., & Ofosu, E. A. (2018). Small scale irrigation development in Upper West region, Ghana; challenges, potentials and solutions. *Small*, *10*(3).

Damon, P. M., Bowden, B., Rose, T., & Rengel, Z. (2014). Crop residue contributions to phosphorus pools in agricultural soils: A review. *Soil Biology and Biochemistry*, *74*, 127-137.

Das, I., & Pradhan, M. (2016). Potassium-solubilizing microorganisms and their role in enhancing soil fertility and health. In *Potassium solubilizing microorganisms for sustainable agriculture* (pp. 281-291). Springer, New Delhi.

Davis, K., Nkonya, E., Kato, E., Mekonnen, D. A., Odendo, M., Miiro, R., & Nkuba, J. (2012). Impact of farmer field schools on agricultural productivity and poverty in East Africa. *World development*, *40*(2), 402-413.

Dawson, C. J., & Hilton, J. (2011). Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. *Food Policy*, *36*, S14-S22.

De Groote, H., & Traoré, O. (2005). The cost of accuracy in crop area estimation. *Agricultural Systems*, *84*(1), 21-38.

Dennis, E. I., Usoroh, A. D., & Ijah, C. J. (2013). Soil properties dynamics induced by passage of fire during agricultural burning. *International Journal of Advance Agricultural Research*, *1*, 43-52.

Derpsch, R. (1998). Historical review of no-tillage cultivation of crops. In *Conservation*

Tillage for Sustainable Agriculture. Proceedings from an International Workshop, Harare (pp. 22-27).

Devi, S., Gupta, C., Jat, S. L., & Parmar, M. S. (2017). Crop residue recycling for economic and environmental sustainability: The case of India. *Open Agriculture*, *2*(1), 486-494.

Dietz, T., Millar, D., Dittoh, S., Obeng, F., & Ofori-Sarpong, E. (2004). Climate and livelihood change in North East Ghana. In *The Impact of Climate Change on Drylands: With a Focus on West Africa* (pp. 149-172). Dordrecht: Springer Netherlands.

Dixon, J. A., Gibbon, D. P., & Gulliver, A. (2001). *Farming systems and poverty: improving farmers' livelihoods in a changing world*. Food & Agriculture Org. pp. 1-26.

Doube, B. M., Buckerfield, J. C., & Kirkegaard, J. A. (1994). Short-term effects of tillage and stubble management on earthworm populations in cropping systems in southern New South Wales. *Australian Journal of Agricultural Research*, *45*(7), 1587-1600.

Drijber, R. A., Doran, J. W., Parkhurst, A. M., & Lyon, D. J. (2000). Changes in soil microbial community structure with tillage under long-term wheat-fallow management. *Soil Biology and Biochemistry*, *32*(10), 1419-1430.

Dugan, E., Verhoef, A., Robinson, S., Sohi, S., Gilkes, R., & Prakpongkep, N. (2010, August). Bio-char from sawdust, maize stover and charcoal: Impact on water holding capacities (WHC) of three soils from Ghana. In *19th World congress of soil science, soil solutions for a changing world* (Vol. 11).

Duguma, B., & Janssens, G. P. J. (2016). Assessment of feed resources, feeding practices and coping strategies to feed scarcity by smallholder urban dairy producers in Jimma town, Ethiopia. *SpringerPlus*, *5*(1), 1-10.

Duiker, S. W., & Lal, R. (1999). Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. *Soil and Tillage Research*, *52*(1-2), 73-81.

Duku, M. H., Gu, S., & Hagan, E. B. (2011). Biochar production potential in Ghana—a review. *Renewable and Sustainable Energy Reviews*, *15*(8), 3539-3551.

Eagleton, G. (2017). A review of options for using organic soil amendments to raise crop productivity in East Sumba, Indonesia. In *Proceedings the SATREPS Conference* (Vol. 1, No. 1, pp. 59-81).

Ekboir, J., Boa-Amponsem, K., & Enkyi, A. A. (2005). Impact of no-till Technologies in 7. *Effect of some agronomic practices*.

Emerson, W. W. (1995). Water-retention, organic-C and soil texture. *Soil Research*, *33*(2), 241-251.

Erenstein, O. (2002). Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. *Soil and tillage research*, *67*(2), 115-133.

Escobar Ortega, J. S., Aguilar Vásquez, N. N., Ávila Alba, T., & Garcia de Salamone, I. E. (2021). Impact of management of cover crop–soybean agro-ecosystems on rhizosphere microbial communities. *European Journal of Soil Science*, *72*(3), 1154-1176.

Fang, C., Smith, P., Moncrieff, J. B., & Smith, J. U. (2005). Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature*, *433*(7021), 57-59.

FAO. (2018). Food and agriculture organization of the United Nations. *Rome, URL: http://faostat. fao. org*.

FAO. (2001). *The State of Food and Agriculture 2001* (No. 33). Food & Agriculture Organization.

Feng, Y., Motta, A. C., Reeves, D. W., Burmester, C. H., Van Santen, E., & Osborne, J. A. (2003). Soil microbial communities under conventional-till and no-till continuous cotton systems. *Soil Biology and Biochemistry*, *35*(12), 1693-1703.

Fennell, C. W., Light, M. E., Sparg, S. G., Stafford, G. I., & Van Staden, J. (2004). Assessing

African medicinal plants for efficacy and safety: agricultural and storage practices. *Journal of Ethnopharmacology*, *95*(2-3), 113-121.

Fermont, A., & Benson, T. (2011). Estimating yield of food crops grown by smallholder farmers. International Food Policy Research Institute, Washington DC, 1, 1-68.

Fischer, G., Prieler, S., van Velthuizen, H., Berndes, G., Faaij, A., Londo, M., & de Wit, M. (2010). Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures, Part II: Land use scenarios. *Biomass and bioenergy*, *34*(2), 173-187.

Fissore, C., Giardina, C. P., Kolka, R. K., Trettin, C. C., King, G. M., Jurgensen, M. F., ... & McDowell, S. D. (2008). Temperature and vegetation effects on soil organic carbon quality along a forested mean annual temperature gradient in North America. *Global Change Biology*, *14*(1), 193-205.

Florindo, T., Ferraz, A. I., Rodrigues, A. C., & Nunes, L. J. (2022). Residual biomass recovery in the wine sector: creation of value chains for vine pruning. *Agriculture*, *12*(5), 670.

Franke, A. C., Van Den Brand, G. J., & Giller, K. E. (2014). Which farmers benefit most from sustainable intensification? An ex-ante impact assessment of expanding grain legume production in Malawi. *European Journal of Agronomy*, *58*, 28-38.

Franzluebbers, A. J. (2015). Farming strategies to fuel bioenergy demands and facilitate essential soil services. *Geoderma*, *259*, 251-258.

Fu, B., Chen, L., Huang, H., Qu, P., & Wei, Z. (2021). Impacts of crop residues on soil health: A review. *Environmental Pollutants and Bioavailability*, *33*(1), 164-173.

Gao, F., Hu, J., Ren, B., Liu, P., Zhao, B., & Zhang, J. (2020). Improving soil properties and grains yield of winter wheat and summer corn under residue management strategies. *Agronomy Journal*, *112*(5), 4287-4302.

García-Ruiz, R., Ochoa, V., Vinegla, B., Hinojosa, M. B., Pena-Santiago, R., Liébanas, G.,

& Carreira, J. A. (2009). Soil enzymes, nematode community and selected physico-chemical properties as soil quality indicators in organic and conventional olive oil farming: Influence of seasonality and site features. *Applied soil ecology*, *41*(3), 305-314.

Gelderman, R., R. Beck, R. Fanning, and L.Wagner. (2011). "The Value of Crop Residue." iGrow South Dakota State University Extension. Accessed June 22, 2017.

Ghimire, B., Ghimire, R., VanLeeuwen, D., & Mesbah, A. (2017). Cover crop residue amount and quality effects on soil organic carbon mineralization. *Sustainability*, *9*(12), 2316.

Giller, K. E., Tittonell, P., Rufino, M. C., Van Wijk, M. T., Zingore, S., Mapfumo, P., ... & Vanlauwe, B. (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural systems*, *104*(2), 191-203.

Gilmour, J. T., & Mauromoustakos, A. (2011). Nitrogen mineralization from soil organic matter: a sequential model. *Soil Science Society of America Journal*, *75*(1), 317-323.

Ginovart, M., López, D., & Gras, A. (2005). Individual-based modeling of microbial activity to study mineralization of C and N and nitrification process in soil. *Nonlinear analysis: real-world applications*, *6*(4), 773-795.

Gladwin, C. H., Thomson, A. M., Peterson, J. S., & Anderson, A. S. (2001). Addressing food security in Africa via multiple livelihood strategies of women farmers. *Food policy*, *26*(2), 177-207.

Golchin, A., Baldock, J. A., & Oades, J. M. (2018). A model linking organic matter decomposition, chemistry, and aggregate dynamics. In *Soil processes and the carbon cycle* (pp. 245-266). CRC Press.

González, G. (2002). Soil organisms and litter decomposition. *Modern trends in applied* *terrestrial ecology*, 315-329.

Greenfield, H., & Southgate, D. A. (2003). *Food composition data: production, management, and use*. Food & Agriculture Organization.

Grigera, M. S., Drijber, R. A., Eskridge, K. M., & Wienhold, B. J. (2006). Soil microbial biomass relationships with organic matter fractions in a Nebraska corn field mapped using apparent electrical conductivity. *Soil Science Society of America Journal*, *70*(5), 1480-1488.

Grillo, G., Tabasso, S., Cravotto, G., & van Ree, T. (2020). Burning biomass: Environmental impact on the soil. *Biomass Burning in Sub-Saharan Africa: Chemical Issues and Action Outreach*, 15-30.

Grzyb, A., Wolna-Maruwka, A., & Niewiadomska, A. (2020). Environmental factors affecting the mineralization of crop residues. *Agronomy*, *10*(12), 1951.

Guerif, J., Richard, G., Dürr, C., Machet, J. M., Recous, S., & Roger-Estrade, J. (2001). A review of tillage effects on crop residue management, seedbed conditions and seedling establishment. *Soil and Tillage Research*, *61*(1-2), 13-32.

Guo, Y., Fan, R., Zhang, X., Zhang, Y., Wu, D., McLaughlin, N., & Liang, A. (2020). Tillage-induced effects on SOC through changes in aggregate stability and soil pore structure. *Science of the Total Environment*, *703*, 134617.

Guo, Z., Liu, H., Hua, K., Wang, D., & He, C. (2018). Long-term straw incorporation benefits the elevation of soil phosphorus availability and use efficiency in the agroecosystem. *Spanish Journal of agricultural research*, *16*(3), e1101-e1101.

Gupta, V. V. S. R., Roper, M. M., Kirkegaard, J. A., & Angus, J. F. (1994). Changes in microbial biomass and organic matter levels during the first year of modified tillage and stubble management practices on red earth. *Soil Research*, *32*(6), 1339-1354.

Hadas, A., Kautsky, L., Goek, M., & Kara, E. E. (2004). Rates of decomposition of plant residues and available nitrogen in soil, related to residue composition through simulation of carbon and nitrogen turnover. *Soil Biology and Biochemistry*, *36*(2), 255-266.

Hayes, J. E., Richardson, A. E., & Simpson, R. J. (2000). Components of organic phosphorus in soil extracts that are hydrolysed by phytase and acid phosphatase. *Biology and Fertility of Soils*, *32*(4), 279-286.

He, Q., & Walling, D. E. (1996). Interpreting particle size effects in the adsorption of 137Cs and unsupported 210Pb by mineral soils and sediments. *Journal of Environmental Radioactivity*, *30*(2), 117-137.

Herrero, M. T., Thornton, P. K., Notenbaert, A. M. O., Msangi, S., Wood, S., Kruska, R. L., & Rao, P. P. (2010). Drivers of change in crop-livestock systems and their potential impacts on agro-ecosystems services and human well-being to 2030.

Hiloidhari, M., Bhuyan, N., Gogoi, N., Seth, D., Garg, A., Singh, A., ... & Kataki, R. (2020). Agroindustry wastes: biofuels and biomaterials feedstocks for sustainable rural development. In *Refining Biomass Residues for Sustainable Energy and Bioproducts* (pp. 357-388). Academic Press.

Hofman, G., & Van Cleemput, O. (2004). Soil and plant nitrogen.

Hoskinson, R. L., Karlen, D. L., Birrell, S. J., Radtke, C. W., & Wilhelm, W. W. (2007). Engineering, nutrient removal, and feedstock conversion evaluations of four corn stover harvest scenarios. *Biomass and Bioenergy*, *31*(2-3), 126-136.

House, G. J., & Parmelee, R. W. (1985). Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. *Soil and Tillage Research*, *5*(4), 351-360.

Howari, H., Parvez, M., Khan, O., Alhodaib, A., Mallah, A., & Yahya, Z. (2023). Multi-objective optimization for ranking waste biomass materials based on performance and emission parameters in a pyrolysis process—an approach. *Sustainability*, *15*(4), 3690.

Hoyle, F. C., Murphy, D. V., & Fillery, I. R. P. (2006). Temperature and stubble management influence microbial CO2–C evolution and gross N transformation rates. *Soil Biology and Biochemistry*, *38*(1), 71-80.

Hunter, R.C., Halverson, T.L. and Anderson, R.D. (1984). Quality assurance for plant tissue analysis by ICP-AES. Commun. In Soil Sci. Plant Anal., 15(11), 1285-1322.

Idan, F., Adogla-Bessa, T., & Amaning-Kwarteng, K. (2020). Preference, voluntary feed intake, and digestibility of sheep fed untreated rice straw and supplemented with sole or combined fodder tree leaves. *European Journal of Agriculture and Food Sciences*, *2*(4).

Illo, A. I., Kamba, A. A., Umar, S., & Abubakar, A. (2018). Analysis of crop residues availability for animal feed in Kebbi State, Nigeria. *International Journal of Agricultural Extension*, *6*(2), 89-97.

Ingram, J., & Kirwan, J. (2011). Matching new entrants and retiring farmers through farm joint ventures: Insights from the Fresh Start Initiative in Cornwall, UK. *Land Use Policy*, *28*(4), 917-927.

Iqbal, A., Beaugrand, J., Garnier, P., & Recous, S. (2013). Tissue density determines the water storage characteristics of crop residues. *Plant and Soil, 367*, 285-299.

Iqbal, A., Khan, A., Green, S. J., Ali, I., He, L., Zeeshan, M., & Jiang, L. (2021). Long-term straw mulching in a no-till field improves soil functionality and rice yield by increasing soil enzymatic activity and chemical properties in paddy soils. *Journal of Plant Nutrition and Soil Science*, *184*(6), 622-634.

Iqbal, Y., Lewandowski, I., Weinreich, A., Wippel, B., Pforte, B., Hadai, O. & Peters, D. (2016). *Maximising the yield of biomass from residues of agricultural crops and biomass from forestry*. ECOFYS.

Islam, S., & Khan, M. R. I. (2021). The Potentiality of Major Crops by Products as Livestock Feed in Bangladesh, A Review. *Adv. Anim. Vet. Sci*, *9*(12), 2103-2115.

Issaka, R. N., Buri, M. M., Tobita, S., Nakamura, S., & Owusu-Adjei, E. (2012). Indigenous fertilizing materials to enhance soil productivity in Ghana. *Soil Fertility Improvement and Integrated Nutrient Management—A Global Perspective; Whalen, KJ, Ed*, 119-134.

Jain, N., Bhatia, A., & Pathak, H. (2014). Emission of air pollutants from crop residue burning in India. *Aerosol and Air Quality Research*, *14*(1), 422-430.

Jaleta, M., Kassie, M., & Erenstein, O. (2015). Determinants of maize stover utilization as feed, fuel and soil amendment in mixed crop-livestock systems, Ethiopia. *Agricultural Systems*, *134*, 17-23.

Jamala, G. Y., Boni, P. G., Abraham, P., & Teru, C. P. (2012). Evaluation of environmental and vulnerability impact of bush burning in Southern Guinea Savanna of Adamawa State, Nigeria.

Jiang, N., Hu, B., Wang, X., Meng, Y., Chen, B., & Zhou, Z. (2019). Effects of crop residue incorporation and inorganic potassium fertilization on soil potassium supply power. *Archives of Agronomy and Soil Science*, *65*(9), 1223-1236.

Jin, Z., Shah, T., Zhang, L., Liu, H., Peng, S., & Nie, L. (2020). Effect of straw returning on soil organic carbon in rice–wheat rotation system: A review. *Food and Energy Security*, *9*(2), e200.

Joshi, G. R., & Joshi, B. (2017). Household food security: Trends and determinants in mountainous districts of Nepal. 1-14.

Jouquet, P., Dauber, J., Lagerlöf, J., Lavelle, P., & Lepage, M. (2006). Soil invertebrates as ecosystem engineers: intended and accidental effects on soil and feedback loops. *Applied soil ecology*, *32*(2), 153-164.

Kabba, B. S., & Aulakh, M. S. (2004). Climatic conditions and crop-residue quality differentially affect N, P, and S mineralization in soils with contrasting P status. *Journal of Plant Nutrition and soil science*, *167*(5), 596-601.

Kaleeem Abbasi, M., Mahmood Tahir, M., Sabir, N., & Khurshid, M. (2015). Impact of the addition of different plant residues on nitrogen mineralization–immobilization turnover and carbon content of a soil incubated under laboratory conditions. *Solid Earth*, *6*(1), 197-205.

Karbo, N., & Agyare, W. (2002). Crop–livestock systems in northern Ghana. *Improving crop–livestock systems in the dry savannas of West and Central Africa. Ibadan: IITA*, 112-126.

Karbo, N., & Agyare, W. (2002). Crop–livestock systems in northern Ghana. *Improving crop–livestock systems in the dry savannas of West and Central Africa. Ibadan: IITA*, 112-126.

Kastori, R., Maksimović, I., & Putnik-Delić, M. (2012). Environmental aspects of burning field residues for use as an alternative fuel. *Ratarstvo i povrtarstvo*, *49*(3), 313-319.

Keftasa, D. (1987, April). Role of crop residues as livestock feed in Ethiopian highlands. In *African Forage Genetic Resources, Evaluation of Forage Germplasm and Extensive Livestock Production Systems. Proceedings of a Workshop Held in Arusha, Tanzania* (pp. 430-439).

Khatoon, H., Solanki, P., Narayan, M., Tewari, L., Rai, J., & Hina Khatoon, C. (2017). Role of microbes in organic carbon decomposition and maintenance of soil ecosystem. *International Journal of Chemical Studies*, *5*(6), 1648-1656.

Konlan, S. P., Ayantunde, A. A., Weseh, A., Dei, H. K., & Avornyo, F. K. (2015). Opportunities and challenges of emerging livestock feed markets in northern Ghana. pp. 1-31.

Krull, E. S., Skjemstad, J. O., & Baldock, J. A. (2004). *Functions of soil organic matter and the effect on soil properties* (p. 129). Canberra: Cooperative Research Centre for Greenhouse Accounting.

Kugbe, J. X., Mathias, F., Desta, T. L., Denich, M., & Vlek, P. L. (2012). Annual vegetation burns across the northern savanna region of Ghana: period of occurrence, area burns, nutrient losses and emissions. *Nutrient cycling in agroecosystems*, *93*, 265-284.

Kumar, B., Gupta, R. K., & Bhandari, A. L. (2008). Soil fertility changes after long-term application of organic manures and crop residues under rice-wheat system. *Journal of the Indian Society of Soil Science*, *56*(1), 80-85.

Kumar, P., Kumar, S., & Joshi, L. (2015). *Socioeconomic and environmental implications of agricultural residue burning: A case study of Punjab, India* (p. 144). Springer Nature.

Kushwaha, C. P., Tripathi, S. K., & Singh, K. P. (2000). Variations in soil microbial biomass and N availability due to residue and tillage management in a dryland rice agroecosystem. *Soil and Tillage Research*, *56*(3-4), 153-166.

Kusi, L. Y., Agbeblewu, S., Anim, I. K., & Nyarku, K. M. (2015). The challenges and prospects of the commercial poultry industry in Ghana: A synthesis of literature.

Lado, M., Ben-Hur, M., & Shainberg, I. (2004). Soil wetting and texture effects on aggregate stability, seal formation, and erosion. *Soil Science Society of America Journal*, *68*(6), 1992-1999.

Lal, R. (2000). Physical management of soils of the tropics: priorities for the 21st century. *Soil science*, *165*(3), 191-207.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, *304*(5677), 1623-1627.

Lal, R. (2005a). *Climate change, soil carbon dynamics, and global food security* (pp. 113-43). Climate change and global food security. Boca Raton (FL): CRC Press.

Lal, R. (2005b). World crop residues production and implications of its use as a biofuel. *Environment International*, *31*(4), 575-584.

Lal, R. (2009). Soil quality impacts of residue removal for bioethanol production. *Soil and tillage research*, *102*(2), 233-241.

Laube, W., Schraven, B., & Awo, M. (2012). Smallholder adaptation to climate change: dynamics and limits in Northern Ghana. *Climatic change*, *111*(3), 753-774.

Lavelle, P., Spain, A., Blouin, M., Brown, G., Decaëns, T., Grimaldi, M., ... & Zangerlé, A. (2016). Ecosystem engineers in a self-organized soil: a review of concepts and future research questions. *Soil Science*, *181*(3/4), 91-109.

Li, H., Cao, Y., Wang, X., Ge, X., Li, B., & Jin, C. (2017). Evaluation on the production of food crop straw in China from 2006 to 2014. *BioEnergy Research*, *10*, 949-957.

Li, J., Ye, X., Zhang, Y., Chen, J., Yu, N., & Zou, H. (2021). Maize straw deep-burying promotes soil bacteria community abundance and improves soil fertility. *Journal of Soil Science and Plant Nutrition*, *21*(2), 1397-1407.

Li, Z., Song, Z., Singh, B. P., & Wang, H. (2019). The impact of crop residue biochars on silicon and nutrient cycles in croplands. *Science of the Total Environment*, *659*, 673-680.

Lin, P., Engling, G., & Yu, J. Z. (2010). Humic-like substances in fresh emissions of rice straw burning and in ambient aerosols in the Pearl River Delta Region, China. *Atmospheric Chemistry and Physics*, *10*(14), 6487-6500.

Lin, S., Iqbal, J., Hu, R., Shaaban, M., Cai, J., & Chen, X. (2013). Nitrous oxide emissions from yellow brown soil as affected by incorporation of crop residues with different carbon-to-nitrogen ratios: a case study in central China. *Archives of environmental contamination and toxicology*, *65*(2), 183-192.

Liu, C., Lu, M., Cui, J., Li, B., & Fang, C. (2014). Effects of straw carbon input on carbon dynamics in agricultural soils: a meta-analysis. *Global change biology*, *20*(5), 1366-1381.

Liu, G., Zheng, F., Jia, L., Jia, Y., Zhang, X. C. J., Hu, F., & Zhang, J. (2019). Interactive effects of raindrop impact and groundwater seepage on soil erosion. *Journal of Hydrology*, *578*, 124066.

Lobley, M. (2010). Succession in the family farm business. *Journal of Farm Management*, *13*(12), 839-851.

Logah, V. (2011). Chemical properties of maize residues under application of organic and inorganic nutrient sources. *International Journal of Environmental Science and Development*, *2*(5), 344.

Long, X., Tie, X., Cao, J., Huang, R., Feng, T., Li, N., & Zhang, Q. (2016). Impact of crop field burning and mountains on heavy haze in the North China Plain: a case study. *Atmospheric Chemistry and Physics*, *16*(15), 9675-9691.

Lou, Y., Liang, W., Xu, M., He, X., Wang, Y., & Zhao, K. (2011). Straw coverage alleviates seasonal variability of the topsoil microbial biomass and activity. *Catena*, *86*(2), 117-120.

Lupwayi, N. Z., Clayton, G. W., O'Donovan, J. T., Harker, K. N., Turkington, T. K., & Soon, Y. K. (2007). Phosphorus release during decomposition of crop residues under conventional and zero tillage. *Soil and Tillage Research*, *95*(1-2), 231-239.

MacCarthy, D. S., Adiku, S. G., Freduah, B. S., Gbefo, F., & Kamara, A. Y. (2017). Using CERES-Maize and ENSO as decision support tools to evaluate climate-sensitive farm management practices for maize production in the northern regions of Ghana. *Frontiers in plant science*, *8*, 31.

Maharjan, K. L., & Khatri-Chhetri, A. (2006). *Household food security in rural areas of Nepal: Relationship between socio-economic characteristics and food security status*

(No. 1004-2016-78861).

Malhi, S. S., Lemke, R., Wang, Z. H., & Chhabra, B. S. (2006). Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. *Soil and Tillage Research*, *90*(1-2), 171-183.

Malik, K., Tokkas, J., Anand, R. C., & Kumari, N. (2015). Pretreated rice straw as an improved fodder for ruminants-An overview. *Journal of Applied and Natural Science*, *7*(1), 514-520.

Malobane, M. E., Nciizah, A. D., Mudau, F. N., & Wakindiki, I. I. (2020). Tillage, crop rotation and crop residue management effects on nutrient availability in a sweet sorghum-based cropping system in marginal soils of South Africa. *Agronomy*, *10*(6), 776.

Mandal, K. G., Misra, A. K., Hati, K. M., Bandyopadhyay, K. K., Ghosh, P. K., & Mohanty, M. (2004). Rice residue-management options and effects on soil properties and crop productivity. *Journal of Food Agriculture and Environment*, *2*, 224-231.

Marenya, P. P., & Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy*, *32*(4), 515–536.

Masika, D. A. N. I. E. L. (2016). *Using Dssat-Ceres Maize Model to Estimate District-Level Yields in Northern Ghana* (Doctoral dissertation, University Of Ghana). 111, 10-28.

Massaccesi, L., De Feudis, M., Leccese, A., & Agnelli, A. (2020). Altitude and vegetation affect soil organic carbon, basal respiration and microbial biomass in Apennine forest soils. *Forests*, *11*(6), 710.

Mathis, C. P., & Sawyer, J. E. (2007). Nutritional management of grazing beef cows. *Veterinary Clinics of North America: Food Animal Practice*, *23*(1), 1-19.

Mbah, C. N., & Nneji, R. K. (2011). Effect of different crop residue management techniques on selected soil properties and grain production of maize. *African Journal of Agricultural Research*, *6*(17), 4149-4152.

Mbanya, W. (2011). Assessment of the constraints in soybean production: A case of Northern Region, Ghana. *Journal of Developments in Sustainable Agriculture*, *6*(2), 199-214.

McIntire, J., Bourzat, D., & Prabhu, P. (1992). *Crop-livestock interaction in sub-Saharan Africa*. Washington, DC: World Bank.

Mgolozeli, S., Nciizah, A. D., Wakindiki, I. I., & Mudau, F. N. (2020). Innovative pro-smallholder farmers' permanent mulch for better soil quality and food security under conservation agriculture. *Agronomy*, *10*(4), 605.

Miaomiao, H., Wenhong, L., Xinqiang, L., Donglei, W., & Guangming, T. (2009). Effect of composting process on phytotoxicity and speciation of copper, zinc and lead in sewage sludge and swine manure. *Waste Management*, *29*(2), 590-597.

Mikkelsen, R. L. (2007). Managing potassium for organic crop production. *HortTechnology*, *17*(4), 455-460.

Mohammadi, K., Heidari, G., Khalesro, S., & Sohrabi, Y. (2011). Soil management, microorganisms and organic matter interactions: A review. *African Journal of Biotechnology*, *10*(86), 19840-19849.

Mohammed, A. M., Naab, J. B., Nartey, E., & Adiku, S. G. K. (2014). Carbon mineralization from plant residue-amended soils under varying moisture conditions. 1, 491-498.

Mohammed, Y. S., Mokhtar, A. S., Bashir, N., & Saidur, R. (2013). An overview of agricultural biomass for decentralized rural energy in Ghana. *Renewable and Sustainable Energy Reviews*, *20*, 15-25.

Moise, E., Delpeuch, C., Sorescu, S., Bottini, N., & Foch, A. (2013). Estimating the constraints to agricultural trade of developing countries. 47-75.

Mora, P., Miambi, E., Jiménez, J. J., Decaëns, T., & Rouland, C. J. S. B. (2005). Functional complement of biogenic structures produced by earthworms, termites and ants in the neotropical savannas. *Soil Biology and Biochemistry*, *37*(6), 1043-1048.

Moraine, M., Duru, M., Nicholas, P., Leterme, P., & Therond, O. (2014). Farming system design for innovative crop-livestock integration in Europe. *Animal*, *8*(8), 1204-1217.

Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., & Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, *14*, 1-8.

Murdia, L. K., Wadhwani, R., Wadhawan, N., Bajpai, P., & Shekhawat, S. (2016). Maize utilization in India: an overview. *American Journal of Food and Nutrition*, *4*(6), 169-176.

Murungu, F. S., Chiduza, C., Muchaonyerwa, P., & Mnkeni, P. N. S. (2011). Decomposition, nitrogen and phosphorus mineralization from winter-grown cover crop residues and suitability for a smallholder farming system in South Africa. *Nutrient Cycling in Agroecosystems*, *89*, 115-123.

Naab, F. Z., Dinye, R. D., & Kasanga, R. K. (2013). Urbanisation and its impact on agricultural lands in growing cities in developing countries: a case study of Tamale in Ghana. *Modern Social Science Journal*, *2*(2), 256-287.

Nath, T. N. (2014). Soil texture and total organic matter content and its influences on soil water holding capacity of some selected tea growing soils in Sivasagar district of Assam, India. *Int. J. Chem. Sci*, *12*(4), 1419-1429.

Nelson, D. R., & Mele, P. M. (2006). The impact of crop residue amendments and lime on microbial community structure and nitrogen-fixing bacteria in the wheat rhizosphere. *Soil Research*, *44*(4), 319-329.

Nelson, D.W. and Sommers, L.W. (1982). Total carbon and organic matter. In: Page, A.L., Miller, R.H. and Keeney, D.R. (eds.): Methods of soil analysis Part 2, 2nd ed. No.9. American Society of Agronomy. Soil Science of America. Madison, Wisconsin, USA.

Nkonya, E., Kaizzi, C., & Pender, J. (2005). Determinants of nutrient balances in a maize farming system in eastern Uganda. *Agricultural systems*, *85*(2), 155-182.

Ntonta, S., Mathew, I., Zengeni, R., Muchaonyerwa, P., & Chaplot, V. (2022). Crop residues differ in their decomposition dynamics: Review of available data from world literature. *Geoderma*, *419*, 115855.

Ntow, W. J., Gijzen, H. J., Kelderman, P., & Drechsel, P. (2006). Farmer perceptions and pesticide use practices in vegetable production in Ghana. *Pest Management Science: formerly Pesticide Science*, *62*(4), 356-365.

Obi, F. O., Ugwuishiwu, B. O., & Nwakaire, J. N. (2016). Agricultural waste concept, generation, utilization and management. *Nigerian Journal of Technology*, *35*(4), 957-964.

Ohyama, T., Tewari, K., Ishikawa, S., Tanaka, K., Kamiyama, S., Ono, Y., & Takahashi, Y. (2017). *Role of nitrogen on growth and seed yield of soybean and a new fertilization technique to promote nitrogen fixation and seed yield* (pp. 153-185).

Ojha, R. B., & Devkota, D. (2014). Earthworms:'Soil and ecosystem engineers'–a review. *World Journal of Agricultural Research*, *2*(6), 257-260.

Okereke, P. O. (2021). Principles of Crop Production. *Agricultural Technology for Colleges*, 87.

Olk, D. C., Cassman, K. G., Schmidt-Rohr, K., Anders, M. M., Mao, J. D., & Deenik, J. L. (2006). Chemical stabilization of soil organic nitrogen by phenolic lignin residues in anaerobic agroecosystems. *Soil Biology and Biochemistry*, *38*(11), 3303-3312.

Otchere-Appiah, G., & Hagan, E. B. (2014). Potential for electricity generation from maize residues in rural Ghana: A case study of Brong Ahafo Region. *International Journal of Renewable Energy Technology Research*, *3*(5), 1-10.

Pan, X. Y., Shi, R. Y., Hong, Z. N., Jiang, J., He, X., Xu, R. K., & Qian, W. (2021). Characteristics of crop straw-decayed products and their ameliorating effects on an acidic Ultisol. *Archives of Agronomy and Soil Science*, *67*(12), 1708-1721.

Pankhurst, C. E., Hawke, B. G., McDonald, H. J., Kirkby, C. A., Buckerfield, J. C., Michelsen, P. & Doube, B. M. (1995). Evaluation of soil biological properties as potential bioindicators of soil health. *Australian Journal of Experimental Agriculture*, *35*(7), 1015-1028.

Parker, B. Q., Osei, B. A., Armah, F. A., & Yawson, D. O. (2010). Impact of biomass burning on soil organic carbon and the release of carbon dioxide into the atmosphere in the coastal savanna ecosystem of Ghana. *Journal of Renewable and Sustainable Energy*, *2*(3), 033106.

Partey, S. T., Avornyo, F. K., Ouédraogo, M., & Zougmoré, R. B. (2018). Candidate fodder species for goat production in Northern Ghana.

Pascault, N., Cécillon, L., Mathieu, O., Hénault, C., Sarr, A., Lévêque, J., ... & Maron, P. A. (2010). In situ dynamics of microbial communities during decomposition of wheat, rape, and alfalfa residues. *Microbial ecology*, *60*, 816-828.

Pasukphun, N. (2018). Environmental health burden of open burning in northern Thailand: a review. *PSRU Journal of Science and Technology*, *3*(3), 11-28.

Paustian, K., Six, J., Elliott, E. T., & Hunt, H. W. (2000). Management options for reducing CO_2 emissions from agricultural soils. *Biogeochemistry*, *48*(1), 147-163.

Perfecto, I., & Vandermeer, J. (2010). The agroecological matrix as alternative to the land-sparing/agriculture intensification model. *Proceedings of the National Academy of Sciences*, *107*(13), 5786-5791.

Peou, C. (2016). Negotiating rural-urban transformation and life course fluidity: Rural young people and urban sojourn in contemporary Cambodia. *Journal of Rural Studies*, *44*, 177-186.

Petersen, L. W., Moldrup, P., Jacobsen, O. H., & Rolston, D. E. (1996). Relations between specific surface area and soil physical and chemical properties. *Soil Science*, *161*(1), 9-21.

Pikuła, D., & Ciotucha, O. (2022). The Composition of the Organic Matter Fractions of Loamy Sand after Long-Term FYM Application without Liming. *Agronomy*, *12*(10), 2385.

Place, F., Barrett, C. B., Freeman, H. A., Ramisch, J. J., & Vanle, B. (2003). Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. *Food policy*, *28*(4), 365-378.

Powlson, D. S., Whitmore, A. P., & Goulding, K. W. (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science*, *62*(1), 42-55.

Prajapati, K., & Modi, H. A. (2012). The importance of potassium in plant growth–a review. *Indian Journal of Plant Sciences*, *1*(02-03), 177-186.

Quansah, C., Drechsel, P., Yirenkyi, B. B., & Asante-Mensah, S. (2001). Farmers' perceptions and management of soil organic matter–a case study from West Africa. *Nutrient Cycling in Agroecosystems*, *61*(1), 205-213.

Quansah, E. S. T. (2012). Land tenure system: Women's access to land in a cosmopolitan context. *Ogirisi: A New Journal of African Studies*, *9*, 141-162.

Quartey, E. T., & Chýlková, J. A. R. O. M. Í. R. A. (2012). Challenges and opportunities in managing agricultural waste in Ghana. *Advances in Environment, Biotechnology and Biomedicine*, 235-239.

Randhawa, P. S., Condron, L. M., Di, H. J., Sinaj, S., & McLenaghen, R. D. (2005). Effect of green manure addition on soil organic phosphorus mineralisation. *Nutrient Cycling in Agroecosystems*, *73*(2), 181-189.

Rasche, F., & Cadisch, G. (2013). The molecular microbial perspective of organic matter turnover and nutrient cycling in tropical agroecosystems-What do we know? *Biology and fertility of soils*, *49*(3), 251-262.

Rasmussen, P. E., Allmaras, R. R., Rohde, C. R., & Roager, N. C. (1980). Crop Residue Influences on Soil Carbon and Nitrogen in a Wheat‐Fallow System 1. *Soil Science Society of America Journal*, *44*(3), 596-600.

Reddy, A. K., Williams, R. H., & Johansson, T. B. (1997). *Energy after Rio: prospects and challenges* (p. 176). New York: United Nations Development Programme.

Rezig, F. A. M., Mubarak, A. R., & Ehadi, E. A. (2013). Impact of organic residues and mineral fertilizer application on soil–crop system: II soil attributes. *Archives of Agronomy and Soil Science*, *59*(9), 1245-1261.

Roy, R. N., Finck, A., Blair, G. J., & Tandon, H. L. S. (2006). Plant nutrition for food security. *A guide for integrated nutrient management. FAO Fertilizer and Plant Nutrition Bulletin*, *16*(368).

Rumosa Gwaze, F., Chimonyo, M., & Dzama, K. (2009). Communal goat production in Southern Africa: a review. *Tropical animal health and production*, *41*(7), 1157-1168.

Rymuza, K., Radzka, E., & Wysokiński, A. (2020). Nitrogen uptake from different sources by non-GMO soybean varieties. *Agronomy*, *10*(9), 1219.

Sahrawat, K. L., Wani, S. P., Pathak, P., & Rego, T. J. (2010). Managing natural resources of watersheds in the semi-arid tropics for improved soil and water quality: A review. *Agricultural Water Management*, *97*(3), 375-381.

Salaam, J. B. (2016). *Determinants Of Use Intensity Of Inorganic Fertilizer And Its Effect*

On Maize Yield Among Smallholder Maize Farmers In Northern Ghana (Doctoral dissertation, University of Ghana).

Salami, S. A., Luciano, G., O'Grady, M. N., Biondi, L., Newbold, C. J., Kerry, J. P., & Priolo, A. (2019). Sustainability of feeding plant by-products: A review of the implications for ruminant meat production. *Animal Feed Science and Technology*, *251*, 37-55.

Salas, A. M., Elliott, E. T., Westfall, D. G., Cole, C. V., & Six, J. (2003). The role of particulate organic matter in phosphorus cycling. *Soil Science Society of America Journal*, *67*(1), 181-189.

Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science*, *295*(5562), 2019-2020.

Sarkodie-Addo, J., & Mahama, O. (2012). Growth and yield response of early and medium maturity soybean (Glycine max (L.) Merrill) varieties to row spacing. *International Journal of Science and Advanced Technology*, *2*(11).

Sarnklong, C., Cone, J. W., Pellikaan, W., & Hendriks, W. H. (2010). Utilization of rice straw and different treatments to improve its feed value for ruminants: a review. *Asian-Australasian Journal of Animal Sciences*, *23*(5), 680-692.

Saxena, P., Sonwani, S., Srivastava, A., B, M., Srivastava, A., Bharti, A., & Bhardwaj, S. (2021). Impact of crop residue burning in Haryana on the air quality of Delhi, India. *Heliyon*, *7*(5), e06973.

Seglah, P. A., Wang, Y., Wang, H., & Bi, Y. (2019). Estimation and efficient utilization of straw resources in Ghana. *Sustainability*, *11*(15), 4172.

Seglah, P. A., Wang, Y., Wang, H., Bi, Y., Zhou, K., Wang, Y., & Feng, X. (2020). Crop straw utilization and field burning in Northern region of Ghana. *Journal of Cleaner Production*, *261*, 121191.

Shaver, T. (2010). Crop residue and soil physical properties. In *Proceedings of the 2010 Central Plains irrigation conference, Kearney, Nebraska, February 24-25*. Colorado

State University. Libraries.

Shaxson, F., & Barber, R. (2003). *Optimizing soil moisture for plant production: The significance of soil porosity*. Rome, Italy: UN-FAO.

Shen, Z., Ruan, Y., Wang, B., Zhong, S., Su, L., Li, R., & Shen, Q. (2015). Effect of biofertilizer for suppressing Fusarium wilt disease of banana as well as enhancing microbial and chemical properties of soil under greenhouse trial. *Applied Soil Ecology*, *93*, 111-119.

Singh, A., & Sharma, S. (2002). Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. *Bioresource technology*, *85*(2), 107-111.

Singh, P., Kumar, R., Sabapathy, S. N., & Bawa, A. S. (2008). Functional and edible uses of soy protein products. *Comprehensive reviews in food science and food safety*, *7*(1), 14-28.

Singh, Y., & Sidhu, H. S. (2014). Management of cereal crop residues for sustainable rice-wheat production system in the Indo-Gangetic plains of India. *Proceedings of the Indian National Science Academy*, *80*(1), 95-114.

Six, J., Frey, S. D., Thiet, R. K., & Batten, K. M. (2006). Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal*, *70*(2), 555-569.

Smil, V. (1999). Crop Residues: Agriculture's Largest Harvest: Crop residues incorporate more than half of the world's agricultural phytomass. *Bioscience*, *49*(4), 299-308.

Smith, P. (2016). Soil carbon sequestration and biochar as negative emission technologies. *Global change biology*, *22*(3), 1315-1324.

Smith, P., Soussana, J. F., Angers, D., Schipper, L., Chenu, C., Rasse, D. P., & Klumpp, K. (2020). How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. *Global Change Biology*, *26*(1), 219-241.

Snapp, S. S., Rohrbach, D. D., Simtowe, F., & Freeman, H. A. (2002). Sustainable soil management options for Malawi: can smallholder farmers grow more legumes?. *Agriculture, ecosystems & environment*, *91*(1-3), 159-174.

Sopanrao, P. S., Abrar, A. S., Manoharrao, T. S., & Vaseem, B. M. M. (2010). Nutritional value of Pleurotus ostreatus (Jacq: Fr) Kumm cultivated on different lignocellulosic agro-wastes. *Innovative Romanian food biotechnology*, (7), 66-76.

Spencer, D. S. (1972). Micro-level farm management and production economics research among traditional African farmers.

Stavi, I., Bel, G., & Zaady, E. (2016). Soil functions and ecosystem services in conventional, conservation, and integrated agricultural systems. A review. *Agronomy for sustainable development*, *36*(2), 32.

Steiner, C., Glaser, B., Geraldes Teixeira, W., Lehmann, J., Blum, W. E., & Zech, W. (2008). Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. *Journal of plant nutrition and soil science*, *171*(6), 893-899.

Stoop, W. A., Uphoff, N., & Kassam, A. (2002). A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource-poor farmers. *Agricultural systems*, *71*(3), 249-274.

Su, Y., Lv, J. L., Yu, M., Ma, Z. H., Xi, H., Kou, C. L., & Shen, A. L. (2020). Long-term decomposed straw return positively affects the soil microbial community. *Journal of Applied Microbiology*, *128*(1), 138-150.

Sui, Y., Gao, J., Liu, C., Zhang, W., Lan, Y., Li, S., & Tang, L. (2016). Interactive effects of straw-derived biochar and N fertilization on soil C storage and rice productivity in rice paddies of Northeast China. *Science of the Total Environment*, *544*, 203-210.

Sumner, M. E., & Miller, W. P. (1996). Cation exchange capacity and exchange coefficients. *Methods of soil analysis: Part 3 Chemical methods*, *5*, 1201-1229.

Swanson, B. E. (2008). *Global review of good agricultural extension and advisory service practices* (Vol. 82). Rome: Food and Agriculture Organization of the United Nations, 563, 62-75.

Tan, X., Liu, Y., Zeng, G., Wang, X., Hu, X., Gu, Y., & Yang, Z. (2015). Application of biochar for the removal of pollutants from aqueous solutions. *Chemosphere*, *125*, 70-85.

Tang, C., & Yu, Q. (1999). Impact of chemical composition of legume residues and initial soil pH on pH change of a soil after residue incorporation. *Plant and Soil*, *215*(1), 29-38.

Taye, D., & Abebe, G. (2000). Socioeconomic aspect and husbandry practices of sheep kept in Awassa city. *E (Kika) de la Garza Institute for Goat Research, Langston University, Langston*, 175-181.

Tejada, M., Hernandez, M. T., & Garcia, C. (2009). Soil restoration using composted plant residues: Effects on soil properties. *Soil and Tillage Research*, *102*(1), 109-117.

Tetteh, F., Larbi, A., Nketia, K. A., Senayah, J. K., Hoeschle-Zeledon, I., & Abdulrahman, N. (2016). Suitability of soils for cereal cropping in Northern Ghana.

Timsina, J. (2018). Can organic sources of nutrients increase crop yields to meet global food demand?. *Agronomy*, *8*(10), 214.

Tivet, F., de Moraes Sa, J. C., Lal, R., Briedis, C., Borszowskei, P. R., dos Santos, J. B., ... & Séguy, L. (2013). Aggregate C depletion by plowing and its restoration by diverse biomass-C inputs under no-till in sub-tropical and tropical regions of Brazil. *Soil and* *tillage research*, *126*, 203-218.

Tobita, S., & Nakamura, S. (2018). *Soil Fertility Improvement with Indigenous Resources in Lowland Rice Ecologies in Ghana*. Japan International Research Center for Agricultural Sciences. pp. 1-98.

Todes, A., Kok, P., Wentzel, M., Van Zyl, J., & Cross, C. (2010, August). Contemporary South African urbanization dynamics. In *Urban forum* (Vol. 21, pp. 331-348). Springer Netherlands.

Tonamo, A. (2016). A review on cattle husbandry practices in Ethiopia. *International Journal of Livestock Production*, *7*(2), 5-11.

Torma, S., Vilček, J., Lošák, T., Kužel, S., & Martensson, A. (2018). Residual plant nutrients in crop residues–an important resource. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, *68*(4), 358-366. November 2017 DOI: 10.1080/09064710.2017.1406134

Turmel, M. S., Speratti, A., Baudron, F., Verhulst, N., & Govaerts, B. (2015). Crop residue management and soil health: A systems analysis. *Agricultural Systems*, *134*, 6-16.

Ubuoh, E. A., Ejekwolu, C. C., & Onuigbo, I. V. (2017). The effect of burnt and un-burnt land on soil physicochemical characteristics in Ekeya-Okobo Local Government Area, Akwa Ibom State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *21*(5), 923-929.

Ukalska-Jaruga, A., Smreczak, B., & Klimkowicz-Pawlas, A. (2019). Soil organic matter composition as a factor affecting the accumulation of polycyclic aromatic hydrocarbons. *Journal of Soils and Sediments*, *19*(4), 1890-1900.

Unger, P. W., & Kaspar, T. C. (1994). Soil compaction and root growth: a review. *Agronomy Journal*, *86*(5), 759-766.

Val'Kov, V.F., Kazadaev, A.A., Kremenitsa, A.M., Suprun, V.A., Sukhanova, V.M. and

Tashchiev, S.S. (1996). The effect of stubble burning on Chernozem. Eurasian Soil Sci 29:1412–1416

Van Loo, S., & Koppejan, J. (2002). Handbook of Biomass Combustion and Co-firing, I*EA Bioenergy Task 32*. The Netherlands: Twente University Press.

Vanlauwe, B., Ramisch, J. J., & Sanginga, N. (2006). Integrated soil fertility management in Africa: From knowledge to implementation. *Biological approaches to sustainable soil systems*, *113*, 257-272.

Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B., & Nolte, C. (2014). A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, *155*, 10-13.

Waigwa, M. W., Othieno, C. O., & Okalebo, J. R. (2003). Phosphorus availability as affected by the application of phosphate rock combined with organic materials to acid soils in western Kenya. *Experimental Agriculture*, *39*(4), 395-407.

Wang, D., Li, C., Parikh, S. J., & Scow, K. M. (2019). Impact of biochar on water retention of two agricultural soils–A multi-scale analysis. *Geoderma*, *340*, 185-191.

Wang, H., Wang, S., Yu, Q., Zhang, Y., Wang, R., Li, J., & Wang, X. (2020). No tillage increases soil organic carbon storage and decreases carbon dioxide emission in the crop residue-returned farming system. *Journal of environmental management*, *261*, 110261.

Wardle, D. A., Bonner, K. I., Barker, G. M., Yeates, G. W., Nicholson, K. S., Bardgett, R. D., ... & Ghani, A. (1999). Plant removals in perennial grassland: vegetation dynamics, decomposers, soil biodiversity, and ecosystem properties. *Ecological monographs*, *69*(4), 535-568.

Watson, C. A., Atkinson, D., Gosling, P., Jackson, L. R., & Rayns, F. W. (2002). Managing soil fertility in organic farming systems. *Soil use and management*, *18*, 239-247.

Whitbread, A. M., Blair, G. J., & Lefroy, R. D. (2000). Managing legume leys, residues and fertilisers to enhance the sustainability of wheat cropping systems in Australia: 2. Soil physical fertility and carbon. *Soil and Tillage Research*, *54*(1-2), 77-89.

Wilson, R. T. (2018). Domestic livestock in African cities: Production, problems and prospects. *Open Urban Studies and Demography Journal*, *4*(1).

Wójcik, M., Jeziorska-Biel, P., & Czapiewski, K. (2019). Between words: A generational discussion about farming knowledge sources. *Journal of Rural Studies*, *67*, 130-141.

Wood, T. N. (2013). *Agricultural development in the northern savannah of Ghana*. The University of Nebraska-Lincoln.

Xu, J. M., Tang, C., & Chen, Z. L. (2006). The role of plant residues in pH change of acid soils differing in initial pH. *Soil Biology and Biochemistry*, *38*(4), 709-719.

Xu, X., Du, X., Wang, F., Sha, J., Chen, Q., Tian, G., & Jiang, Y. (2020). Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Frontiers in Plant Science*, *11*, 904.

Yadav, A. N. (2021). Beneficial plant-microbe interactions for agricultural sustainability. *Journal of Applied Biology and Biotechnology*, *9*(1), i-v.

Yageta, Y., Osbahr, H., Morimoto, Y., & Clark, J. (2019). Comparing farmers' qualitative evaluation of soil fertility with quantitative soil fertility indicators in Kitui County, Kenya. *Geoderma*, *344*, 153-163.

Yang, Y., He, C., Huang, L., Ban, Y., & Tang, M. (2017). The effects of arbuscular mycorrhizal fungi on glomalin-related soil protein distribution, aggregate stability and their relationships with soil properties at different soil depths in lead-zinc contaminated area. *PloS one*, *12*(8), e0182264.

Yang, Y., Ma, S., Zhao, Y., Jing, M., Xu, Y., & Chen, J. (2015). A field experiment on enhancement of crop yield by rice straw and corn stalk-derived biochar in Northern

China. *Sustainability*, *7*(10), 13713-13725.

Yi, X., Lin, D., Li, J., Zeng, J., Wang, D., & Yang, F. (2021). Ecological treatment technology for agricultural non-point source pollution in remote rural areas of China. *Environmental Science and Pollution Research*, *28*(30), 40075-40087.

Yin, S., Wang, X., Zhang, X., Guo, M., Miura, M., & Xiao, Y. (2019). Influence of biomass burning on local air pollution in mainland Southeast Asia from 2001 to 2016. *Environmental Pollution*, *254*, 112949.

You, Y., Wang, J., Huang, X., Tang, Z., Liu, S., & Sun, O. J. (2014). Relating microbial community structure to functioning in forest soil organic carbon transformation and turnover. *Ecology and evolution*, *4*(5), 633-647.

Yuan, G. D., Theng, B. K. G., Churchman, G. J., & Gates, W. P. (2013). Clays and clay minerals for pollution control. In *Developments in clay science* (Vol. 5, pp. 587-644). Elsevier.

Yulistiani, D., Gallagher, J. R., & Van Barneveld, R. J. (2003). Intake and digestibility of untreated and urea treated rice straw base diet fed to sheep. *Jurnal Ilmu Ternak dan Veteriner*, *8*(1), 8-16.

Zaniewicz-Bajkowska, A., Franczuk, J., & Kosterna, E. (2009). Direct and Secondary Effects of Soil Mulching with Straw on Fresh Mass and Number of Weeds, Vegetable Yield. *Polish Journal of Environmental Studies*, *18*(6).

Zeng, X., Ma, Y., & Ma, L. (2007). Utilization of straw in biomass energy in China. *Renewable and sustainable energy reviews*, *11*(5), 976-987.

Zhang, C., Lin, Z., Que, Y., Fallah, N., Tayyab, M., Li, S., & Zhang, H. (2021). Straw retention efficiently improves fungal communities and functions in the fallow ecosystem. *BMC microbiology*, *21*(1), 1-13.

Zhao, H., Shar, A. G., Li, S., Chen, Y., Shi, J., Zhang, X., & Tian, X. (2018). Effect of straw return mode on soil aggregation and aggregate carbon content in an annual maize-wheat double cropping system. *Soil and Tillage Research*, *175*, 178-186.

Zhao, X., Yuan, G., Wang, H., Lu, D., Chen, X., & Zhou, J. (2019). Effects of full straw incorporation on soil fertility and crop yield in rice-wheat rotation for silty clay loamy cropland. *Agronomy*, *9*(3), 133.

Zhao, Y., Li, Y., Wang, J., Pang, H., & Li, Y. (2016). Buried straw layer plus plastic mulching reduces soil salinity and increases sunflower yield in saline soils. *Soil and Tillage Research*, *155*, 363-370.

APPENDICES

QUESTIONNAIRE(S)

ASSESSMENT OF THE QUALITY AND QUANTITY OF MAIZE, RICE AND SOYBEAN BIOMASS IN NORTHERN REGION OF GHANA

QUESTIONNAIRE FOR FARMERS

INFORMED CONSENT

Good morning/Afternoon. My name is Nicholas Tigtig. We are final year students/project students from the University for Development Studies (UDS), conducting a study on the topic "**Assessment of the Quality and Quantity of maize, Rice and Soybean Biomass in Northern Region of Ghana".** I would like to have an interview with you on the said topic and would be very much appreciate your participation in this study. This interview will take between 30 and 40 minutes to complete. All the answers you will give would be confidential and will not be seen by anyone. However, we hope you will participate fully in the study since your views are important.

IDENTIFICATION

District…………………………………………………………………………………………
………

Name of
Community……………………………………………………………………………......

GPS co-
ordinate……………………………………………………………………………………….

Interview Date………………………………………….. Interview

#...

House

number/Name……………………………………………………………………………….

Name of

Interviewer…………………………………………………………………………………..

SECTION A: DEMOGRAPHIC AND SOCIO-ECONOMIC FACTORS

1. How old are you?

   A. 15-25 { } B. 26-35 { } C. 36-45 { } D. 46-55 { } E. 56 above { }

2. What is your sex?

   A. Male { } B. female { }

3. Religion i. Islam { } ii. Christianity { } iii. African Traditional Religion { } iv. Others Specify…………………………………

3. What is the highest level of education you have completed?

   A. Primary { } B. Junior { } C. Secondary { } D. Tertiary { } E. No schooling { } F. Others (Specify)……………………….

4. What is your marital status?

   A. Married { } B. Single { } C. Divorce { } D. Widowed { }

5. How many dependents do you have?

0-15 years ………………… Above age 64 Years ………………..

   A. 0-5 { } B. 6-10 { } C. 11-15 { } D. 16-20 { } E. 20 Above { }

6. Are you a farmer?

   A. Yes { } B. No { }

7. Is farming you major occupation?

   A. Yes { } B. No { }

8. Which of the following agricultural activities are you engaged in? *(multiple answers possible)*

Crop farming	**Yes (√)**	**No (√)**
Maize		
Rice		
Millet		
Yam		
Soya bean		
Guinea corn		
Groundnut		
Cassava		
Beans		
Leafy green vegetables(Bra, ayoyo, allefu etc)		
Other 1………………………………		
Other 2………………………………		
Livestock	**Yes (√)**	**No (√)**
Cattle		
Sheep		
Goat		
Pig		
Poultry		
Other 1………………………………		
Other 1………………………………		

9. Which of the following other minor occupations are you engaged in? *(If none, skip to 14).*
   A. Trade { } B. Salaried employment { } C. None { }
10. If Trade, what kind of trade are you engaged in?

    …………………………………………

11. What is your monthly income from the trade you are engaged in?
    A. <100 { } B. 100-400 { } C. 401-700 { } D. 710-1000 E. 1000> { }

12. If salaried employment, what kind of work are you engaged in?

    ……………………………………..

13. What is your monthly income from the salaried employment?
    B. <100 { } B. 100-400 { } C. 401-700 { } D. 710-1000 E. 1000> { }

SECTION B: Farm Ownership Information and Management Practices of the Farmer

14. How long have you been farming this particular crop? ………………………………..

15.

i. How much land do you: own? (A) ……….. Acres. (B) Lease in /rent in ………..acres

ii. What is the utilized agricultural area taken by the arable crop? .

SECTION C:

16. Fill the blank spaces with the most appropriate answers (where applicable).

	Description of management practices	**Farmer Response**
Crop variety	What variety of crop do you plant?	
Fertilizer Application	**N- application:**	
	Amount of application.	
	Method of application	
	Number of times of application	
	P- application:	
	Amount of application	
	Method of application	
	Number of times of application.	
	K- application:	
	Amount of application	

	Method of application	
	Number of times of application	

17. Indicate the chosen option by underling (_) Yes / No

Crop protection	Do you spray crops with fungicides?	YES/ NO.
	Do you spray crops with herbicides?	YES/ NO.
	Do you use mechanical for weeding, eg. Hoe, cutlass, tractor.	YES/ NO.
Soil fertility management	Do you practice crop rotation?	YES/ NO
	Do you practice mixed cropping?	YES/ NO
-Compost	Do you apply compost on soil?	YES/NO
-Biochar	Do you apply biochar to soil?	YES/NO
-Manure	Do you apply manure on farm?	YES/NO

17 (ii) Which of these crops do you farm as a major crop?

A. Maize B. Rice C. soybean

18. **Fill in the Spaces with the most appropriate answer for the major crop**

Crop farming	Acres	(√)	How many bags or basins did you harvest per acre last year?	How many bags or basins did you sell per acre last year?	How much did you realize from the sale per acre last year? (GHS)
Maize					
Rice					
Soybean					

19. Fill in the Spaces with the most appropriate answer

Crop farming	Planting distance of crops	How much residue was generated/ acre	What tools do you use to harvest residue
Maize			
Rice			
Soybean			

Q10. Do you practice irrigation or rain fed farming? …………………………

Q11What farming system do you practice?

(a) Mono cropping. (b) Mixed cropping.

SECTION D: Assessment of the uses of crop residue and determining the cost at which residue will be obtained for re-use.

Q13. Fill the following table below

Fate of residue	Quantity in percentage (%)
Left on farm	
Fed to animals	
Sell for income	
Use for composting	

Use for fuel	

Q14.Which section of the residue are you much interested in? I-III

I. **Maize** (a) cobs (b) stalk and leaves (c) husk

State the uses…………………………….

II. **Rice** (a) straw (b) husk State the uses……………………………………

III. **Soybean** (a) stalk (b) pods (c) leaves State the uses………………………

……………………………………………..

Q15. What additional usage does farmer put the residue?

……………………………………………………………………………..

Q16 (i). Do other people compete with you for residue on the farm?

(a) Yes (b) No

Q16 ii. Explain? If **yes** to question Q16 (i)………………………………

…………………………………………………………………………………………

Q17. What time of the season do you harvest residue?

(a) September- October (b) October- November (c) November- December

Q18. How do you transport the residue from the farm?

(a) Bicycle. (b) Tricycle. (c) By foot. (d) Tractor. (e) Vehicle.

Q19. What material do you use for bagging the residue?

(a) Jute sack. (b) Fertilizer sack. (c) Polythene bag. (d) A rope. (e) None.

Q20. Are residues stored for some time before use?

(a) Yes. (b) No.

Q21. How long do you store residue before use? ……………………………

Q22. If yes, what do you use to store the residue during storage?

(a) Pesticides. (b) Sun drying. (c). state…………………………

Q23. Are the residues used occasionally or frequently? …………………………

NO ANOVA TABLES

Analysis of variance for Nitrogen content in crop residues from the three district

Variate: Nitrogen

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Districts	2	1.76882	0.88441	16.00	<.001
Feedstock	2	1.81245	0.90623	16.39	<.001
Districts.Feedstock	4	0.79359	0.19840	3.59	0.008
Residual	126	6.96513	0.05528		
Total	134	11.33999			

Tables of means

Variate: Nitrogen

Grand mean 0.947

Districts	Kumbungu	Savelugu	Tolon
	0.888	1.108	0.847

Feedstock	Maize	Rice	Soybean
	0.825	0.914	1.103

Districts	Feedstock	Maize	Rice	Soybean
Kumbungu		0.805	0.927	0.931
Savelugu		0.879	1.065	1.379
Tolon		0.792	0.750	0.999

Standard errors of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
e.s.e.	0.0350	0.0350	0.0607

Standard errors of differences of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
s.e.d.	0.0496	0.0496	0.0859

Least significant differences of means (5% level)

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15

d.f.	126	126	126
l.s.d.	0.0981	0.0981	0.1699

Analysis of variance for Phosphorus content in crop residues from the three districts

Variate: Phosphorus

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Districts	2	0.017849	0.008925	1.00	0.371
Feedstock	2	0.038126	0.019063	2.13	0.123
Districts.Feedstock	4	0.039947	0.009987	1.12	0.351
Residual	126	1.125727	0.008934		
Total	134	1.221650			

Tables of means

Variate: Phosphorus

Grand mean 0.0732

Districts	Kumbungu	Savelugu	Tolon
	0.0895	0.0649	0.0653

Feedstock	Maize	Rice	Soybean
	0.0622	0.0606	0.0970

Districts	Feedstock	Maize	Rice	Soybean
Kumbungu		0.0735	0.0504	0.1446
Savelugu		0.0579	0.0695	0.0672
Tolon		0.0551	0.0618	0.0791

Standard errors of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
e.s.e.	0.01409	0.01409	0.02441

Standard errors of differences of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
s.e.d.	0.01993	0.01993	0.03451

Least significant differences of means (5% level)

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
l.s.d.	0.03943	0.03943	0.06830

Analysis of variance for Potassium in crop residues from the three districts

Variate: Potassium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Districts	2	0.49232	0.24616	3.22	0.043
Feedstock	2	16.90120	8.45060	110.51	<.001
Districts.Feedstock	4	1.42908	0.35727	4.67	0.002
Residual	126	9.63537	0.07647		
Total	134	28.45797			

Tables of means

Variate: Potassium

Grand mean 0.948

Districts	Kumbungu	Savelugu	Tolon
	0.889	1.031	0.923

Feedstock	Maize	Rice	Soybean
	0.788	0.617	1.438

Districts	Feedstock	Maize	Rice	Soybean
Kumbungu		0.700	0.587	1.380
Savelugu		1.061	0.587	1.445
Tolon		0.602	0.677	1.489

Standard errors of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
e.s.e.	0.0412	0.0412	0.0714

Standard errors of differences of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
s.e.d.	0.0583	0.0583	0.1010

Least significant differences of means (5% level)

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
l.s.d.	0.1154	0.1154	0.1998

Analysis of variance for crop residue from the three district

Variate: Carbon

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Districts	2	103.772	51.886	29.59	<.001
Feedstock	2	32.594	16.297	9.29	<.001
Districts.Feedstock	4	232.956	58.239	33.22	<.001
Residual	126	220.928	1.753		
Total	134	590.250			

Tables of means

Variate: Carbon

Grand mean 36.95

Districts	Kumbungu	Savelugu	Tolon
	36.63	36.07	38.14

Feedstock	Maize	Rice	Soybean
	36.28	37.11	37.45

Districts	Feedstock	Maize	Rice	Soybean
Kumbungu		38.38	35.35	36.15
Savelugu		35.03	36.39	36.79
Tolon		35.43	39.58	39.42

Standard errors of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
e.s.e.	0.197	0.197	0.342

Standard errors of differences of means

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
s.e.d.	0.279	0.279	0.484

Least significant differences of means (5% level)

Table	Districts	Feedstock	Districts Feedstock
rep.	45	45	15
d.f.	126	126	126
l.s.d.	0.552	0.552	0.957